iDistributedPV: Solar PV on the Distribution Grid: Smart Integrated Solutions of Distributed Generation based on Solar PV, Energy Storage Devices and Active Demand Management

PHOTOVOLTAICS PROMISING PROSUMER SOLUTIONS

The sun emits energy at a rate of 3.8x1023 kW per second. Of this total, approximately 1.8x1014 kW is intercepted by the earth, in this about 60% of this amount reaches the surface of the earth. The rest is reflected back into space and absorbed by the atmosphere. Even if only 0.1% of this energy could be converted at an efficiency of only 10% it would be four times the world's total generating capacity of about 3 000 GW. Looking at it another way, the total annual solar radiation falling on the earth is more than 7 500 times the world's total annual primary energy consumption of 450 EJ. [World Energy Council]

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SOLAR PHOTOVOLTAIC ENERGY

Photovoltaic (PV) is one of the most promising and environmentally friendly energy sources. Among new sources, it has the largest spectrum of opportunities to achieve energy and non-energy benefits.

Due to its inexhaustible potential, associated with direct conversion of commonly available solar radiation to electricity, photovoltaics can be alternative to fossil fuels in near future.

During the last decades, the solar photovoltaic technology has improved its effectiveness and its manageability significantly, and progressively reduced its costs per each installed megawatt. Additionally, the massive application of telecommunication and information technologies has produced great advances in terms of control and monitoring of the renewable energies and their integration in distribution grids.

The idea of prosumer energy production is developing rapidly in the European Union countries. A prosumer is an active energy consumers, or group of energy consumers who both consume and produce electricity, may store it or the excess energy deliver to distribution grid and thus actively participate in the electricity market.

PROMISING PROSUMER SOLUTIONS

The term “prosumers” broadly refers to energy consumers who also produce their own energy from a range of different onsite generators, but the focus of this brochure, is primarily on prosumers using solar PV to generate electricity.

Homeowner - Single Family House

PV systems for households are usually selected considering the size of available roof space and the amount of electricity which can be consumed by household.

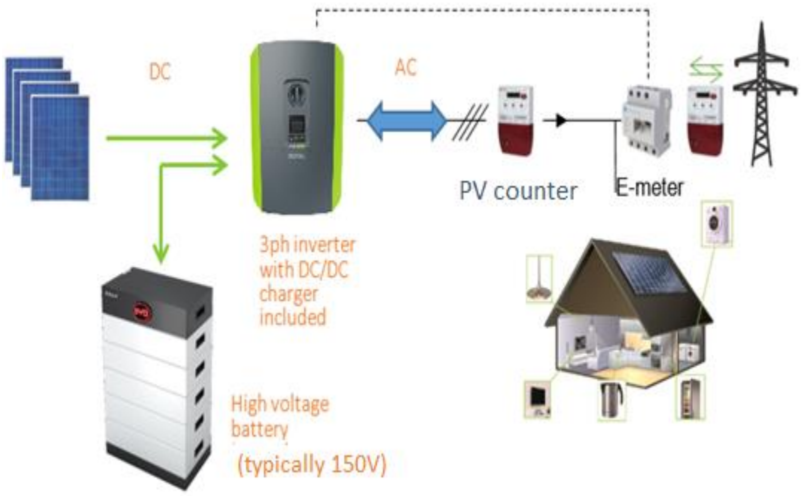

Figure 1. Example 3-phase homeowner system. Source: KOSTAL

The PV power installed and storage capacity in single family houses are typically in the following range:

- PV installed power: 2 kWp – 20 kWp
- Storage capacity: 2 kWh – 10 kWh.

The technology chosen for the storage system is based on high voltage lithium iron phosphate batteries, typically on the range of 250 V- 500 V.

Company as Investor

The investor in the PV-storage solution and the consumer of the electricity is the same entity. The electricity generated by the PV system is self-consumed whenever possible.

The excess electricity that is not consumed will be stored in batteries or fed into the grid, according to the profitability of each action.

Depending on the electricity consumption and available roof area, PV systems can range in special cases up to 1 MWp.

Typically, following system sizes are taken into account:

- PV installed power: 10 kWp – 250 kWp
- Storage capacity: 10 kWh – 250 kWh

Due to the high consumption, compared to the rooftop area, usually high own consumption rates can be achieved. Installation of storage capacities is not common yet, but rising with decreasing storage system prices.

For companies with high electricity prices the installation of a PV system for own consumption can be profitable. The consumer can therefore profit from reduced electricity cost, and depending on the type of consumer, creation of a green image can be an additional advantage.

Contractor Concept

Companies which do not want to invest in energy systems themselves can profit from the contractor concept. In this case a third entity invests in the energy generation system on the site and sells the produced electricity to the consumer and excess electricity is sold to the market. The consumer therefore has savings due to the lower electricity price without any financial risk. The investor profits from selling the electricity to the consumer and to the market. Even though there is no data on the number of contracted PV systems in Europe available, the number is assumed to be lower than that of the directly invested systems.
An appropriate battery system can increase the own consumption rate and can also provide peak shaving and possibly backup in case of power outages.

In Europe, there are only few systems in operation, mainly in Spain, where also some PV systems are combined with battery systems.

Municipal Buildings

PV systems for companies, municipality buildings and multi-family houses are mainly rooftop systems, as usually no land is available. In most cases, the PV system size is therefore limited by the roof area.
Municipal buildings can be equipped with PV battery. Several examples in various European

countries show that this solution is feasible, however not yet common.
Depending on the electricity consumption and the available roof area, PV systems can range in special cases up to 1 MWp. Following system sizes are taken into account:

- PV installed power: 10 kWp – 250 kWp
- Storage capacity: 10 kWh – 250 kWh

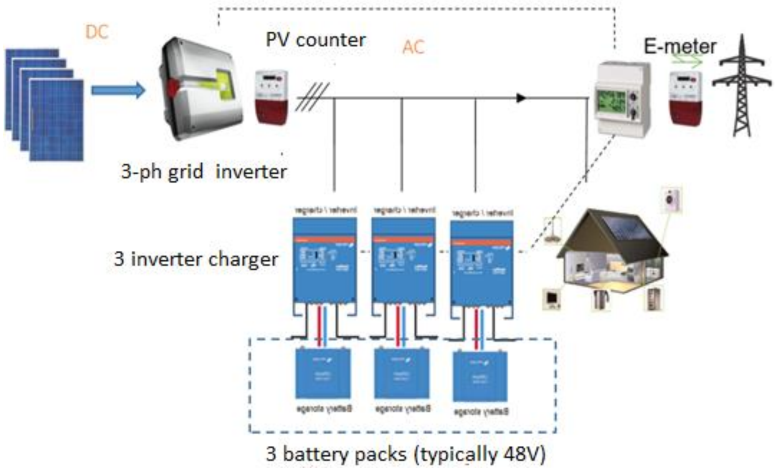

Figure 2. Example medium/large PV system. Source: KOSTAL.

Controllable Load

Operators of controllable loads such as irrigation systems or refrigerator systems can use PV systems for their own consumption. If cost of purchasing electricity is lower than the revenues for selling excess electricity, operators of controllable loads can profit from high own consumption rates when the load is adapted to the PV electricity generation. This business model is more profitable and more commonly used in Southern Europe.

The following range of peak power and battery capacity is taken into account:

- PV installed power: 4 kWp – 250 kWp
- Storage capacity: 2 kWh – 100 kWh

The technology chosen for the storage system is based on lithium iron phosphate batteries. This technology offers a high depth of discharge and a relative high number of cycles.

Multi-Family House

PV systems built on multi-family houses can provide electricity for the tenants by making use of available roof space in cities.

The electricity generated by the PV system is self-consumed if possible by residents in the building. Excess electricity can optionally be partially stored in a battery system to be self-consumed at a later point in time, and partially fed into the grid.
The tenants can profit from savings due to the use of less expensive PV electricity, while the investor profits from selling electricity. In addition, value of the house may increase with the PV system installed, which could cause longer rental contracts.
Due to charges on electricity sold to third parties and due to accounting issues, this business model is only used to a small extent in Germany so far, where the government grants a subsidy.

Similar to the contractor case, origin of electricity fed to tenants in the multi-family house must be identified.
Either by directly measuring the power flow if the output of the solar inverter is connected to the tenants without entering the external grid or through a virtual market where the consumer demands energy and the investor provides it. The latter configuration requires a device that assures correct communication and control between the investor and the consumers.

Community Storage

The households consume electricity from their own and/or from the shared PV system when available. Excess electricity from the PV systems is stored in the individual or communal battery storage system or fed to the public grid. If there is a need for electricity by the households, the communal storage can supply electricity. If the storage system is empty the demand will be covered with electricity from the grid. Each PV system consists of PV modules and an individual inverter to allow individual electricity consumption. The inverter of the communal battery needs to have sufficient power to be able to store electricity from the connected PV systems. A smaller storage system may be installed in each household, but this is an optional part of the solution.

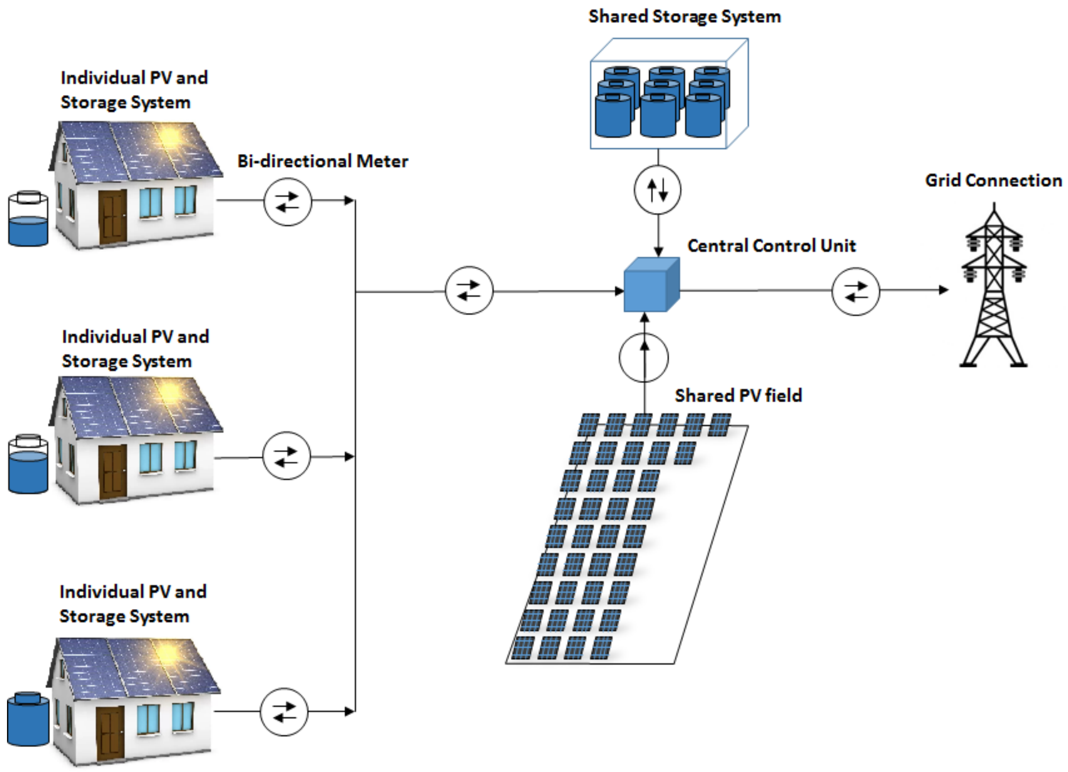

Figure 5. A community storage system. Source: Deloitte.

In a community storage system or shared storage system, residents in one area can commonly use the infrastructure for storing PV electricity for later use as own consumption.
In comparison to single separate storage systems in each household, community storage systems can profit from economies of scale – due to the larger system size, the per kWh price of the storage system will be lower.

In addition, a smaller sized storage system can be installed due to the differing load profiles of the community members. Each household can profit from a higher own consumption rate at lower cost. Due to regulatory issues which need to be solved there are only pilot and demonstration projects to be found in Europe.

A community storage system can be understood as one single storage system in a local community, or as a virtual storage composed of several distributed battery systems. A large scale storage system may have physical advantages such as lower specific system cost and reduced losses due to balancing effects between the users.

On the other hand, interconnection of distributed systems can bring the advantage of using the owners' systems more efficiently while private capital is invested. Also this system avoids questions of ownership and reduces risk of the investor.

Peak PV power and storage capacity installed is likely to be within the following range:

- PV installed power: 50 kWp – 500 kWp
- Storage capacity: 50 kWh – 500 kWh

Lithium batteries suit community storage applications, no matter the size of the system. For instance, ABB has developed energy storage modules that can deliver up to 75 kW with a total energy capacity of 75 kWh.

Virtual Power Plant

Virtual power plants can consist of several renewable energy sources in different geographical locations. An investor uses flexibility of the different generation capacities to produce and sell electricity at the electricity market. Combination of several generation plants results in larger volumes sold and a more favorable generation profile. The operator of the virtual power plant can profit from revenues for electricity sold to the market. Across Europe, there are only few virtual power plants in operation, mainly to be found in Germany.

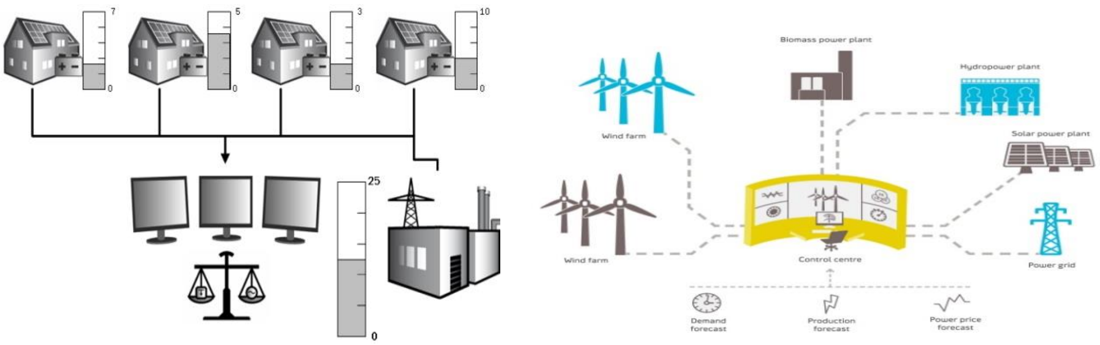

Figure 6. A Virtual Power Plant. Source: Deloitte.

Electricity generated by the PV is managed according to a contract of the PV owner with the VPP owner. The PV responds to the VPP dispatch either based on a price signal or based on the contract (most likely for PV systems). The VPP operator sells the PV fed into the public grid to a third party (e.g. via the power exchange market).

A virtual power plant aggregates multiple small and medium producers. They resemble the community storage in the aggregation of producers, but in this case the main aim is to sell back to the grid surplus electricity they generate.

- PV installed power: 100 kWp – 20 MWp
- Storage capacity: 100 kWh – 20 MWh

DIFFERENCES AMONG PROSUMERS

- Household case studies reflect a favourable profitability despite their demand profiles are commonly not fit into the solar production hours. The barrier to overcome in the single-family house PV solutions is the price of the equipment at such size of installation.

The presented eight prosumer solutions were assessed and the simulations were carried out in case studies for PV energy prosumers in: Germany, Greece, Lithuania, Poland and Spain.

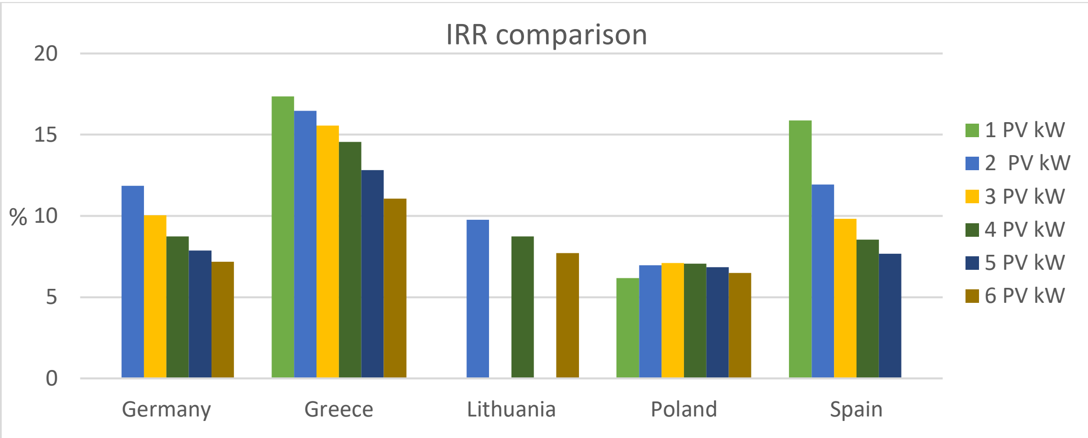

Figure 7. Homeowner: IRR comparison among all the countries.

- The companies and municipal buildings studied present relatively high demands which translates into larger profitable installations. Thus, it makes the investment per kW installed diminish. The consumption pattern often matches the solar production profile, which contributes to a better profitability for the solution.

- The cases related to groups of prosumers, like in the community storage or multifamily house, indicates that there can be a leverage on the economy of scale when acquiring the equipment. The management of the energy share along with the assignment of the possible profits from energy excess fed into the grid, turn out to be the main inconvenient when applying this type of solution. The ICT systems, like the blockchain schemes, ease the emergence of the energy prosumer communities.

- In the study of the controllable load case, the integration of the electric vehicle and its battery in the distributed generation solutions can be analysed in two different approaches with:
  - The combined demands of a building, like a household, by the use of the electric vehicle.

  - It would enhance the profitability of the PV installations, as an electric vehicle adds energy consumption to the building, and then, the self-consumption level is susceptible to rise. This increase depends on the electric vehicle charge period, which should overlap with the PV production hours;
  - Attached to electric vehicle charging stations. In this type of solution is crucial that the system can rely on a method for the storage of the energy produced, through either batteries or net metering schemes, in order to supply the consumption of the incoming vehicles at any time.

- Related to the Virtual Power Plant case, there is a potential business on the primary control reserve and other ancillary services for the electricity system. The configuration of distributed generation, batteries and load can be more cost-effective than a conventional power plant when providing these services.
- In countries with a net-metering supporting scheme, solutions without storage systems show the most promising results. Analysis of Net Present Value (NPV) and Internal Rate of Return (IRR) confirm this.
- In Spain and Germany, where there are not net-metering schemes, solutions with energy storage devices show less economic benefit due to the high price of batteries.
- The NPV and the IRR are noticeably higher for the PV system without battery than for combination of PV and battery system. Combination of PV and battery system results in low profitability or even unprofitability of these investments.
- Load flow analyses performed in each country show that there is no need for grid reinforcement. Neither loading violations nor voltage violations are found.

SOLUTIONS FOR PROSUMERS

- The solar PV panels cover most of the demand at sunlight hours while the rest of the time the electricity is purchased from the grid.
  In order to reach favourable profitability in the investment, a proper sizing of the installation must be carried out. This profitability comes from avoiding the purchase of electricity at retail tariff prices.

- The savings in the electricity tariff obtained from the substitution of energy can be complemented with the reduction of power contracted. The tariff associated should allow the consumer the possibility of having different periods with its corresponding power contracted. Besides, the prices for the energy consumed in the different existing periods should also vary, and by this method, the prosumer should be able to maximize savings (as long as the peak price periods coincide with the PV production moments).

- The most effective retribution scheme for the prosumer is the net-metering model, which transforms the grid in a "storage system". The prosumer will be able to retrieve the energy fed into the grid when the energy demand is higher than the production.

Thus, the investment yields higher profit as the PV production is fully exploited and can even allow the prosumer to produce the whole demand needed along a year. This scheme should set limits to avoid the oversizing of installations, which can lead to unbalances in the distribution grid.

- Establishing a maximum period for the recovering of energy, preferably a year. This period should start in spring, in order to let the prosumer make use of the energy excess produced on summer, later on winter period when the production is lower. Basically, it would assure that the prosumer does not have a production greater than the annual consumption.
- Including costs for retrieving the energy stored in the grid. There are several schemes for this type of charge. In a simpler way, the prosumer would take on payments per kWh, and alternatively or in combination, with monthly fees per kW installed.
- Another method for net metering process is to give back to the prosumer only a percentage of the energy exported. The player responsible for the retribution should analyse the convenience of each method in its operative.

- Provide ancillary services to the energy system with the distributed generation of the prosumers. An aggregation of the production, shifts in the demand or storage system utilization can be leveraged by a player who will act in the market on behalf of the prosumers involved.

- The storage systems attached to the PV installation can take advantage of the surplus generated to cover the demand when there is no production or it is lower than the demand.
  By including an intelligence or automation system, batteries would be able to perform activities that enhance its effectiveness:
    - Using the energy stored to satisfy the demand in peak price periods, according to tariffs with hourly discrimination.
    - During low PV production seasons, batteries can charge its capacity from the grid at low price periods and use it in more expensive tariff times.
    - Adapt the discharge of the stored energy to the consumption peaks, with the purpose of allowing the reduction of power contracted.
    - Enable the prosumer to participate in the provision of ancillary services.

- The electric vehicle charging station represents a target for the deployment of solar PV solutions with storage systems.
- The clustering of prosumers into communities allows for obtaining more affordable investment in the PV installation equipment.
  These groups rely on an ICT infrastructure to manage the energy and economic flows derived from the operation of the solution.
  The electric vehicle charging station represents a target for the deployment of solar PV solutions with storage systems.

The **aim** of iDistributedPV project is **developing affordable integrated solutions to enhance the large scale penetration of distributed solar PV**.

Consortium members:

Asociación de Empresas de Energías Renovables
Fraunhofer-Institute for Solar Energy Systems ISE
Institute of Power Engineering (Task lead)
Enea Operator Sp. z o.o.
Exide Technologies
Kostal Solar Electric Iberia, S.L.
Deloitte Advisory, S.L.
Institute of Communication and Computer Systems - National Technical University of Athens
Hellenic Electricity Distribution Network Operator S.A
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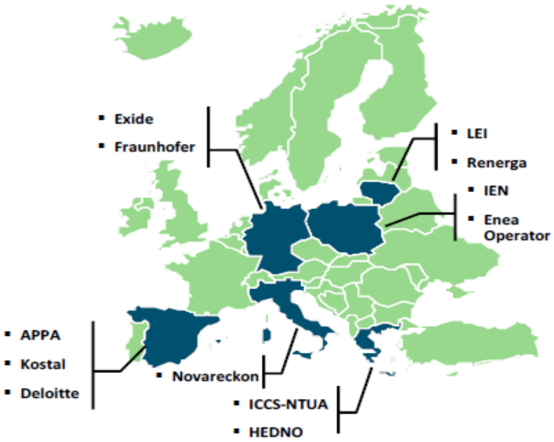
Deutsche Energie-Agentur GmbH (DENA) – German Energy Agency



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