U.P.B. Sci. Bull., Series C, Vol. 86, Iss. 4, 2024 ISSN 2286-3540

VARIABILITY ASSESSMENT OF NET POWER PROFILES FOR PROSUMERS WITH PV GENERATION

Anca Petruța BRÎNCOVEANU[1], Radu PLĂMĂNESCU[2], Ana-Maria DUMITRESCU[3], Mihaela ALBU[4]

The high impact of the variability in the prosumer's power profiles is analyzed to achieve a more efficient control of microgrids, particularly during off-grid operation. In this paper we propose an evaluation procedure for the prosumers as a function of their net power profile, using statistical analysis performed on high reporting rate measurement information on legacy assessments windows.

Keywords: net power profiles, variability, high-reporting rate, statistics, steady-state

1. Introduction

Microgrids, as grid support of prosumers, play a pivotal role in fostering local exploitation of renewable energy sources (RES) while simultaneously enhancing the efficiency of electric distributions grids [1]. As the emerging power networks increasingly rely on decentralized, volatile, random, uncontrollable, and intermittent RES-based generation, the available system inertia is decreasing [1]. Consequently, the energy transfer is susceptible to voltage and frequency deviations, voltage waveform distortions, three-phase voltage imbalances, and other power quality issues within microgrids [2]. Hence, achieving optimal energy control requires real-time access to both the load and generation power profiles. The high variability of the power exchange of prosumers [3] can impact on the control mechanisms of microgrids, particularly during off-grid operation.

In this paper we analyze the variability in net power flow within a microgrid operated by a PV-enabled prosumer and subject to regulatory constraints. This indicator and methodology can be further used to categorize microgrids based on the variability in their energy transfer.

[1] PhD student, Doctoral School of EE, UNST POLITEHNICA Bucharest, Romania, e-mail: anca.brincoveanu@upb.ro
[2] Assistant prof., Dep. of Measurements, Electrical Devices and Static Converters, UNST POLITEHNICA Bucharest, Romania, e-mail: radu.plamanescu@upb.ro
[3] Assoc prof., Department of Electrical Machines, Materials and Drives, UNST POLITEHNICA Bucharest, Romania, e-mail: anamaria.dumitrescu@upb.ro
[4] Prof., Dep. of Measurements, Electrical Devices and Static Converters, UNST POLITEHNICA Bucharest, Romania, e-mail: mihaela.albu@upb.ro

2. Methodology

The quality of the measurement process is subject to the alignment between the information derived from the analyzed phenomena and the capabilities of the measurement devices [4]. However, in power systems, the widespread deployment of power converters together with other uncontrolled external factors such as weather variability, can significantly impact the electricity transfer, this resulting in a disparity between the idealized model of operation (with constant measurands assumed during the measurement process) and the actual operating conditions, where the quantities are always variable [5].

In the ideal case, the signal model is presumed to be identifiable and consistent throughout both the measurement/sample time (T_w), reporting time (T_r) and the subsequent aggregation time interval (T_a), if any.

To assess the variability in net power profiles we use an adapted statistical approach [6]. The measurement process involves generating information by aligning the observed signal with its implicit model that is assumed during the measurement and for this we are using the coefficient of variation (CV) of the Root Mean Square Deviation (RMSD), generally used as CV(RMSD).

CV(RMSD) serves as a statistical measure offering a normalized assessment of the variability observed in RMSD values. RMSD is frequently employed in evaluating the disparities between predicted (y_i) and measured (x_i) values [7] and is defined as:

$$CV(RMSD) = \frac{1}{\bar{y}_p}\sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n}} \quad (1)$$

where:

- x_i measured values,
- y_i assumed model values,
- n number of values in the assessment window,
- $\bar{y}_p$ represents an assumed model value that reflects the characteristics of the selected process time window. It can be selected, for example as the mean $\bar{y}$ of the model samples y_i calculated within the reporting window T_r. The selection of the representative model value depends on the specific application context [8]; for instance, it may be chosen as the rated power of the grid connection.

In this study we consider three different reporting rates RR, for which the associated time windows ($T_r = 1/RR$) are: T_r=15 minutes, T_r=30 minutes and T_r=1 h. Over those time frames the model (y_i) is represented by a constant power profile: y_i =mean (x_i). We use for $\bar{y}_p$ the mean value of x_i (representing the acquired power). Therefore, the parameters used in the CV(RMSD) computation are:

$$x_i = P_i;\ y_i = \bar{y} = \bar{y}_p = \frac{\sum_{i=1}^{N_r} P_i}{N_r}; \quad (2)$$

To better understand the sequence of the windows T_r and T_a in relation to the measured signal x, and to compute various metrics assessing the deviation from the assumed model y, we have an illustrative example in Fig.1. The parameters for the three reporting time intervals used in (2) are given in Table 1. In this table, T_{ss} is the overall analysis window, with the measurement information available for daily analysis over 24h, f_s is the sampling rate for the available measurement information (as detailed in section 3 below), N_r is the number of samples used in the assessment and evaluation process for CV(RMSD) corresponding to the reporting time intervals, N_a is the number of samples within the aggregation window T_a, and N_{ss} is the number of samples during a day of observation.

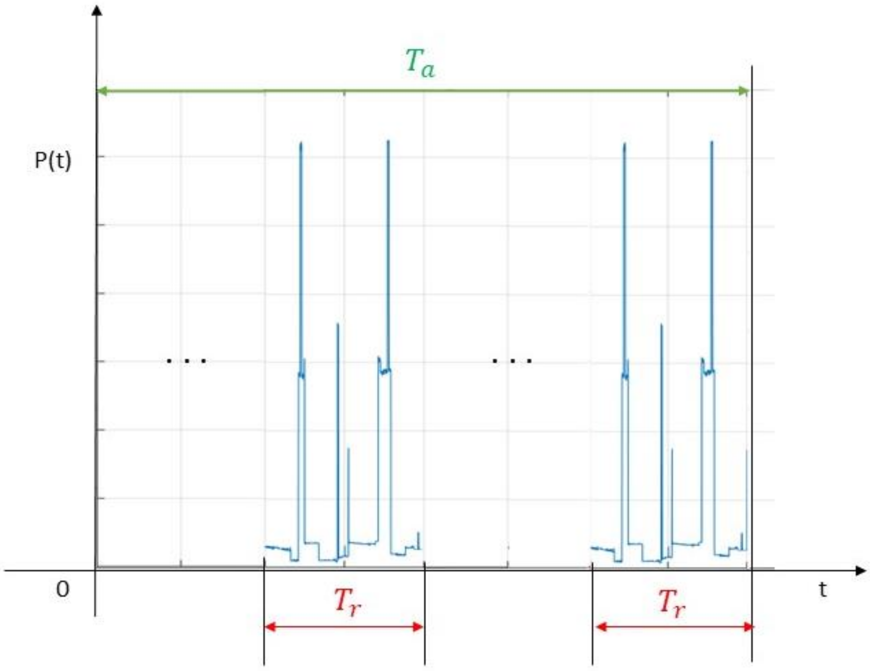


Fig.1. Example of time intervals succession

Table 1.

Parameters for CV(RMSD) computation

Parameters					
T_r	T_a	T_{ss}	N_r=T_r/f_s	N_a=T_a/f_s	N_{ss}=T_a/f_s
15 min	2 h	24 h	900	7200	86400
30 min	2 h	24 h	1800	7200	86400
1 h	2 h	24 h	3600	7200	86400

3. Net power profile assessment

The study presented in this paper is based on data obtained through measurements using the Unbundled Smart Meter (USM) [9],[10], operating at a reporting rate of 1 frame per second, equivalent to a power profile available with a sampling rate of 1 Hz (T_w= 1 s), on the prosumer grid topology presented in Fig. 2. The USM includes two components: the Smart Metrology Meter (SMM) and the Smart Meter eXtension (SMX). The SMM serves as the measurement component, adhering to metrology standards and furnishing the measurements, while the SMX acts as a configurable extension with versatile capabilities to extract, process, and stream the instrumentation values obtained from the SMM [9].

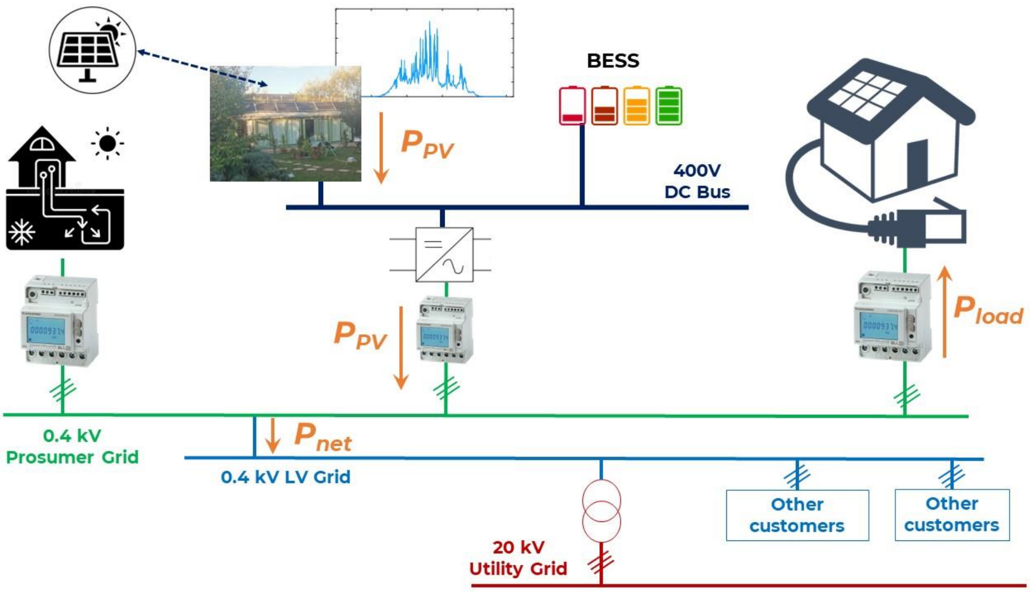
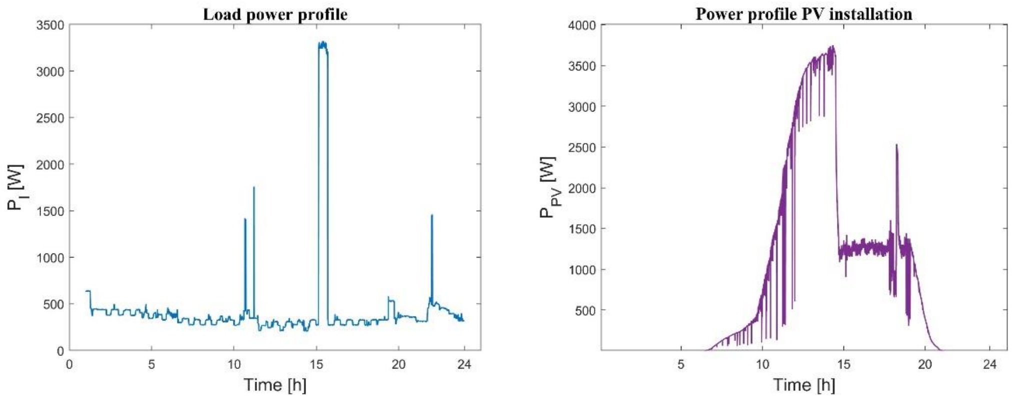


Fig. 2. Prosumer grid topology

In the following, we apply the CV(RMSD) metric for three-time intervals over which the assumed model is “constant power profile”, i.e. the reporting rates are: 4 frames/h, 2 frames/h and 1 frames/h. The difference between the PV power profile P_{PV} (Fig. 3b) and the load power profile P_l (Fig. 3a) is the net power profile P_{net} (Fig. 4).

The data for load- and PV power profiles are acquired synchronously (relative to the measurement frequency, one sample/s).



a) b)

Fig. 3. Load power profile (a), active power profile for PV installation (b), on 21 July 2023, in a prosumer node (T_w= 1 s)

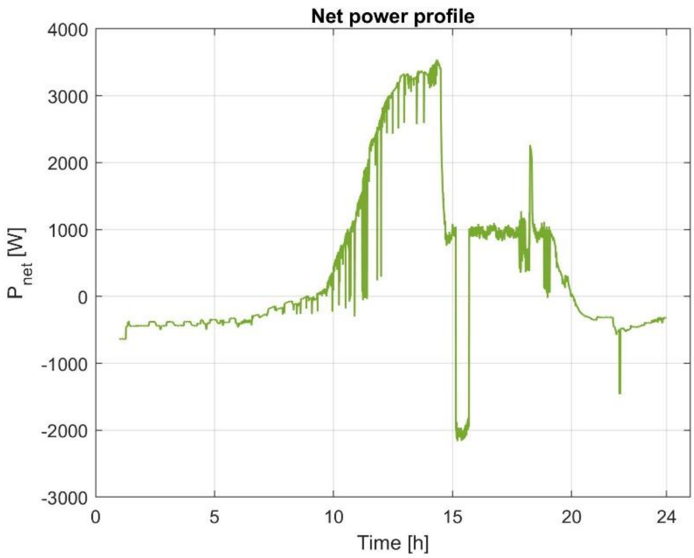


Fig. 4. Net power profile, on 21 July 2023 (T_w = 1 s)

A. Assessment of absolute net power profile

We perform the statistical analysis on the absolute net power profile $|P_{net}|$, using the selected 3 reporting rates (1 h, 30 minutes and 15 minutes, respectively). The CV(RMSD) metric results are presented in Fig. 5. It can be observed that for T_r = 1 h the maximum value is 1.06, recorded at 10:00, corresponding to T_{r10}. For the analysis made with T_r = 30 minutes it can be observed that the maximum value is 0.88 at 10:00 pm, corresponding to window T_{r44}. The computed results using a reporting rate of 4 frames/h (or T_r =15 minutes) present a maximum value of 1.04 at 10:00 pm, corresponding to window T_{r88}. To observe how the net power profile variability evolves we repeat the process for a weekend day, on 23 July 2023. The net power profile P_{net} (Fig. 7) is computed based on the PV power profile P_{PV} (Fig. 6b) and the load power profile P_l (Fig. 6a).

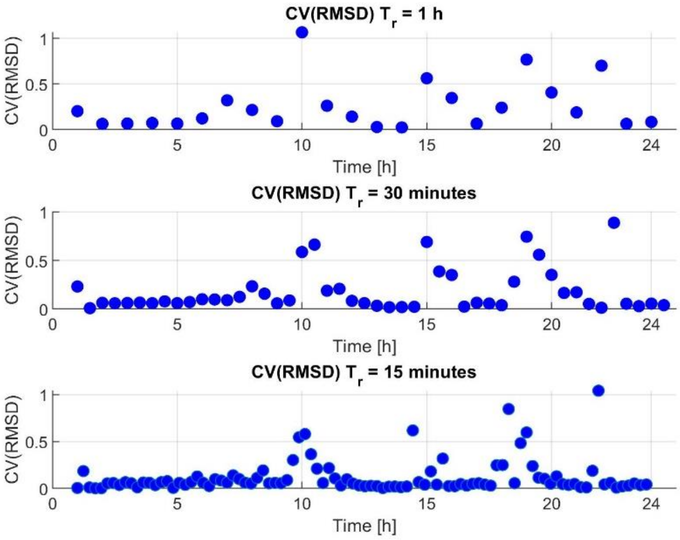
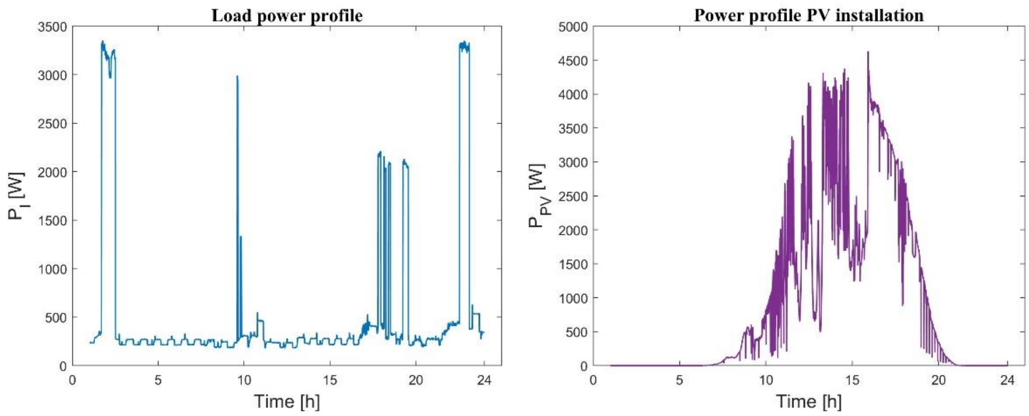


Fig. 5. CV(RMSD) values for $|P_{net}|$, 21 July 2023



a) b)

Fig. 6. Load power profile (a) and active power profile for PV installation (b), on 23 July 2023 (T_w= 1 s)

The CV(RMSD) metric applied to the absolute net power profile $|P_{net}|$, using the 3 reporting rates 1 frame/h, 2 frame/h and 4 frames/h, is presented in Fig. 8. It can be observed that for T_r = 1 h the maximum value is 1.11, recorded at 11:00 PM, corresponding to window T_{r23}. The results obtained using a reporting rate of 2 frames/s (or T_r =30 minutes) present a maximum value of 1.13 at 9:30 PM, corresponding to window T_{r19}. The analysis results for T_r = 15 minutes present a maximum value of 1.57 at 9:15 PM, corresponding to window T_{r37}.

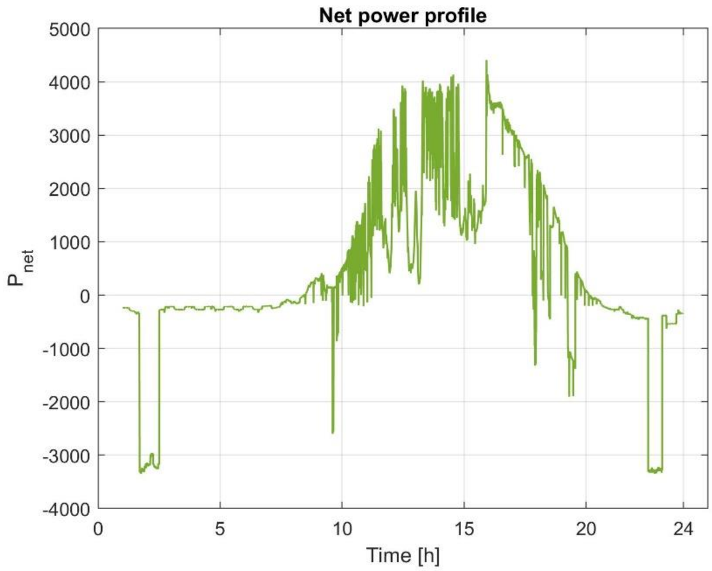


Fig. 7. Net power profile on 23 July 2023 (T_w = 1 s)

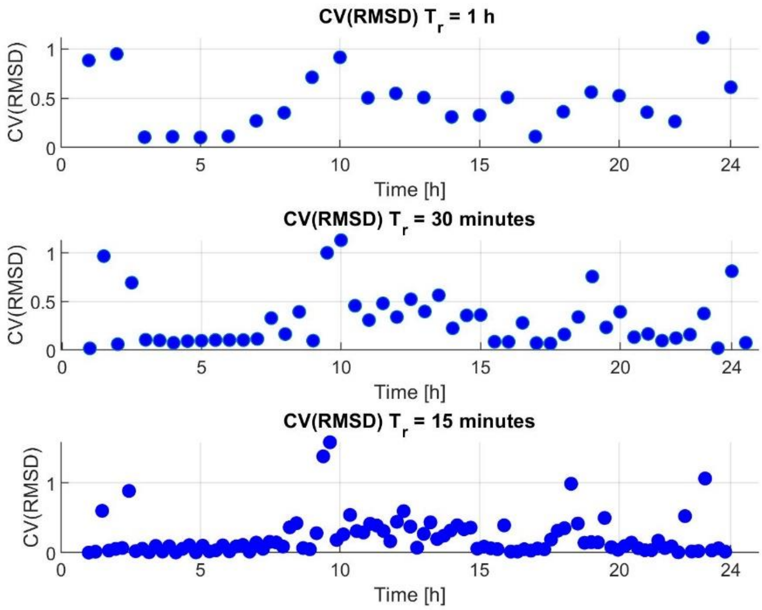


Fig. 8. CV(RMSD) values for $|P_{net}|$, 23 July

To decide how high the variability in the microgrid is, we propose to analyze the median value of the CV(RMSD) for the three signals: load-, PV- and absolute net power profile.

We applied the metric CV(RMSD) on the load power profile, active power profile from the PV installation and absolute net power profile data using different time reporting windows, for two days 21.07.2023 and 23.07.2023, and results for the median values are presented in Table 2. It can be observed that the power variability (in terms of CV(RMSD)) is higher for the weekend day 23 July 2023, having the maximum values of 43% for $|P_{net}|$, 15% for P_l and 25% for P_{PV} when T_r = 1 h.

Table 2

CV(RMSD) median values

T_r	21.07.2023	23.07.2023	21.07.2023	23.07.2023	21.07.2023	23.07.2023
	CV(RMSD) [%] for $\|P_{net}\|$		CV(RMSD) [%] for P_l		CV(RMSD) [%] for P_{PV}	
1 h	16	43	9	15	6	25
30 min	8	16	8	10	3	7
15 min	6	9	6	6	2	5

B. Assessment of net power profile

However, for specific loading conditions and/or weather (clouds) – depending on power generation, the use of absolute net power profile is hiding the two processes variability and by such is hindering the effectiveness of power control algorithms. Therefore, the CV(RMSD) applied to the net power profile (instead of absolute power profile) appears to be more appropriate.

In this case we use for $\bar{y}_p$ in (1) the nominal power of the PV installation:

$$y_i^* = \frac{\sum_{i=1}^{N_r} P_i}{N_r}; \bar{y}_p = P_n = 5\ kW \tag{3}$$

Results for CV(RMSD) applied over the net power profile P_{net} on 21.07.2023 using the assumed model y_i^*, on different time reporting windows, are presented in Table 3. In can be observed that the maximum depicted values are around 30% when the median value is situated around 1%.

Table 3

CV(RMSD) values for net power profile

T_r	CV(RMSD) [%]		
	min	max	median
1 h	0.50	33	1.5
30 min	0.08	30	0.9
15 min	0.02	27	0.7

One can observe that the median CV(RMSD) of the same day 21.07.2023 is significantly lower when using net power profile - with equation (3) - than when using absolute power profile (Table 2).

We repeat the procedure for one week in June 2023 (17.06.2023 to 23.06.2023) using to observe the net power profile variability. Results for CV(RMSD) applied over P_{net} using the assumed model y_i^*, on time reporting window T_r = 15 minutes, are presented in Table 4. One can observe that the maximum CV(RMSD) value is 34.43 % on 17 June 2023, the minimum value is 0 for half of the week (recall that a value of 0 signifies an ideal alignment between the model and reality). The median CV(RMSD) value is around 1% for the studied week.

Table 4

CV(RMSD) values for one week on net power profiles

Day	CV(RMSD) [%]		
	min	median	max
17.06.2023	0.00	0.72	34.43
18.06.2023	0.00	1.05	25.86
19.06.2023	0.02	1.07	31.48
20.06.2023	0.02	0.98	33.95
21.06.2023	0.00	1.00	30.15
22.06.2023	0.00	0.69	26.71
23.06.2023	0.02	1.38	30.56

4. Conclusions

In this paper we consider a prosumer for which both loading, and generation power profiles are available with a synchronous sample rate of 1 sample/s. The variability has been quantified for two different loading conditions (weekday and weekend day) and three different constant power models (T_r = 1 h, 30 minutes and 15 minutes). To assess the impact of the prosumer on the distribution grid the indicator CV(RMSD) has been calculated for net power profile and absolute power profile. The use of net power profile with a presumed model value selected as a nominal PV generation power proves to be more appropriate for assessing power profiles variability in LV networks. To examine the variability of the system the net power profile over the course of one week was evaluated.

R E F E R E N C E S

[1] *A. Kotsonias, M. Asprou, L. Hadjidemetriou, and E. Kyriakides*, "State Estimation for Distribution Grids with a Single-Point Grounded Neutral Conductor", IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 10, pp. 8167–8177, Oct. 2020.

[2] *Theo W.L., Lim J.S., Ho W.S. et al.,* "Review of distributed generation (DG) system planning and optimisation techniques: comparison of numerical and mathematical modelling methods," Renewable Sustainable Energy Reviews, vol. 67, pp. 531– 573, Jan. 2017.

[3] *S. Backe, S. Zwickl-Bernhard, et. al.*, "Impact of energy communities on the European electricity and heating system decarbonization pathway: Comparing local and global flexibility responses", Applied Energy, vol.323, pp. 1-18, Oct. 2022.

[4] *Artis Riepnieks, Harold Kirkham,* "An Introduction to Goodness of Fit for PMU Parameter Estimation", IEEE Transactions on Power Delivery, Vol. 32, Issue 5, October 2017, pp. 2238 – 2245

[5] *Olivia Florencias-Oliveros; Juan-Jose Gonzalez-de-la-Rosa; J.M. Sierra Fernandez; Manuel-Jesus Espinosa-Gavira; Agustin Aguera-Perez; Jose-Carlos Palomares-Salas*, "Power Quality Measurement and Analysis Using Higher-Order Statistics: Understanding HOS contribution on the Smart(er) grid", Wiley-IEEE Press, 2023

[6] *A. P. Brîncoveanu, R. Plămănescu, A. -M. Dumitrescu and I. Ciornei*, "Assessment of Power Profiles in LV Distribution Grids", 2023 8th International Symposium on Electrical and Electronics Engineering (ISEEE), Galati, Romania, 2023, pp. 69-74,

[7] *Rob J. Hyndman, Anne B. Koehler*, "Another look at measures of forecast accuracy", Intern. Journal of Forecasting 22 (2006) 679–688

[8] *Pallavi Bharadwaj, Janak Agrawal, Rupamathi Jaddivada, Min Zhang, Marija Ilic,* "Measurement-based Validation of Energy-Space Modelling in Multi-Energy Systems", 52nd North American Power Symposium (NAPS)

[9] *M. Sanduleac, L. Pons, G. Fiorentino, R. Pop and M. Albu*, "The unbundled smart meter concept in a synchro-SCADA framework", 2016 IEEE International Instrumentation and Measurement Technology Conference Proceedings, pp. 1-5, Taipei, Taiwan, 23-26 May 2016.

[10] *R. Plamanescu, Mihai Valentin Olteanu, Viorel Petre, Ana-Maria Dumitrescu, Mihaela Albu,* „Knowledge Extraction From Highly-Variable Power Profiles In University Campus", U.P.B. Sci. Bull., Series C, Vol. 84, Iss. 4, 2022, ISSN 2286-3540, WOS:000907279800019