Electrical Profile of User with Photovoltaic System

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***Abstract* - Energy and fuel-distribution management performed by suppliers is usually based on daily predictions created by distributors. Those predictions are based on data measured the day before; weather predictions such as ambient temperature, wind, precipitation along with some general information such as day of the week, whether it is weekend or not, are there any preannounced events within the distribution area etc. There's been a rapidly growing trend in demand for micro photovoltaic systems in single user installation for the last few years, which implies that classic user profiles are becoming obsolete for more users, both new and existing ones. This research focuses on a single example representing a consumer with an integrated micro photovoltaic system. In order to keep electrical energy management up to date with latest developments, it is essential to create a user profile for consumers with micro photovoltaic systems. This paper focuses on a classic user profile combined with estimated energy production prediction for a micro photovoltaic system, which results in a new profile of a user with a micro photovoltaic system. Measured data will express current user energy consumption as a consumer, compared to the same user energy consumption/production when the consumer is upgraded with a photovoltaic system. With the new profile, it is possible to analyze main characteristics of transformation of the user profile.**

Keywords – electrical energy; energy planing; energy consumption; modeling

I. Introduction

Energy becomes most precious asset when geopolitical situation introduces unstable energy market. In these times it is most necessary to be able to manage energy production wisely and as cheep as possible, as described in [1] and [2]. In order to do so, one must have access to information and mathematical models which will allow rather accurate prediction of energy consumption in time ahead. Mathematical models of energy consumption behavior is usually generated from monitoring and recording energy consumption in past. From these information it is possible to generate simple or complex presumption of energy consumption for one day, week or month in advance, called profile. Such profiles, as described in [3] can even use ambiental temperature, weather forecast, etc. In this paper simple mathematical model and measured data is used for transformation of electrical energy consumption of classic user profile to user profile with photovoltaic system, like used in [4]. Results are compared using single day measured data and basic statistical analysis. All models are based on Kirchhoff's junction rule using standard measured data.

II. Electrical consumption load profile

Classic energy consumption user profile is most simple production-consumption system where all energy claim of such user is provided from distribution network. Therefore, the electrical energy passed through electrical counter is actual electrical energy consumed by user, as shown in Figure 1.

Energy consumption user with photovoltaic system is introducing second energy source working in parallel with distribution network. User is described as passive block which can only take energy, and never produce any of it. Such models are presented in [5] and [6]. At the same time photovoltaic system is described as active block which can only produce energy, and never consuming any of it. Distribution network is transformed from active block for classic user profile into reactive block for user with photovoltaic system. Reactive block is described as part of system which can adjust to system demands, and therefore can produce energy in the system when there is energy shortage or can absorb energy from system when there is extra produced energy in system, as shown in Figure 2.

Distribution network can also be described as large battery bank with endless capacity. Therefore, one can take reduced cost of photovoltaic system working in parallel to distribution network.

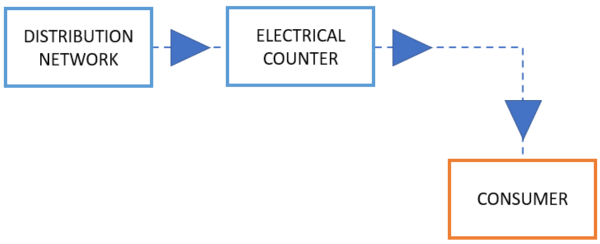

Figure 1. Energy flow in Classic consumption user profile

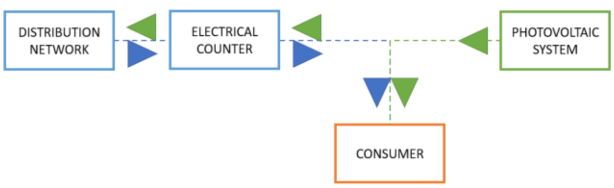

Figure 2. Energy flow in Consumption user profile with photovoltaic system

III. Modeling of User Profile with Photovoltaic System

TABLE I. LIST OF ENERGY FLOWS FOR USER PROFILE

No.	*Name*	*Description*	*Symbol*
1	Consumer instalation	Only consumes electrical energy	$\mathbf{E_I}$
2	Photovoltaic system	Only produces electrical energy	$\mathbf{E_{PV}}$
3	Electrical energy counter - positive	Energy taken from distribution network	$\mathbf{E_+}$
4	Electrical energy counter - negative	Energy given into distribution network	$\mathbf{E_-}$

When transferring from classic user profile to user with photovoltaic system profile, there is only one installation point that is important. It is the point of connection between distribution network and consumer installation. Photovoltaic is introduced as third party, integrating into system at that very point.

In order to describe classic user profile and user with photovoltaic system profile, one must consider all possible electrical energy flows. From Figure 1. and Figure 2. such list of energy flows can be observed. The list is presented in Table 1.

A. *Classic user profile*

When energy flows list from Table 1. is introduced to Figure 1., it can be seen that there are three major statements describing classic user profile. They are listed in Equation 1., Equation 2. and Equation 3.

$$E_I = E_+ \tag{1}$$

Since there is no photovoltaic system, there is no active production of electrical energy inside consumer installation, or possibility to give any energy to distribution network.

$$E_{PV} = 0 \tag{2}$$

$$E_- = 0 \tag{3}$$

B. *User with photovoltaic system profile*

When energy flows list from Table 1. is introduced to Figure 2., it can be seen that there is only one statement describing user with photovoltaic system profile. It is expanded Equation 1. with additional energy coming in system from photovoltaics (E_{PV}), but part of that energy can pass through into distribution network (E_-). Expression is presented in Equation 4.

$$E_I = E_{PV} + E_+ - E_- \tag{4}$$

Figure 3. Sample building with integrated photovoltaic system

All presumptions made in chapters III.A. and III.B. will be analyzed using measured data from distribution network and photovoltaic system, all supplying electrical consumption of sample building with integrated photovoltaic system.

This photovoltaic system is 103 kW peak power of production, which is provided with 4 inverters with 25 kW nominal production power each. Figure 3. shows placement of photovoltaic modules on the roof of sample building.

IV. Measured Data and Profile Results

In order to transform classic user profile to user profile with photovoltaic system it is necessary to introduce exact photovoltaic system information and classic consumption measured values. Corresponding energies from Equation 1. are measured and presented in Figure 4.

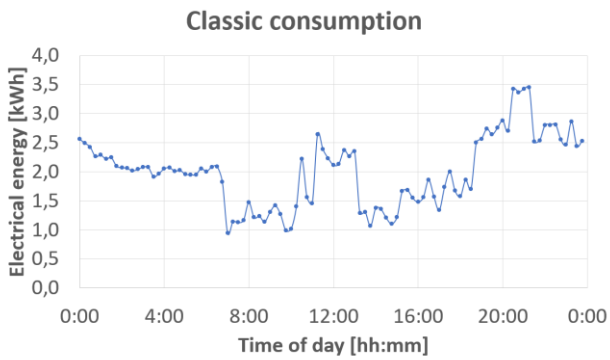

Figure 4. Daily Classic consumption for Sample building, November 2022

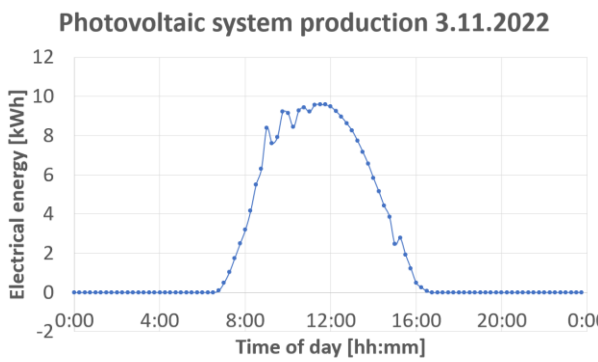

Figure 5. Daily Photovoltaic system energy production, November 2022

Transformation to user with photovoltaic system requires measured data from photovoltaic system, given with energy production regardless of whether it will be consumed inside installation or given into distribution network. Photovoltaic system production can be planed with simulations, but real-time measured data is used in this research in order to get valid results and conclusions. Photovoltaic system production is presented in Figure 5.

Electrical energy counter is split in two separate measurements, one for energy taken from distribution network to consumer and second one for energy given from photovoltaic system to distribution network. Separation is done for financial purposes only, so in this research counter values of E_+ and E_- can be presented as joined value. Measured values presented in Figure 6. and Figure 7. are selected for days where weather conditions were very similar to days of measured values in Figure 4. and Figure 5. Same dates, 3rd November in two separate years are presented. First in Figure 6. real measured data is presented for selected date in 2021, and then in Figure 7. same date in 2022. Therefore, all given measured values in Figures 4-7 are valid comparative information.

If placing measured values of electrical counter energy flow and photovoltaic system production in Equation 4., one can calculate generic classic user consumption by combining Counter energy flow (E_+ - E_-, Figures 6. and 7.) with photovoltaic system energy production (E_{PV}), Figure 5.).

Final results in Figure 8. and Figure 9. confirm that user energy consumption is still the same as it was without photovoltaic system. It also confirms that classic user profile is still valid. Introduction of photovoltaic system only adds new direction of energy flow, so while planning one must take into consideration specific properties of all three participants in energy exchange. Main goal is to get the same energy distribution quality as it was before integration of photovoltaic system, but at the same time disburden distribution network.

TABLE II. DAILY AVERAGE ELECTRICAL POWER VALUES

No.	*Name*	*Value*	*Unit*
1	Profile 2022	1,99	kW
2	3. 11. 2021.	3,30	kW
3	3. 11. 2022.	1,88	kW

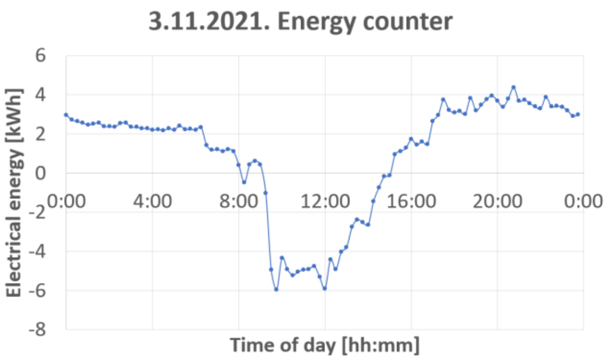

Figure 6. Daily energy flow trough Counter, 3rd November 2021

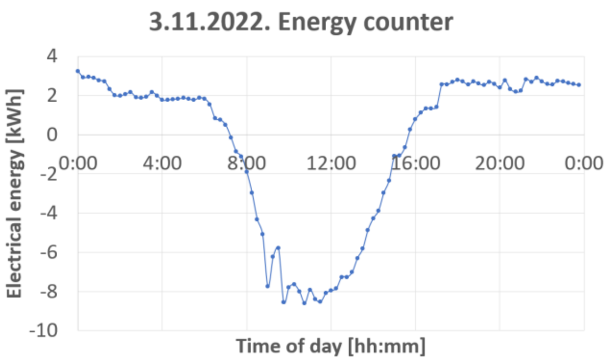

Figure 7. Daily energy flow trough Counter, 3rd November 2022

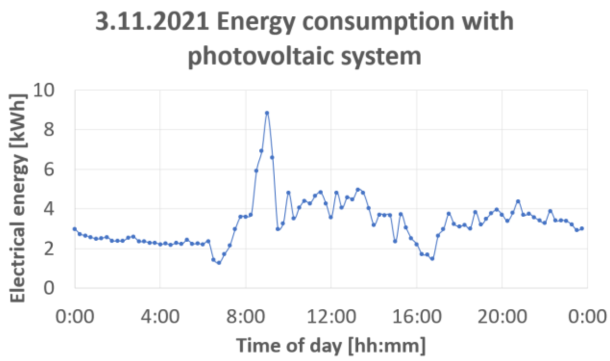

Figure 8. Generic user energy consumption, 3rd November 2021

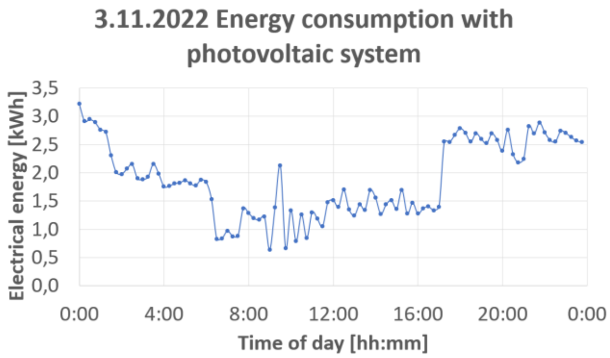

Figure 9. Generic user energy consumption, 3rd November 2022

In order to be able to compare given results presented in Figure 4. (Profile 2022) with generic user energy consumption it is necessary to transform each of them in per unit values. In this research transformation is done using daily average value. Daily average values for electrical power are presented in Table 2.

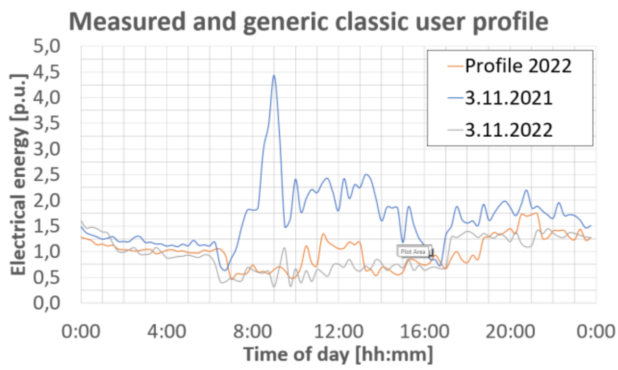

Figure 10. Transformed daily consumptions for energy comparison

Transformed daily energy consumptions are presented in in Figure 10. When comparing each result to another one can conclude that:

- Daily averages of Profile 2022 and 3. 11. 2022. are relatively close in values, while 3. 11. 2021. has some significant deviation.
- Night consumptions for all daily diagrams are relatively close in values, while day consumption has some significant deviation.
- Daily consumptions for Profile 2022 and 3. 11. 2022. have relatively small gap between daily minimum and daily maximum values, while 3. 11. 2021. has relatively large gap between daily minimum and daily maximum values

V. CONCLUSION

In order to maintain good energy management and reasonable energy resource usage it is necessary to have usable model of distribution network and electrical energy consumers. Implementation of photovoltaic system in classic user consumption installation changes behavior this user energy flow. In this research model of transformation from classic user to user with photovoltaic system. Transformation model is derived from profile data while user did not have installed photovoltaic system, and energy production planning for photovoltaic system. Results are presented, compared and analyzed. Transformation model is verified using data of measured classic profile and generic consumption load profile after photovoltaic system is implemented.

After analyzing and comparing results one can conclude that transformation model from classic user profile to user with photovoltaic system is more accurate if user profile matches real daily consumption. Therefore, transformation model will be at least equal in profile accuracy to classic user profile, and will not introduce new errors in energy management and energy resource usage.

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