SMART GRID СИСТЕМИ І ТЕХНОЛОГІЇ SMART GRID SYSTEMS AND TECHNOLOGIES

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AGGREGATION PRICE MODELS FOR MICROGRIDS WITH DISTRIBUTED ENERGY RESOURCES

The development of Microgrid states the problem of choosing the optimal technologies for its composition. This paper is to present cost based demand-side management methods for the Microgrids with Distributed Generation sources to optimize their operation. While implementing variable pricing models the aggregator should take into account characteristics of different Distributed Energy Resources (DER) (diesel engines, gas turbines, fuel cells, solar panels, small hydropower plants and wind turbines) and LCOE for each type of DER to stimulate each local electricity market participant separately. The system Microgrid using three diesel generators and the option of replacing one generator with a solar electric and wind generator installation was considered.

Keywords: *Microgrids, dynamic pricing, demand-side management*

Introduction. The shift towards a consumer-centric energy transition has placed particular emphasis on the improvement of the low-voltage distribution networks. This improvement is due to the integration of various types of the Distributed Energy Resources (DER), modern equipment, ICT technologies and Market mechanisms which allow such systems to operate efficiently [1, 2, 7].

The concept of the Microgrid is one of the advancements in the electricity distribution network that supports such consumer-centric approach using DERs that are independent of or only partially dependent on the main grid. It has also empowered consumers or only partially dependent on the main grid. It has also empowered consumers to support the grid by activating their assets for energy services whenever required.

Consumers can also support each other by forming a microgrid that can be managed or operated by the users of a community with or without the support from an operational entity, thereby creating a community-based microgrid (C-MG) [7].

The microgrid concept is well established and has been the subject of significant research efforts in recent years. According to [1] the defining characteristics/features of an advanced microgrid:

1) Geographically delimited or enclosed.
2) Connected to the main utility grid at one point of common coupling (PCC).
3) Fed from a single substation.
4) Can automatically transition to/from and operate islanded:
   a) operates in a synchronized and/or current-sourced mode when utility-interconnected
   b) Is compatible with system protection devices and coordination
5) Includes DER, but generator agnostic and according to needs of customer with
   a) renewables (inverter interfaced),
   b) fossil fuel based (rotating equipment generators), and/or
   c) integrated energy storage,
6) Includes an EMS with
   a) controls for power exchanges, generation, load, storage, and demand response,
   b) load-management controls to balance supply and demand quickly,
7) Includes power and information exchanges that take place on both sides and across the PCC in real time.

To ensure the compliance of the modern Microgrids with all mentioned features, the main objective of this paper is to develop market based mechanisms needed to increase the ranges and applications of modern Microgrids. They also should ensure the capability of Microgrids in maintaining or improving the power quality, reliability, and resilience of the utility grid during times of interoperability. The fulfillment of these objectives will improve the energy infrastructure resilience, provide value added that improves electric power quality, enables assurance of power to critical loads, creates avenues for personal security, and supports emergency services.

Spinoff devices and secure communication will be beneficiaries for other applications such as more intelligent grid infrastructure, smarter loads that will be considered part of the smart grid infrastructure, building energy management, and optimized demand-side management (DSM) [1, 3, 6].

Microgrids architecture. With generation becoming more decentralized due to DER, energy markets and power grids need to adapt on the transmission and distribution level. Thus, microgrids and the associated concept of local energy markets become increasingly important for a sustainable and resilient network [4-6].

Modern Microgrids architectures should be in accordance to the Smart Grid Architecture Model (SGAM) which consists of three dimensions: Domains, Zones and Interoperability Layers (Fig. 1). It focuses on the interoperability of smart grid architectures by modelling electrical connections, information flows and communication technologies between physical components and software applications, while considering existing regulatory and business constraints. All important aspects of a smart grid are represented on the five interoperability layers: Component, Communication, Information, Function, and Business Layer.

The horizontal axis of the SGAM is structured into five domains. It consists of the traditional elements within the energy supply chain: Generation, Transmission and Distribution, and two rather decentralized domains, DER and Customer Premise.

The last domain includes (industrial, commercial and residential) prosumers.

The third dimension represents the hierarchical zones of power system management in a smart grid. It includes: Process (transformations of energy and the physical equipment involved), Field (equipment to protect, control and monitor the power system), Station (areal aggregation level for field level), Operation (power system control operation), Enterprise (commercial and organizational processes, services and infrastructures), and Market (possible market operations) [2, 5].

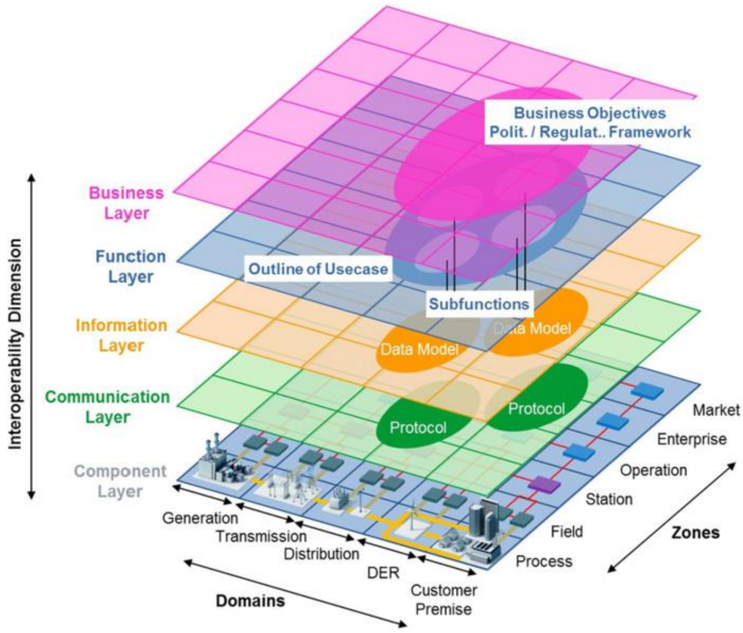

Figure 1 – Smart Grid Architecture Model (SGAM) [2].

Such architectures are presented in [7] (figure 2) represent the variety of technical and business processes which are all represented in one Microgrid model with huge amount of elements which have different purpose and technological base.

Microgrid Architecture

Power Grid layer	Device layer	Infrastructure layer	Physical equipment	Infrastructure	Physical layer
ICT layer	Smart meter layer	Comm. Layer	Protection and control	Communications	ICT layer
	Transmission layer	Intelligence layer	Automation and control	Operation and control	Control layer
Control layer	Communication layer		Optimisation and dispatch	Climate conditions	Market and business
Business layer	Management layer	Business models	Market operations	Business	
		Regulatory framework		Policies and standards	Regulatory layer

Figure 2 – Microgrid architecture models [7]

For the layers presented on Fig.2 One can distinguish main elements (see Fig. 3) which are required to provide the achievement of the Microgrid's stable operation.

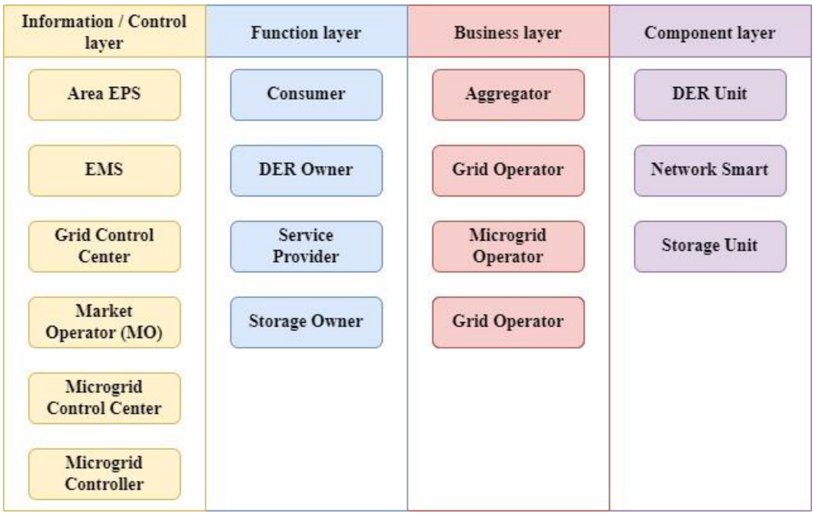

Figure 3 – Main elements of Microgrid in accordance with SGAM model

As we may see (Fig.4) such elements as "consumer", "DER owner" and "Storage owner" can perform as a prosumer both consuming and producing electricity in the local electricity market.

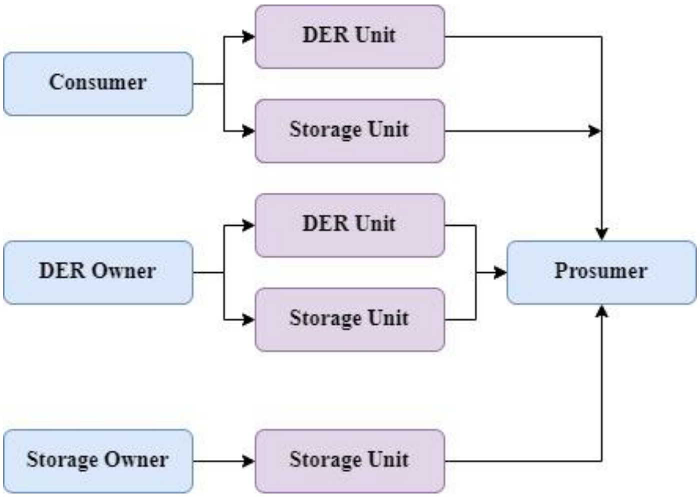

Figure 4 – Multilayer Microgrid elements interconnection

To provide the successful interaction between all these elements the market participant that purchases/sells electricity products on behalf of two or more consumers/ generators/ DERs or energy storage owners is needed. Aggregator or in case of small Microgrid – Microgrid operator performs such work.

Aggregation Price Models

One of the most complicated tasks for the aggregator is to hold the balance between diverse DER's and provide energy storage system when it is required. This complication can be solved by the application of various pricing mechanisms and DSM programs (see Fig. 5) [4, 6].

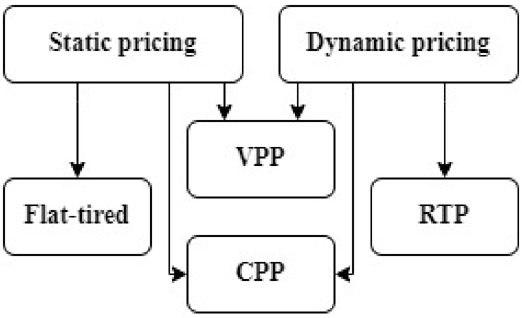

Figure 5 – DSM electricity pricing models.

While implementing variable pricing models the aggregator should take into account characteristics of different DER's and LCOE for each type of DER to stimulate each local electricity market participant separately.

The modern set of distributed technologies includes natural gas and diesel engines, gas turbines, fuel cells, solar panels, small hydropower plants and wind turbines (Table 1).

Table 1 - Characteristics of DER [3, 8]**.**

Characteristic	**PV**	**WP**	**SHPP**	**Fuel cell**	**Gas turbine**	**Steam turbine**	**Diesel generator**
Output	DC	DC / AC	AC	DC	AC	AC	AC
Management	-	-	-	+	+	+	+
Type of conv.	DC-DC-AC	AC-DC-AC	Synchr. or asynchr. generator	DC-AC	-	-	-
Eff-cy	6-20%	1-35%	92-94%	up to 85 %	30-45%	20-40%	30-45%
Ability to work on schedule	Restricted	Restricted	possibly	possibly	possibly	possibly	possibly
GHG level	-	-	-	-	High	High	High

According to peculiarities described in table 1 all DER (including storage systems) can be divided into 3 groups: Non-controllable DER, controllable DER and Storage system (see. Fig. 6). For each group of DER separate pricing model should be applied.

Cost analysis is one of the important components of the analysis of the effectiveness of an investment project. This analysis is especially important at the initial stage of performance appraisal, when there is still no complete clarity regarding the tariff policy of the project [3].

In general, the costs of generation in Microgrid include: investment costs, operating costs, fuel costs, external and liquidation costs. The cost of electricity production depends solely on the type of technology and fuel [9-12].

The target function is the minimization of the total annual costs of the Microgrid system.

Multi-criteria optimization is generally a difficult task, since even with two contradictory criteria, the choice of the optimal option requires expert evaluation and is often not obvious.

Variable costs are dependent on the capacity of consumers. For diesel generators, it depends on fuel consumption and power, costs for purchasing and delivering fuel. For wind generators and solar installations, consumption is associated with the inconstancy of their potentials.

Let's consider the system of dynamic pricing in real time (RTP). Electricity prices are calculated based on at least hourly measurement of consumption or with even greater detail.

Prices change at regular intervals of 1 hour or several minutes. Changing the price in such small intervals increases the effectiveness of the pricing scheme in reflecting the actual cost of supply, but such schemes require advanced technology to communicate and manage these frequent changes.

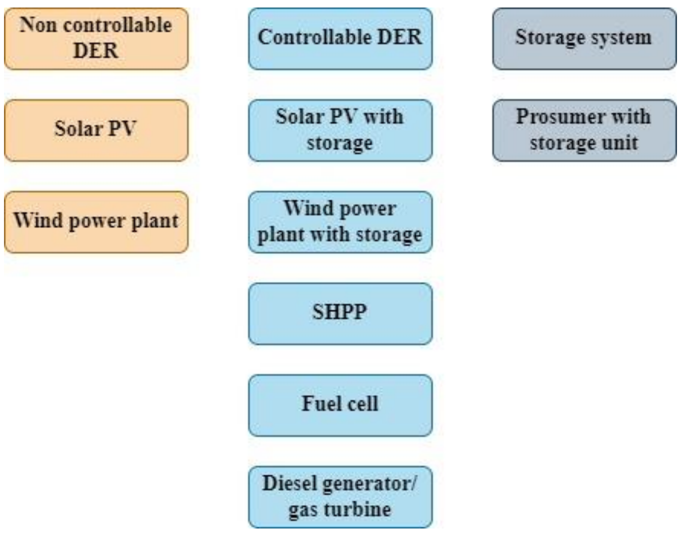

Figure 6 – DSM electricity pricing models.

The power of the consumer (load) is presented in the form of a stepped daily schedule of electrical loads (fig. 7) for 24 intervals.

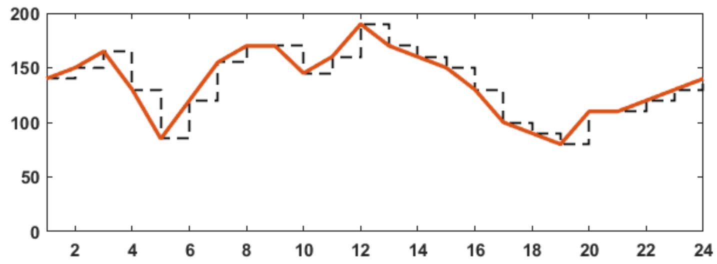

Figure 7 – Power of load

The Microgrid 1 system consists of diesel-generators.

Diesel generators have a low cost, ease of management and operation. But they have a number of disadvantages: high cost, impact on the environment and the need to deliver fuel. The introduction of renewable energy sources into the local system leads to savings in diesel fuel, but increases the installed capacity and cost of Microgrid energy equipment, and also affects reliability and operating modes.

In the system Microgrid 1, in order to reduce the cost of energy and reduce greenhouse gas emissions, one of the generators was replaced by a PV solar power plant with a DC-DC-AC converter (PV – non-controllable) (Microgrid 2).

The system Microgrid 3 consists of a solar generator with a storage system and a diesel generator as a guaranteed power source.

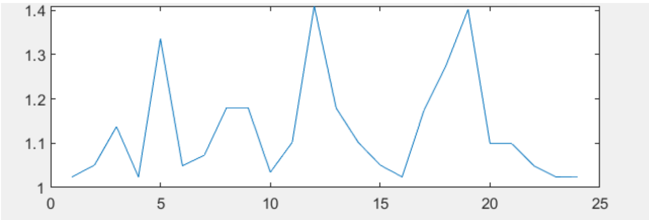

Figure 8 – Microgrid1

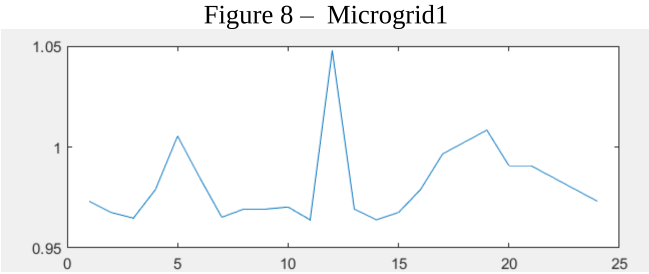

Figure 9 – Microgrid2

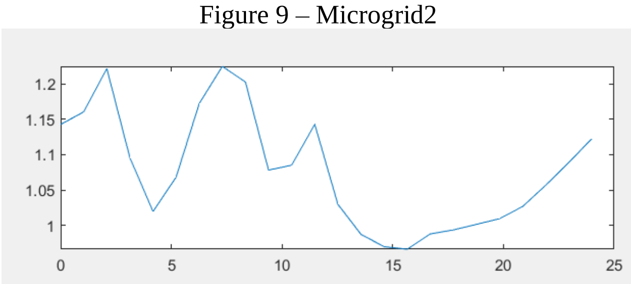

Figure 10 – Microgrid3

The analysis shows that with three types of Microgrids with different composition (fig 8 – 10). The system with a storage element has the best results, it has less energy consumption of diesel generators, which are the most expensive per 1 kW of energy.

Conclusion

The rapid development of Microgrid as part of the general power supply system states the problem of choosing the optimal technologies for its composition. The cost based approach presented in this paper allows to make optimal choice for the Microgrid structure depending only on the local prices on the market.

Methods for increasing the power factor of power converters are presented, which will increase the reliability of the system and reduce the number of failures. As a result, the cost of producing kWh of electricity will decrease.

The introduction PV with a storage system made it possible to increase energy efficiency, reduce primary fuel costs, and reduce the price due to lower current costs of PV, the cost per 1 kWh decreased by an average of 17% in relation to structures with diesel generators and depends on the characteristics of the generators, which currently generating electricity in the local system.

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ЦІНОВІ МОДЕЛІ АГРЕГУВАННЯ ДЛЯ MICROGRID СИСТЕМ З РОЗОСЕРЕДЖЕНИМИ ДЖЕРЕЛАМИ ЕНЕРГІЇ

Розвиток Microgrid систем викликав появу проблем пов'язаних з вибором складових для забезпечення оптимальної структури означених систем. У даній статті представлено цінові методи керування попитом для Microgrid систем з джерелами розосередженої генерації для оптимізації їх роботи. Обґрунтовано, що під час впровадження різноманітних цінових/ тарифних моделей агрегатор повинен враховувати характеристики різних розосереджених джерел енергії (РДЕ) (дизельні генератори, газові турбіни, паливні елементи, сонячні батареї, малі гідроелектростанції та вітрові турбіни) і LCOE для кожного типу РДЕ, щоб стимулювати до участі у програмах керування попитом кожного учасника локального ринку електричної енергії окремо. Розглянуто Microgrid систему з використанням трьох дизель-генераторів і варіантами заміни одного генератора на фотоелектричну або вітрогенераторну установку.

Ключові слова: мікромережі, динамічне ціноутворення, управління попитом

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