Electricity metering in power supply systems with grid-connected solar power plants

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Abstract. The article discusses the experience of using an induction meter of electrical energy in power supply systems with a network solar power plant connected in parallel to the centralized network. Amendments to Federal Law No. 35-FZ "On the Electricity Industry" of December 27, 2019, which determine the relevance of the construction and operation of grid solar power plants in Russia, have been studied. The block diagram of an experimental solar power plant (SPP) is presented. An experimental network solar power plant has been developed and tested, which makes it possible to assess the possibility of using this type of power plant in rural areas of the central Chernozem region, in a private courtyard. The calculation of the characteristics and the selection of brands of the main components used in the installation of the station, including an induction meter of electric energy, were made. The authors analyzed the consumption of electrical energy from a centralized electrical network without using a solar power plant and during its operation according to the readings of an electric meter. On the basis of the analysis carried out, conclusions were drawn about the reduction of electricity consumption from the centralized network during the operation of a network solar power plant. The operating modes of the electricity meter generated by the solar power plant, the consumption of electricity from the centralized network and the load of the consumer of electrical energy are described mathematically. The relationship between the direction of the current flowing through the counter, the magnetic fluxes induced on the counter disk and the direction of rotation of the disk is described on the basis of mathematical relationships. The authors draw conclusions about the possibility of using induction meters of electrical energy in parallel operation of solar power plants with a centralized network as devices for offsetting consumed and supplied electricity to the network.

1. Introduction

The use of electricity by consumers is constantly increasing, which leads to the use of environmentally friendly renewable energy sources. In this regard, most countries, as well as Russia [1] and many of its regions [2-4], are considering the possibility of increasing the share of energy obtained from renewable sources. The number of private solar power plants is also increasing [5]. In this regard, a number of problems arise when connecting these sources to the power system. The main problems: requirements for power quality, power limitations, safety measures, protection systems, synchronization process, reduction of system inertia, etc.

According to the amendments to Federal Law No. 35-FZ, dated December 27, 2019, micro-energy facilities owned by private and legal entities are allowed to connect to the centralized power grid with the possibility of supplying excess electricity to the grid [6]. The law specifies several restrictions for...
such facilities: connection is possible to power grid facilities with a voltage level of up to 1000 V, technical connection of a micro-generation facility must ensure that the power is limited to no more than 15 kW.

This law and regulations [7-9] consider only the issues of connecting private power plants to the network, while the requirements for the regulation of the quality of electricity, reliability of power supply, environmental friendliness, synchronization of the network and distributed generation facilities are not specified. Also, there are no regulatory documents describing the accounting of electricity supplied to the network and its payment.

At the moment, bi-directional electricity meters have been developed and are being operated, which make it possible to account for the amount of electricity received from the centralized network and the amount of excess energy supplied to the network from the solar power plant. However, many consumers of electrical energy (EEE) use induction (disk) electricity meters for electricity metering, so it is necessary to consider the possibility of metering electricity in power supply systems with solar power plants with meters of this design.

2. Materials and methods
The study was carried out on the basis of a developed experimental private solar power plant with a capacity of 1.1 kW, the diagram of which is shown in figure 1. Based on this station, a simulation model was built [10], which makes it possible to assess the efficiency of the station and the impact on its operation of emergency modes in a centralized network.

![Figure 1. Scheme of a network solar power plant.](attachment:image.png)

At the heart of the SES of such power are 4 modern solar monocrystalline panels (SP) of the TW Solar TW310MWP-60-H brand with a power of 310 W each. One panel contains 60 solar cells. This brand of panels is based on PERC (Passivated Emitter Real Cell) technology. Its main difference between silicon panels is the presence of a dielectric layer (passivation), which is located over the entire surface of the panel between the silicon base and the back contact. An additional layer, acting as a reflector of solar radiation, leads to an increase in the efficiency of the panels up to 20%. The choice of the number and brand of panels was carried out taking into account the required maximum power of
1.1 kW, as well as taking into account the minimum voltage required to start the inverter - 80 Volts, i.e.:

\[
U_f = U_1 + U_2 + U_3 + U_4 \geq 80 \text{ V} \tag{1}
\]

The installation site was selected based on the orientation of the solar panels to the south, the absence of objects shading the panels and the convenience of installing and connecting the panels. The panels are mounted on a rigid frame with the possibility of natural ventilation (figure 2).

![Figure 2. Placement of solar panels.](image)

To convert direct current into alternating current (i.e.), a Sofar 1100TL-G3 inverter manufactured by Sofar Solar was chosen. The inverter has a peak power of 1.1 kW. The data transmission from the inverter about the generated energy, its quality, operating errors, the input parameters of the batteries and energy are transmitted via Wi-Fi to the Internet, after which graphs are automatically built and a daily report on the operation of the entire installation is generated.

An induction electricity meter of the SO-50 ME brand, accuracy class 2 [11], was used as an electricity meter.

The study was carried out when the illumination of the location of the station, the given load connected to the SES, and the power stations generated during the day changed.

3. Results
The counter readings were recorded in the morning and evening. The results of the study are presented in (table 1).

| Date       | Energy from SPP, generated per day, kWh | Morning meter reading, kWh | Evening meter reading, kWh |
|------------|----------------------------------------|-----------------------------|-----------------------------|
| 5th of August | 6.4                                    | 2875.6                      | 2875.3                      |
| 6 August   | 6.6                                    | 2875.9                      | 2875.7                      |
| August 7   | 6.8                                    | 2876.7                      | 2876.7                      |

4. Discussion
The value of the current of the consumer of electrical energy (EEC) \( i_{\text{ECC}} \) is determined by the load of the EEC and the value of the current of the inverter \( i_\text{i} \) of solar panels (figure 1) and determines the operating modes of the meter of electrical energy (SEE), when:

- The missing energy (2) of the consumer gets from the centralized network:
\[ i_{ue} > i_a; i_{ue} = i_a + i_g \]  \hspace{1cm} (2)

SEE sums up the electricity coming from the network (3):
\[ W_1 = \sum W + U_g I_g \cos (\theta_g) \]  \hspace{1cm} (3)

- Energy metering is not performed, current \( i_c \) does not flow through the meter (3). Counter disc does not rotate:
\[ i_{ue} = i_a; i_g = 0 \]  \hspace{1cm} (4)

- Excess energy from the SES (5) goes to the centralized network:
\[ i_{ue} < i_a; i_a = i_{ue} + i_g \]  \hspace{1cm} (5)

SEE subtracts electricity from \( \sum W \) (6). A current \( i_g \) flows through the SEE in the opposite direction. The counter disk rotates in the opposite direction:
\[ W_1 = \sum W - U_c I_c \cos (\theta_c) \]  \hspace{1cm} (6)

Where \( i_g \) is the network current consumed by the EEC or supplied to the SES network; \( U_g \) - voltage of the centralized network; \( W_1 \) - current reading of the electricity meter, kW * h; \( \sum W \) - total SEE reading, kW * h; \( \cos (\theta_{ig}) \) - power factor of the angle between current and voltage.

When electrical energy is consumed from the network (2), magnetic flux circuits are formed on the meter disk; \( +F_{ig} + F_{Ug}; F_{ig} \) where \( F_{Ug} \) is the magnetic flux loop formed by the voltage of the centralized network; \( F_{ig}, F_{Ug} \) the contour of magnetic fluxes formed by horseshoe-shaped alternating current cores.

The interaction of currents caused by the direction of the magnetic flux leads to the formation of a counterclockwise rotational moment of the SEE disk. If through the electric meter, no current flows (3), magnetic flux; \( +F_{ig} + F_{Ug}; F_{ig} \) are not formed, the rotational moment of the disk is not created. With an excess of energy (4) \( i_a = i_{ue} + i_g \) and a change in the direction of the current \( i_g \) through the counter, the magnetic fluxes of the disk reverse signs, creating a clockwise rotation moment of the SEE disk.

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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 study allows us to assess the prospects for the use of induction meters in power supply systems with solar power plants and the efficiency of such a system. Taking into account the data obtained, it can be concluded that it is possible to use such meters as devices for automatic offsetting of electricity received and supplied to the centralized network by the consumer. At the same time, the indicators of the quality of the generated electricity must meet the requirements for centralized networks [7].

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