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CONCEPTUAL MODEL OF A MICRONETWORK WITH DISTRIBUTED ENERGY RESOURCES

V.P. Nerubatskyi*, D.A. Hordiienko**
Ukrainian State University of Railway Transport,
Feuerbach Square, 7, Kharkiv, 61050, Ukraine
e-mail: D.Hordiienko@i.ua

Micronetwork configurations are considered regarding the form of electricity transmission and distribution. The structures of connected units of distributed energy resources under different operating modes are described, in which special attention is paid to the primary control elements of distributed energy resources units for the instantaneous balance of active and reactive power, as well as to dispatch control architectures for long-term energy management. The characteristics of static and dynamic load are studied, the simulation of which is carried out by building physical models of typical loads. The parameters of the system of instantaneous balances of active and reactive power in micronetworks determined by instantaneous load tracking and load distribution between blocks of distributed energy resources are obtained. The circuit of resistive active filtering of blocks of distributed energy resources for active compensation of distorted loads is given. The presented method effectively suppresses harmonic voltage distortions at the output of blocks of distributed energy resources. Ref. 10, fig. 2.

Keywords: micronetwork, electricity converter, distributed energy resource, load distribution, control system.

Introduction. Recently, distributed energy resources have become widespread in power supply systems [1, 2]. Relative to small combined heat and power plants and renewable energy sources based on distributed generation units, distribution systems can no longer be considered as passive networks. The entire architecture of the future power supply system must be modernized in order to carry out more complex operations.

The concept of micronetworks connects several customers with several blocks of distributed energy resources, including blocks of distributed generation [3, 4]. In the context of a micronetwork, customers and units of distributed energy resources can not only operate in parallel with the main network, but also require a smooth transition to autonomous mode during abnormal network conditions. Unlike conventional distribution systems, such a network structure has much more flexibility in managing blocks of distributed energy resources, and therefore the potential benefits of better power quality, more reliable electricity and dispatching, and higher capacity in terms of supply efficiency due to the optimal location of micro-thermal power plants.

Characteristics of loads and blocks of distributed energy resources determine the stability of frequency and voltage in micronetworks [5, 6]. The widespread use of power electronic converters in power distribution units not only provides cost-effective and flexible interfaces, but also enables micronetworks to effectively control and manage electricity flows.

Thus, the issue of further improving the energy efficiency of electrical micronetworks is an urgent task.

The purpose of the paper. The purpose of the study is to increase the energy efficiency of the electric micronetwork with distributed energy resources. To achieve this purpose, the following tasks are set:

– consider micronetwork configurations regarding the form of electricity transmission and distribution;

– to investigate the control structure of blocks of distributed energy resources in the alternating current micronetwork;

– present a method of controlling instantaneous active and reactive power for an alternating current micronetwork.

The main material and study results. Usually, a micronetwork consists of a static switch, distributed critical and non-critical loads, several blocks of distributed energy resources with

ORCID ID: *https://orcid.org/0000-0002-4309-601X , **https://orcid.org/0000-0002-0347-5656

various interfaces of power electronics, protection devices, as well as measuring devices, control and control units [7, 8].

Micronetworks are divided into three categories depending on the application [9]: communal micronetworks; industrial and commercial micronetworks; remote micronetworks.

Another classification of micronetwork configurations can be made according to the method used for transmission and distribution of electricity by micronetworks [10]: direct current micronetworks; high-frequency alternating current micronetworks; linear-frequency alternating current micronetworks; hybrid DC and AC micronetworks.

Micronetwork and power management includes several issues that differ from low-voltage distribution networks of distributed energy resource units. Traditional power systems usually have kinetic energy stored in generator rotors, and these are considered essential for the stability of the systems. On the contrary, electronic-based micronetworks are dominated by units of distributed energy resources with electronic connection, inherently without inertia, but with the possibility of more flexible operation. Another problem is related to the resistive nature of low-voltage distribution networks, which leads to a coupling between active power and system voltage, and as a result, complicates the control of power flows and the voltage profile of the micronetwork. In addition, the entire energy system in the context of the micronetwork is expected to be interactive, smart and distributed, so advanced architectures are needed to manage energy consumption.

The general three-level hierarchical micronetwork control system is shown in Fig. 1.

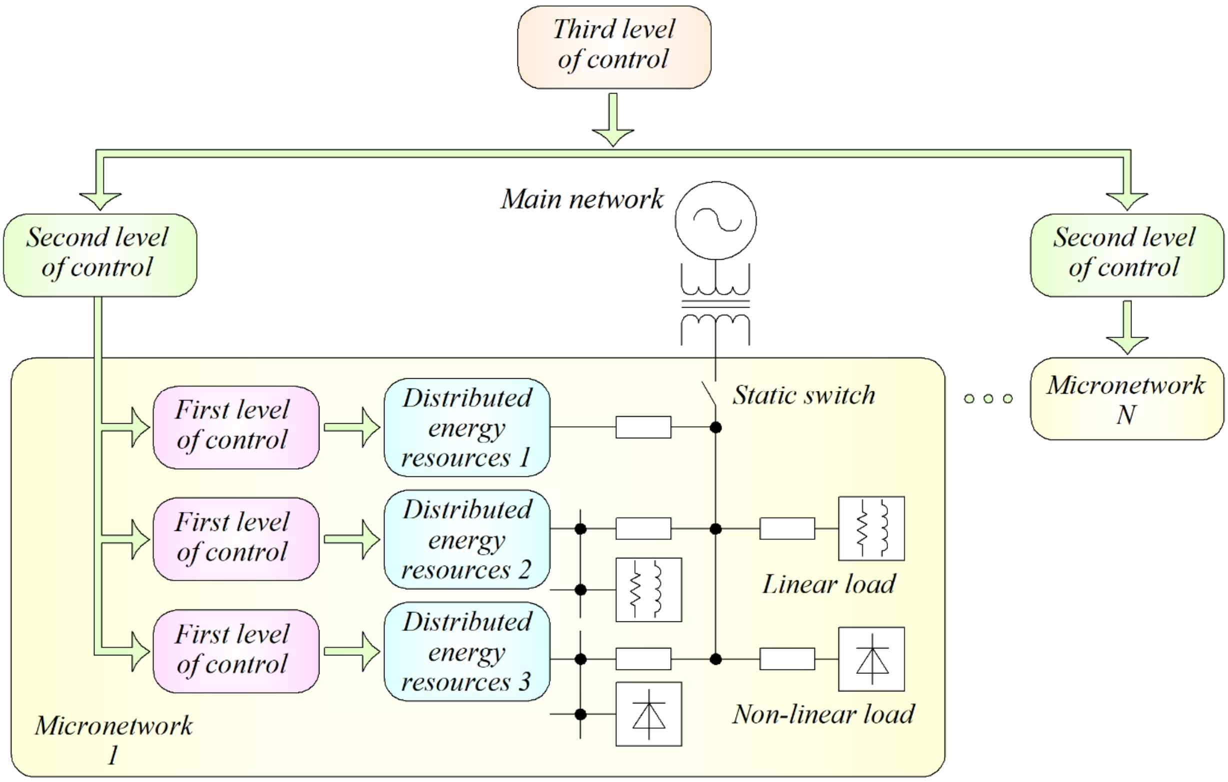

Fig. 1

The hierarchical control system for the micronetwork is organized as follows. The first level of control is the instantaneous balance of active and reactive power. The second level of control restores the voltage and frequency of the deflection system after transients and resynchronizes with the main network. The third level of control is intended for long-term energy management tasks. The throughput of the control system gradually decreases from the initial level to the higher level. The main differences from the control hierarchies of large power systems are the control methods used at each level. Special attention is paid to the primary control elements of distributed energy resources units for instantaneous balance of active and reactive power, as well as dispatch control architectures for long-term energy management.

Load characteristics have a significant effect on micronetwork characteristics such as transient stability and voltage stability. It is important to have a good understanding of load characteristics and to implement micronetwork management strategies.

Load modeling is carried out by building physical models of typical loads. Such load models are generally classified as static and dynamic models. The static load voltage characteristics can be set as:

$$\begin{cases} P = P_n \cdot \left[a_p \cdot \left(\dfrac{U}{U_n} \right)^2 + b_p \cdot \left(\dfrac{U}{U_n} \right) + C_p \right]; \\ Q = Q_n \cdot \left[a_q \cdot \left(\dfrac{U}{U_n} \right)^2 + b_q \cdot \left(\dfrac{U}{U_n} \right) + C_q \right], \end{cases} \tag{1}$$

where U_n is the nominal voltage; P_n is the active load power at rated voltage; Q_n is the reactive load power at rated voltage; a_p, b_p, C_p, a_q, b_q, C_q are the coefficients representing the proportion of different types of loads.

The coefficients must meet the following conditions:

$$\begin{cases} a_p + b_p + C_p = 1; \\ a_q + b_q + C_q = 1. \end{cases} \tag{2}$$

The frequency dependence of the load characteristic can be expressed using polynomials:

$$\begin{cases} P = P_n \cdot \left[a_p \cdot \left(\dfrac{U}{U_n} \right)^2 + b_p \cdot \left(\dfrac{U}{U_n} \right) + C_p \right] \cdot \left(1 + K_{pf} \cdot \Delta f \right); \\ Q = Q_n \cdot \left[a_q \cdot \left(\dfrac{U}{U_n} \right)^2 + b_q \cdot \left(\dfrac{U}{U_n} \right) + C_q \right] \cdot \left(1 + K_{qf} \cdot \Delta f \right), \end{cases} \tag{3}$$

where Δf is the frequency deviation from the nominal frequency f_0.

Based on formulas (1) and (3), the influence of static load voltage and frequency characteristics on the performance of the first-level droop control system shows that the dependences of voltage and frequency of loads require that the blocks of distributed energy resources adopt the characteristics of the decay of the frequency of active power and reactive voltage.

Instantaneous balances of active and reactive power in micronetworks are usually guaranteed by instantaneous load tracking and load sharing among blocks of distributed energy resources.

For the static characteristics of micronetworks, the low resistance coefficient of the distribution network affects the accuracy of load distribution. In addition, there are harmonic and unbalanced powers that are poorly compensated in the presence of non-linear and unbalanced loads.

For the dynamic behavior of micronetworks, when choosing the drop characteristics for blocks of distributed energy resources, it is necessary to take into account the dependences of voltage and frequency of loads, otherwise the controllers may not provide proper sharing and this will lead to instability.

It is possible to use a circuit of resistive active filtering of blocks of distributed energy resources with electronic communication for active compensation of distorted loads. And in order to mitigate the above disadvantages, improved variations based on *P-ω* and *Q-V* drop characteristics can be used. This method presents new decay characteristics between different frequency components of the controlled signal and active power (*P*), reactive power (*Q*) and distortion power (*H*), respectively.

The circuit based on the resistive active filtering method is shown in Fig. 2.

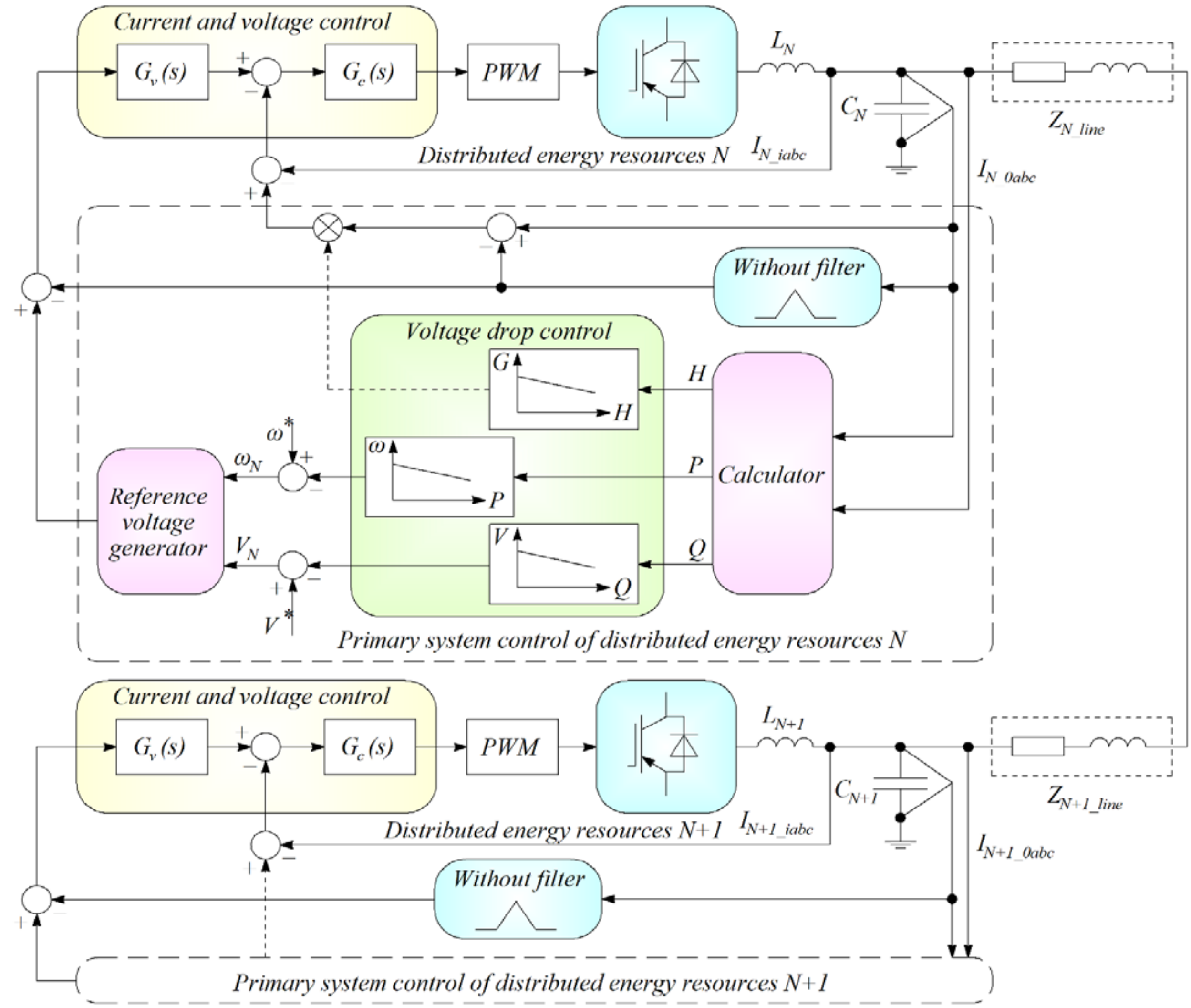

Fig. 2

The output resistance of the electronically coupled distributed energy resource units can be chosen arbitrarily, which provides a flexible way to stabilize the load characteristic. The output impedance consists of an inductance and a parallel load connection is suggested for accurate distribution of non-linear loads.

This method effectively suppresses the harmonic distortion of the output voltage of the distributed energy resource units, only a high-bandwidth current control circuit is required, which simplifies the internal voltage and current of the control circuit.

Conclusions. On the basis of the conducted research, the following conclusions can be drawn:

– of the considered configurations, the micronetwork of hybrid direct and alternating current has the best efficiency, as it provides the highest productivity for aggregates of distributed energy resources;

– from the described structure of connected blocks of distributed energy resources under different operating modes, the approach of multi-loop control is a promising solution for forming a network;

– from the presented method of resistive active filtering of blocks of distributed energy resources, harmonic distortions of voltage at the output of blocks of distributed energy resources are effectively suppressed.

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КОНЦЕПТУАЛЬНА МОДЕЛЬ МІКРОМЕРЕЖІ З РОЗПОДІЛЕНИМИ ЕНЕРГЕТИЧНИМИ РЕСУРСАМИ

В.П. Нерубацький, канд. техн. наук, **Д.А. Гордієнко**
Український державний університет залізничного транспорту,
майдан Фейєрбаха, 7, Харків, 61050, Україна
e-mail: D.Hordiienko@i.ua

Розглянуто конфігурації мікромережі щодо форми передачі та розподілення електроенергії. Описано структури з'єднаних блоків розподільних енергетичних ресурсів за різних режимів експлуатації, у яких особлива увага приділяється первинним елементам контролю одиниць розподільних енергетичних ресурсів для миттєвого балансу активної та реактивної потужностей, а також архітектурам диспетчерського керування для тривалого терміну енергетичного менеджменту. Досліджено характеристики статичного та динамічного навантаження, моделювання якого здійснюється завдяки побудові фізичних моделей типових навантажень. Отримано параметри системи миттєвих балансів активної та реактивної потужностей у мікромережах, що визначаються миттєвим відстеженням за навантаженням та розподіленням навантаження між блоками розподілених енергетичних ресурсів. Наведено схему резистивної активної фільтрації блоків розподілених енергетичних ресурсів для активної компенсації спотворених навантажень. Представлений метод ефективно гасить гармонічні спотворення напруги на виході блоків розподільних енергетичних ресурсів. Бібл. 10, рис. 2.

Ключові слова: мікромережа, перетворювач електроенергії, розподілений енергетичний ресурс, розподілення навантаження, система керування.

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