PV integration and Demand Side Management: First results from Cyprus

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ABSTRACT

The trend towards high penetration of renewable energy sources (RES) in the energy mix and particularly grid-connected photovoltaic (PV) systems in the low voltage (LV) network, offers the benefits of green decentralized generation, at the same time requiring the development of energy management tools to alleviate potential problems. More specifically, the fact that PV energy production does not coincide with the electricity demand, necessitates the grid to be called upon to act as a sink and a source thus changing the classical role of the grid requiring re-adaptation of the grid operation. To this effect, an advanced demand side management (DSM) scheme can be introduced to mitigate RES integration stability issues by minimizing and alleviating system capacity violations. In this work, a dynamic price-based DSM tool has been developed and implemented based on real data from households in Cyprus. Smart meters (SMs) have been installed at 300 households equipped with grid-connected PV systems, in order to acquire consumption and production profile details of typical Cypriot prosumers. The selected pilot sites that are equipped with a 3 kWp grid-connected PV system, will use a ToU tariff allowing rates and charges to vary based on the consumption, i.e. day or night and seasonality.

1 INTRODUCTION

Grid stability issues arise with the increasing penetration of renewable energy sources (RES) and particularly grid-connected photovoltaic (PV) systems at the low-voltage network. It may offer the associate benefits of a decentralized and distributed electricity generation however, this does not remedy the problem of intermittency. To this effect, demand side management (DSM) schemes have been introduced in the most developed countries aiming to control the demand, levelise peak demand and allow higher penetration of RES [1]–[4].

In this work, a dynamic price-based DSM tool has been developed and implemented based on real data from households in Cyprus. The aim is to motivate residential customers to shift load from peak to valley periods resulting to lower electricity bills. The validation of the price-based DSM tool and comparative analysis started in July 2015 when the data acquisition process has begun. The comparative results of the average daily consumption profile for a typical domestic consumer as obtained from the Electricity Authority of Cyprus (EAC) and the measured datasets from the pilot sites are analysed showing strong correlation indicating that the participants represent the typical domestic customer. Finally, the self-consumption and self-sufficient rates for two seasons, summer and autumn, were derived. The yearly self-consumption and self-sufficient rates will be derived with the acquisition of measured datasets in July 2016 and yearly comparative results will be presented between the typical domestic consumer and the pilot sites.

2 PROSUMERS FEATURES

In support of this work, three hundred prosumers in Cyprus have been selected through the implementation of the SmartPV project (http://www.smartpvproject.eu/), in order to collect real measurements from a representative sample for the Cypriot consumer. Smart meters (SMs) have been installed to acquire consumption and production profile details. The selected pilot sites are equipped with a 3 kWp grid-connected PV system as is the case with the existing net metering scheme for households in Cyprus.

In addition, the participants will be able to monitor their energy habits through the use of different monitoring devices. For one-hundred prosumers "In-House Displays (IHDs)" will be installed at their households, while others will have access either to a web application or receive information about their energy habits through the traditional bi-monthly mail bill. This enables an in-depth examination of the prosumer energy behaviour changes using different monitoring accessibilities.

3 METHODOLOGY

The development of the dynamic price-based DSM tool relies strongly on the analysis of the basic input parameters such as electricity demand and initial rates and charges. The first step for the development of the price-based DSM tool was to identify the peak and valley periods of the total electricity demand. The load duration curve of the provided total electricity demand in Cyprus for each season was provided and using statistical analysis the ToU block periods were identified. Then, optimization procedures were performed in order to improve the load curve fitting, resulting in an optimized price-based DSM measure [5].

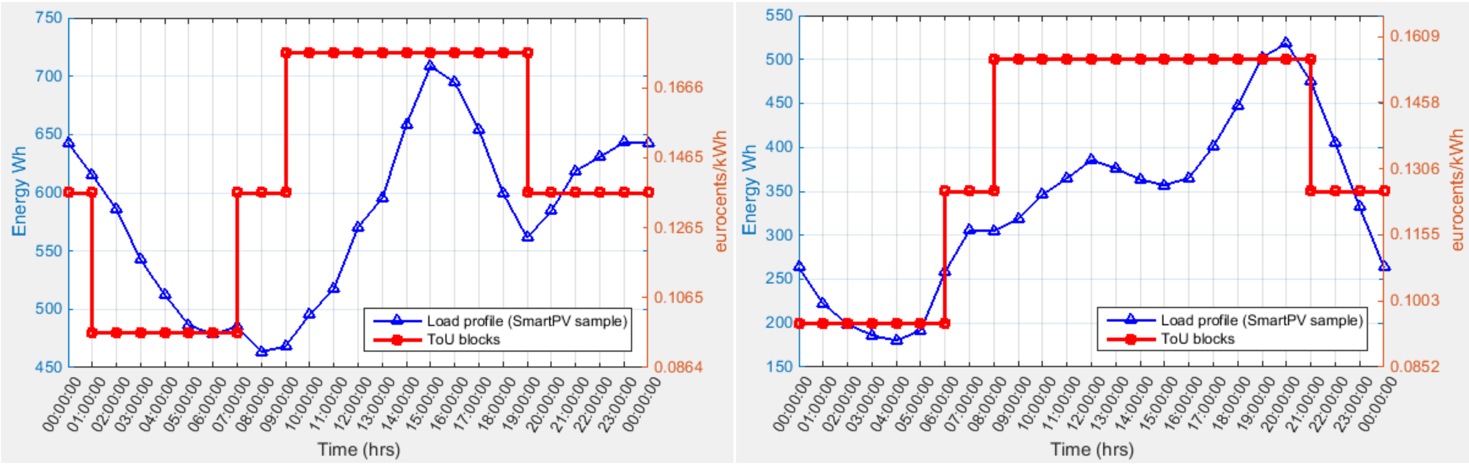
Beyond the identification of the ToU block periods, the tool calculates the electricity bill based on optimum ToU tariffs which are calculated using the well-known fminocn solver [6] which finds a constrained minimum of a scalar function of several variables [5]. The computation of the electricity bill is based on the ToU blocks, ToU tariffs and the associated load curve.

The collected datasets for the summer and autumn seasons have been processed and the optimized ToU tariffs for the corresponding seasons were derived as shown in Table 1. Figure 1 (a) presents the daily average profile for the summer period with the corresponding ToU blocks and tariffs while Figure 1 (b) presents the daily average profile for the autumn period with the corresponding ToU blocks and tariffs.

Table 1. Derived ToU blocks and tariffs for summer and autumn period.

Summer	**Off-peak**	**Shoulder**	**Peak**
Blocks/Time	01:00 – 06:59	19:00 – 00:59 07:00 – 08:59	09:00 – 18:59
Tariff/price	0.0964 €/kWh	0.1365 €/kWh	0.1766 €/kWh
Middle			
Blocks/Time	00:00 – 05:59	06:00 – 07:59 21:00 – 23:59	08:00 – 20:59
Tariff/price	0.0961 €/kWh	0.1261 €/kWh	0.1561 €/kWh

Although, the ToU block periods have been derived based on the total electricity demand, the residential load profile falls within the ToU peak and valley periods. Further analysis was performed in order to examine the correlation between the participants load profile and the provided domestic profile from the EAC. For this purpose, the Pearson product-moment correlation coefficient was calculated which is defined as the covariance of the two variables divided by the product of their standard deviations and then the correlation rate is found. Strong correlation rate indicates that the two profiles have similar pattern while weak correlation rate implies to two jarring patterns. This analysis is important to clarify the representativeness of the sample relatively to the average Cypriot consumer.



(a) (b)

Figure 1. Derived ToU tariffs for: (a) summer and (b) autumn season.

Beyond the price-based DSM tool, the self-consumption rate is important to be identified. The self-consumption rate shows the PV energy which is directly used over the total PV production. For this reason, participants with 2 SMs installed at their premises provide measurements of import, export and PV production energy. Hence, the self-consumption rate is possible to be calculated, an analysis which was performed for the summer and the autumn period where real measurements acquired. For the calculations of the self-consumption rate the Eq. (1) is used to find the self-consumption energy and then converting it to the percentage rate. The self-sufficient rate shows the share of the load consumption that is supplied by the PV energy and is calculated using the Eq. (2).

$$\text{Self-consumption} = (\text{total PV production} - \text{export}) / \text{total PV production} \quad (1)$$

$$\text{Self-sufficient} = (\text{total consumption} - \text{import}) / \text{total consumption} \quad (2)$$

Below, results from correlating the measured with the provided average consumption profiles are provided along with the self-consumption/sufficient rates for both seasons, summer and autumn.

4 RESULTS

4.1 Correlation rates

The first results from the pilot sites show impressive correlation rates between the participants and the provided average consumption profile. Specifically, the correlation rate for the summer season (Figure 2) is up to 92.56 % with an increased consumption by 32.03 %. This is mainly due to the fact that the provided average load consumption profile includes vulnerable groups, cottages etc., which reduce the average daily consumption profile. Similar results occurred for the autumn season (Figure 3), at which the correlation rate between the measured consumption energy and the provided average consumption profile is about 96.5 % with an increased consumption of 19.40 %.

The strong correlation rates from the first analyses confirm the representativeness of the selected sample over the average Cypriot consumer thus any behaviour change due to the application of the ToU tariffs can be extrapolated to a larger scale.

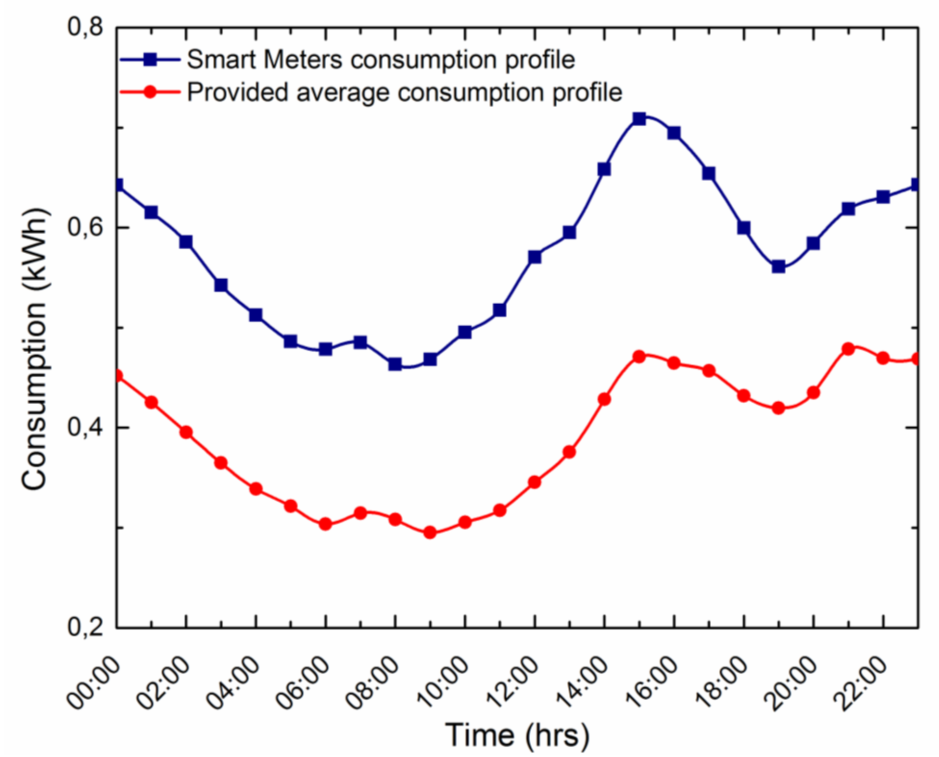


Figure 2. Comparison of household consumption profiles between measured and provided average consumption data-sets for the summer season.

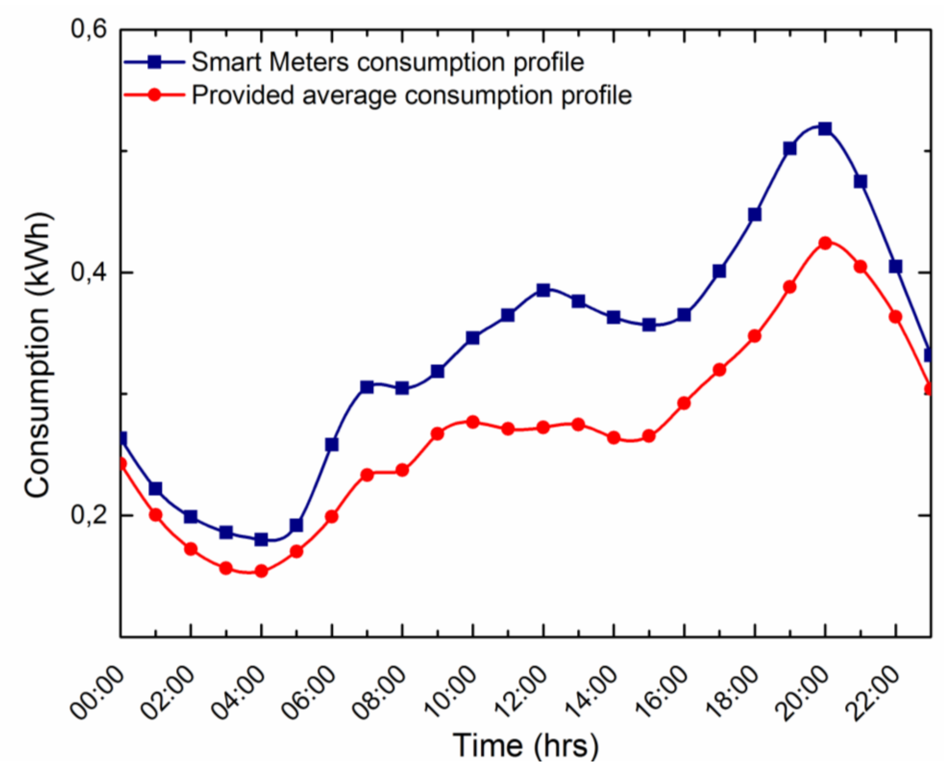


Figure 3. Comparison of household consumption profiles between measured and provided average consumption data-sets for the autumn season.

4.2 Self-consumption/sufficient rates

The average daily energy profiles for import, export, PV production and consumption were derived for the summer and autumn seasons as shown in Figure 4 and Figure 5 respectively. The self-consumption/sufficient energy and rate were calculated for each period as presented in Table 2. The self-consumption rate for the summer period is about 53 % while for the autumn period is around 40 %. The self-consumption rates are high, due to the fact that the participants have high energy needs. This can be observed from the fact that the production energy does not match with the consumption resulting in a positive-bias self-consumption rates. The rate difference is caused due to the seasonal customers' energy behaviour as also due to the PV energy generation. In autumn the daily PV production is by 2.46 kWh less than the summer period. The self-consumption energy in the summer period was almost double than the autumn period indicating that different loads are utilizing during the summer period which coincide with the PV production profile.

The self-sufficient rates which show the share of the load consumption that is supplied by the PV are 29.98 % and 26.88 % for the summer and autumn period respectively. These percentage values indicate the need of shifting load to the PV production period.

Table 2. Calculation of self-consumption/sufficient energy from average daily energy data.

	SmartPV sample - summer	**SmartPV sample - autumn**
Consumption (kWh)	13.81	8.07
PV production (kWh)	7.77	5.31
Import (kWh)	9.67	5.90
Export (kWh)	3.64	3.14
Self-Consumption (kWh)	**4.13**	**2.17**
Self-Consumption (%)	**53.17**	**40.81**
Self-sufficiency (kWh)	**4.13**	**2.17**
Self-sufficiency (%)	**29.98**	**26.88**

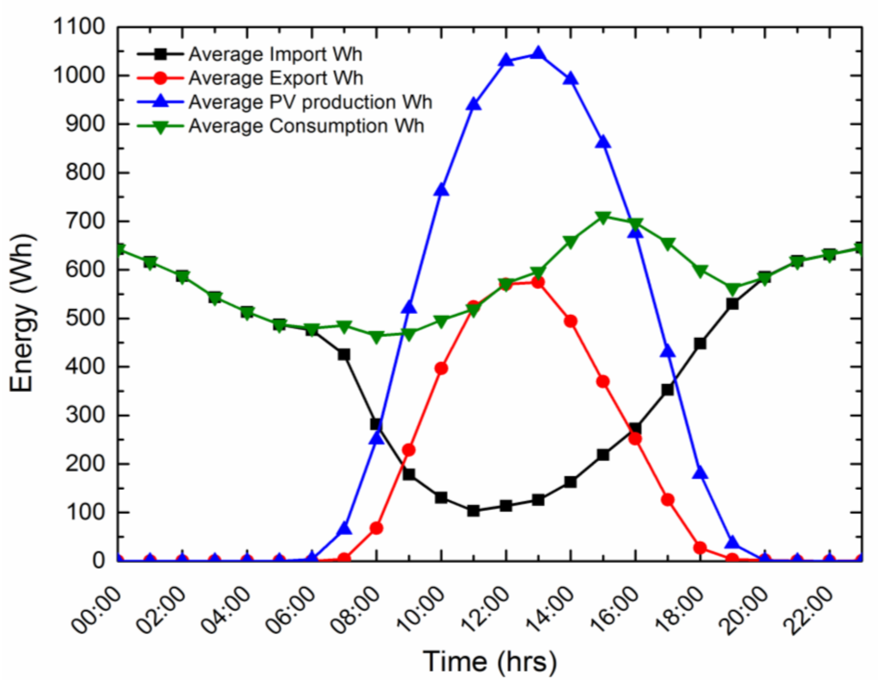


Figure 4. Energy pattern of the average SmartPV sample with 2 SMs during the summer period 2015.

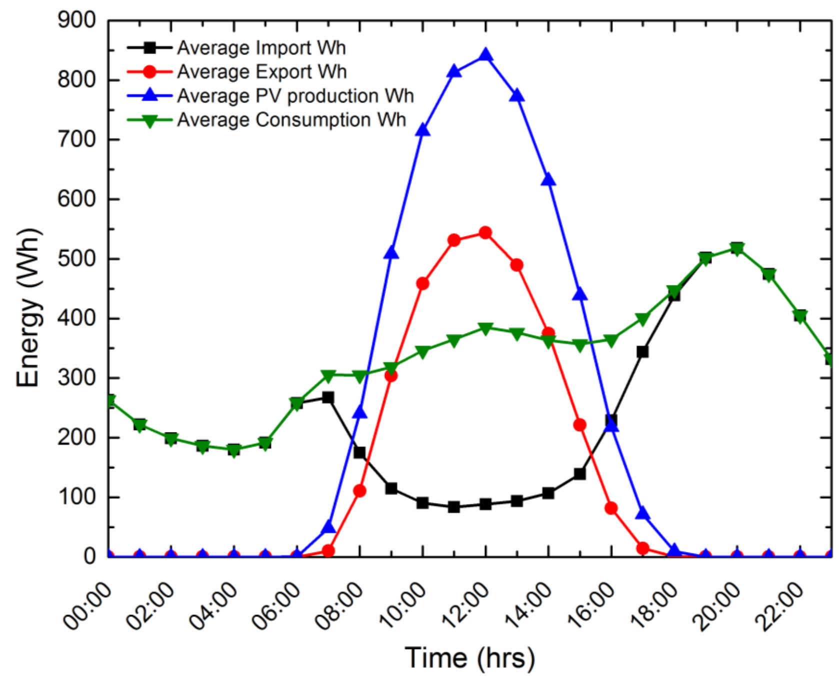


Figure 5. Energy pattern of the average SmartPV sample with 2 SMs during the autumn period 2015.

The results exhibit the need for energy behavior change in order to increase the season self-sufficient rate especially for the autumn period which will further allow higher PV penetration and better utilization of the grid assets. The price-based DSM tool which is developed aims to motivate customers to shift loads from peak periods to off-peak periods thus smoothing the profile.

5 CONCLUSION

In this paper, the development of the dynamic price-based DSM tool was presented. The methodology followed to derive the optimum ToU blocks and tariffs was analysed and the first results derived from the pilot sites were demonstrated. The correlation rate between the participants and the provided average energy consumption indicated strong correlation for both seasons, summer and autumn, clarifying the representative sample of the selected customers. A self-consumption rate of 53.17 % and 40.81 % for the summer and autumn period respectively was derived. Due to the fact that customers have increase energy needs these rates are positively-biased. On the other hand, the self-sufficient rates are about 29 % and 26 % for the summer and autumn periods demonstrating the need for better matching the load utilization with the available PV generation. The rates are expected to change after the application of the ToU tariffs.

AKNCOWELEDGE

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