Improving efficiency in a distribution network with asymmetric load due to connected solar panels with a phase relationship

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Abstract. In the article, the distribution of symmetrical loads operating in extreme load, taking into account the total power of the consumers in the power network, was modeled by installing solar panels in apartments. As a result, as a result of the use of solar panels with a total power of 34 kW in the houses in the cable distribution network with a length of 0.444 km, a reduction of active power loss of 21382 kWh (37%) is achieved, a reduction of reactive power loss is achieved by 7309kVAR*hour (37%), the level of overloading of the cable network was 1- in the section of households, from 105% to 85%, and in the section of the last households, a decrease is achieved from 14% to 6%. In addition, it was found that the voltage drop at the ends of the apartments is not at the required level, and when the solar panels are connected, it is at the limit values.

1 Introduction

Comprehensive measures are being implemented in our republic to provide consumers with uninterrupted and high-quality electricity, to use alternative energy sources and direct them to production areas, to increase the efficiency of solar panels, and to organize phase-to-phase symmetrical loads, and certain results are being achieved. In the development strategy of New Uzbekistan for 2022-2026, important tasks are defined, including "... continuous supply of the economy with electricity and active introduction of "Green economy" technologies in all sectors, increasing the energy efficiency of the economy by 20%...". In implementing these tasks, it is important to determine the possibilities of additional energy saving through a comprehensive study of the efficiency of electric power networks.

Analysis of electricity quality indicators in symmetrical load distribution power networks by scientists of our country and the world to develop a system of efficient use of solar panels to ensure the stability of symmetrical load distribution power networks and reduce power wastage; develop a mathematical model for power flows between solar panels and symmetrical distribution grid; creation of an algorithm for the elimination of

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irregularities in the distribution power grid through solar panels; improvement of power control in solar panels connected to symmetrical load distribution grid; several works were carried out, such as substantiating the economic efficiency of distribution power grids with a symmetrical load connected to solar panels [2, 3, 4].

According to the analysis results, the increase in the demand for electricity in the upper figures is due to the increase in the manufacturing industry and residential complexes. Suppose the increase in the volume of exports at the country level ensures the economy's growth. In that case, this will improve people's economic income and increase the demand for technical equipment [16].

As the demand for electricity increases, so does the peak load demand. Figure 1 shows the graph of the change in the demand for electricity and the demand for maximum power consumption [1, 16].

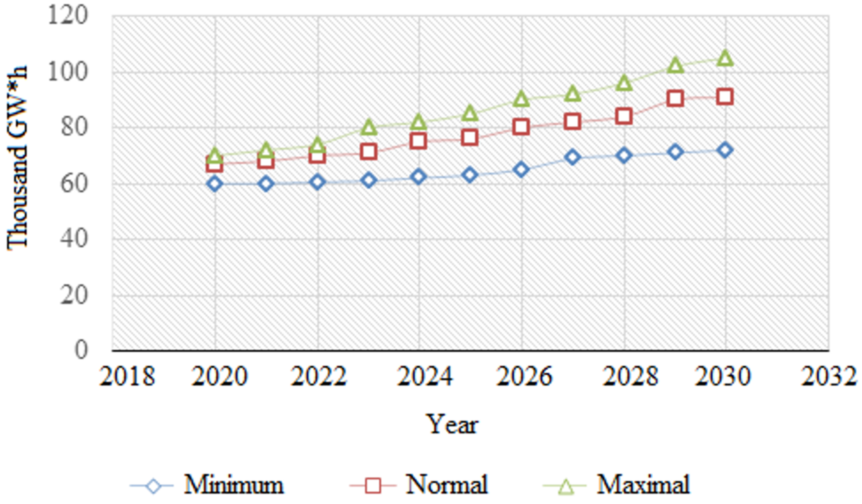

Fig. 1. Changes in demand for electricity [18].

The fact that the power factor in distribution networks is not at the level of demand is one of the main reasons for the wastage of electricity.

2 Methods and Materials

To calculate the load level of low-voltage distribution networks, the annual increase in load was taken as 6%. Considering the air temperature in summer and winter, the heaviest loading level, coefficients of 0.74 for 45^{0}C and 1.15 for an air temperature of 10^{0}C were adopted [5, 6].

Transformers with a voltage of 6/0.4 kV and a power of 400 kVA have a special place among low-voltage distribution networks. Therefore, the load level in these transformers is 83%. The voltage value at the main transformer substations was also found to be much lower than the specified value.

In the study, small power solar photoelectric stations were considered; we will mention the technical parameters of the station working in parallel with the distribution network with a total capacity of 34 kW. The solar station occupies 400 square meters of the roof area. A total of 96 solar panels are installed, each of which produces 350 W of electricity. The technical parameters of the inverter installed in the solar photovoltaic plant are listed in Table 1 below.

Table 1. Technical parameters of solar station inverter

Type	SG350HX
Power	350 kVA, 50˚C(PF1)
Rated output current	254 A
Rated output voltage	800 V
Output voltage variation	640 – 920 V
Nominal frequency/frequency change	50 Hz / 45 – 55 Hz
Power Factor/Flexibility	> 0.99/0.8 ahead – 0.8 behind
Useful work coefficient	99.01 %
Total nonsinusoidal coefficient	< 3 % (at nominal power)

The dependence of the inverter power on the output voltage is shown in Fig. 2. According to it; the inverter can operate at maximum power when the inverter output voltage is rated (power factor is equal to one). Even when the output voltage increases to 880 V, the inverter can operate at maximum power. Still, a further increase in the output voltage leads to a sharp decrease in the inverter power. The inverter can operate at 175 kVA when the output voltage is 920 V. The low output voltage also prevents the inverter from operating at full capacity. When the output voltage is 640 V, the inverter can operate with 224 kVA.

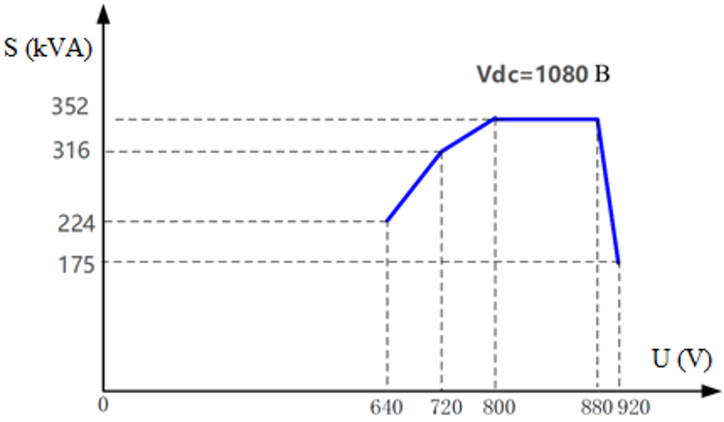

Fig. 2. Dependence of inverter power on output voltage [33].

A mains voltage meter uses the mains voltage as input. It produces two signals: one with a parallel component corresponding to the mains voltage and one 900 ahead of the mains voltage (orthogonal component). This counter works through the following feedback block scheme [7, 8, 20]:

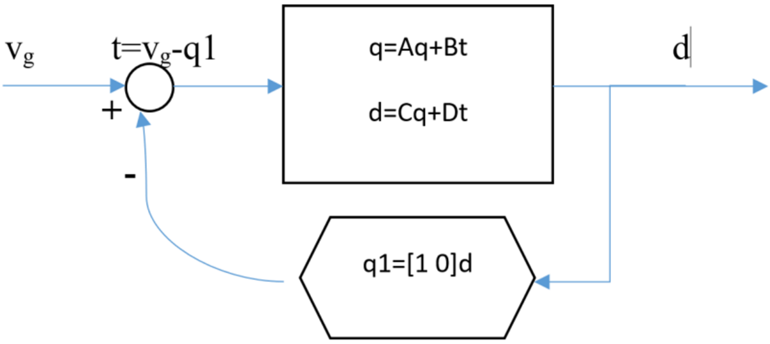

Fig. 3. The feedback unit in estimation of power grid voltage [8].

$$\begin{pmatrix} q1 \\ q2 \end{pmatrix} = \begin{bmatrix} 0 & \omega_0 \\ -\omega_0 & 0 \end{bmatrix} \begin{bmatrix} q1 \\ q2 \end{bmatrix} + \begin{bmatrix} k_{sinx} \\ 0 \end{bmatrix} (v_g - q_1) \quad (1)$$

$$\begin{pmatrix} v_g \\ v_t \end{pmatrix} = \begin{bmatrix} d1 \\ d2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} q1 \\ q2 \end{bmatrix} \quad (2)$$

In the above feedback block diagram, the input signal is equal to $v_g - q_1$, where q_1 is the parallel component of the common signal. As shown in Figure 3, q_1 tries to change v_g.

The signal offered by the feedback block is v_g, which is a sinusoidal signal that oscillates according to the main frequency. In the mentioned matrix, A represents the power grid voltage at the frequency ω_0 [7, 20, 20].

In this case, k_{sinx} determines the voltage values of the fundamental frequency ω_0 from the electrical network and through $q1$, v_g adjusts the voltage to the network parameters. The most important aspect of the $q1$ signal is that it does not recognize higher harmonic signals in the power network, which means that the higher harmonic voltage values of the network have no effect [9, 10, 11].

Power losses for a transformer with a rated capacity of 250 kVA at a transformer point are considered in low-voltage distribution power networks and consumers connected to it. The analysis was carried out in two stages. In the first step, the power losses of the real distribution network were calculated, and in the second step, the power losses after the solar panels were connected to the distribution network were calculated. The technical parameters of the transformer are listed in Table 2 below.

Table 2. Technical parameters of TP transformer

Nominal voltage kV (HV/LV)	10 / 0.4
Nominal power kVA	250
Short Circuit Current (%)	4
Automatic voltage adjustment	ЮК ±5
AVA Rank %	1.25
Connection group and scheme	YNd11

27 households are supplied with electricity through a cable line from a transformer in TP. The power consumption of the apartments during the experiment is presented in Table 3. It was taken between 12:00 and 2:00 in the daytime.

Table 3. Power consumption of apartments

Number of houses	Active power kW	Reactive power kVAR	Mutual distance m
1st house	7.4	2.4	78+7
2nd house	2.4	0.8	19+6
3d house PV	4.1	1.3	8+5
4th house	1.9	0.6	17+6
5th house	1.9	0.6	6
6th house	5.9	1.9	22+6
7th house	3.1	1	6
8th house	6.3	2.1	14+6
9th house	3.8	1.2	10+6
10th house PV	8	2.6	12+12
11th house	3.9	1.3	12
12th house	7.1	2.3	20+13
13th house	10.3	3.4	13
14th house	3.8	1.3	21+12
15th house	5.6	1.8	12
16th house	7.1	2.3	21+12
17th house	5.5	1.8	12
18th house	11.7	3.9	23+6
19th house	11.3	3.7	6
20th house	4	1.3	18+6
21st house	4.1	1.3	6+7
22nd house	4.4	1.4	16+6
23rd house	5.2	1.7	6
24th house	10.9	3.6	21+6
25th house	6.1	2	6
26th house PV	15	4.9	20+6
27th house	7.3	2.4	6
Total	175.2	54.6	515

The third, tenth, and twenty-sixth of the 27 households consuming electricity through TP have installed solar panels and modeled them in the Power Factory program. The production capacities of solar panels are presented in Table 4.

Table 4. Total power of solar panels installed in apartments

Number of houses	Active power, kW
3d house	8
10th house	10
26th house	16

The following expression was used to determine the annual energy loss of the transformer (in terms of reactive power) [12, 13, 19, 18].

$$\Delta W_{tr} = \Delta Q_{avr.} \frac{S_h^2}{S_n^2} \tau + \Delta W_{\text{т}} \qquad (3)$$

where ΔW is the constant available energy loss during the year, S_n is the rated power of the transformer, S_h is the transformer load, $\tau = 320 \cdot 10\ hour = 3200\ hour$, the average duration of operation of the solar panels during the year.

3 Results and Discussion

For the case where solar panels are not used in the apartments, the transformer's load was 116.66%, and the reactive power loss was found to be 1.61 kVAR. Through the above expressions, the value of energy waste during the year is as follows.

$$\Delta W_{tr} = 13.61 \cdot 1.1666^2 \cdot 3200 = 59\,272\ kVAR \cdot hour$$

For the case of solar panels used in apartments, the transformer's load was 101.63%, the reactive power loss was determined to be 10.33 kVAR, and the DigSilent program was used to obtain the results. Through the above expressions, the value of energy waste during the year is as follows.

$$\Delta W_{tr} = 10.33 \cdot 1.0163^2 \cdot 3200 = 34\,142\ kVAR \cdot hour$$

In a transformer with a power of 250 kVA, it was found that the energy loss is reduced by 59272-34142=25130 kVAR·hour per year, which means that the energy loss is reduced by 42%.

The power losses in the transformer and the cable line in the distribution network are determined by the following expressions[15, 17].

$$\Delta P = R(P^2 + Q^2)/U^2 \tag{4}$$

$$\Delta Q = X(P^2 + Q^2)/U^2 \tag{5}$$

where P (W) and Q (VAR) are active and reactive power consumption, U (V) is the nominal voltage of the distribution network, R and X (Ohm) are the active and reactive resistances of the cable line in the distribution network.

To determine the efficiency achieved by using solar panels, the annual energy consumption was calculated for daytime hours, which is expressed as follows [14].

$$\Delta W = \Delta P_{avr.}\tau = (\Delta P_1 + \Delta P_2 + \Delta P_3 + \cdots + \Delta P_{27})\tau \tag{6}$$

where $\Delta P_{avr.}$ is the average value of power loss (kW), $= 320 * 10 hour = 3200\ hour$ is the average duration of operation of solar panels during the year.

The total length of the cable network is 444 meters; energy loss was determined by the power consumption of households (Fig. 4).

According to the situation before installing solar panels in apartments:

$$\Delta W_{active} = \Delta P_{avr.}\tau = 17.93\ kW \cdot 3200\ hour = 57\,376\ kW \cdot hour$$

$$\Delta W_{reactive} = \Delta Q_{avr.}\tau = 6.21\ kVAR \cdot 3200\ hour = 19\,872\ kVAR \cdot hour$$

After installing solar panels in apartments:

$$\Delta W_{active} = \Delta P_{avr.}\tau = 11.248\ kW \cdot 3200\ hour = 35\,994\ kVAR \cdot hour$$

$$\Delta W_{reactive} = \Delta Q_{avr.}\tau = 3.926\ kVAR \cdot 3200\ hour = 12\,563\ kVAR \cdot hour$$

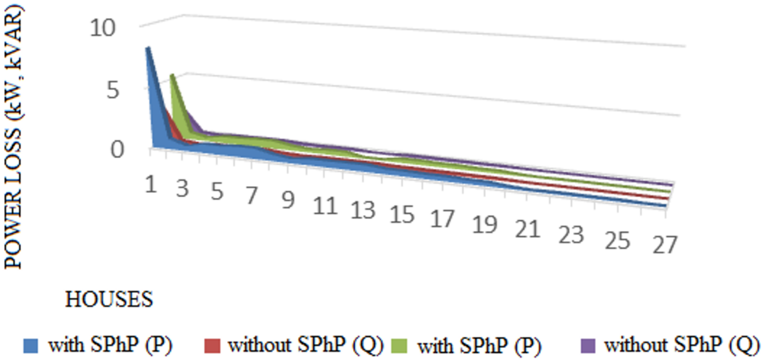

Fig. 4. Energy consumption in cross-section of apartments

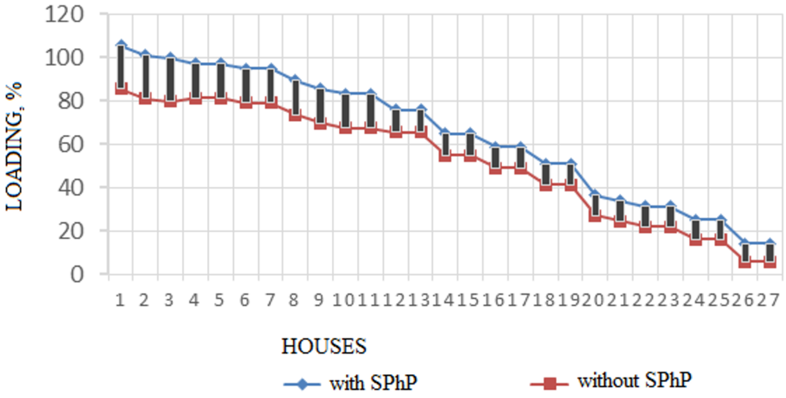

Fig. 5. Overcrowding in cross-section of apartments

As a result of the use of solar panels with a total capacity of 34 kW in the houses in the cable distribution network with a length of 0.444 km, a reduction of active power consumption by $57376 - 35994 = 21382\ kWh$ (37%), reactive power consumption by $19872 - 12563 = 7309\ kVar \cdot hour$ (37%) was achieved.

Cable network overload was reduced from 105% to 85% in the 1st apartment section and from 14% to 6% in the last apartment section (Figure 5).

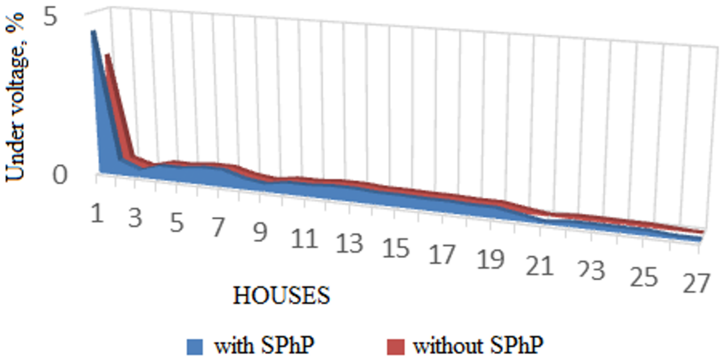

Fig. 6. Level of voltage drop in section of apartments

It is shown in Figure 6 that the voltage drop in the section of apartments is not at the required level at the ends of the apartments without using solar panels, and it is at the limit values when solar panels are connected.

4 Conclusions

Thus, considering the power of consumers of the distribution network, solar panels were installed in some houses, and the results were modeled. As a result of the use of solar panels with a total capacity of 34 kW in the houses in the cable distribution network with a length of 0.444 km, a reduction of 21382 kW·h (37%), and 7309kVar·h (37%) of reactive power was achieved. The cable network overload rate decreased from 105% to 85% in the 1st household section and from 14% to 6% in the final household section. It was shown that the voltage drop in the cross-section of the apartments is not at the required level at the ends of the apartments without using solar panels, and it is at the limit values when the solar panels are connected. It has been proven that using solar panels in low-voltage symmetrical load distribution networks is very important from the point of view of energy efficiency.

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