Small Energy Prosumer Revenue Diversification with ASIC hardware

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***Abstract* - This paper observes the market participation possibilities of a small electricity producer with its own electricity consumption - prosumer. Based on actual 10-minute measurements of consumption and production for a household with an installed PV system and considering the current legal and regulatory framework in the Republic of Croatia, this paper proposes a solution for net producers - prosumers who on annual level deliver more energy to the grid than they take from the power supplier. By using ASIC hardware in the optimal mode for observed household, it is possible to significantly increase the revenue of the prosumer while simultaneously having a favorable effect on the power network. With precise methodology and data validation, this paper indicates how the integration of a managed ASIC consumption unit into each prosumer node enables more harmonious cooperation with the supplier, while creating an additional revenue stream for the end users of the network. In addition to the presentation of models, calculations, and results, the paper presents the possibility of combining approaches and forming energy communities based on the consolidation of ASIC hardware with the aim of joint market performance.**

Keywords - ASIC, blockchain, prosumers, self-consumption, revenue

I. Introduction

Technological developments and innovation over the last decade resulted in efficient renewable energy sources (RES) applications, both on a small and large scale, with significant cost reduction and reasonable payback periods. As a result, businesses and households can participate in electricity generation, which they can partially or completely consume at the spot of generation. Thus, passive consumers become active consumers and active consumers with excess of energy that can be released to grid are called prosumers [1]. The concept of self-consumption signifies the consumption of energy produced by power generation plants that are close to the consumer, i.e. photovoltaic (PV) panels or vertical-axis wind turbines installed locally at the premise of power consumer [2].

The self-consumption model opens new optimization challenges and market possibilities in savings on electricity bills and reducing consumers CO_2 footprint while making consumer more independent of a supplier [3]. The latter has greater significance today than even before, considering the recent rise in electricity prices on the market followed with increase in electricity prices for the end-consumers and households. Other factors contributing to growing number of prosumers is: steady decrease in the equipment prices of PV systems which are most chosen technology for consumer's transition to prosumer; attractive feed-in tariff system which subsidizes RES-based power generation; and, various national-level measures to reduce the amount of capital investments required [4].

Production of the prosumer system depends on the availability of primary energy source. When it comes to PV plant installations on the end-user premises, mostly households, peak production occurs mid-day. When the power generation of such system is higher than the electricity demand in the same measurement point, there is a surplus of electrical energy that is fed into the grid. A supplier of electrical energy takes that surplus energy, which is delivered through the bidirectional, and often dual-rate, power meter, either by obligatory regulatory framework or by bidding against other suppliers and offering better financial conditions [5].

However, a multitude of such prosumers can have a negative impact on the grid and it may be uninteresting for suppliers to take energy from them because grid constraints are being violated [6]. There are attempts and research to make PV systems manageable and that there are no negative impacts on the network [7]. Today this goal can be achieved by integrating battery storage systems (BSS) that can even help the power system [8]. Today's technology goes so far that Braeuer et al. explain how BSS can establish an additional revenue stream for prosumers. Authors prove this by analyzing 50 different German companies with different systems and load profiles. The authors successfully identify how a flexible consumer like a BSS can participate in arbitrage trading on day-ahead or intraday electricity market, provide a reserve for frequency containment, and successfully reduce peak loads for consumers close to them [9].

A slightly progressive approach is observed in this paper. Instead of charging the battery at low electricity market prices and releasing the energy at high prices, this paper proposes a model in which excess electricity on the prosumer side is stored in digital value. The model is based on real-life power measurements in 10-minute resolution for a typical household prosumer in Croatia. The paper also provides an overview of the financial effects of kWh storage in chemical or digital form. The conversion of electricity into digital value takes place using specialized ASIC hardware used for transaction validation process called *mining* in the digital cryptocurrency ecosystem.

This paper is organized as follows: Section 2 provides an overview of the environment in which the observed prosumer is located and a description of the system that uses ASIC hardware instead of BSS. Section 3 provides insight into the evolutionary process of the observed prosumer and provides model results with and without dedicated ASIC hardware. Section 4 provides a comparison of the market opportunities and performance of this prosumer with BSS versus the ASIC hardware approach. Finally, Section 5 concludes on the applicability of ASIC hardware in circumstances of more favorable prosumer performance on the distribution network.

II. System Description

In the Croatian legal framework prosumers as the end users of electricity are defined by two categories: self-sufficient end-user; and consumers with own production. self-sufficient end-users are the end customer of electricity of the household category, who within their premises have a power plant that enables them to be partially or completely self-sufficient. A self-sufficient power plant uses renewable energy sources or high-efficiency cogeneration, and possible excess of energy in any billing period can be taken over by a supplier or market participant. Such system needs to take care that the amount of electricity delivered to the network is less than or equal to the electricity taken from the network. If at the end of the billing period the amount of energy delivered to the network, expressed by price C_{iT}, is higher than the energy taken from network, expressed by price C_{pT}, the price of surplus electricity delivered to the network is reduced and calculated by:

$$C_{iT} = 0.8 \times C_{pT} \quad (1)$$

If the supplier or market operator determine that the self-sufficient end-user delivered more energy to the grid in the previous year than he took from the grid, he would be considered the consumer with own production.

A consumer with own production is defined as the end-user whose grid connection point (GCP) has adjacent installation of a RES-based power plant which meets the need of the customer(s) at that GCP and that is allowed to deliver surplus electricity to the power network. Price for the surplus energy delivered to the grid, C_i, in the billing period of one month is calculated according to Eq. (2) and Eq. (3).

$$C_i = 0.9 \times PK_{Ci} \quad (2)$$

$$C_{iT} = 0.9 \times PK_{Ci} \times \frac{E_p}{E_i} \quad (3)$$

Where PK_{Ci} is the average price of electricity paid by the consumer to the supplier for the sold electricity, excluding network usage fees and other fees and taxes, within the billing period i; E_p is the electricity consumed from the grid; and E_i is the electricity fed to the grid from the RES-based power plant. Eq. (3) indicates how it is financially viable for prosumers to bring up their self-consumption. The breakdown of prosumers into two categories allows end-users with production to take care of their own consumption and reduce their bill. But at the same time, such a two-stage reduction in the price of delivered energy discourages abuses and fictitious consumers with connections where only power plants are located.

A. Measures to increase self-consumption

Measures to increase self-consumption usually imply demand side techniques or BSS usage. The most often used demand side technique is load shifting which encourages consumers to shift their consumption in periods of cheaper tariffs or period with surplus of energy production.

Demand side techniques at prosumer level encourage consumption shift towards periods of peak production to increase the self-consumption ratio. Significant disadvantage of such approach is the change in the behavior pattern of consumers, hence impairing their comfort. BSS enables prosumers to store surplus energy in periods when electricity production surpasses household demand. By doing so, the stored energy can be used during times of insignificant or no production. Although BSS is an acceptable solution, over the past few years new technology has appeared that when compared to a battery can be described as Digital Energy Storage (DES).

DES consists of a specialized ASIC-type hardware with the ability to turn electrical energy into a digital asset within the cryptocurrency eco-system, bringing prosumer additional profit. By installing such system and regulating the operation of it in accordance with the power production, the prosumer could in periods of surplus energy, use it to make additional earnings instead of giving it to the grid or charging the BSS.

Prosumer enriched with ASIC hardware that takes the role of DES participates in the global digital eco-system for confirming transactions in the world of cryptocurrencies, thus creating additional revenue stream. Overview diagram of such prosumer is presented in Fig.1.

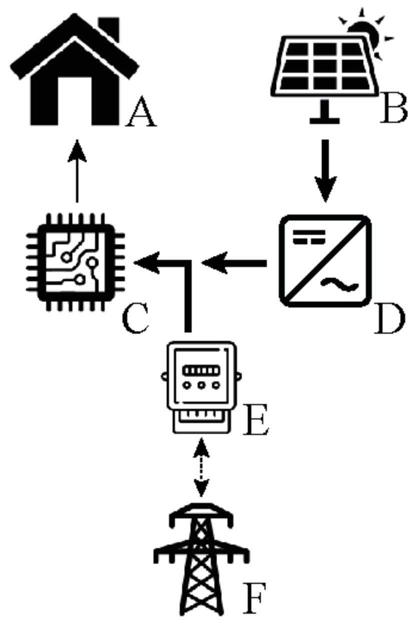

Figure 1. Observed Prosumer system with DES based on ASIC hardware

In Fig.1 household and its consumption are marked with letter (A); PV system is marked with letter (B); ASIC-based DES is marked with letter (C); Inverter is marked with (D); Bidirectional power meter is marked with letter (E); and power grid is marked with letter (F). Mid-day the PV System (B) produces more power than the household (A) requires. On an annual level that results in more energy being fed into the grid (F) over the meter (E) than the energy being taken from the grid. This fact is validated by real-life measurements of the household consumption and PV power plant production.

B. *Measuremente data and data validation*

The observed system consists of the household with standard loads and rooftop PV system of nominal power 5 kW located in Osijek, Croatia. Measurement sample is given by Fig. 2 in which three areas are visible: blue area represents household consumption; orange area stands for PV production curve; and gray area is ASCI-based DES operation. The chart represents one typical day with values that correspond to annual averages.

Load and production measurements for the household are given for a typical workday in March since that day corresponds to annual average values of electricity production and consumption. The correctness of this approach and the reasoning behind the fact that a typical working day in March can be taken as representative is confirmed by data from Photovoltaic Geographical Information System (PVGIS) platform of the Joint Research Centre (JRC) of the European Commission [10].

Calculations were done in the PV Performance tool which gave average energy production for the given system in the amount of 481.88 kWh for March. Compared to measured values, where produced energy was 485.22 kWh, the difference is less than 1 %.

Also, PVGIS indicates how 1 kW on installed PV modules with standard system losses and with optimal slope and orientation can yield in 1226 kWh of annual energy.

The confirmation of correctness and accuracy of the measured data allow a detailed analysis of the application of ASIC-based DES systems in the prosumer environment, considering the legal framework and market constraints

III. Simulation and Observed Cases

The research for this paper was done for three different cases: standard consumer, prosumer, and prosumer with ASIC-based DES.

A. *Case I - Consumer*

The first case is the standard consumer case. This case observes only blue area in the Fig. 2. Although electricity demand varies throughout the day, some behavior patterns are to be noticed: consumers are most active in the early morning and during the evenings and night. This makes perfect sense being the household consumption curve. Tenants wake up in the morning, prepare for going to work and then leave after having breakfast and morning routine. In the early evening tenants return home to clean, cook, and do overall household activities. Consumption during the night occurs due to Croatian two-tariff system that still incentivizes turning on large consumers, such as washing machine, dryer and/or dishwasher during the night. During the day when tenants are not present in the household some appliances still work, like a refrigerator or freezer, boiler, etc.

The price of consumed electricity is defined by the tariff system with the mentioned consumer being in the household consumption category. Prices are different depending on the daily tariff. In given example the higher daily tariff is from 7 AM to 9 PM, while the lower daily tariff is from 9 PM to 7 AM. Price of electricity with VAT rate of 1 % for the higher daily tariff is 0.95 HRK/kWh, while for the lower night tariff is 0.46 HRK/kWh. In addition, all consumers pay a special fee for renewable sources and high-efficiency cogeneration in the amount of 0.105 HRK/kWh, making final electricity prices 1.06 HRK/kWh for the daily tariff, and 0.56 HRK/kWh for the night tariff.

During the observed day, consumer electricity demand is 21.73 kWh, with 9.85 kWh demanded during the higher daily tariff and 11.88 kWh for the lower daily tariff. This fact reflects the mindset of the standard Croatian consumer of electricity, accustomed to a cheaper night tariff. The cost of electricity for the higher daily tariff is 9.35 HRK, and 5.46 HRK for the lower night tariff.

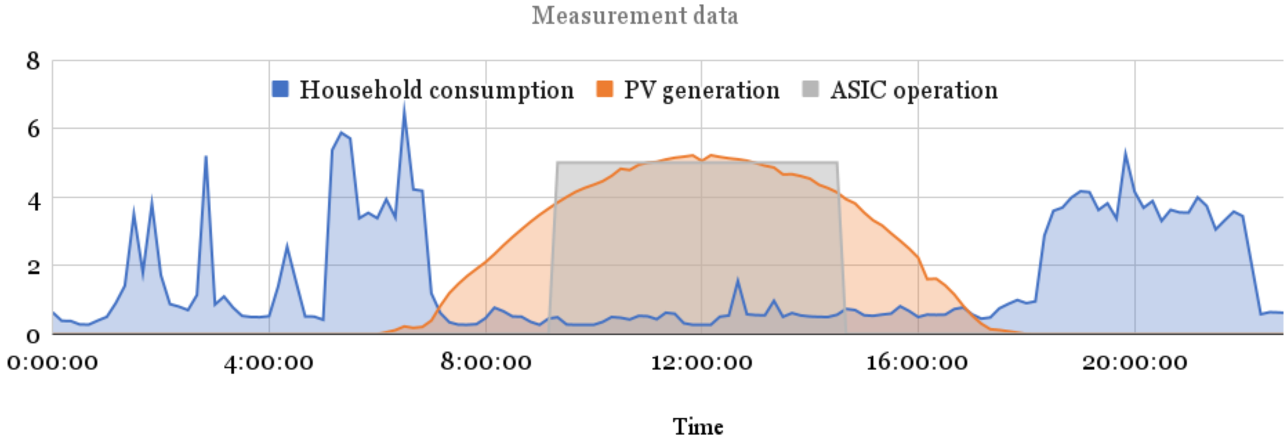

Figure 2. Measurement sample for a prosumer observed in this paper

In total, the amount that the consumer-type end-user must pay for the exemplary day of 14.81 HRK. The daily sum of 14.81 HRK results in monthly bill of 450 HRK which is valid value for a family household that uses electric cooking appliances

B. Case II - Prosumer

The second case observes same household but with prosumer option. Prosumer generates electricity from the PV system installed at the location. Consumption in the second case stays the same as in the first case, 21.73 kWh, but compared to the previous case, part of the electricity demand is supplied from the prosumer's PV production which is 21.87 kWh. Consequently, less energy is taken from the grid and that fact downgrades this self-sufficient end-user to a consumer with own production after the observational billing period.

During the higher daily tariff, 6.62 kWh of electrical energy with the total cost of 7.01 HRK is taken from the grid. In the same daily period, the 11.82 kWh with the total cost of 6.85 HRK for the lower night tariff is required from the power grid. The total cost of energy bought from the grid for the observed day is 13.86 HRK, just a bit lower than in the first case without PV system installed. This is due to tenants' behavior and lifestyle that requires most of the energy during the period in which PV system does not generate any energy.

As shown in Fig. 2., from 7:10 AM to 5:00 PM, electrical energy production is higher than the total demand of the household, reaching its peak around midday. The surplus electricity is fed into the grid in the total amount of 18.59 kWh. Due to energy fed into the grid is higher than the energy taken from the power grid, the observed prosumer is assumed to be the consumer with own production. When Eq. (3) is considered the price of surplus electricity is calculated according to:

$$C_i = 0.9 \times 0.49 \frac{HRK}{kWh} \times \frac{18.45\,kWh}{18.59\,kWh}$$

$$C_i = 0.43\,HRK/kWh \tag{4}$$

In this case, the prosumer pays for the energy taken from the grid and is being paid for the energy produced by PV system. Since the consumption happens in the period of the day when there is no PV system power generation, the prosumer pays the price difference between the price of electricity demanded and delivered to the grid, which amounts to 5.77 HRK per average day. Although this price paid by the end-user to the energy supplier is 60 % less than in the first case, the goal has not been fully achieved.

In terms of reducing the amount that the end-user must pay, that goal has been achieved, creating savings for the end-user. Still, due to more energy being delivered to the grid than taken from it, the prosumer does not get the full financial benefits of power generation with the PV system being installed. The ratio of self-consumption during the PV system daily operation is low, just around 15 %.

Of course, raising the awareness of the end-user that the appliances with the highest consumption are better to be turned on during the day is not an easy challenge because the daily and night tariffs are deeply rooted in end-users in Croatia. This is precisely the goal of the explained two-stage system of paying for final power generation at end-user premises.

C. Case III – Prosumer with ASIC-based DES

In the third case, the same prosumer household from the second case is observed, with the addition of the ASIC-based DES. The DES with a rated power of 3 kW is set to turn on in times of energy production being higher than demand and power of PV system production being higher than 2 kW. Energy generation and consumption values are identical as in the two prior cases, but amount of energy delivered to the grid and the amount of energy required from the grid change in accordance with the new system setup.

The DES electricity demand is observed separately from the household demand. Household electricity demanded from the grid is the same as in the first two cases making the total cost of it 13.86 HRK. The DES starts running at 9:20 AM, when a PV power production threshold is reached, and is in operation continuously until 2:40 PM, when the PV system power production declines under 2 kW continuously in a 10-minute period. Total energy consumption of DES for those 5 hours and 20 minutes is 16 kWh.

During the observed period electricity production is higher than household demand, but surplus electricity is not sufficient to power the DES without additional energy from the grid. Thus, for exactly 5 hours and 20 minutes, while the DES is running, an additional 2.45 kWh of electrical energy is taken from the grid, all of it during higher daily tariff making the cost of it 2,59 HRK at current prices. Because of the DES being in operation, the prosumer delivers less energy to the grid in comparison to the second case.

The amount of electrical energy being fed to the grid is 5.05 kWh and since total delivered energy is less than energy demanded, the price for it is calculated by the Eq. (1) and results in 0.44 HRK/kWh for a higher daily tariff. Therefore, the cost of delivered energy is 2.22 HRK.

Using the industry-leading profitability calculator, the amount the DES can make in a day if in operation the entire 24-hours period time could be 135,35 HRK in the time of writing this paper. The profitability of DES depends on many global factors: the total number of similar hardware involved in the same operation; a digital ecosystem parameter called *difficulty*; and joining into globally available hardware communities called *pools*. An excellent explanation of how the whole *mining* process takes place and what role the ASIC-based DES system plays can be found in the book by Academic Press, Handbook of Digital Currency [11].

In this observed operation mode, the installed DES is not running through the whole day, but for 5 hours and 20 minutes. There are *pools* that allow intermittent presence during the day if the one's hardware is reporting regularly.

In the case presented by this paper, DES yields to the prosumer an additional 30.07 HRK in daily revenue.

Understandably, since the rated power of the ASIC-based DES is 3kW, and the power threshold of turning it on is set to 2 kW of PV production, the prosumer will have to pay an additional price for the required electricity until the PV production reaches 3 kW or more. Compared to the initial 13.86 HRK, which is the total cost of energy consumption of this prosumer, the amount that the prosumer with DES must pay to the supplier increased by 2.59 HRK, to a total of 16.45 HRK.

Finally, when the price paid by the supplier to the prosumer for the excess electricity is deducted from the price paid by the prosumer for consumption, the final new amount of the prosumer’s bill is in the amount of 14.23 HRK. Comparison of financial benefits of three observed cases in presented by Fig. 3.

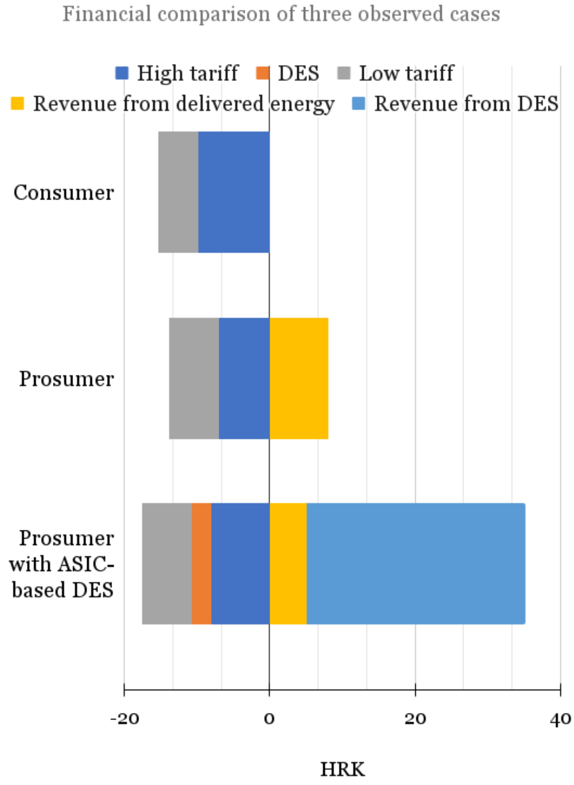

Figure 3. Financial benefit comaprison of three observed cases

The prosumer's total electricity cost is in this case higher compared to the two previous cases, but earnings from the ASIC hardware make up for it, leaving the prosumer with 15,84 HRK in total profit each day.

Using the DES, the self-consumption ratio rises to 76 %. Taking this into account and assuming such a case for a year, prosumer would be a candidate for self-sufficient end-user classification where the price at which the supplier takes electricity from prosumer is higher than in the case observed.

In this case, the prosumer will get paid more for the excess of energy being delivered to the grid, and that price will always correspond to the price that prosumer pays to the supplier for power consumption. Such a situation opens the possibility of additional optimizations and shifts of the DES turning on and off points towards a greater or lesser PV production threshold, all depending on the profitability of the hardware and the prices in the electricity market.

IV. BSS and ASIC Financial Comparison

For the sake of discussion, a model in which BSS is used as an alternative to the ASIC-based hardware is observed. Instead of the surplus of electricity being fed into the grid, it is used to charge the BSS. The surplus energy stored in the BSS during peak energy production is intended to cover electricity demand in periods of no or low production.

If all the surplus energy in the amount of 18,59 kWh was stored in the BSS, the prosumer gets the opportunity to use that energy to cover his needs. The stored energy is enough to cover the demand completely, making the prosumer fully independent of the supplier.

Energy is not being fed into the grid and no electricity is demanded from the grid, making the prosumer save 13.86 HRK.

Therefore, the advantage of the BSS integration only comes in the form of financial savings, compared to the ASIC-based DES which brings financial gain and additional revenue stream from a global market to the prosumer. Important to note is how the investment in BSS or ASEC-based DES is approximately the same in terms of rated power in this research.

V. Conclusion

Prosumers have a big challenge ahead of them - the consumer part must get used to new paradigms and regimes of energy consumption, and the production part must be properly dimensioned and optimized to achieve maximum benefit for the prosumer, without negative impacts on the distribution system. Increasing own consumption is just one of the solutions, and this paper brings an innovative solution to increase own consumption by participating in the global digital cryptocurrency eco-system.

Such participation necessarily generates revenue for the prosumer, and in this paper a mode of operation is proposed that is optimal for the supplier, the distribution system operator, and the typical residential prosumer. Through the presentation of three evolutionary cases, the cognitive sequence is shown in which the integration of ASIC-based hardware plays a key role in increasing the self-consumption of the prosumer and significantly increasing prosumer’s total revenue by adding a new earnings stream.

Comparing the proposed solution with a typical battery storage system sets the framework within which the application of this solution can be considered as a Digital Energy Storage. Such multi-domain Energy Storage is not limited by the constraints of the physical world and enables market competitions that have never been seen before.

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