

# Study of energy parameters in alternative power source microgrid systems with multilevel inverters

Исследование энергетических параметров в microgrid системах с альтернативными источниками энергии при использовании многоуровневых инверторов

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**Abstract:** Microgrid-systems with alternative energy sources in which multilevel inverters are used are becoming more widespread. Possible circuit implementations of multilevel inverters for thus systems are shown. A comparative analysis of the energy parameters of multilevel inverters using various modulation algorithms is presented. important requirement of multilevel voltage inverters is to ensure high quality output voltage, as well as ensuring minimum power loss and maximum efficiency. An overview of known modulation algorithms for output voltage generation in multilevel inverters is presented. The analysis of existing algorithms was performed and the choice of the optimal algorithm for use in the scheme of solar power plants was carried out.

**KEYWORDS:** MICROGRID SYSTEM, MULTILEVEL INVERTER, SOLAR POWER PLANT, PWM, AMPLITUDE MODULATION.

## 1. Introduction

Researchers are increasingly paying attention to alternative power sources [1, 2]. A wind power plant is designed to convert the kinetic energy of a wind stream into mechanical energy of rotation of the rotor with its subsequent conversion into electrical energy [3, 4]. Schematic diagram of a wind farm is shown in Fig. 1.

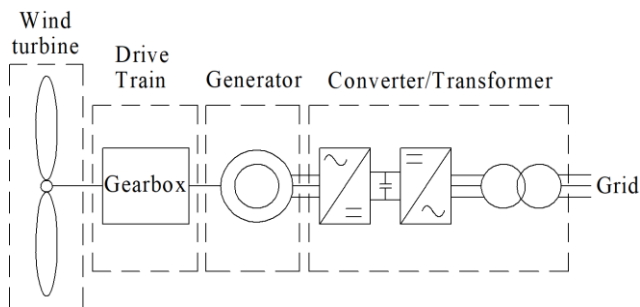


Fig. 1. Schematic diagram of a wind farm

A solar power plant is designed to convert solar radiation into electrical energy [5, 6]. The most common type of solar power plants is based on flat photovoltaic modules of single crystalline or polycrystalline type, which provide conversion of solar radiation to direct current. Depending on the circuit used, the direct current can be inverted to AC or stabilized to charge the batteries [7, 8]. Schematic diagram of a solar power plant is shown in Fig. 2.

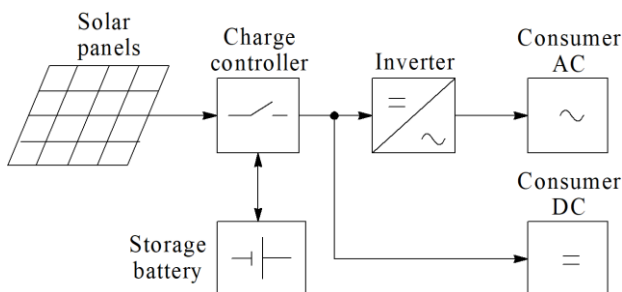


Fig. 2. Schematic diagram of a solar power plant

The peculiarity of a solar power plant is that a large number of solar panels can be connected in series. In this case, the voltage on the solar panels, depending on the degree of illumination is variable [9, 10].

The task of the conversion system of both solar and wind power plants is the formation of sinusoidal output voltages with stable amplitude and frequency [11].

Different types of semiconductor converters as well as different control systems can be used to form a sinusoidal output voltage [12, 13].

At the same time, the urgent task is to create and research transformer systems that provide the creation of autonomous power supply systems with stable voltage.

## 2. The power part – conversion systems

It is possible to use different topologies of semiconductor converters in microgrid systems with alternative power sources [14, 15]. The most common topologies are as follows: multilevel inverters with fixed diodes (Fig. 3), modular multilevel inverters (Fig. 4), cascade multilevel inverters (Fig. 5). Each of these topologies has its advantages and disadvantages [16, 17].

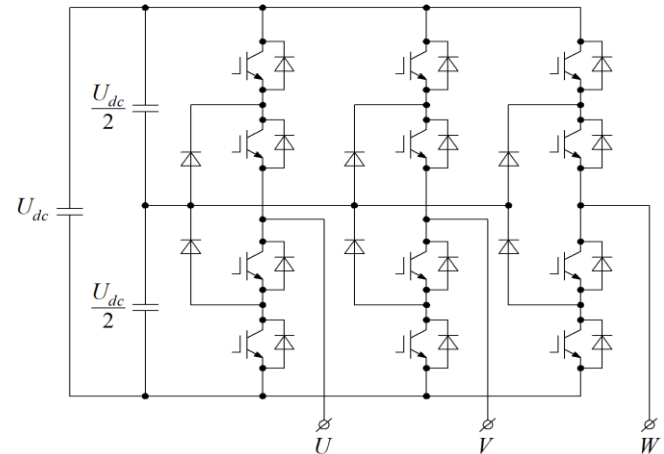


Fig. 3. Multilevel inverter with fixed diodes

Advantages of multilevel inverter with fixed diodes include adjusting the amplitude of the first harmonic of the output current, which is necessary for scalar and vector control. At the same time, the disadvantages include high switching frequency of the power keys, which leads to the heating of semiconductor elements, parts of the isolation of the converter, increasing the dynamic losses and consequently reducing the efficiency of the converter. Other hybrid control systems are known, such as:

- phase disposition;
- phase opposition disposition;
- alternate phase opposition disposition;
- inverted sine carrier.

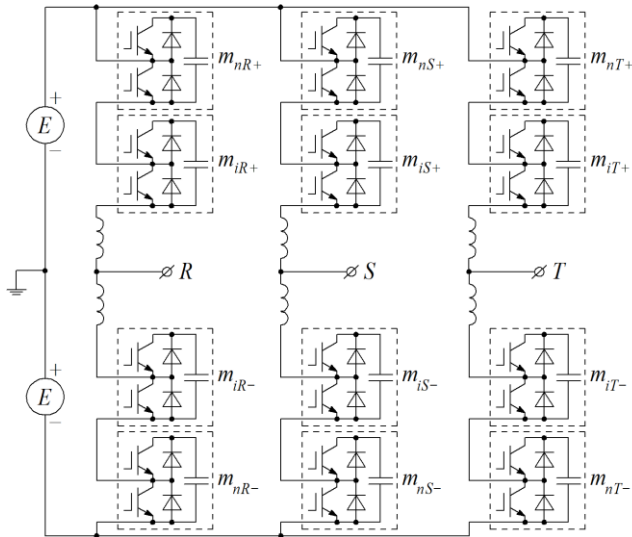


Fig. 4. Modular multilevel inverter

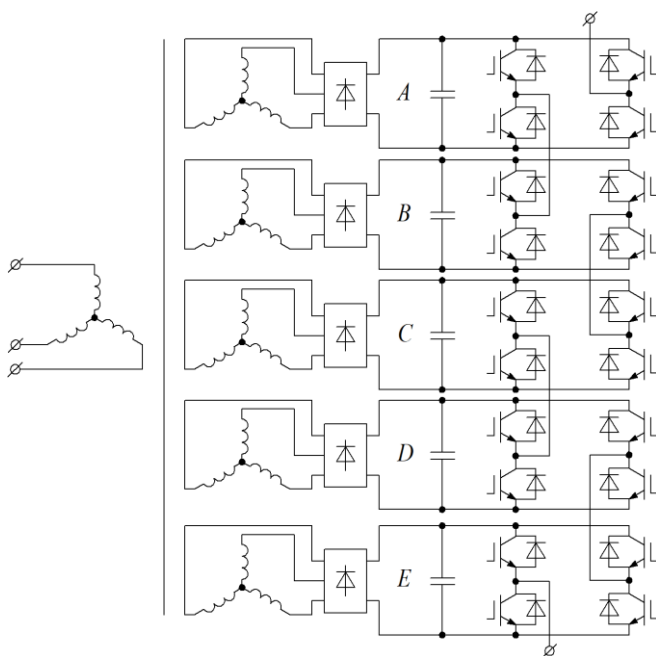


Fig. 5. Cascade multilevel inverter

One of the basic requirements for multilevel inverters is to provide high sinusoidal output voltage and output current. Particularly relevant requirements for the form of output voltage for converters that operate as a power source for their own power supply [18, 19].

Therefore, the most critical requirements for the output inverter are:

- maximum efficiency;
- increased reliability (work in case of failure);
- providing maximum sinusoidal output voltage.

In this case, the realized parameters depend not only on the applied power scheme, but also on the applied modulation algorithm [20, 21].

### 3. Modulation algorithms in multilevel inverters

One of the most important parameters of multilevel inverters is the sinusoidality of output voltage. There are quite a number of different modulation algorithms that allow to obtain different sinusoidality of the output voltage and different contents of higher harmonics [22, 23].

The sine wave of the output voltage in multilevel inverters is accepted to be estimated by the total harmonic distortion (THD), which is an integral indicator of sine wave, which determines the rms content of higher harmonics [24, 25].

The realized sinusoidality of the output voltage are directly dependent on the modulation type implemented. There are many different modulation algorithms for output voltage generation in multilevel inverters. The most common of them are: various variations of sinusoidal PWM (level-shifted, phase-shifted, level-phase-shifted), space-vector PWM, amplitude modulation, etc. [26, 27]. At the same time, all these algorithms cause different sinusoidality (THD) of output voltage and current, as well as different power losses in the converter. This is due to the fact that higher voltage harmonics cause the presence of higher current harmonics, which causes additional power losses in the power lines and load. Among the described algorithms, the best indicators of sinusoidal output voltage are algorithms based on a single modulation [28, 29].

The main varieties of sinusoidal PWM are shown in Fig. 6.

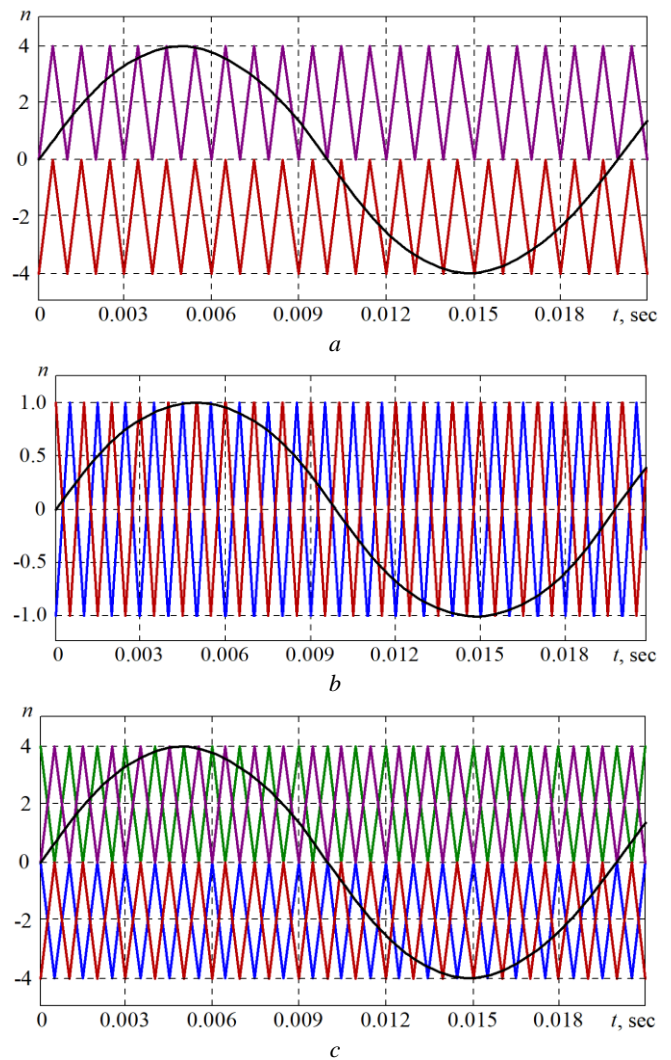


Fig. 6. Variations of pulth-width modulation: a – level-shifted; b – phase-shifted; c – level-phase-shifted

Spatial-vector PWM modulation algorithm is shown in Fig. 7. Space-vector modulation is used to control active three-phase converters. With vector-modulation, it is not instantaneous voltage values applied to the windings that are calculated, but the moments of connecting the windings to the power bridge in order to form a given voltage vector.

The switch management algorithm of the autonomous inverter in the space-vector modulation mode is based on the formation of

the required position of the voltage vector in space at each time interval.

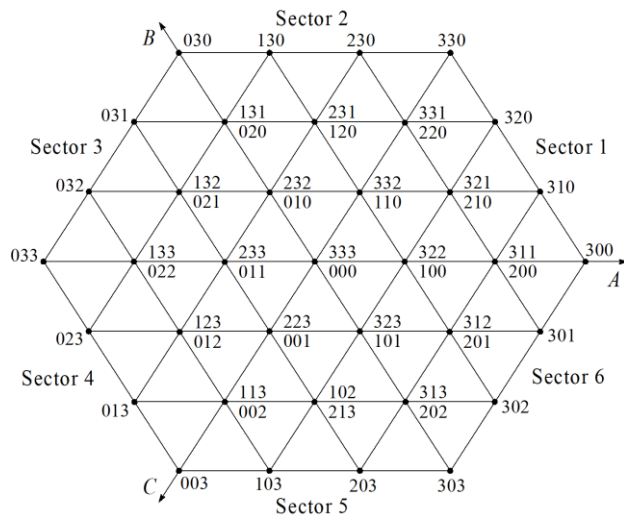


Fig. 7. Space-vector PWM

The amplitude modulation algorithm is shown in Fig. 8. The switching time of each level is determined during the intersection of sine amplitudes of 0.5; -0.5; 1.5; -1.5; 2.5; -2.5. The effect of amplitude sampling is the amplitude quantization of a sinusoidal signal into a stepped view. The output is calculated using the rounding method to the nearest value, which creates an output signal symmetric about zero [30, 31]. The number of quantization steps is determined by the physical number of possible stages when forming the output voltage in a multilevel inverter. Form optimization is achieved by determining the value of the  $A_{sin}$  amplitude, in which the rms content of the higher harmonics will be minimal [32, 33]. The concept of obtaining the optimum form of gradual-discrete voltage is reduced to minimizing and symmetrizing the area of higher harmonics with respect to the fourth period of the output voltage form [34].

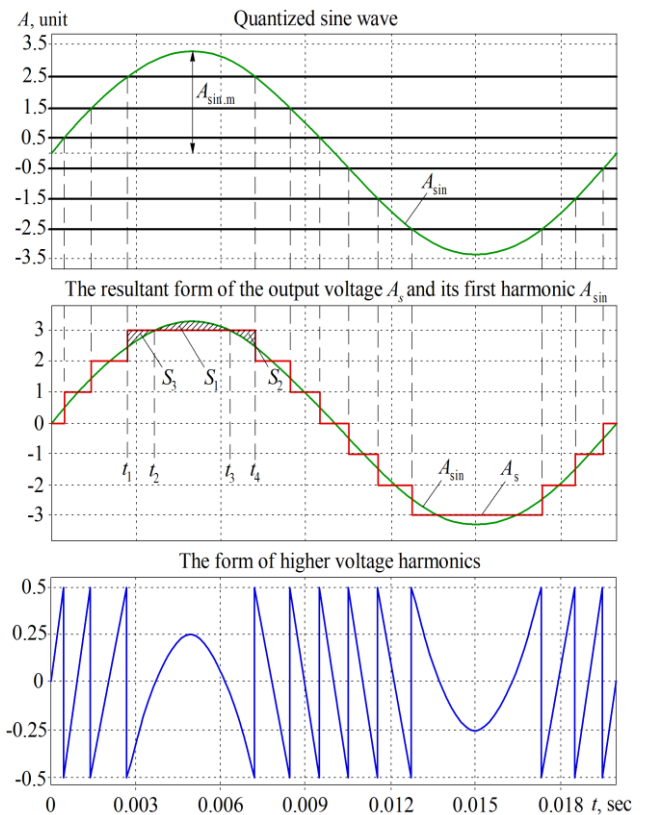


Fig. 8. The algorithm of amplitude modulation

Comparison of the harmonic distortion coefficient for different modulation algorithms is shown in Table 1.

Table 1

Comparison of harmonic distortion coefficient for different modulation algorithms

Cell type and modulation algorithms	Output voltage CMLI, V	Output voltage of one cell, V	THD of the output voltage of one cell, %	THD total output voltage, %	THD output current, %
2-level cell with sinusoidal PWM	2571.44	2998.5	99.29	68.27	14.91
2-level phase-shifted PWM cell	2284.67	2392.47	51.74	40.05	4.54
2-level cell with phase-shifted PWM without interleaving	2320.9	2395.27	51.74	44.06	5.77
3-level cell with level-shifted PWM with interleaving	2666.4	2390.03	52.82	32.22	3.91

#### 4. Results and discussion

Of the presented algorithms, the best performance is the algorithm of amplitude modulation, which allows to obtain the form of output voltage of a multilevel inverter with any number of degrees, optimized by the content of higher harmonics, namely by the minimum of the coefficient of harmonic distortions. The proposed algorithm allows to obtain the lowest possible THD for any voltage level. The advantage of the proposed algorithm in comparison with similar optimization algorithms is the provision of smaller harmonic distortions and its relative simplicity. The presented algorithm is based on the amplitude modulation of a

sinusoidal signal with 25 % remodulation relative to the highest discretion.

#### 5. Conclusion

The paper presents an overview of energy parameters of cascade multilevel inverter with different modulation algorithms. The best power parameters has MVSI with level-shifted PWM in interleaving mode. The analysis of existing algorithms was performed and the choice of the optimal algorithm for use in the scheme of solar power plants was carried out.

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