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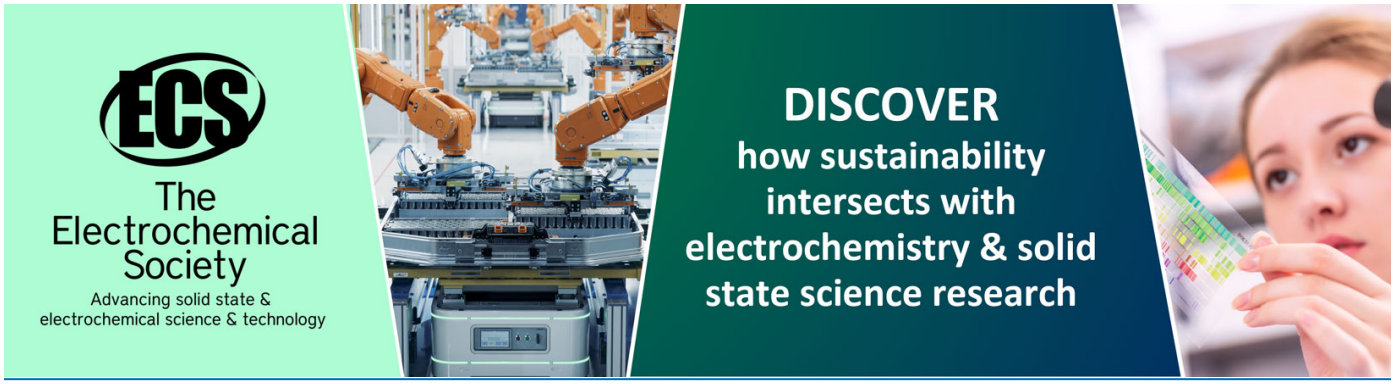

Analysis of energy quality in power supply systems with grid-connected solar power plants

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Abstract. The article presents an analysis of the quality of voltage at a consumer of electricity in power supply systems with a network solar power plant connected in parallel to the centralized network. The legislative base of the Russian Federation, regulating the construction and operation of grid solar power plants, requirements for the quality of energy in a centralized grid have been studied. The block diagram of the operating experimental solar power plant is presented. On the basis of this station, experimental studies of the influence of the operation of a solar power plant on the quality of energy at the consumer have been carried out. This study was carried out using a Fluke 345 power quality analyzer. The authors analyzed the experimentally obtained data on voltage changes and harmonic distortions at the consumer in two series of experiments (with a solar power plant in operation and with a solar power plant disconnected). On the basis of the analysis, conclusions were drawn about the reduction of peak voltage deviations at the consumer and a decrease in the total harmonic distortion factor when the solar power plant is operating. The relationship between voltage and harmonic distortion is described mathematically. Based on the results of the studies, conclusions were drawn about improving the quality of energy for an agricultural consumer when supplied with electricity from a grid solar power plant in parallel with a centralized grid.

1. Introduction

The constant growth of electricity consumption by the population of Russia requires the construction of new environmentally friendly generating plants (public and private), operating on renewable energy sources. In this regard, the regions of Russia [1-4] are considering the possibility of increasing the share of energy obtained from renewable sources. For example, at the moment in the Saratov region there are about four relatively large solar power plants with a total capacity of 55 MW [5].

According to the amendments [6], generating plants operating on renewable energy sources of various forms of ownership, the issuance of surplus generated electricity to the centralized network. The law regulates the procedure for connecting such installations to networks with a voltage of up to 1 kV and limits the power of the connected installation to 15 kW.

Normative acts [7-9] prescribe provisions for connecting solar power plants to the centralized network, while there are no requirements for standardizing the quality of electricity. In addition, the results of studies of the effect of low-power solar power plants on the quality of energy at the consumer have not been recorded.

2. Materials and methods

The study of the voltage quality was carried out on the basis of a private solar power plant with a capacity of 1.1 kW described in [10]. The experimental setup is shown in figure 1.

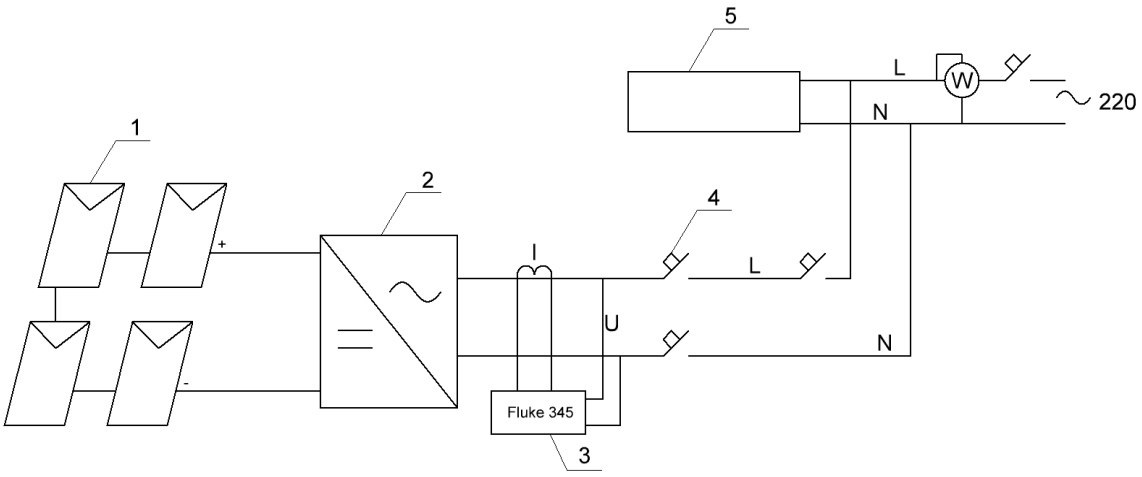

Figure 1. Schematic of a grid solar power plant: 1 - solar panels, 2 - grid inverter, 3 - Fluke 345 power quality analyzer, 4 - circuit breaker, electricity consumer (private house).

The circuit is a grid-connected solar power plant operating in parallel with a centralized grid, at the output of which a Fluke 345 power quality analyzer is connected.

The experimental study was carried out in two stages. In the first step, using a Fluke 345 power quality analyzer, the voltage and harmonic distortion were recorded while the solar power plants were operating in parallel with the centralized grid. The device was connected at the output of the inverter, as shown in figure 1. At the second stage, similar measurements were carried out with the grid station disconnected. The place of connection of the device has not changed.

3. Results

The results of measurements of the maximum and minimum voltage deviation with the operating and disconnected grid solar power plant are presented in table 1.

Table 1. Voltage deviations.

The station is working		Station disconnected	
Umin, V	Umax, V	Umin, V	Umax, V
216.6	235.4	212.1	240.3

The maximum and minimum values of voltage harmonic distortion recorded during measurements are presented in table 2.

4. Discussion

The reasons for the appearance of higher harmonics are consumers connected to the mains, which have non-linear input circuits and, as a result, consume a pulse current. The nonlinear nature of the circuit is determined by the presence of semiconductor nonlinear elements in it (rectifier bridges, diodes, thyristors, etc.).

Harmonic current components will interact with source currents, thereby causing voltage harmonics. The harmonic components of the voltage are superimposed on the fundamental sine wave of the voltage,

which distorts the voltage waveform. It can be mathematically described by the Fourier form equation (1):

$$f(t) = \alpha_0 + \sum_{n=1}^{\infty} \alpha_n \cos(n\omega_0 t) + \sum_{n=1}^{\infty} b_n \sin(n\omega_0 t) \quad (1)$$

Where α_0, α_n, b_n - are functions of the trigonometric series, n - is the harmonic number, ω_0 - is the angular frequency of the fundamental component.

Table 2. Harmonic distortion.

	The station is working		Station disconnected	
	min	max	min	max
THD_U	0.1%	4%	1.2%	4.5%
3rd harmonic	0.5%	3%	0%	4.4%
5 harmonic	1.4%	3.6%	0.9%	2.9%
7 harmonic	0%	1.7%	0%	1.5%
9th harmonic	0%	1.2%	0%	0.9%
11th harmonic	0%	0.6%	0%	0.5%

Total harmonic voltage distortion (THDU) is defined as (2):

$$TDH_U = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2 + \cdots}}{V_1} \quad (2)$$

Where V1 is the effective value of the phase-to-phase (phase) voltage of the 1st harmonic (fundamental frequency); V2, V3 ... Vn - values of the phase-to-phase (phase) voltage of higher harmonics, multiples of the fundamental frequency.

Based on the data presented in Tables 1 and 2, we can talk about an increase in the quality of voltage at the electricity consumer, if the power supply is from a grid solar power plant and a centralized network. When the solar power plant is operating, the peak voltage values are reduced by 9 V, which in turn, according to formula (2), leads to a decrease in the harmonic distortion THD_U by approximately 1.6%.

5. Conclusion

The use of solar power plants in the agro-industrial complex and in the private sector allows solving various problems - saving electricity, preserving heat, reducing electricity losses during transmission).

The analysis of the data obtained showed that the use of grid-connected solar power plants makes it possible to improve the quality of voltage and reduce harmonic distortions at the electricity consumer. At the same time, the indicators of the quality of the generated electricity will meet the requirements for centralized networks [7].

References

[1] *The Energy Strategy of the Russian Federation for the period up to 2035* Retrieved from: http://static.government.ru/media/files/w4sigFOiDjGVDYT4IgsApssm6mZRb7wx.pdf

[2] *Resolution of the Head of the Republic of Khakassia "Scheme and program for the prospective development of the electric power industry in the Republic of Khakassia for 2016–2020" dated May 16, 2016 No. 36-PP* Retrieved from: https://r-19.ru/documents/2016-g/28303/

[3] *Order of the Head of the Republic of Bashkortostan "Scheme and program for the prospective development of the electric power industry of the Republic of Bashkortostan for the period 2016-2020" dated April 29, 2016* Retrieved from: https://www.garant.ru/files/3/6/733363/

prilojenie_n_2.pdf
[4] Gimadi V, Amiragyan A, Pominova I et al 2017 *Development of solar energy* (Moscow: Analytical Center for the Government of the Russian Federation) 27
[5] *Electricity and capacity market* Retrieved from: https://www.np-sr.ru/ru/market/vie/index.htm
[6] *Federal Law of December 27, 2019 No. 471-FZ "On Amendments to the Federal Law "On the Electricity Industry" in terms of the development of microgeneration"* Retrieved from: http://www.consultant.ru/document/cons_doc_LAW_341801/
[7] *GOST 32144-2013 "Electrical energy. Electromagnetic compatibility of technical means. Standards for the quality of electrical energy in general-purpose power supply systems"* Retrieved from: https://www.elec.ru/viewer?url=/files/2014/05/06/GOST-32144-2013-Elektricheskaja-energija.pdf
[8] *GOST R 61727 - 2016 (IEC / TS 62257-2: 2004) PHOTOELECTRIC SYSTEMS Connection to power distribution networks* Retrieved from: http://docs.cntd.ru/document/1200136686
[9] *GOST R56124.2 - 2014 (IEC / TS 62257-2: 2004) Renewable energy Hybrid power plants based on renewable energy sources for rural electrification. Recommendations. Part 2* Retrieved from: http://docs.cntd.ru/document/1200113476
[10] O V Leshtayev et al 2021 *IOP Conf. Ser .: Earth Environ. Sci.* **723** 052012
[11] *Certificate of registration of measuring instruments for a single-phase induction meter SO 50-ME* 2001 (Moscow, Rostest) Retrieved from: https://all-pribors.ru/opisanie/21505-01-so-50me-17721