

IMPROVING THE EXCESS LOAD OF AN ASYMMETRIC LOADING DISTRIBUTION NETWORK USING PHOTOVOLTAIC STATIONS

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ABSTRACT

This article analyzes the process of analyzing power quality indicators and voltage variations in distribution electrical networks. It is shown that using each consumer's daily load profile rather than their maximum power results in more accurate estimates. It is determined that photovoltaic systems connected to the central power grid via the distribution network are a source of harmonics, and proposals for their mitigation are developed. It is shown that the quality of the alternating current delivered by the inverter can be adjusted to meet international and national electrical power quality standards using filters, and the payback period for the costs incurred in the distribution network with nonlinear loads connected to photovoltaic has been calculated.

KEYWORDS: photovoltaic, distribution network with asymmetric loads, inverter, network

1.0 INTRODUCTION

The global demand for electric power is steadily increasing, while fuel and energy reserves are decreasing year by year, which inherently necessitates the widespread use of "green" energy sources.^[1] In particular, in our republic, the power quality indicators of the distribution electric networks are not at the required level, the number of consumers is increasing day by day, resulting in transformer overloading, and distribution networks are exceeding the prescribed norms.^[2]

Across the republic, as of September 1, 2021, the 10 kV overhead power transmission networks totaled 84,870 km, and the 6 kV overhead power transmission networks – 13,902 km, and the 0.4 kV distribution power networks – 133,529 km, and the fact that the number of household consumers exceeds 7.2 million is proof of how high the demand for "green" energy sources is.

To successfully carry out this work, the Decree of the President of the Republic of Uzbekistan No. PQ-4477 of October 4, 2019, numbered decision "On Approving the Strategy for the Republic of Uzbekistan's Transition to a 'Green' Economy for the Period 2019-2030" is of great importance.^[1]

The relatively distant location of consumers from transformer substations causes voltage drops and increased power losses, resulting in the furthest consumers receiving poor-quality electric power. The proposed solution is viewed as a remedy for these exact issues.

This section analyzes one of the four distribution electrical networks supplied by a transformer substation located at the specific site. This network serves 13 households, and the phase voltage at the farthest households is 180 V. Four additional small-scale photovoltaic (PV) stations were connected to this network. The distribution electrical network was modeled in PowerFactory to study voltage variations and network loading. As a result, it was observed that voltage levels at the end-point consumers were also satisfactory, and the network's overload was eliminated.

2.0 METHODOLOGY

The network analyzed in this study is a real-world object located in the Shamsi-koul village of Namangan district. Households on Yangiobod, Do'stlik, Beshkapa, and Shamsiko'l streets are supplied with electricity by a 160 kVA transformer. The distribution network on Shamsikul Street was selected as the research object because it has the lowest voltage and the highest overload. The network on Shamsi-kul Street is 0.7 km long and serves 13 households (Figure 1). The phase voltage at the homes at the end of the street is 180 V instead of 220 V. This indicator is considered absolutely unsatisfactory in terms of electrical energy quality requirements.^[3] During the network modeling process, PV systems were installed in apartments 1, 4, 9, and 13. The maximum installed capacity of the PV systems is 15 kW.

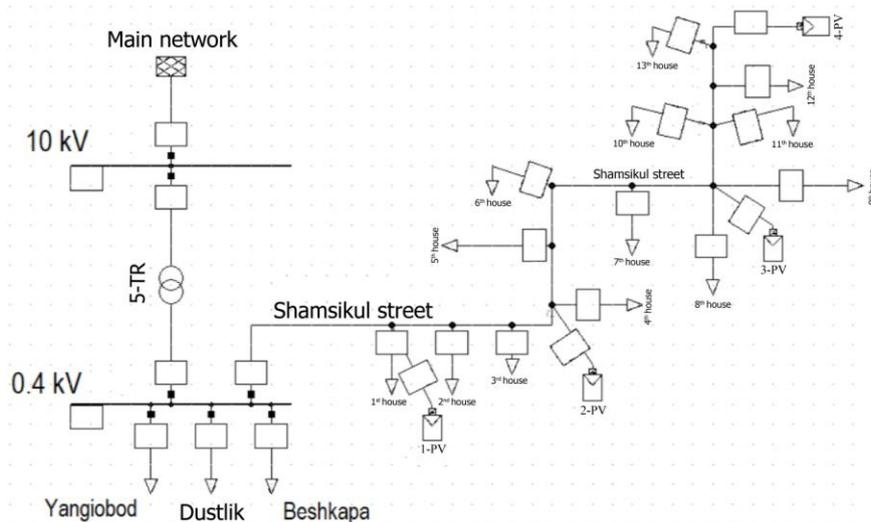


Figure 1: Model of the Shamshikol Street power supply and distribution network in the "PowerFactory" software.

When analyzing power quality indicators and voltage variations in distribution electric networks, using each consumer's daily consumption profile rather than their peak power provides more accurate results.^[4] To generate the consumer's daily profile, the load factor must first be determined.^[5] The following expression exists for calculating daily electricity consumption based on households' daily consumption profiles.

$$W_{\text{consump daily}} = \sum P_{\text{instantaneous daily}} \Delta t \quad (1)$$

Here, W_{consump} - daily electricity consumption (for work and rest days) [kW], $P_{\text{instantaneous}}$ - short-term electricity consumption [kW], Δt - duration of the daily consumption profile interval [hours].

The load factor is determined by the ratio of the daily energy consumption of the rated power to the energy consumption of the maximum power over the course of a day and is expressed as follows:

$$f_{\text{load daily}} = \frac{W_{\text{consump daily}}}{24 * P_{\text{consump.Max}}} \quad (2)$$

where $f_{\text{load daily}}$ is the daily correction factor of the load, and $P_{\text{consump.Max}}$ is the consumer's maximum consumption power. The Newton-Raphson method was used to analyze power flows and the network.^[6]

To determine the coefficient at a given time, the instantaneous consumption power is divided by the maximum power:

$$f_{\text{instantaneous}} = \frac{P_{\text{instantaneous}}}{P_{\text{consump.Max}}} \quad (3)$$

Based on the power consumption of household electrical appliances, the maximum household power consumption was assumed to be 10 kW·h. However, this amount may not remain constant throughout the day, so the operating times of each electrical appliance were examined. After that, the households' daily consumption power was expressed as a coefficient of the maximum power. Consumers' daily profiles are divided into two types: one reaches its maximum power consumption during the day, and the other at night (Figure 2).

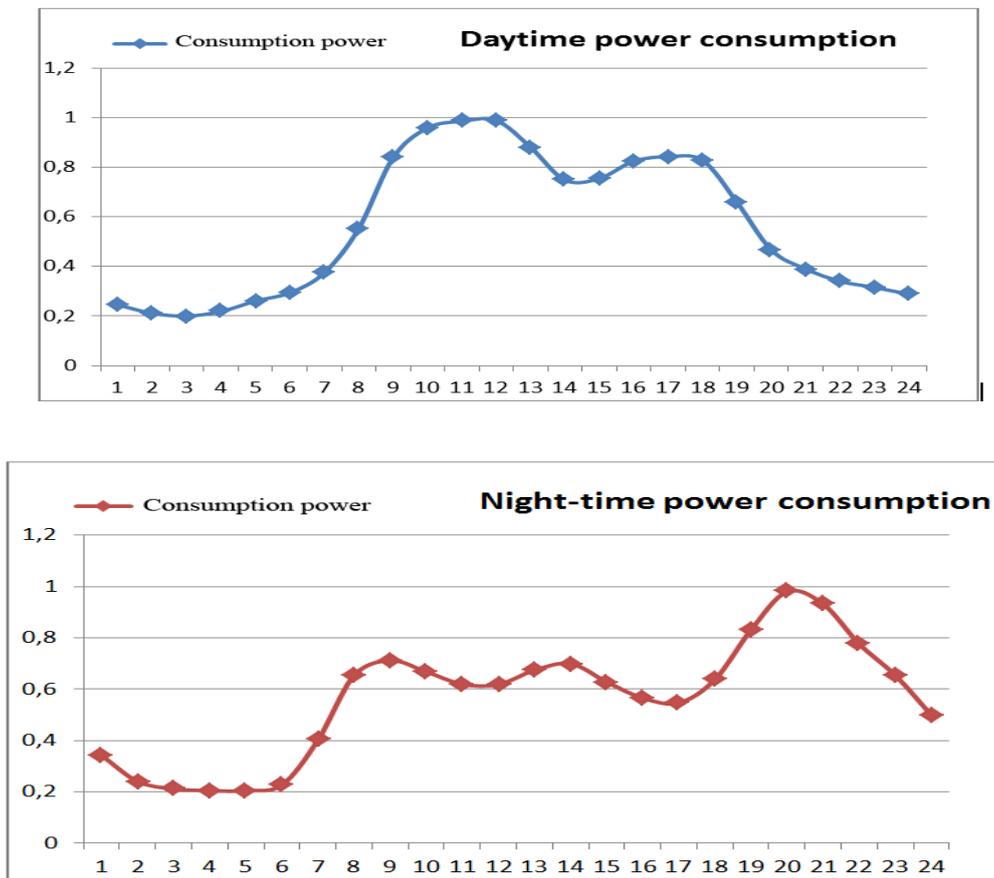


Figure 2: Variation of the daily consumption factor coefficients for households.

An analysis of the daily operating regime of the Shamshikol Street electrical network as of April 29, 2022, revealed that the network was overloaded from 8:00 AM to 1:00 PM. Additionally, from 6:00 PM to 8:00 PM, the network also operated under a load near its maximum transmission capacity.

Table 1: Parameters of the conductor wire of the Shamshikul Street distribution electrical network.

Conductor type	Network length, km	R Ohm/km	X Ohm/km	Conductivity A
AC-150/19	0.7	0.206	0.072	450

The network's daily load chart is shown in Figure 3. The conductor of this network consists of aluminum wire of type AC-150/19, and the conductor's parameters are given in Table 1.

When evaluating the power transmission capability of PVs connected to low-voltage distribution networks, symmetrical parameters are used. Under nominal operating conditions, the current and voltage are symmetrical and sinusoidal. Therefore, all calculations and analyses are carried out using a single-phase network model.

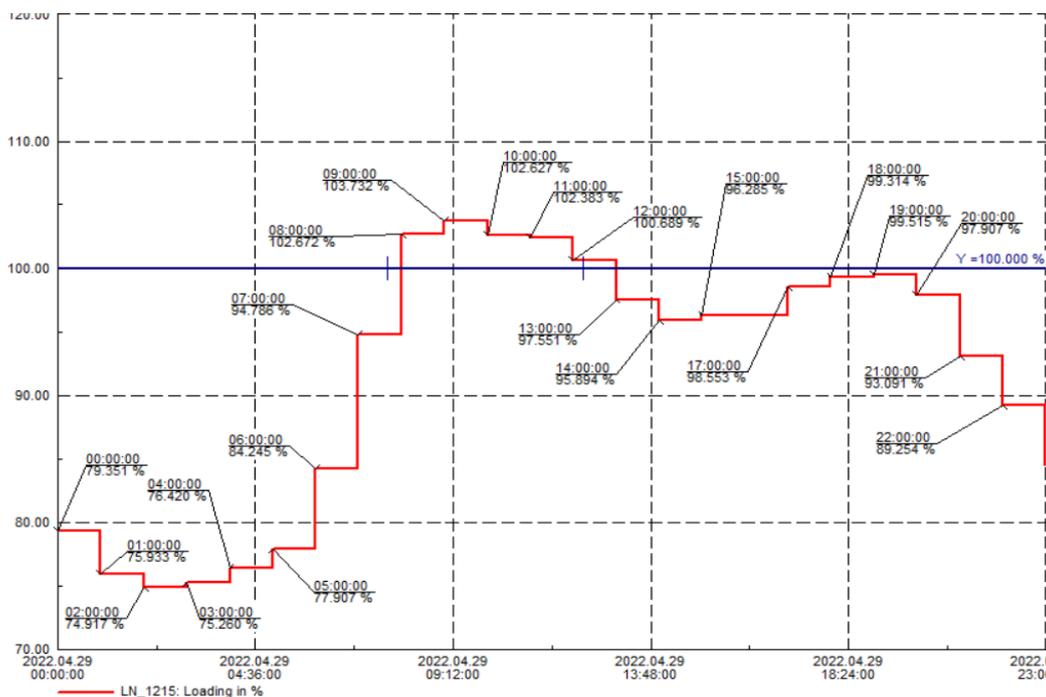


Figure 3. Daily load chart of the distribution network on Shamshikul Street, dated April 29, 2022.

Consumers on the distribution network are typically connected in a star configuration. The resistance of a phase of the distribution network is denoted R_{phase} , and the resistance of a consumer connected to the network is denoted R_{load} . The current flowing through each phase to the consumers equals the consumer's phase current I . The relationship between the network voltage $V_{network}$, and the phase voltage V_{phase} is given by $V_{network} = \sqrt{3}V_{phase}$.

We know that current and voltage are vector and scalar quantities, respectively, and they are defined as follows:

$$\dot{V} = \ddot{V} + j\ddot{V} = V e^{j\theta_V} \quad (4)$$

$$\dot{I} = \ddot{I} + j\ddot{I} = I e^{j\theta_I} \quad (5)$$

$$\dot{W} = P + jQ = W e^{j\theta} \quad (6)$$

Here, \ddot{V} , \ddot{I} , and P – denote active voltage, current, and power, respectively, while \ddot{V} , \ddot{I} , and Q – denote reactive voltage, current, and power. V , I , W – denote the algebraic values of the quantities, while θ_V , θ_I , θ – denote the angles between the active and reactive voltages, currents, and powers, respectively.

3.0 RESULTS AND DISCUSSION

When determining the payback period for the costs incurred in the distribution network with an unsymmetrical load to which the PVs are connected, the proposed station's accumulator section is absent, and it operates in synchronism with the power grid. Currently (01/06/2025), in Uzbekistan, the cost to install a 1 kW PV system averages 5 million UZS. The cost of installing PV with a total capacity of 34 kW in houses 3, 10, and 26 is determined as follows. $S = 5 \text{ million} * 34 = 170 \text{ million UZS}$.

The annual amount of electricity generated by the PV was determined as follows.

$$\begin{aligned} P_{pv} &= P_{daily} * 320 = \frac{P_{max}}{2} * 10hours * 320 = \frac{34 kW}{2} * 10hours * 320 \\ &= 54400kW * hours \end{aligned}$$

The total value of electricity generated by the PV is $21,382 + 54,400 = 75,782 \text{ kWh}$, based on the annual reduction in electricity consumption.

The annual revenue, calculated using the current electricity price (as of 01/05/2025) from (<https://www.het.uz/oz/lists/view/2191>).^[7] (set at 600 UZS per kWh as of 01/05/2025).^[7] is the following value.

$$\begin{aligned} D &= (54400 kW * hours + 21382 kW * hours) * 600^{sum} / kW * hours \\ &= 45469200 \text{ UZS/year} \end{aligned}$$

For installing PV, the state provides up to a 3-year exemption from land tax (<https://old.soliq.uz/taxation/land-property-tax>).^[8] According to source.^[8] the average cost is 411, 84 UZS per square meter. The proposed PV requires a total area of 340 square meters.

The total amount saved on land tax was determined as follows.

$$T = (411.84 \text{ UZS/m}^2 * 34 * 10 \text{ m}^2) = 140025 \text{ UZS/year}$$

Therefore, the annual income from the 34 kW PV is as follows:

$$D_{\text{annual}} = D + T = 45469200 + 140025 = 45609225 \text{ UZS/year}$$

The payback period of the expenses is determined as follows:

$$M_{\text{shelf life}} = \frac{S}{D_{\text{annual}}} = \frac{170000000 \text{ UZS}}{45609225 \text{ UZS/year}} = 3.7 \text{ year}$$

Thus, if a total of 34 kW of PV is installed in households supplied by a 250 kVA transformer through a 444-meter-long cable network, the costs will pay for themselves in 3.7 years and will generate an annual profit of 45609225 UZS.

4.0 CONCLUSION

In conclusion, when analyzing the quality indicators of electric energy and voltage variations in distribution networks, using each consumer's daily consumption profile rather than their peak power allows for more accurate results. It was determined that the PV connected to the central power grid via the distribution network is a source of harmonics, and proposals were developed to eliminate them. Transformer overload is prevented by the PV installed in the distribution network, resulting in a 42% reduction in reactive power losses. It was determined that the excess voltage drop at the ends of the distribution cable network can be eliminated using PV.

The quality of alternating current transmitted by the inverter is shown to meet international and national electricity quality requirements through filtering, and the payback period for a symmetrical load distribution network with photovoltaics is calculated.

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