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Effect of the Electricity Metering Interval on the Profitability of Domestic Grid-Connected PV Systems and BESSs

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Abstract – *Installations of photovoltaic (PV) systems on residential buildings have increased over the last few years, and this trend will continue. PV systems can increase the production of sustainable energy. Many homeowners want to do something to decrease their emissions or increase their energy self-sufficiency. The most important issue in the decision to invest in a PV system is profitability. In the EU, electricity metering practices will be harmonized, and this will affect the profitability of PV systems and battery energy storage systems (BESSs). In many countries, electricity is metered by hourly intervals, but metering will be changed to 15-minute intervals. In this study, the effect of the metering interval on the profitability of PV systems and BESSs was studied has been studied in Tampere area in Finland. A shorter metering interval will decrease the profitability of photovoltaic systems, while the profitability of BESS will increase. However, the change is so minimal that the attractiveness of PV systems will only decrease slightly. Investment in BESSs in addition to PV systems will become more attractive and will benefit the evolution of smart grids, because batteries enable flexibility in the grid.* ***Copyright © 2020 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords*: Solar Energy, Energy Storage, Batteries, Meter Reading, Simulation*

Nomenclature

β_P	Temperature coefficient of the solar cell power
η_c	Battery charging efficiency
η_{dc}	DC-converters efficiency
η_{inv}	Inverter efficiency
B_t	Storage energy transmission during an hour t
B_{eff}	Efficiency of the storage energy transfer
C_v	Verification coefficient
D	Electricity consumption of building
$E_{\max}$	Maximum capacity of storage
E_t	Amount of stored energy at time t
G	Demand to power grid
$G_{b,i}$	Beam component of solar irradiance
$G_{d,i}$	Diffuse component of solar irradiance
G_i	Global irradiance
$G_{r,i}$	Reflected component of solar irradiance
i	Discount rate
I_c	Battery charging current
n	Length of lifetime
NPV	Net Present Value
P_{dc}	Production after DC-converter
P_{PV}	Production of photovoltaic system
P_{STC}	Nominal power in standard test conditions
R_b	Battery internal serial resistance
R_y	Cost saving at the year y
SOC_t	State of charge at time t
T_c	Solar cell temperature
T_{STC}	Standard solar cell test temperature
V_b	Battery nominal voltage

I. Introduction

Electricity metering practices vary across the EU. The market time unit in balancing markets will be harmonized. In the Nordic electricity market, the balancing and metering period is one hour. Based on EU regulations (2017/2195) that establish guidelines for electricity balancing, all the Transmission System Operators (TSO) shall apply an Imbalance Settlement Period (ISP) of 15 minutes [1]. This change will happen gradually, and in Nordic countries, it will be implemented first in the intraday markets and then in the balancing settlement and balancing markets [2]. After some time, the 15-minute ISP will be implemented in day-ahead markets. ISP changes will set new requirements for electricity metering. Advanced metering infrastructure requires updating so that 15-minute measurements can be registered. The measurements are currently registered on an hourly basis (i.e., hourly energy).

When the time unit of electricity billing changes, this could affect the profitability of self-production and the Demand Response (DR) operations of customers. Self-production refers to electricity production by a customer (i.e., a prosumer), e.g., using solar energy and a photovoltaic (PV) system. Self-production can be used by an individual, but, in many cases, self-production exceeds an individual's consumption. Prosumers can sell surplus electricity to the grid, but the feed-in price of electricity is much lower than the purchase price [3]. It consists of the energy price, distribution price, and taxes,

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but the feed-in price consists only of the energy price.

The profitability of a PV system depends on the difference between the feed-in and purchase prices, the share of self-consumption and the investment price of the PV system [4]. Common sense says that probability for the same timing of consumption and production is higher when the time unit is an hour, opposed to 15 minutes. This hypothesis is under study in this paper. The share of self-consumption can be increased with a Battery Energy Storage System (BESS), so the change of market time unit can affect also the profitability of BESSs. The effect of changes to the market time unit on the profitability of PV systems and BESSs is the main research question of this study.

The profitability of a BESS can increase when different incentives from electricity billing structures are combined in the control of BESSs, as in [5] and [6].

These incentives of market-price-based control and peak cutting depend on the pricing structure, so the market time unit also affects these cost benefits. At the beginning, the time unit in day-ahead electricity markets remains an hour, and the 15-minute price for customers is the same during an hour. In this study, the market price is kept the same during an hour regardless of the metering interval. If the electricity distribution tariff from a Distribution System Operator (DSO) includes power-based fees, customers can get cost savings by peak cutting. The metering interval can affect the power-based charge because peak power can be very different in 15-minute increments compared to hourly increments.

Therefore, peak cutting with BESSs can also lead to very different results with different metering intervals. In this study, BESSs are used only to increase the self-consumption of PV production.

Although the general profitability of PV systems and BESSs has been studied thoroughly, the effect of the metering interval on the profitability of PV systems and BESSs has not been considered. Studies have used data from places such as Nordic countries where the hour metering interval is used. PV system and BESS profitability in Finland has been studied in [5]. In Germany, 15-minute data has been used in [7]. The profitability of grid-connected PV storage systems with five-minute data has been studied in [8]. Additionally, the profitability of battery energy storage alongside PV production has been studied in Greece in [9] and in Switzerland in [10].

Energy storages and effects of different control systems have been studied widely in many previous papers. The profitability of battery energy storage system connected to low voltage distribution network in case of Finland has been studied in [11]. Minimizing monthly peak powers in domestic real estate by using the control of BESS and charging of electric vehicle has been studied in [12]. Off-grid PV system in residential home with energy storage has been designed in [13]. Energy storage peak saving has been used for the optimization of a PV and energy storage system in [14].

This novel study is the first on where the effects of different metering intervals are compared. The results of this study are very important for the attractiveness of customers to participate smart grid via small scale PV production and DR with BESS. Previous studies do not compare different metering intervals and their effect on the profitability of PV and energy storage systems. In this study, three different metering intervals are compared: a one-hour interval, which is used in Nordic countries; a quarter-hour interval, which will be a common metering interval in the near future in the EU; and a one minute-interval because in the future the metering interval could be even shorter than a quarter-hour. In this study, the billing of electricity is based on metering when the interphase and time unit net metering are used. During every metering interval, only one measured value is used, and billing based on consumption differences between phases is not taken into account.

The paper is organized as follows. A simulation model that includes PV production and battery modeling is described in Section II. Section III presents the input data used in the simulations. The PV system and BESS are sized in Section IV. The simulations and their results are discussed in Section V. Section VI presents the conclusions of the study.

II. Simulation Model

II.1. PV Production

The PV production model is based on the global solar irradiance components of beam $G_{b,i}$, diffuse $G_{d,i}$ and reflected $G_{r,i}$. The model of the global solar irradiance based on the location on Earth has been introduced in [15]. Used panels are tilted and this is accounted in the model. In this study, the PV panels are tilted at a 45º angle facing south. Different irradiance components can be measured separately and global irradiance is the sum of these components $G_i = G_{b,i} + G_{d,i} + G_{r,i}$.

The production of a PV system (P_{PV}) can be calculated by equation (1), where P_{STC} is the nominal power in Standard Test Conditions (STC), β_P is the solar cell power temperature coefficient (0.006), T_c is the solar cell temperature and T_{STC} is the standard solar cell test temperature (25ºC) [16]. Theoretical PV production in real PV production is not same. For this reason, the verification coefficient C_v is added to the equation:

$$P_{PV} = C_v P_{STC} G_i \big(1 - \beta_P (T_c - T_{STC})\big) \tag{1}$$

The simulation model of PV production has been verified with real measurements of PV systems in [5]. The result has been that the verification coefficient C_v is 0.85. In modeling, the actual temperature of panel cannot know, so the outdoor temperature is used. In real situation, panel temperature rises higher than outdoor temperature because the panel absorbs solar radiation.

Wind speed affects also the panel temperature.

Additionally, the efficiency of the solar panels is decreased because of the aging of the cells and the type of solar cell affects this. The Effect of these error sources can be minimized by using verification. The verified simulation model gives realistic PV production data.

II.2. BESS Modeling

In this study BESS simulator, which has been developed for research the profitability of BESS during long periods, is used. A model of a BESS simulator has been developed and presented previously in [4], [5] and [6]. The type of BESS used in the model includes a Li-ion battery with a lithium iron phosphate (LFP or $LiFePO_4$) cell-type and a graphite negative electrode.

LFP is good for domestic use because of its good safety features [17]. Its long cycle and calendar lifetime and high efficiency increase the profitability. The BESS system and its connection to the building's electricity network are shown in Fig. 1.

Modeling of the BESS state is based on the state of charge (SOC), as shown in equation (2):

$$SOC_t = 100\frac{E_t}{E_{max}} = 100\frac{B_{eff}B_t}{E_{max}} + SOC_{t-1} \tag{2}$$

where E_t is the amount of stored energy at time t, and E_{max} is the maximum capacity of the BESS. The SOC at time t is SOC_t, and SOC_{t-1} is the SOC of the previous time step.

Variable B_t is the charged or discharged energy, and B_{eff} is the efficiency of the charging and discharging. Efficiency depends on the SOC, charging or discharging powers and aging of BESS. The positive and negative directions of current flow, if they are possible, are shown in Fig. 1.

To simplify, the losses are assumed to be the same in charging and discharging. In actual losses are not same, but when the using of BESS is cyclic, the overall losses is in realistic level. In this study, the efficiency of the inverter η_{inv} is 98%, and the converters' efficiency η_{dc} is 99%.

Thus, the efficiency of charging battery from the grid is 97%, and the efficiency of charging overproduced energy from PV panels is 98%. BESS losses occur mainly in the converters and in the battery itself [17].

Very high or low SOC increase the losses [18].

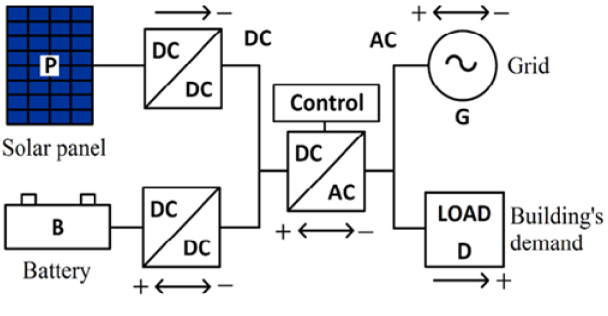

Fig. 1. BESS components and connections to building's electricity network [5]

For this reason, the SOC limits of the battery are set at 25-95%. Inside these limits, losses are almost linearly dependent on the charging current I_c, assuming that the internal serial resistance R_b is constant [19]. In this case, the charging and the discharging efficiency η_c can be calculated using equation (3):

$$\eta_c = 100\frac{V_b - I_cR_b}{V_b} \tag{3}$$

where V_b is the nominal voltage of the battery. The efficiency B_{eff} in (1) can be obtained by multiplying the efficiencies η_{dc}, η_{inv}, and η_c. The charged or discharged energy of battery B_t is calculated by multiplying the charging current I_c with the charging voltage V_c, which can be calculated using equation (4):

$$V_c = V_b - I_cR_b \tag{4}$$

The suitable voltage level of battery is constructed by connecting series battery cells. Battery capacity can increase, so the voltage level is kept stable by connecting these battery cell packages in parallel. In this paper, the internal serial resistance value of one modeled LFP cell has been 0.026 Ω, the cell voltage has been 3.3 V, and the capacity of one cell has been 2.5 Ah [20]. C-rate of battery tells the ratio of maximum power on capacity.

The C-rate 0.7 C has been the most profitable for the multi-incentive control type used in the study of [6], so this C-rate is also used in this study. The electricity demand of customers from the grid (G) perspective, so the effect of BESS and PV is accounted, can be modeled using equation (5):

$$G = \begin{cases} \eta_{inv}(-B_t - P_{dc}) + D, \| \eta_{inv}P_{dc} < D \\ -\eta_{inv}(P_{dc} - B_t) + D, \| \eta_{inv}P_{dc} \geq D \end{cases} \tag{5}$$

where P_{dc} is the self-produced PV energy between the converter and the inverter, and D is the electricity consumption of a building. From the grid perspective, the electricity demand of prosumers could be positive or negative. Negative demand means that the surplus energy is fed to the grid.

II.3. BESS Control System

In this study, the BESS is used to store the overproduced solar energy. The BESS control strategy is described in Fig. 2, where the SOC of the battery varies between 25% and 95% as a result of the properties of Li-ion batteries [18]. Battery degeneration can be slowed by not completely discharging the battery or by completely charging it. A battery is charging if production is higher than demand, and the stored energy is designed to discharge immediately when the demand rises higher than production.

This leads to a situation in which the battery is completely empty most of the time if the BESS is too large with respect to the size of the PV system.

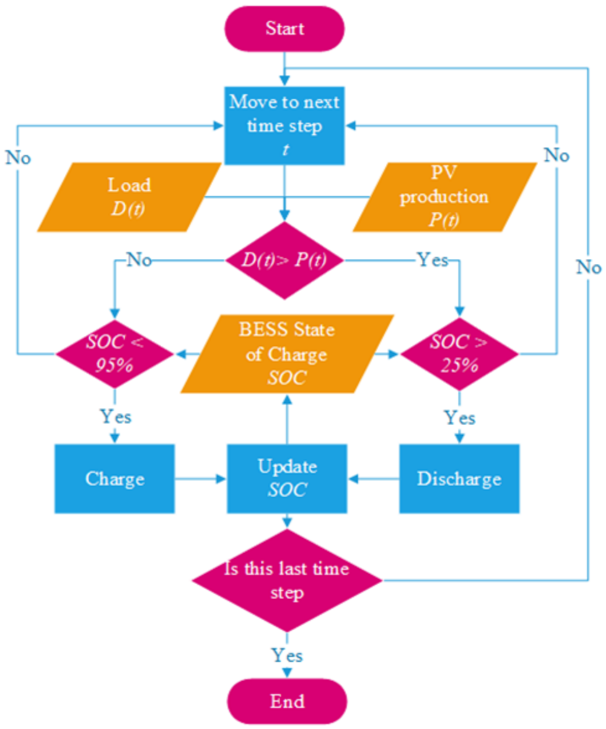

Fig. 2. BESS control process for increase the self-consumption of PV production

If the BESS is too small, the battery is fully charged most of the time. The price of electricity is not taken into account in the BESS control, because it is assumed to be same, when the metering interval change and the costs savings from electricity price control is same. The possible effects are taken into account in the discussion of this paper.

III. Initial Data

III.1. Load Profiles

The load data consist of the electricity consumption measurements from three detached houses in Finland.

These houses are located outside of Tampere city. Table I shows the detailed information of the houses. H1 and H2 were built in 2011 and 2012, respectively. The newest house is heated by a water boiler, and the second newest one is heated by a ground heat pump. The total consumption is much lower in the house with ground heating compared to the house where the water boiler is used even though the area of the former house is much higher. The third house (H3) was built in 1988, where underfloor heating resistors are used. The area of this house is much larger than the ones of the other houses, and the total consumption is also much higher. These three houses represent three kinds of typical detached houses in Finland, so the data include enough variations for this study.

Data have been measured with Efergy Engage online energy monitoring [21]. Measurements have been registered as the average power for a minute interval for the entire year of 2018. Five different channels have been used, which have made it possible to measure the total consumption and four other outputs at the same time.

One sensor has measured the total consumption of a house, and the other ones have measured four final circuits for which the consumption is assumed to be the highest, e.g., heating, electric sauna or kitchen stove. The entire year of minute-interval measurements consists of 525600 values, including short gaps when data have been missed because of connection breaks or other failures.

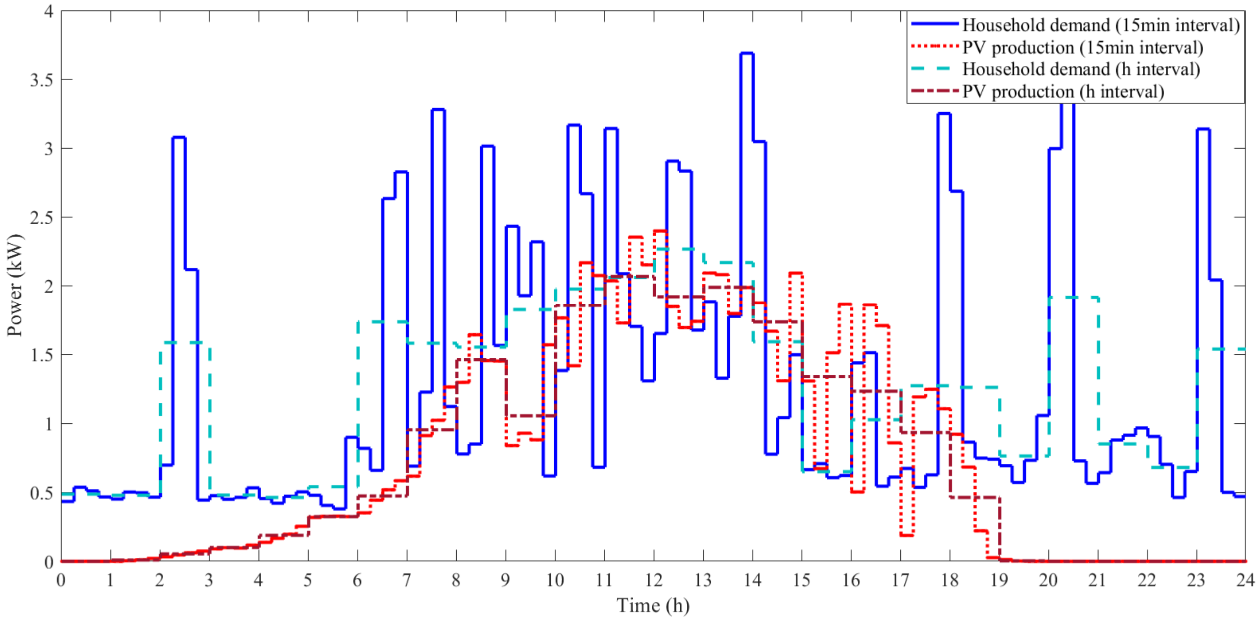

Fig. 3. An example of one day on a household customer's electricity demand and PV production (3 kWp) measured by 15-minute and hour metering interval

TABLE I
STUDY GROUP

House	H1	H2	H3
Construction year	2012	2011	1988
Area (m^2)	152.5	190	220
Warming (primary)	Water boiler	Ground heat pump	Underfloor heating resistors
Warming (secondary)	Electric heaters in garage + fireplace	Heat recovery + fireplace	Heat recovery + fireplaces
Yearly electricity consumption	18.7 MWh	13,2 MWh	24,2 MWh
Heating power	13 kW + (4.5kW water top up heater)	13.5 kW	14 kW + (4.5 kW water heater)

These gaps in total consumption have been replaced by the sum of the measurements from the other sensors, which nearly corresponds to the total consumption. If there has been a gap in the other sensors, then it has been replaced by the value of the previous minute. However, the total number of gaps is so low that there is not a notable effect on the results of the study.

III.2. Solar Radiation Data and Weather Data

The input data of PV production are based on a mathematical model of PV panel output, which is calculated from real one-minute solar radiation data.

Measurements of solar radiation were taken from the open data of the Finnish Meteorological Institute. The data have been measured at the weather station of Jokioinen, which is the nearest one to the studied houses.

The beam, the diffuse, and the reflected solar radiations for the entire year of 2018 have been measured in Jokioinen [22].

Fig. 3 shows an example of one day of household consumption and PV production metered by an hour interval and a 15-minute interval.

It can be seen that the variation of consumption is much higher for the 15-minute interval than the hour interval.

The variation of PV production is not so high in this example because this specific day was mostly sunny. During a day when cloudiness changes rapidly, the variation of PV production could be much higher.

III.3. Electricity Price Data

In Finland, end-use electricity bills consist of the costs of electrical energy, distribution fees and taxes. A customer can sell surplus energy to the same energy retailer who is the seller of electrical energy. The price of energy is typically based on the market price of electricity in Nordic electricity markets [23]. Customers can tender out of retailers, and retailers can compete via margins, which are the amounts retailers add to the market price. When a retailer buys a customer’s surplus energy, this margin is taken off from the market price. Energy selling contracts have typically been based on a constant price, but the average price is more inexpensive in market-price-based contracts than in constant-price contracts because the risks of retailers are lower. In this study, the margin of energy retailers is 0.25 c/kWh, which is typical in Finland. Market price changes for each hour, and if the metering interval is shorter than an hour, the price is constant during the entire hour.

Distribution System Operators (DSOs) have local monopolies, and they set the distribution prices under the control of public authority.

Customers have to pay electricity taxes based on the amount of used energy, which is charged with the distribution bill.

The value of the electricity tax is 2.79 c/kWh for household customers. In addition, there is a value tax (i.e., 24%), which is paid on all the cost components. In this study, the general distribution tariff of the local DSO has been used, and the volumetric charge is a constant 3.93 c/kWh [24].

The level of the volumetric charge affects the profitability of PV self-consumption because this price determines the difference between electricity purchase and feed-in prices, but it does not affect the differences between metering intervals because the costs increases in proportion with the price component.

IV. Sizing of PV Systems and BESSs

IV.1. Sizing of BESSs

In [4], it has been states that when PV systems and BESSs are sized based on electricity cost optimization, the suitable size of a BESS relative to the load profile of a customer has to be chosen first. After this, the PV system is sized relative to the size of the BESS. In this study, the sizing model from [4] is used. The same BESS can be used for several control targets. In this study, the increase of self-consumption is the only control target, so the size of the PV system affects the size of the BESS more than when other targets are involved.

In the sizing of the BESS, few potential sizes are selected at first, from 0 to 12 kWh, with an increment of 2 kWh. Then, we simulated the cost savings for each size have been when the size of the PV system varies between 0 and 6 kWp. After this, linear regression has been used to fit the lines for the first and last two result points. The intersection of the fitted lines indicates the optimal size for a PV system, as discussed in [4]. This has been done for all the three customers with all the three metering intervals.

Fig. 4 shows the average cost savings per 1 kWp of PV panels in the intersection of the fitted lines. At the beginning, the cost savings increase when the size of the BESS increases, but the growth slows down very quickly. The highest growth can be noticed for a 2-kWh BESS. For systems larger than 6 kWh, there is no increase in cost savings. The changes are similar with different metering intervals, but the differences are higher for small BESSs than for larger BESSs. For these three customers, 2 kWh is the best BESS size if the system is used only for increasing the self-consumption of PV energy.

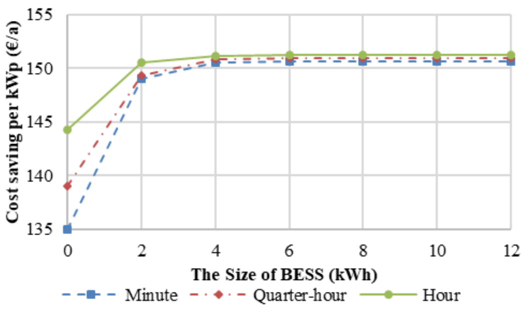

Fig. 4. Average annual cost saving per 1 kWp PV, with optimal sized PV for different BESS sizes and variable metering interval

Henceforth, a 2-kWh BESS is considered, and a 6-kWh system is used for comparison because it is largest size when cost savings still increase in the sizing simulations.

IV.2. Sizing of PV System

Fig. 5 shows the optimal size of the PV system with the 2- and 6-kWh BESSs. They come from the intersection of fitted lines as in [4]. The PV array consists of panels with nominal powers of approximately 300 Wp. Thus, the potential sizes of the PV array are 2.1, 2.4, 2.7 and 3.0 kWp. With a 2-kWh BESS, suitable PV array sizes for customers H1, H2 and H3 are 2.1 kWp, 2.4 kWp and 2.1 kWp, respectively. In the simulations, the PV sizes are divided into 1-kWp intervals, and to maintain comparability for both BESS sizes, one PV size is chosen for all the customers. Thus, PV array sizes of 2 kWp and 3 kWp are chosen for 2-kWh and 6-kWh BESSs, respectively.

V. Results

In order to compare different metering intervals, simulations have been completed for all the customers with the chosen PV system and BESS sizes and with the minute, quarter-hour and hour metering intervals. Fig. 6 shows the benefits of a 2-kWp PV system and a 2-kWh BESS. Fig. 7 shows the benefits of a 3-kWp PV system and a 6-kWh BESS. These benefits refer to the amount of yearly cost savings that customers can expect. The investment is not accounted for the benefits.

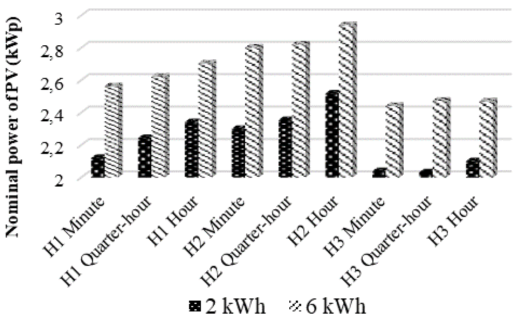

Fig. 5. Optimal size of PV with two different BESS size for three customers, when different metering intervals are used

The benefit of a PV system means the cost savings without a BESS, and the benefit of a BESS means the increase of cost savings when the BESS is involved. The total cost savings of a customer is the sum of these benefits. When considering money, the benefits of PV systems are much greater than the benefit of BESSs. For comparability, the axis of benefits of a PV system starts from 200 €/a in Fig. 6 and from 300 €/a in Fig. 7. With different y-axes, the levels of benefits in nearly similar conditions are obtained, and the differences of metering intervals can be considered. The effects of metering interval changes largely depends on a customer's load profile. Changes in money and percentage changes, in addition to the mean values, are shown in Table II for all customers separately. Changes in money are higher for the benefits of a PV system than the benefits of a BESS, but the percentage changes are much higher for BESSs. In Table II, the lowest values are shown by light blue, and the highest values are shown by red. Hour-to-quarter-hour and quarter-hour-to-minute changes reduce the benefits of PV systems but increase the benefits of BESSs. For many customers, the increasing benefits from BESSs nearly replace the losses from the decreasing benefits of PV systems. A shorter metering interval decreases the profitability of PV systems. Yearly cost savings decrease on average by 12.28 € for a 2-kWp PV system and by 14.68 € for a 3-kWp system if the metering interval changes from an hour to a quarter-hour, as shown in Table II.

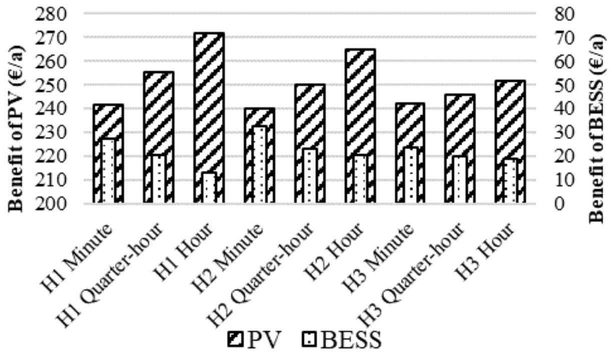

Fig. 6. Benefits of PV and BESS for three customers with different metering intervals, when 2 kWp PV and 2 kWh BESS is used

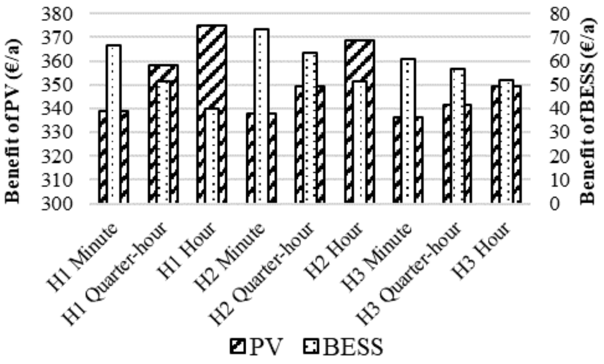

Fig. 7. Benefits of PV and BESS for three customers with different metering intervals, when 3 kWp PV and 6 kWh BESS is used

TABLE II
EFFECT OF METERING PERIOD CHANGE IN MONEY AND PERCENTAGE CHANGES

		PV: 2 kWp BESS: 2 kWh		PV: 3 kWp BESS: 6 kWh	
		PV	BESS	PV	BESS
Hour to Quarter-hour	H1	-16.25 € -5.98 %	7.57 € 58.46 %	-16.71 € -4.46 %	11.64 € 29.16 %
	H2	-14.73 € -5.57 %	2.71 € 13.20 %	-19.25 € -5.22 %	11.85 € 23.05 %
	H3	-5.85 € -2.32 %	1.18 € 6.29 %	-8.09 € -2.32 %	4.54 € 8.70 %
	Mean	**-12.28 €** **-4.67 %**	**3.82 €** **21.93 %**	**-14.68 €** **-4.03 %**	**9.34 €** **19.53 %**
Quarter-hour to Minute	H1	-13.72 € -5.37 %	7.09 € 34.56 %	-19.27 € -5.38 %	15.03 € 29.17 %
	H2	-9.70 € -3.88 %	9.34 € 40.12 %	-11.33 € -3.24 %	9.91 € 15.66 %
	H3	-3.95 € -1.61 %	3.66 € 18.37 %	-5.08 € -1.49 %	4.12 € 7.26 %
	Mean	**-9.12 €** **-3.64 %**	**6.70 €** **31.53 %**	**-11.89 €** **-3.40 %**	**9.69 €** **16.95 %**

The change is slightly lower if the metering interval changes from a quarter-hour to one minute. The lifetime of a PV system can be 30 years [3]. If it is assume that the electricity prices, taxes, customer load profiles and the production of a PV system are similar over the entire lifetime of a PV system, the total effect of metering interval changes on the profitability of a PV system can be evaluated. Net present value (NPV) is a good tool to evaluate the profitability of an investment and it can be calculated using equation (6):

$$NPV = \sum_{y=1}^{n} \frac{R_y}{(1+i)^y} \tag{6}$$

where R_y is the cost savings at the year y, n is the length of lifetime and i is the discount rate. Fig. 8 shows NPV calculations of cost savings over the lifetime of 2-kWp and 3-kWp PV systems with possible system lifetimes of 15 and 30 years and discount rates of 1% and 3%.

Calculations are made for hour, quarter-hour and one minute metering intervals.

V.1. *Effect of Metering Interval on the Profitability of PV Systems*

Additionally, three possible investment prices for a PV system are shown by dashed lines. If the NPV is higher than the investment price, the investment is profitable and the part of the block that is over the investment price indicates the total profit of the investment, which comes over the required return. The results of Fig. 8 show that the change from an hour metering interval to a quarter-hour interval or the change from a quarter-hour interval to a minute interval affects the profitability of PV systems in approximately the same way as an increase of 100 €/kWp in the investment price of a PV system.

The profitability of the PV systems depends mainly on the lifetime of the system, the sizing of the system, the electricity prices, and the discount rate, but the investment costs and the metering interval are also significant. Additionally, how soon a prosumer wants the money back from the investment is important.

V.2. *Effect of Metering Interval on the Profitability of BESSs*

In contrast to the profitability of PV systems, the one of BESSs increases when the metering interval becomes shorter. In Fig. 9, the calculated NPVs for the lifetime cost savings with a BESS are shown. The lifetime of an LFP Li-ion battery with good battery management is approximately 15 years [25]. Thus, a 15-year lifetime and a cautious estimate of an 8-year lifetime are used in the calculations. The discount rates are the same as those used in the PV calculations: 1% and 3%. Additionally, two investment costs for a BESS system are shown.

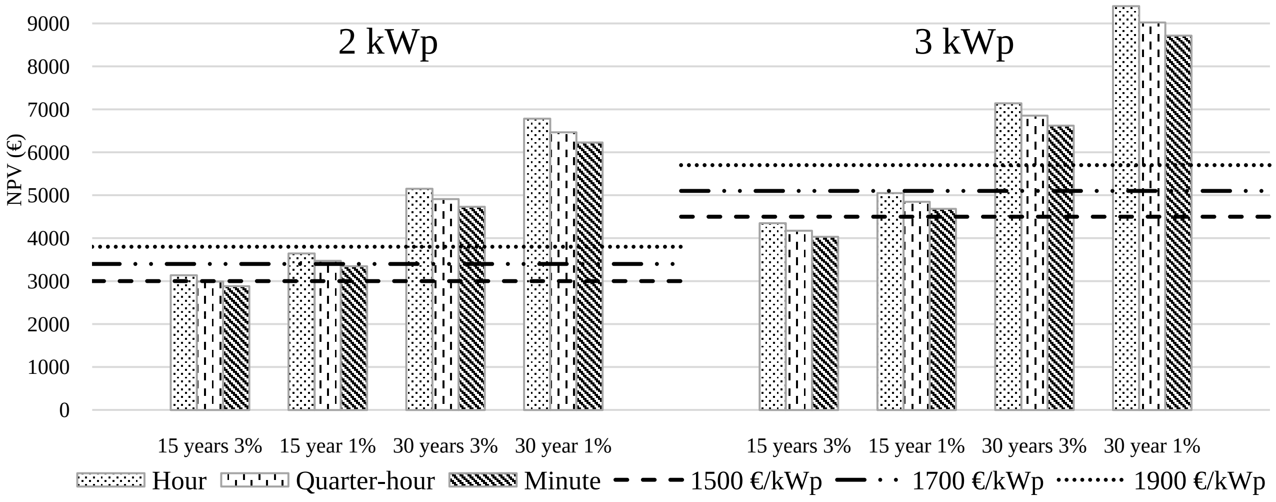

Fig. 8. Net present value of PV lifetime benefits with different metering intervals and three possible investment prices for 2 and 3 kWp PV systems. Two possible lifetimes (15 and 30 years) and two possible discount rates (1% and 3%) are used

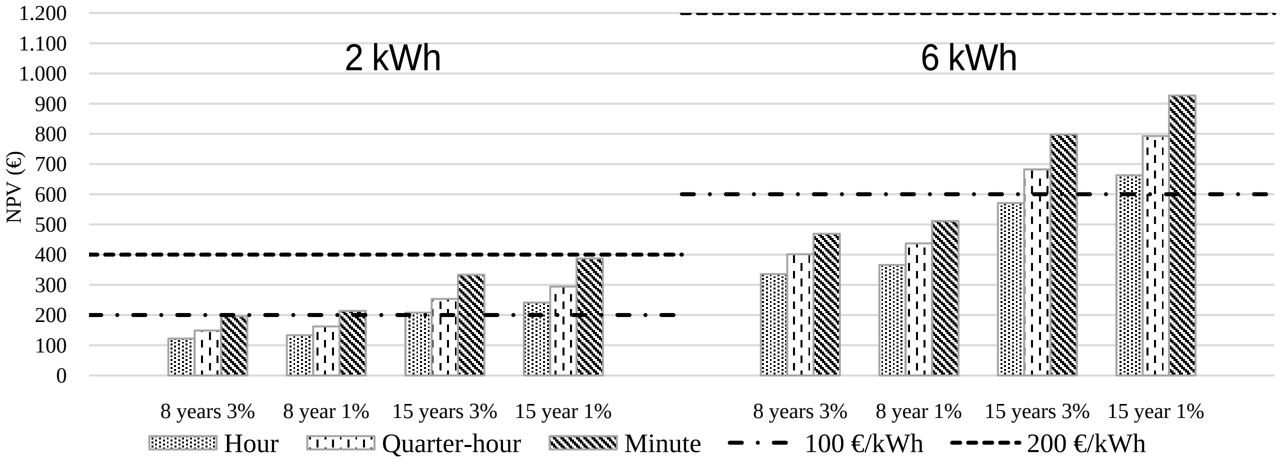

Fig. 9. Net present value of BESS lifetime benefits with different metering intervals and three possible investment prices for 2 and 6 kWh BESS. Two possible lifetimes (8 and 15 years) and two possible discount rates (1% and 3%) are used

The current investment price for Li-ion batteries is 200-400 €, as evaluated in [4] and based on [26] and [27].

Prices have decreased rapidly over the last decade, and development is expected to continue [28]. Power electronics increase the price of BESSs, but when a BESS is used together with a PV system, a portion of the costs are included in the price of the components of the PV system, e.g., a grid inverter. The presented investment prices are 200 €/kWh, which is the lowest possible price today, and 100 €/kWh, which is the expected price in the future as the volume of manufacturing grows. These optimistic prices are used because they are almost at the same level as the NPVs of the cost savings. This strengthens the perception that the use of BESSs with PV systems to increase self-consumption is not currently profitable.

The results of Fig. 9 show that the change from an hour metering interval to a minute metering interval results in the highest effect on the profitability of a 2-kWh BESS with a 15-year lifetime and a 1% discount rate. This change corresponds to a change of approximately 73 €/kWh in the BESS investment price.

A metering interval change from an hour to a quarter-hour corresponds to a change from 11 €/kWh to 26 €/kWh in the BESS investment price. Another observation is that the effect of a metering interval change on the profitability of a BESS is higher for an optimally sized BESS with 2 kWh as opposed to a slightly oversized 6-kWh BESS.

VI. Discussion

In this study, data from three different households in area around of Tampere in Finland have been used. Even though the sample size of the study group is small, these houses represent current domestic houses in Finland, and the size of the houses is slightly larger than average. In all the houses, the primary heating system is different, and the systems are commonly used today and in the future. Two of the houses are quite new, while the other one is older. This leads to the variations in the total consumption of the houses. The results show that the benefits of PV systems and BESSs do not depend on the amount of total consumption. The differences between the houses are not large even though the load profiles vary substantially, confirming that the results are representative.

The benefits of BESSs are calculated when a BESS is used only for increasing the self-consumption of PV production. The same BESS can also be used for other control targets, but these ones are not studied in this paper because the metering interval does not directly affect them if the electricity prices remain constant in relation to the load profile. For this reason, the results of this study do not directly indicate the profitability of using BESSs in houses. A change in the metering interval will affect other control targets due to the changing price components or the changing peak power values. If power-based distribution tariffs are used, the peak power consumption values are higher with a shorter metering interval because when the metered load is averaged for a longer period, e.g., an hour, short high peaks are smoothed. When DSOs keep their revenue the same through a metering period change, the power-based price component will decrease. This means that the savings from peak-cutting will be almost at the same level. The differences between customers will increase, but the effects require additional research.

The savings from market-price-based control will also change when the time unit in the electricity market changes. The price change between quarter-hours could be higher than that between hours [29]. This will increase the profitability of market-price-based control. Second, when the time unit is shorter, BESSs will be used more frequently. This will affect the sizing of BESSs and their actual lifetime.

VII. Conclusion

In a case of Tampere area in Finland, a shorter electricity metering interval decreases the profitability of grid-connected domestic PV systems but increases the profitability of BESSs associated with PV systems.

Currently, PV investment is profitable in the long term in Finland, and transitioning from an hour metering interval to a quarter-hour metering interval does not radically affect the situation. However, this shift increases payback time and notably decreases profits. If the metering interval is shortened to one minute from 15 minutes in the future, the effect of this change will be approximately similar to the change from an hour interval to a quarter-hour interval.

Using a BESS to increase the self-consumption of PV production is not yet profitable. A shorter metering interval will increase the cost savings notably but will not make BESSs profitable. Economically profitable use of BESSs requires other control targets, such as market-price-based control or peak cutting, when power-based distribution tariffs are used. In the long term, a shorter metering interval is a good thing for the future of smart grids because it has many positive effects. Increased profitability makes investments in BESSs, along with investments in PV systems, more attractive. Using BESSs can decrease the surplus energy feeding into the grid and smooth the demand from the grid to restrain the increasing distribution costs when the need to strengthen the grid decreases. Additionally, BESSs use larger PV systems profitable and can increase the total amount of PV production. Without BESSs, the attractiveness of PV investment will decrease when the metering interval becomes shorter.

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