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Deliverable due date: (M12) M36 – (November 2017) November 2019

D4.7 Report on monitoring and control concepts and improvements (WP4, Task 4.3, Subtask 4.3.3)

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**
Project Duration	1st December 2016 – 30th November 2021 (60 Months)
Deliverable	D4.7 Report on monitoring and control concepts and improvements
Diss. Level	PU
Status	☐ Working ☐ Verified by other WPs ■ Final version
Due date	30/11/2019
Work Package	WP4 Demonstration in Helsinki
Lead beneficiary	VTT Technical Research Centre of Finland Ltd
Contributing beneficiary(ies)	City of Helsinki (HEL), HELEN OY (HEN), Forum Virium Helsinki Oy (FVH), FOURDEG Oy (FOU), CARTIF (CAR)
Task description	Subtask 4.3.3: Monitoring and controlling of the district facilities VTT and HEN to lead the definition of a grid performance optimisation by using data and demand response. Business model development for the compensation of reactive power - with solar power at solar plants Kivikko and the integration of existing district level electrical storages will be also part of this subtask.

Date	Version	Author	Comment
02/05/2017	0.1	Atte Löf (VTT)	Structure of the deliverable and work planning
10/10/2017	0.2	Antti Alahäivälä (VTT)	Reactive power compensation and related business models
13/10/2017	0.3	Anna Kulmala (VTT)	Short description of Suvilahti energy storage
13/10/2017	0.4	Kari Mäki (VTT)	Description of Kalasatama and its consumption illustrations
16/10/2017	0.5	Antti Alahäivälä (VTT)	Summaries and conclusions and the compiling of the deliverable
27/11/2017	1.0	CAR	Alignment of contents and final review
24/10/2019	1.1	Suvi Takala (HEN)	Reviewing the deliverable and minor modifications
31/10/2019	1.2	Mikko Virtanen (VTT)	Compiling of final inputs and alignment of contents.
20/11/2019	2.0	Mikko Virtanen (VTT)	Adjusting the deliverable according to internal review, finalized for submission

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Abbreviations and Acronyms

Acronym	Description
DSO	Distribution system operator
EV	Electric vehicle
MPPT	Maximum power point tracking
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
PF	Power factor
PV	Photovoltaic
PWM	Pulse Width Modulation
STATCOM	Static synchronous compensator
SCADA	Supervisory Control and Data Acquisition
SVC	Static Var compensator
V2G	Vehicle-to-grid

1. Executive Summary

This deliverable describes the electricity grid improvements with the monitor and control of solar power plants and energy storages in Helsinki smart city demonstration cases. In addition, the demand response possibilities will be studied in the smart Kalasatama area. The demonstration cases in this deliverable are: 1) Solar power plants in Kivikko and Suvilahti; 2) Energy storage in Suvilahti; and 3) New smart city district called Kalasatama. In its current format, the deliverable mainly focuses on the solar power plant in Kivikko, whereas Suvilahti and Kalasatama are described to form a basis for the coming studies.

Solar power plants provide an attractive resource for the reactive power compensation in distribution networks. They are connected to the grid via a power electronic interface that can be controlled to inject or consume reactive power. Studies indicate that the reactive power compensation could help in the integration of photovoltaic (PV) generation to distribution networks. However, the compensation increases the plant losses and can shorten the interface inverter’s lifetime. Reactive power production and consumption were demonstrated with Kivikko solar power plant. The plant successfully provided compensation also during night-time without solar power production. This deliverable gives a short summary of the demonstration that is more profoundly described in D4.6 Report on smart grid improvements.

Since the reactive power compensation influences the cost-efficient operation of PV plants, the plants cannot be utilized to provide compensation without business models. This report describes two models to motivate the PV participation. The first approach is suitable for a prosumer who could reduce his or her reactive power cost. In such a case, the solar power plant compensates the maximum monthly reactive power consumption and injection, which dictates the reactive power payments at the prosumer’s consumption site. In the second approach, the prosumer sells reactive power compensation to the local distribution system operator.

2. Introduction

2.1 Purpose and target group

This deliverable reports the monitoring and controlling of existing solar power plants and energy storages in demonstration cases in Helsinki. It also creates a comprehensive overview on the reactive power compensation with solar power plants and explores potential business models related to the compensation. In addition, the demand response possibilities will be studied in one of the demonstration cases. The presented cases include: 1) Solar power plants in Kivikko and Suvilahti; 2) Energy storage in Suvilahti; and 3) New smart city district in Kalasatama. The report is targeted to actors that are currently concerned about the use of solar power plants and large scale energy storages in the context of reactive power compensation.

2.2 Contributions of partners

The following Table 1 depicts the main contributions from participating partners in the development of this deliverable.

Table 1: Contribution of partners

Participant short name	Contributions
VTT	Main responsibility of the deliverable
HEN	Input data for Kivikko solar power plant and Suvilahti energy storage Input data for Kalasatama area Reviewing the contents of the deliverable

2.3 Relation to other activities in the project

The following Table 2 depicts the main relationship of this deliverable to other activities (or deliverables) developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

Table 2: Relation to other activities in the project

Deliverable Number	Contributions
D4.1	Baseline report describes the starting situation of the actions
D4.2	Report on retrofitted actions and implemented actions new buildings including RES and storages
D4.6	Report on smart grid improvements

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3. Reactive power compensation with solar power plants

3.1 Compensation of reactive power

3.1.1 Background and the scope of the study

Most of grid loads require reactive power and active power in order to function but it is the delivery of active power why the distribution system has been built. Therefore, the reactive power is often compensated, i.e., its excess flow is removed from the grid. Several reasons motivate the compensation (Dixon et al. 2005). Firstly, reactive power increases current in the grid, which further causes thermal losses. It also takes a part of the grid capacity, which may call for investments in lines with greater capacity. Secondly, reactive power is closely connected to the grid voltage so that the voltage increase with excess reactive power in the system and decrease when it is consumed. Typically, loads consume reactive power and delivering it causes voltage drop in the feeder. Thirdly, compensation is required to ensure system stability in a transmission grid.

Conventional methods to compensate reactive power is to install mechanically switched capacitors or inductors to the grid. Capacitive elements are able to inject reactive power to the grid, thus compensating the reactive power consumption, whereas inductive elements consume reactive power. Synchronous generators are also traditional devices for the compensation. In addition to these traditional methods, power electronic devices have emerged and are currently used to provide compensation. Common devices are static Var compensator (SVC) and static synchronous compensator (STATCOM) (Dixon et al. 2005).

Most forms of distributed generation, such as photovoltaic (PV), wind power, and fuel cells, are connected to the distribution system via a power electronic interface. Thus, they provide an attractive resource for the reactive power compensation in distribution networks. This section of the report focuses on the utilization of solar power plant in the compensation of reactive power. Particular aim is to develop business models, which enable a solar power plant to participate in the compensation economically.

3.1.2 Value of reactive power

In general, reactive power compensation is closely connected to the economical and technical functioning of a distribution grid. Distribution system operators (DSOs) need to invest in compensation and manage reactive power levels in order to provide their customers with economical, reliable, and good quality service. In addition to the investments and maintenance, reactive power causes costs to a

DSO if it is exchanged with the transmission system. In Finland, the transmission system operator, Fingrid, penalizes DSOs if their exchange do not remain within certain allowed limits. These are principally the cost components that the DSO transfers to distribution tariffs and separate reactive power payments.

The purpose of the reactive power payments is to allocate the cost of compensation to those customers who inject or consume reactive power (Vaisanen 2012). Typically, in Finland, DSOs charge the reactive power based on the highest monthly inject or consumption, allowing some exchange (e.g. 20-40% of the maximum active power consumption) without cost. One can note that the payments has a penalizing nature and therefore, they direct the customers to reduce their reactive power exchange with the grid.

In one hand, the installation of distributed generation with their power electronics interfaces cause challenges due to the power flow from low-voltage level towards high-voltage. On the other hand, they provide new resources for the DSOs to manage the grid. For example in Stetz et al. (2013), the authors compared different active and reactive power control strategies of PV systems, which could be employed to manage the grid voltage. They showed that by controlling PVs reactive power consumption, the hosting capacity (ability to accommodate distributed generation) of the studied distribution grid was possible to increase more economically compared to grid reinforcement. Such results could motivate the DSOs to develop products, enabling the trading of ancillary services with distributed generation.

3.1.3 Utilization of a solar power plant in compensation

An example of a PV system is presented in Figure 1, which illustrates typical components (panels, an inverter, and a filter), measurements, and the basic controls. It is also possible to install a step-up (provides also isolation) transformer before the grid and a DC-DC converter between the panels and the inverter. If the system is connected to a distribution grid, the control typically aims to supply maximum possible active power from the panels to the grid, i.e., the inverter operates in grid-feeding mode (Rocabert et al. 2012). Maximum power point tracking (MPPT) is used to keep the DC-link voltage in optimal level so that PV produces maximum available active power.

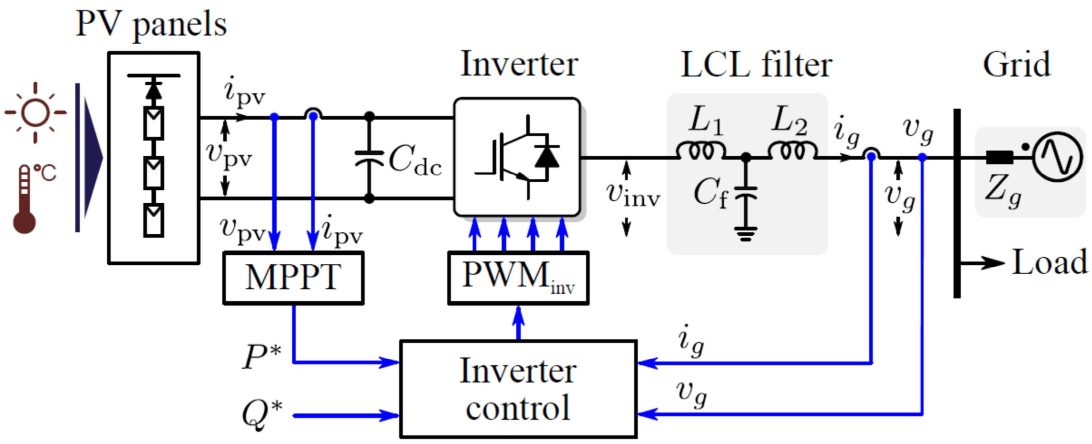

Figure 1: A basic structure of a transformerless, single-phase, grid-connected PV system with an LCL filter (Yang et al. 2016). Black lines indicate electrical circuits, whereas blue is used for measurements and control signals. PWM stands for pulse width modulation of the inverter. P^* is the active power reference and Q^* is the reactive power reference

For the reactive power reference of the inverter's control system, which is indicated by *Q** in Figure 1, several options are possible. For example, in von Appen et al. (2013), these options are divided into local, decentralized, and central controls, which are depicted in Figure 2. In the case of the local control, communication is not required and the control strategies are implemented with inverter functionalities. Some possibilities are to set the inverter to operate with a fixed power factor, to exchange a fixed amount of reactive power with the grid, or to utilize the droop control. The decentralized control strategies refer to approaches, in which the inverter interacts with an intermediate level in the grid. As an example, the inverter can communicate with the closest substation, providing active and reactive power references for the solar power plant. Thus, the solar power plant could assists in the management of voltage level in the substation area. If centralized control is employed, the inverter is connected to the Supervisory Control and Data Acquisition (SCADA) system, enabling the utilization of the inverter functionalities and information from even wider area from the distribution network.

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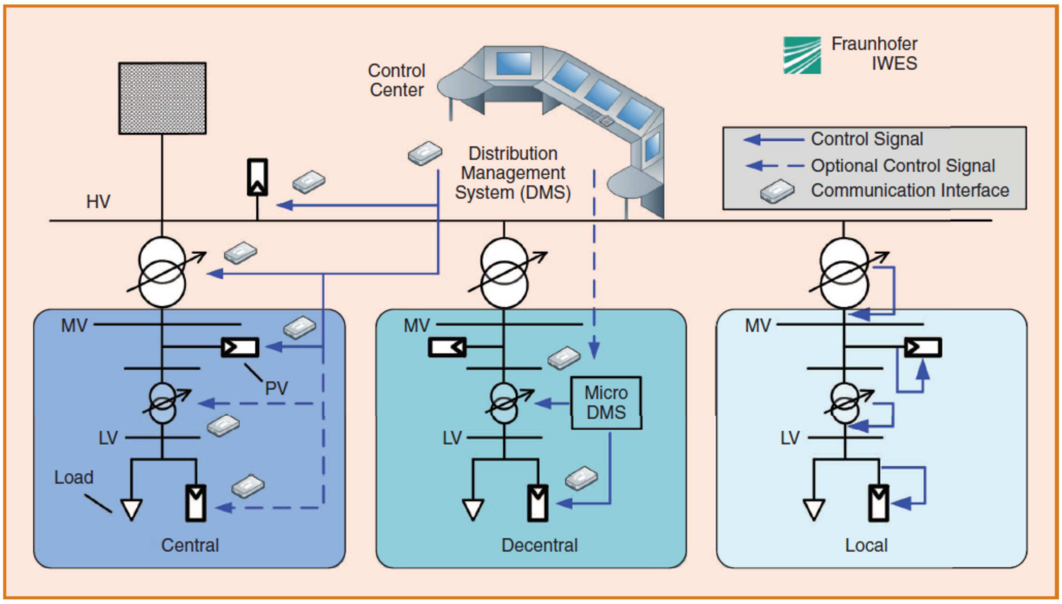

Figure 2: Illustration of different control approaches for a PV system: central, decentralized, and local (von Appen et al. 2013)

The main purpose of the solar power plant is to generate active power and the inverter is sized accordingly. The inverter can be even slightly undersized (capacity is smaller than the output of panels) to improve its utilization, since the solar panels rarely produce their nominal output. This is to say that the inverter may not always have capacity to provide reactive power support, which is demonstrated in Figure 3 that illustrates the relationship between, active, reactive, and apparent power (Stetz et al. 2013). The inverter capacity is defined by the maximum apparent power of the inverter, $S_{max,,}$ so reactive power consumption or injection needs to be limited if the plant produces its maximum active power (or active power needs to be limited if reactive power equals to the maximum apparent power). Consequently, the reactive power compensation functionalities need to be considered in the power plant sizing, i.e., the inverter has to be oversized. Alternatively, active power generation may require limiting when compensation is provided.

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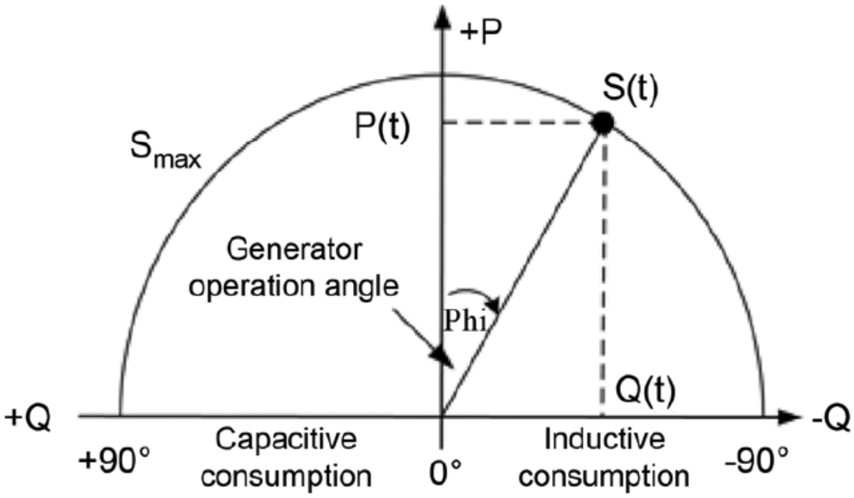

Figure 3: *PQ*-diagram of a solar power plant (Stetz et al. 2013). *P* is the active power, *Q* is the reactive power, and *S* is the apparent power

Even though active and reactive power are connected via the inverter capacity, the plant does not need to generate active power in order to provide reactive power compensation. This enables the compensation at nighttime (Yang et al. 2016). However, the inverter needs to be on and inject or absorb current, which affects its lifetime, reliability, and maintenance. For example, fans are operating when the inverter is online. It is also concluded in Flicker & Gonzalez (2015) that the reactive power compensation affects the inverter losses and thus its efficiency. If the losses increase, thermal stress on the device increases as well, which may have negative influence on the inverter lifetime. In the performed measurements, when the inverter operated with positive power factor (current leads voltage, i.e., reactive power is injected), the efficiency of the inverter decreased by approximately 1.5%. On the other hand, operation with negative power factor increased the efficiency only by 0.5%. It should be noted that the aforementioned measurements assumed also active power generation in addition to the reactive power compensation. However, contrary to the previously presented results, the authors in Braun (2007) state that the inverter losses can be assumed to be nearly independent from the power factor. Instead, the losses depend more on the apparent power of the inverter, which is affected by the reactive power consumption and injection. This is illustrated in Figure 4, where the losses are presented as a function of apparent power with four different power factors. A third study, which focuses on the use of a PV inverter to provide reactive power compensation at night, estimated that the injection of reactive power increased the annual inverter losses more than 300% (from approximately 10 kWh to 40 kWh or from 5% to 20% of annual energy yield) (Anurag et al. 2015). The study is based on the simulation of a single-phase inverter.

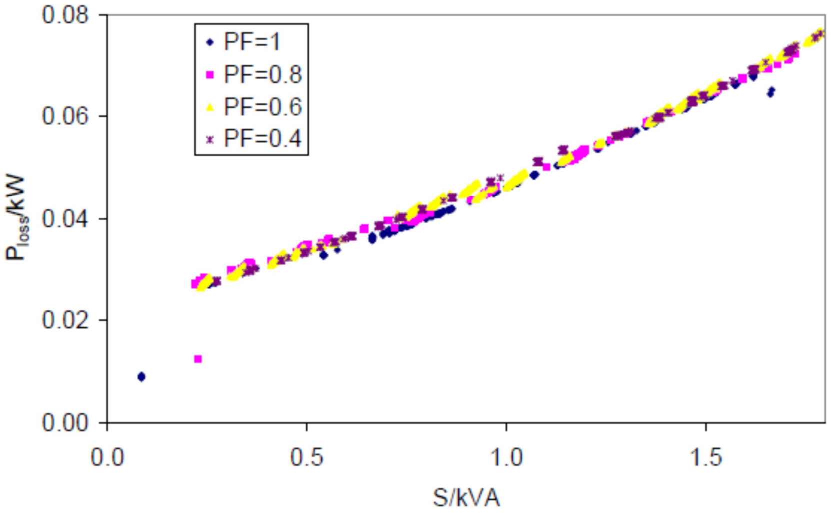

Figure 4: Measured inverter losses as a function of apparent power output with different power factors (PF) for a 3.3 kVA inverter (Braun 2007)

From the aforementioned review, it is possible to conclude that the reactive power compensation can have negative influence on the plant and its performance and thus, it causes costs. The following lists different cost components to consider if the solar power plant is planned to participate in the reactive power compensation:

- Oversizing of the inverter or possible curtailment of active power generation if not enough capacity
- Possible changes to inverter software (e.g. control algorithms)
- Possible changes to power plant installation (e.g. extended cables)
- Installation of communication devices if other than local control is employed
- Cost of implementing the control system (e.g. integration with SCADA system)
- Decreased lifetime of the investment
- Poorer efficiency (increased losses in inverter) and therefore reduced generation
- Increased electricity consumption of the plant due to losses (particularly if operating at nights)
- Other additional losses (conductors and transformer)
- Cost of decreased reliability (loss of energy)
- Increase maintenance cost (e.g. replacement of fans)

3.2 Compensation demonstration with Kivikko solar power plant — Summary

As a part of mySMARTLife, reactive power compensation was demonstrated with Kivikko solar power plant. The demonstration and its results are more profoundly described in Deliverable 4.6 Report on smart grid improvements and only a short summary is provided here. Kivikko's case is used as an example in the next section.

Kivikko is a district in Helsinki and it serves as a location for the studied solar power plant. The plant comprises solar panels of which nominal power is 850 kWp. The panels are connected to two inverters with nominal capacities of 500 kW (total capacity of 1 MW). The inverters are further connected to a medium voltage substation through a transformer. At the site of the power plant, there also locates an arctic sport center. Due to the cooling requirement of the sport center, it consumes a considerable amount of reactive power and thus, provides a suitable target for the compensation studies. The PV power plant is owned by Helen Ltd. and its business model is designated solar panels, i.e. customers can rent a panel from the power plant (Helen). The Arctic Sport Center is owned by the City of Helsinki.

In the demonstration, different reactive power compensation strategies with the solar power plant were investigated. It was of interest to search for a strategy, which would enable the compensation economically at the site. In the current market framework, monetary benefit can be principally obtained by reducing the maximum monthly reactive power injection or consumption from the grid. The reduction should be done without notable modification to the plant (causes costs) and disruption to the active power generation, which is by far the main source of income.

The selected strategy was to inject fixed reactive power (30 kvar) when the plant also generates active power. The demonstration was performed during the time period from 11.5.2017 to 19.6.2017, which is when the inverter of the plant produced the fixed reactive power. Figure 5 presents the reactive and active power production of the solar power plant for the first week of the demonstration. As seen, the injected reactive power is not constant, which is due to the reactive power consumption of the step-up transformer. However, the compensation reduces the reactive power consumption slightly as can be seen in Figure 6. The figure shows the reactive power consumption of the sport center with and without the compensation.

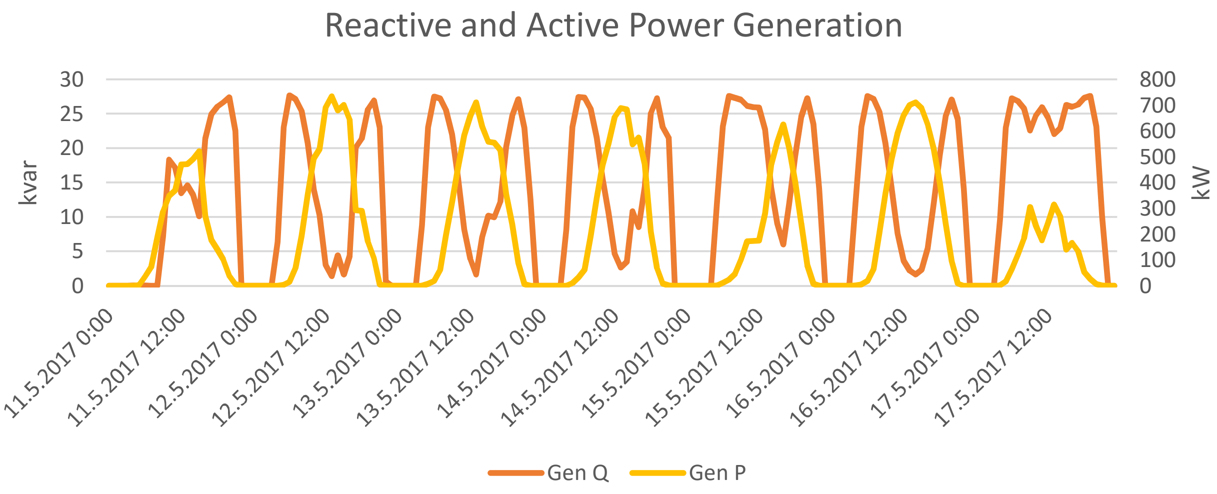

Figure 5: Reactive (Gen Q) and active power (Gen P) production of the solar power plant zoomed to the first week of the demonstration period

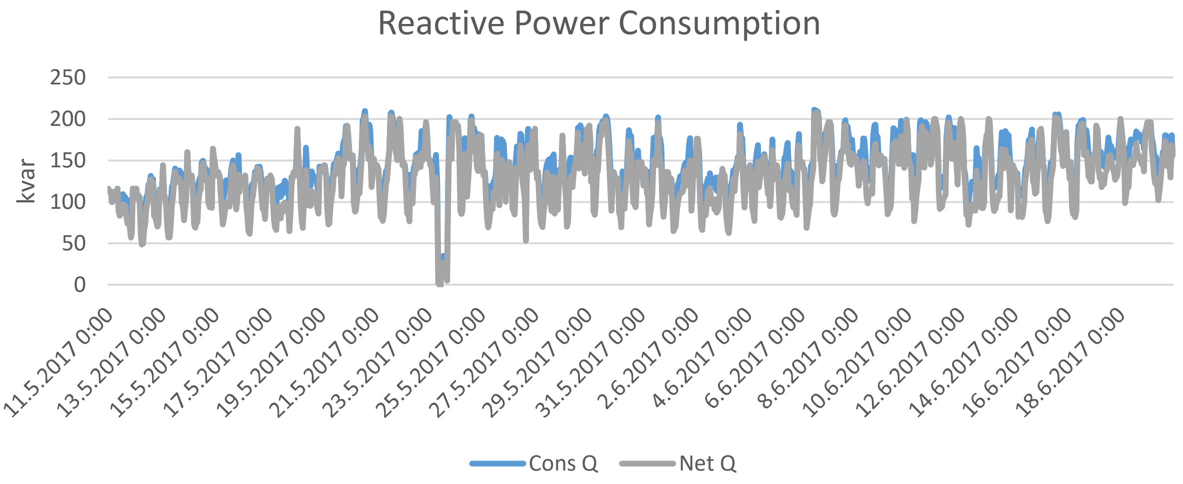

Figure 6: Reactive power consumption of the arctic center with (Cons Q) and without (Net Q) the compensation

Reactive power compensation was also successfully tested with the inverters of Kivikko PV plant during nighttime. The nighttime demonstration tests were motivated by the increased reactive power production of the cabled distribution grid in Helsinki. Since the inverter enables reactive power consumption and injection without PV generation, it can be exploited as a reactor when the grid needs compensation at night. The results of the nighttime reactive power tests are reported in detail in D4.6.

3.3 Business models for reactive power compensation with solar power plants

3.3.1 Definition of business model

It is stated in Section 3.1.3 that the utilization of solar power plant in reactive power compensation causes costs to the owner of the plant. On the other hand, it was also suggested that the utilization could be economical if the compensation is viewed from the DSO's perspective. These observations motivate to investigate potential business models, which allow the utilization of PV systems' compensation potential economically, benefiting both the plant owners and DSO. Two potential models were identified during the work on this report and they are presented by using Kivikko as an example. The business model is defined here as an approach to improve the profitability of the plant, i.e., the plant owner desires to make more money with the PV investment.

In addition to the plant owner and the DSO of the distribution grid where the plant locates, an inverter manufacturer is a potential third-party who can derive benefit from the business model. The manufacturer can reduce the cost of the compensation by considering it during the inverter designed. Further, developing strategies to retrofit the required controls to already existing plants can help in the implementation of economical compensation.

3.3.2 Compensation of own reactive power usage or production (model 1)

This model is practically based on the current situation and it is presented in Figure 7. The owner of the solar power plant is so called prosumer, i.e., the owner has generation as well as consumption at same location. The generation is mainly used to cover the local consumption and excess generation is sold to the grid. The price of the consumed electricity consists of energy and delivery payments and taxes, whereas the monetary compensation for the exported electricity is the same as the energy price. Therefore, it is desirable to utilize the local active power generation to cover the own consumption. In the model, electricity is bought from a retailer and the excess generation is sold via a bilateral contract to a market actor who trades electricity in the electricity market.

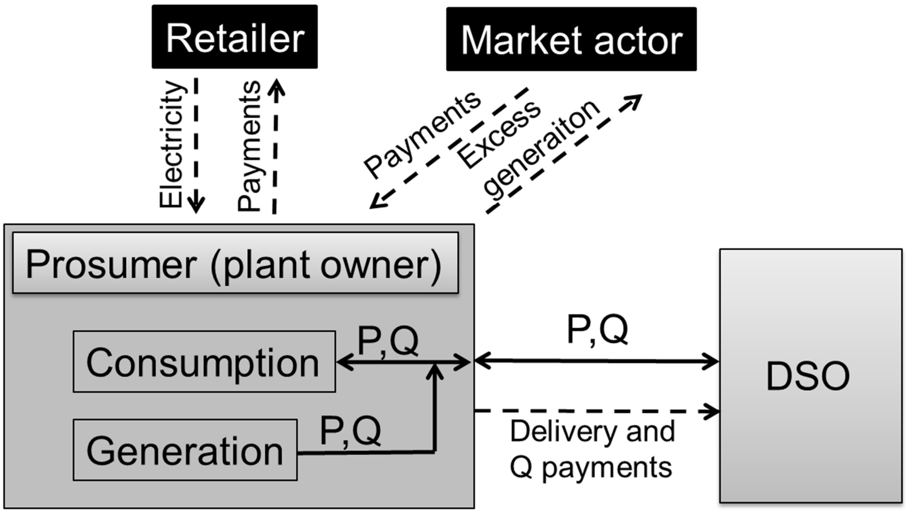

Figure 7: Illustration of the business model for the compensation of own reactive power exchange with the grid. In the figure, dashed lines indicate traded services and payments and solid lines physical products

The prosumer is penalized if there is excess reactive power injection or consumption at the customer's location. The penalization is implemented with reactive power payments (€/kvar) if the monthly maximum value is higher than allowed reactive power exchange with the grid. Thus, the potential business in this model can be described as follows:

> *A prosumer can reduce reactive power cost by using the solar power plant to compensate the maximum monthly reactive power consumption and injection of the prosumer's consumption site.*

The possibilities of the prosumer in this case are either to face the penalty payments that DSO sets, invest in compensation (e.g. capacitor bank), or utilize the solar power plant. Therefore, the compensation with PV should result in the cheapest €/kvar cost in order to become implemented. The cost of compensation with PV system is further discussed in Section 3.1.3. This business model was basically demonstrated with Kivikko's solar power plant in this project. The demonstration is shortly summarized in Section 3.2. Even though the tested compensation resulted only in a minor monetary benefit, steps to implement the compensation strategy were identified:

1. Acquire active and reactive power measurements from the consumption site. What are the maximum monthly values and when do they occur?

2. Evaluate the use of PV system in compensation. What control strategy provides the best compensation? Can the strategy be implemented without substantial modification of the PV system or investments in communication?
3. Evaluate different compensation options and compare their costs.
4. Select the best option

In order to improve the possibility to use the inverter in compensation, the influence of compensation on the PV system and resulting cost should be better understood. Further, data and systematic approach to evaluate the cost is needed. This is where manufacturers could be active and provide data (extra losses, influence on lifetime, efficiency, and maintenance) and services. The compensation requirement at the customer site can also be evaluated when planning to invest in solar generation. In such a case, the inverter and the rest of the PV system should be designed for the task and no retrofitting is needed.

3.3.3 Selling reactive power compensation (model 2)

This business model is an extension to the current market and distribution grid environment. Instead of only penalizing the exchange of reactive power with the grid, DSO provides its customers with a possibility to sell reactive power compensation. The model is depicted in Figure 8, which is similar to Figure 7 except the ancillary service and payment arrows between a customer and the DSO. The rationale behind this model is the fact that DSOs need to invest in compensation in order to operate the grid. Therefore, instead of investments, the compensation is bought from the consumers who are connected to the grid in favorable locations and who can provide an economical option for the investment. The consumers can obtain extra income and the DSO saves in the compensation costs. Furthermore, the reactive power payments decrease if the compensation becomes more economical in general.

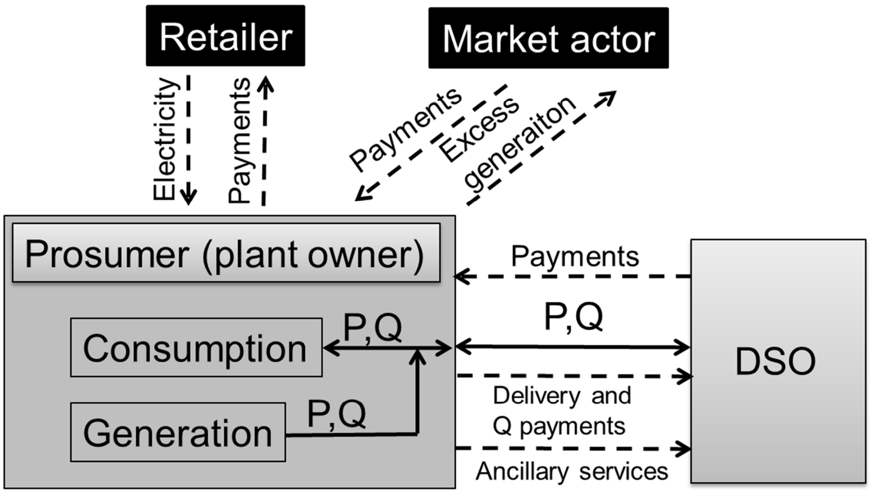

Figure 8: Illustration of the business model for the trading of ancillary services. In the figure, dashed lines indicate traded services and payments and solid lines physical products

One approach to implement this kind of procurement of ancillary services is by using bilateral contracts, i.e., the service provider (e.g. prosumer) and DSO make a contract, which defines the service terms and monetary compensation. The bilateral contract is favored by the fact that each consumption point in the grid has its own compensation requirements and each consumer or producer different resources to provide. Furthermore, if everyone has a right to provide support, DSO may not obtain any economical benefit as it needs to pay for everyone. Thus, the contract is made only in cases where it is the most economical option. Alternatively, since the bilateral contracts may lack transparency, different auctioning approaches and local markets may become in question. This would, however, require that a certain feeder or substation area contains a sufficiently high number of service providers in order to create competition. The reader can note that this business model does not only provide a framework for reactive power compensation but also an approach to acquire other services, such as voltage support in the case of under or over voltages in the grid. Thus, the potential business in this model can be described as follows:

> *A resource owner, such as a consumer, producer, or prosumer, can receive income by selling ancillary services (e.g. reactive power compensation or voltage support) to the local DSO.*

Again, the solar power plant owner should be able to define the cost of providing the ancillary service. It should also be defined and agreed when the service is provided and what is the provided amount. Certain penalties are possible if the terms of the contract are violated, for example, if the plant

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malfunctions and is unable to provide the service. Furthermore, the sold compensation should not increase the amount of billed reactive power and thus, it needs to be considered in the billing.

In Kivikko, this was tested with a scheme to provide reactive power compensation during nighttime for the benefit of the DSO. In Helsinki, the distribution grid contains mainly cables, producing reactive power when the consumption is low at nighttime. Thus, the increased reactive power consumption can be valuable if investments in other compensation, such as in reactors, can be avoided. However, the amount of assets with the capability to provide reactive power compensation should be high in the area in order to compete with the investment of a reactor/capacitor. As an example, the price of 1 Mvar reactor is evaluated to be 61 400 €, while its lifetime is approximately 40–50 years (Energy Authority 2016). This is to say that by using a payback period of 40–50 years, the reactor should have a return of 1200–1500 € per year in order to become profitable investment during its lifetime. From the DSO's point of view, the solar power plant should be able to provide the service at least below this price.

3.3.4 Summary

Table 3 summarizes the influence (obtained benefits) of the proposed business models from the solar plant owner's and the local DSO's point of view.

Table 3: Summary of business model benefits for the plant owner and DSO

	Model 1	Model 2
Plant owner	Possible reduction in reactive power payments (requires load that needs reactive power compensation)	Possibility to receive income by selling services
DSO	Reduced reactive power exchange with the distribution grid	Possibility to procure different services (e.g. reactive power compensation and voltage support)

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4. Energy storage in Suvilahti

A district level electrical battery storage has been installed in Suvilahti. The battery energy storage system (BESS) has an energy capacity of 0.6 MWh and rated power of 1.2 MW. There is also a 340 kWp solar power plant and electric vehicle (EV) charging points at the same location. One of the EV charging points is vehicle-to-grid (V2G, installed in 2017) and the other EV charger in the location is a fast charger (installed in 2018). All these assets are owned by Helen Ltd.

The BESS is used to demonstrate multiuser applications. The active power control of the BESS can be utilized by the transmission system operator for power balancing through the reserve markets and by the distribution system operator for peak shaving and energy time shifting purposes. In addition to the active power operation, the BESS can also produce or consume reactive power. Reactive power can be used for voltage control or for reactive power compensation purposes. The Suvilahti BESS is connected to a strong network that does not experience voltage problems and, therefore, in this location the reasonable reactive power control mode is reactive power compensation mode. Especially when the network load is low, the cable network produces a substantial amount of reactive power that has to be consumed preferable in the distribution network to avoid transmission system reactive power charges. It should be, however, noticed that if the BESS would be located to a weaker network, also voltage control functionality would be useful and could, for instance, enable increasing the amount of distributed generation connected to a particular network.

In mySMARTLife, integration of the Suvilahti BESS with the solar power plant and EV charging point at the same location is studied. These studies are described in detail in D4.8 Report on grid to vehicles strategies and performance and will not be repeated in this deliverable.

5. Smart Kalasatama area demand response potential studies

Demand response potential studies have been conducted in Kalasatama area focusing on two-level cases; new-built city block and single apartments located within the same block. This approach enables us to consider the performance of larger district but also brings details from individual customer level into the picture. The considered block can be generalized for the whole Kalasatama area as it represents typical structures. Similarly, apartments measured with details can be generalized for same block or even wider on Kalasatama area. Figure 9 presents the study area in Kalasatama.

The results of the demand response potential analysis are described in detail in D4.2 chapter 6.

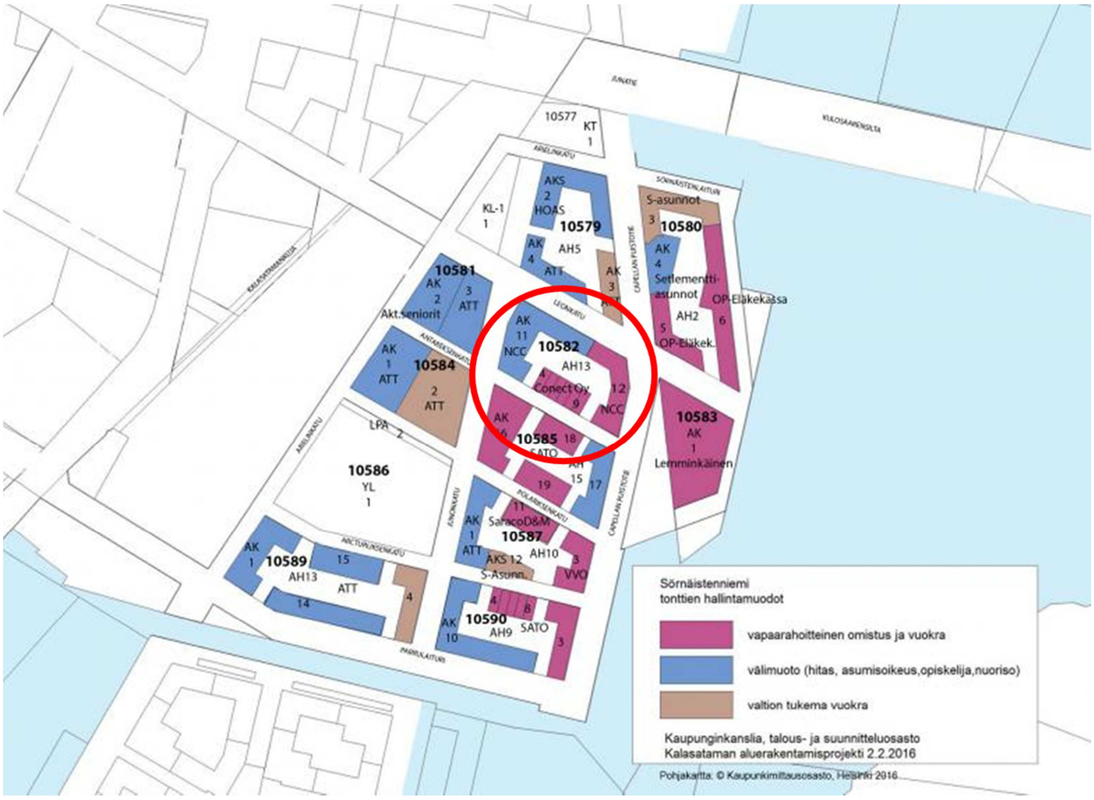

Figure 9: City block used in Kalasatama studies. The studies will cover block circled in the figure as well as individual apartments located within the same block. The figure simply illustrates the location of the studied block while the Finnish text in the figure is not relevant

5.1 City block in Kalasatama area

The block indicated in Figure 9 is used for the analysis. The block consists mainly of big apartment buildings but has also some smaller one-family houses, which are built as connected entities. Table 4 presents generic information for this block for year 2016.

Table 4: Statistics for the studied block in 2016

Number of costumers	Total energy	Max Hourly energy	Time of Max energy	Min Hourly energy	Time of MIN energy	Average hourly energy
130 kpl	699 000 kWh	179 kWh	04.12.2016 20:00:00	27 kWh	21.07.2016 2:00:00	79 kWh

Following figures present block energy use profiles on different time levels. Yearly profile in Figure 10, maximum week profile in Figure 11, minimum week profile in Figure 12 and example of typical daily profile in Figure 13.

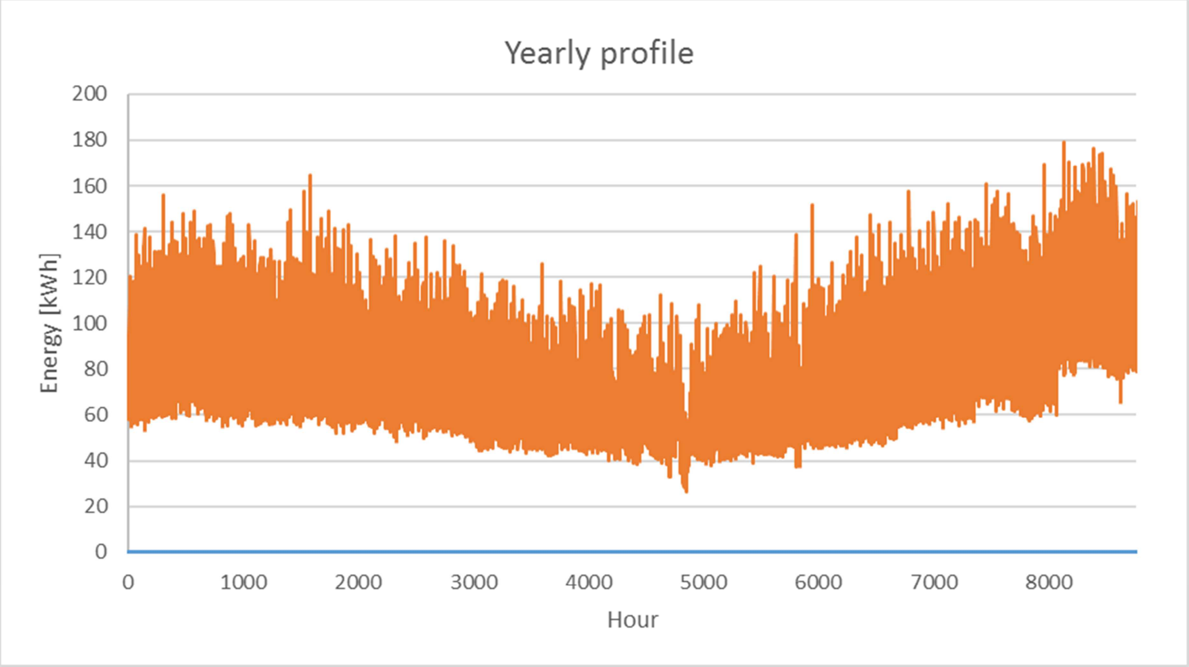

Figure 10: Yearly energy use profile for the studied area

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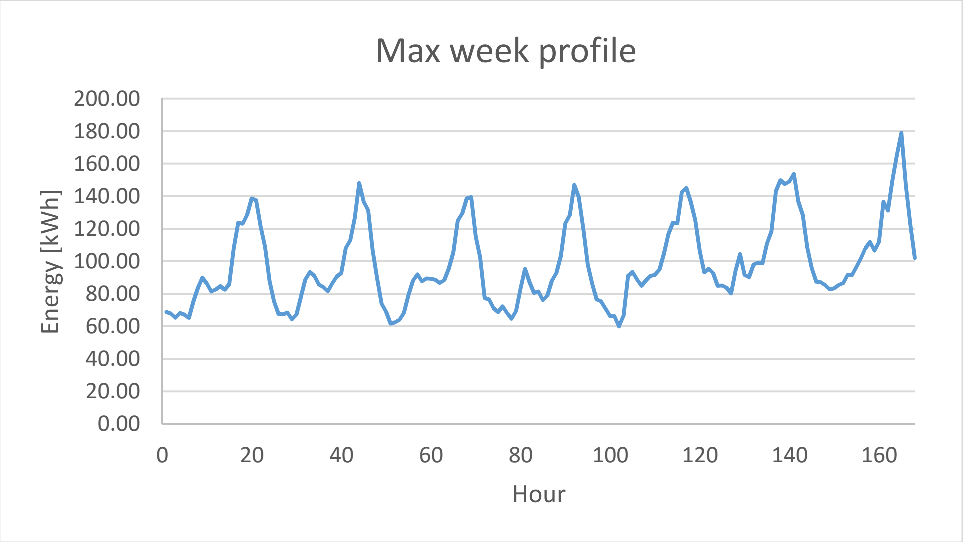

Figure 11: Energy use profile for the week with maximum load hour

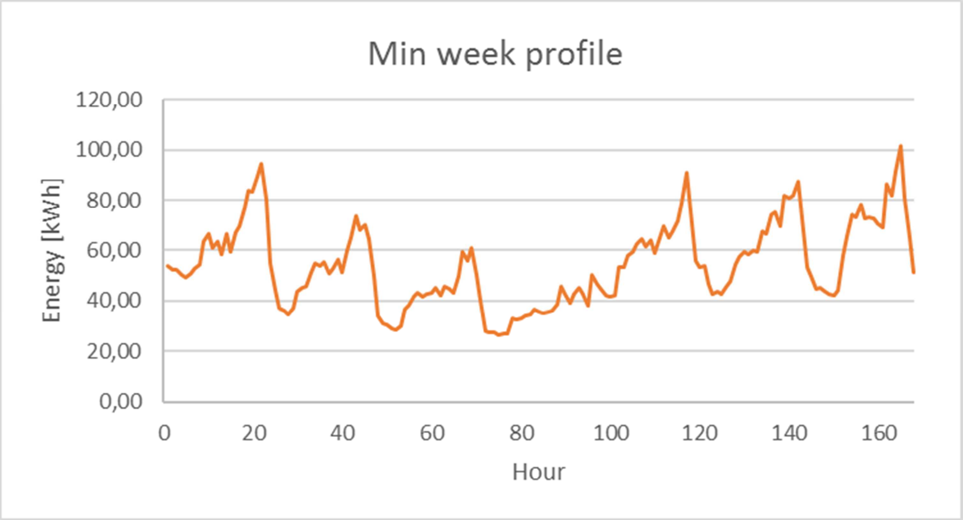

Figure 12: Energy use profile for the week with minimum load hour

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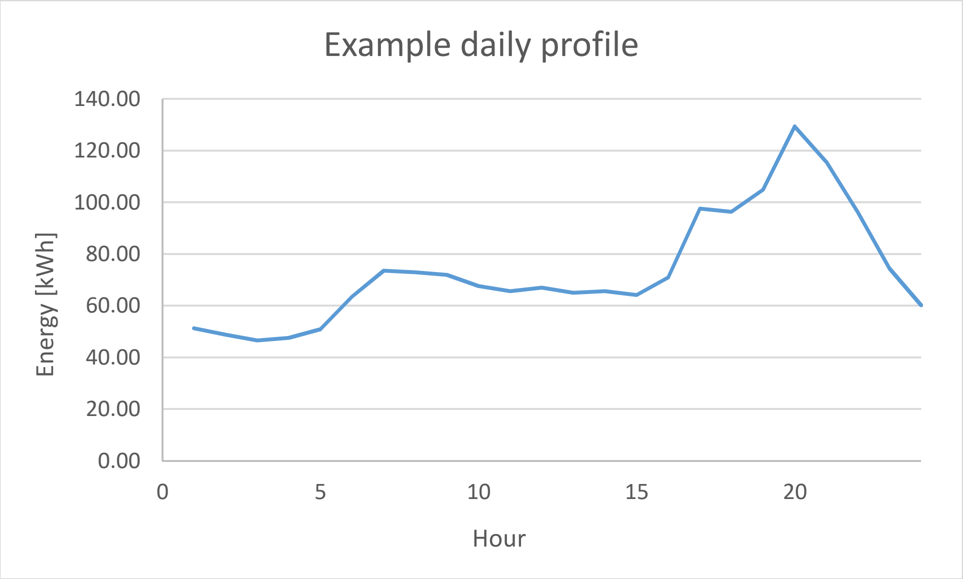

Figure 13: Example of typical daily profile

The profiles have even relative low variation on yearly basis. The range of daily variation remains on a similar scale throughout the year. At the same, the daily variation is rather strong, with peak hours having more than double energy use compared to lower use hours. The area has a typical residential use night hours' peak around 20:00. Smoothing this peak and shifting some consumption for instance to later hours could be an attractive option.

Analysis of the demand response potential still requires more detailed information on customer level loads and their controllability. This information will be sought for while conducting studies for the individual apartments as described in following chapter.

5.2 Apartments in Kalasatama area

The studies will be expanded by including measurements from residential apartments. Within this project, a complex of three apartments will be monitored. The house is equipped with PV panels and EV charging point as well as submetering for three apartments. This enables apartment-level analysis, which can be used to increase the accuracy of block-level results. Demand response potential, matching of PV production as well as apartment level energy efficiency can be considered.

First measurements for PV production are presented in following figures (Figures 14-16). Complementary measurements have been collected from the pilot site and a comprehensive analyses performed on them. The results are described in detail in D4.2 chapter 6.

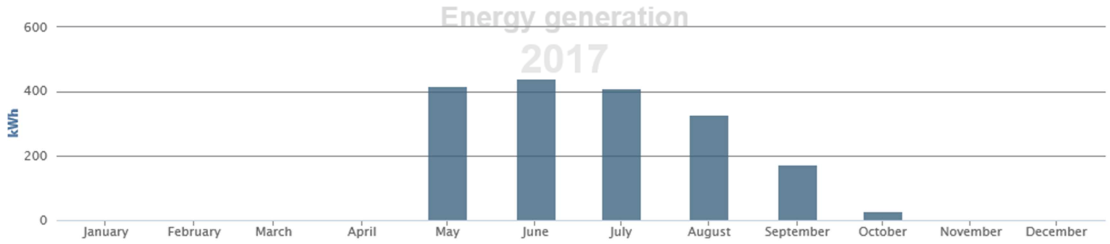

Figure 14: PV production statistics in 2017. The system was installed on May 2017

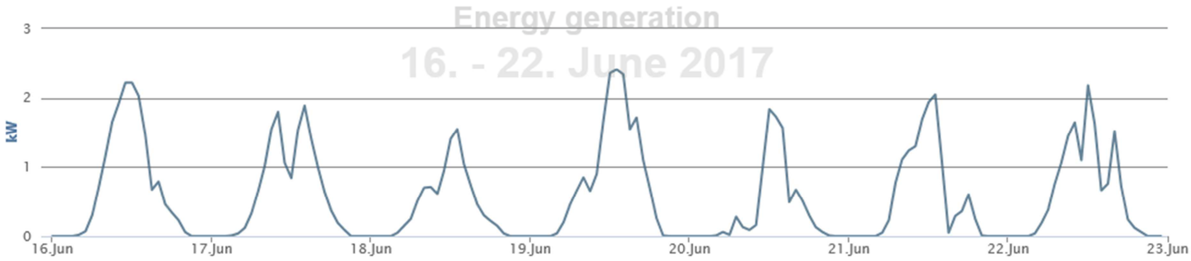

Figure 15: PV production during a typical summer week

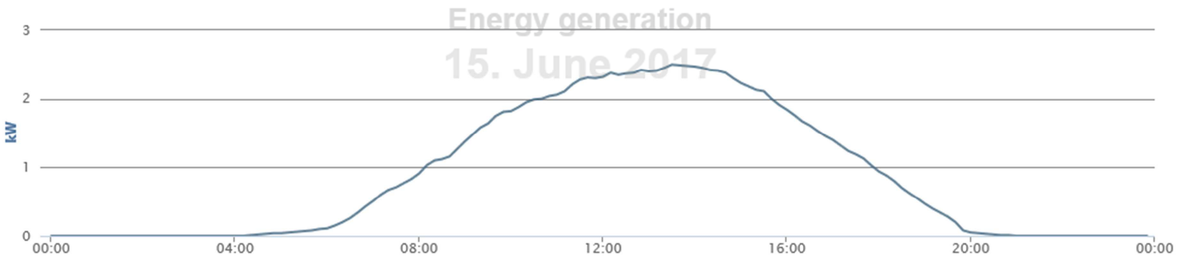

Figure 16: PV production profile for typical summer day

This project has received funding from the European Union‘s Horizon 2020 research and innovation programme under grant agreement No 731297.

6. Conclusions

This deliverable reported monitoring and control concepts and improvements with a particular focus on three case demonstrations: 1) Solar power plants in Kivikko and Suvilahti; 2) Energy storage in Suvilahti; and 3) New smart city district called Kalasatama. This report introduced Suvilahti and its distributed resources and provided an overview of the consumption patterns in Kalasatama. The demand response possibilities in Kalasatama have been investigated and reported in detail in D4.2.

The reactive power compensation with a solar power plant seems a viable and attractive application for the plant's inverter. However, it is yet uncertain how the compensation affects the inverter and therefore, the cost of the consumed or injected reactive power is unknown. The compensation increases the inverter losses and maintenance interval, may shorten lifetime, and may increase the cost of the inverter, for which the cost is difficult to define. Nevertheless, since the compensation causes costs to the plant owner, business models are needed to motivate the owner's participation. This deliverable described two models: One was based on the current reactive power payments, which can be reduced by local compensation by the PV plant. The second model assumed that the compensation could be sold to the local DSO if a reactive power market existed. The reader can note that the proposed business models are fundamentally not technology specific. Therefore, the models could also be applied to the battery energy storage system in Suvilahti.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.