PECULIARITIES OF THE FEASIBILITY STUDY FOR ON-GRID PHOTOVOLTAIC INSTALLATION OF PRIVATE HOUSEHOLD

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Abstract: The article is devoted to the development of alternative energy sources, in particular, on-grid photovoltaic installation of low power. The Ukrainian regulatory framework has created the prerequisites for the active development of this industry by a simplified system of interconnection sources of private households to the electrical power system and a high rate of «green» tariff for electricity for private households, producing electricity from solar energy. Similar tariffs are available in other countries, in particular in the countries of the European Union, under the name feed-in-tariffs, so private households can get paid for excess electricity that do not consume on their own households and sent into the grid.
The article deals with the disadvantages of existing methods for estimating future profits from the sale of electric energy at a «green» tariff (feed-in tariff) and proposes a method for taking into account the technical limitations on normalized electricity quality indices. It is shown, that ignoring the technical limitations, concerning the level of voltage, leads to overestimating the calculated value of the generated electricity up to 33 %, that can grow due to the increase of payback period up to 1,5 times. The possibility of transforming the overage of unrealized electric energy into heat is also considered.
Keywords: on-grid photovoltaic installation, feasibility study, technical limitations, annual electricity production.

1. Introduction

Today, the issue of using environmental sources of electricity generation is very important. The main reasons for the active development of solar energy in Ukraine are the high rate of the green tariff, as well as the fact that due to the improvement of production, prices for generating equipment of alternative energy facilities are reduced. Full information about feed-in tariffs in Europe, including green tariff in Ukraine, can be found in [1].

According to statistics from Association «Solar Power Europe» [2, 3] the significant growth of the solar power industry is observed. In 2018 in EU 8GW of installed power has been put into operation – by 36 % more solar power plants than in the previous year. As for Ukraine, at the end of 2018, there were 7.5 thousand private homes, equipped with solar panels with a summary power 157 MW [3], and this power increases every year. Today, a large number of companies offers their services on finished turnkey projects for on-grid photovoltaic installations for private households. Annual electricity generation at the «green» tariff is within the range of 30–40 MWh for 30 kW photovoltaic installations. The payback period does not exceed 2–4 years.

In accordance with Article 63 of the Law of Ukraine "On the Electricity Market" [4], the supplier of universal services is obliged to purchase electrical energy, produced by generating installations of private households, installed power of which does not exceed 30 kW, at a "green" tariff in excess of monthly electricity consumption by such private households. However, in accordance with Article 58 of this law, the connection of consumers' generating installations, including private households, should not lead to deterioration of normative parameters of the quality of electric energy in the network and security of supply.

The on-grid photovoltaic installation for private households feature is that the investment is proportional and sometimes even smaller than the cost of additional reconstruction, for example, to increase the bandwidth of the electrical network, therefore, as a rule, their connection to low voltage distribution networks is carried out without any additional changes of transmission lines cross sections.

Thus, the real financial payback of an on-grid photovoltaic installation should include not only the meteorological features of the region, but also the peculiarities of the operation modes of electrical networks. So, when generating electricity from a solar power plant into an unloaded distribution network, a situation may arise, when the voltage on the generator reaches the maximum allowable value and it will be necessary to limit generation.

2. Materials and Methods

The annual cost of electricity, generated by installations of private households, is influenced by the following factors:

1) meteorological features of the region (it is possible to consider them by using normative indicators, and (or) by processing the statistics of weather stations, for example [5]);

2) the date of put into service of generating installations (the rate of "green" tariff, according to [4], will decreases from January 1, 2020, and from January 1, 2025);

3) design features of a photovoltaic installation (use of mono or polycrystalline silicon, the presence of trackers for the rotation of a photovoltaic installation perpendicular to solar radiation, etc.);

4) influence on the operation modes of low voltage distribution electrical networks (the need to maintain electricity quality indices within the permissible limits [4, 6–9]).

Fourth of the listed factors is usually checked for one or two modes of work, which in our opinion is incorrect and requires additional analysis.

Consider the change in voltage values in a low voltage distribution network with a voltage of 0.38 kV in length L=0.5 km (which is a characteristic of the private sector) with a photovoltaic installation, at a distance of X from the beginning of the line.

The calculations of the operation modes are carried out with the following assumptions:

– distribution network has no branches;
– the load is evenly distributed along the line;
– given total load power at the beginning of the line;
– during the calculation of flow distribution in the electrical network, the influence of power losses is not taken into account;
– the power of the power supply source is much greater than the power of the load and the power of the photovoltaic installation, which allows to arbitrarily consider it as a source of unlimited power with unchanged electromotive force.

In neglecting the transverse component of voltage loss, on the site from the power source to the photovoltaic installation, the voltage drop is equal to:

$$\Delta U_{01} = \frac{P_L (r_0 + x_0 \cdot tg\phi_L)}{2 \cdot U_{nom} \cdot L} \cdot \left(2L \cdot X - X^2\right) - \frac{P_{PV} \cdot r_0 \cdot X}{U_{nom}}, \qquad (1)$$

where P_L – the load power that occurs at the beginning of the transmission line; $tg\phi_L$ – the averaged load factor; r_0 and x_0 – the running active and reactive resistance of the transmission line; *L* – the length of the transmission line; *X* – the distance from the beginning of the transmission line to the photovoltaic installation; P_{PV} – the active power of the photovoltaic installation; U_{nom} – the rated voltage of the network.

3. Results

Fig. 1 shows the graphical dependencies of voltage variation along the transmission line, when the power of the photovoltaic installation is changed, and its interconnection point is fixed. Dotted line shows the maximum allowable value of voltage. As can be seen, the same values of power generation, connected to different points of the electrical network, can in one case satisfy and in another case not satisfy allowable voltage deviation. However, it can be seen, that the highest voltage values are observed at the beginning of the transmission line and at the point of attachment of the photovoltaic installation, thus it is important to analyze the voltage range in these points.

The following simulation results characterize only one of the possible operation modes of an electrical network with the attached photovoltaic installation. In fact, the load power has daily and seasonal changes, as well as the power, generated by the photovoltaic installation.

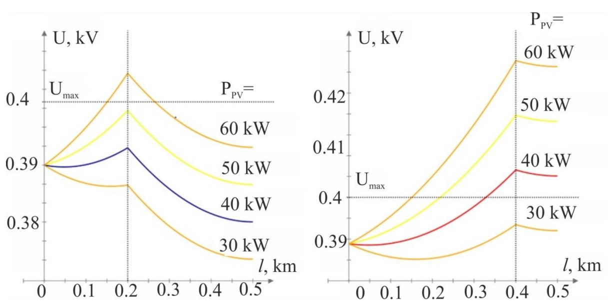

Fig. 1. Voltage variation along the transmission line when the power of the photovoltaic installation is changed, and its interconnection point X is fixed: *a* – X=0.2 km; *b* – X=0.4 km

Fig. 2, *a* shows the mathematical expectation for typical daily graphics for communal household consumer's active power, as well as the change in the active power of the photovoltaic installation in sunny weather in July with intervals of averaging of 1 hour.

Using (1) we obtain a voltage change at the point of interconnection of the photovoltaic installation (**Fig. 2, *b***).

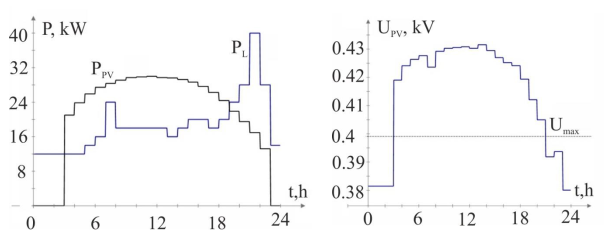

Fig. 2. Daily graphics of power and voltage: *a* – power variation of the photovoltaic installation P_{PV} and the load P_L ; *b* – voltage variation during the sunny day in electrical network with the photovoltaic installation

As can be seen from the graph (**Fig. 2, *b***), the voltage exceeds the maximum permissible values only at certain intervals of time. In order to find out the expediency of increasing the installed power of the photovoltaic installation, a mathematical experiment was conducted, during which annual electricity generation by the photovoltaic installation was calculated, taking into account the technical limitations on the voltage regime and without it. In the course of calculations, the statistics of weather conditions for 2018 year in Chernihiv (Ukraine) were taken into account [5] as well as daily and seasonal changes in the load of consumers in accordance with [10]. The results of the modeling of the indicators for the photovoltaic installation units in accordance with **Fig. 1** are summarized in **Table 1**.

Table 1
Annual volumes of electricity production by the photovoltaic installation

P_{PV}, kV	W_{year}, MWh, interconnected in point			
	X=0.2 km		X=0.4 km	
	with limitation	no limitation	with limitation	no limitation
20	21012	21012	20802	21012
30	31518	31518	29169	31518
40	39671	42024	32106	42024
50	45885	52530	35433	52530

As seen from the table, taking into account the voltage mode leads to a decrease in the calculated value of the electric energy produced, which for the connected power of 50 kW is almost 33 %. When the installed power of the source decreases to a certain value, the excess voltage is not observed, which allows to use a cheaper generation control system.

4. Discussion

The obtained data allows low voltage electrical networks to estimate the power of the attached energy sources, which will not negatively affect the operating modes of these networks.

As you can see from the charts on fig.1, the closer the energy source to the end of the line, the less power can be given to the network, because the value of the voltage will exceed the permissible and not ensured the normalized value of the voltage deviation. In such cases, the energy producer should take care of how to implement the energy, produced in hours of minimum loads, for example, by converting it into heat.

Existing approaches to choosing the power of distributed generation are based on providing optimum power and the place of its interconnection for certain operation modes [11, 12]. The advantage of the proposed in this paper method is increasing of the accuracy of estimated electricity production, but it requires a sufficient amount of statistical meteorological data and statistics on the operation modes of the electric network.

The obtained results can be applied in the feasibility study for on-grid photovoltaic installations of private households and power plants that generate electricity in low voltage distribution networks. Further research will be directed on the availability of several objects of generation at different points in the network.

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