# Energy Management Solutions for Polish Prosumer Systems

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Abstract: Last year the Polish government finally passed an act of parliament concerning renewable energy sources in response to the European Union Directive 2009/28/EC promoting renewable energy. This act liberalizes the interconnection of small on-site generation systems situated on the customer side, consisting of renewable energy sources (prosumer systems), with the electrical distribution system. Although most of the formal barriers have been removed, the proposed economic conditions are not likely to guarantee the expected dynamic growth in volume of renewable energy as part of the overall energy consumption. This paper introduces a solution for the economic and energy-effective management of energy generated in Polish prosumer systems. Moreover, the technical and formal conditions for implementing small-power renewable energy sources into the distribution system are mentioned as a background for the optimal choice of interconnection solution and topology. A complete energy management solution based on available technologies, such as power electronic converters, energy storage devices and home area networks has been proposed as well.

## 1 INTRODUCTION

Nowadays almost 90% of the overall energy consumed in the Polish electrical system is produced at coal-fired power stations. Coal and other fossil fuels, such as natural gas, still remain the cheapest primary energy sources for heat and electricity generation in Poland, although they are charged with high $CO_2$ emission coefficients of 0,89 Mg/MWh and 0,560 Mg/MWh for coal and natural gas respectively. Without modification of the energy generation structure this means that in the near future growing emission payments (from 30% now to full prices in 2020) will also increase the electrical energy costs for Polish consumers. In August 2013, according to the EU Directive (European Parliament, 2009) promoting energy from renewable energy sources, the Polish Energy Act has been finally modified (Parliament of the Republic of Poland, 2013), thus, small systems up to 40 kW consisting of such energy sources, referred to as RES micro installations, now have permission to transfer energy back into the distribution grid without any special concession being required by commercial energy sources other than agricultural biogas fired sources. This was a major barrier in the large scale development of on-site generation micro systems. Unfortunately, the convenience of RES interconnection with the distribution system is not supported by profitable pricing, as is commonly the case in other countries. The Polish version of the Feed-in Tariffs (FIT) system guarantees a price for energy generated in micro installations and transferred into the utility grid below the value of the average price of energy on the energy market. To be precise, it is 80% of the average price, and taking into account the prices in the Polish energy market in 2013 (0,20 PLN / kWh) it is about 0,16 PLN (about 0,04 EUR). In contrast, the prices for energy taken from the grid, including energy delivery tax, comes to 0,53 PLN / kWh (about 0,13 EUR / kWh) on a flat tariff (one averaged price for the whole day and whole year). Hence, this system rather motivates RES energy consumption inside the customer installations than energy reversing to the grid. In other countries, for example, in Germany, the prosumer systems with FIT tariffs have a guaranteed higher price for energy reversed to the grid in relation to energy taken from the same grid, so any reduction of energy consumption leads to a raising of surplus energy transfer to the grid and, as a result, to the higher profits.

In Poland, apart from RES, some other technologies are now being considered, especially

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the energy passive solution allowing for a reduction of energy consumption by using an advanced metering infrastructure (AMI) and load management stimulated by dynamic tariffs. This model doesn't require the significant support, though it could give the expected effect only by involving a number of different technologies working together within one optimally composed energy management system. An example of a prosumer system is shown in Figure 1. Considering the daily load profile variation as well as daily RES power generation profiles, the optimal energy management could be provided only in a system with power electronics interfaces (PEI) working in tandem with energy storage devices (ES). Moreover, apart from using dynamic tariffs, or programs consisting of more than one pricing time zone (usually two price levels – peak power pricing and off peak power pricing geographically located according to daily load curve), or other commercial Demand Side Management (DSM) and Demand Side Response (DSR) programs there are additional possibilities for energy cost reduction such as peak power shaving and power shifting. These processes could be provided either by using a reduction of energy consumption or by using energy from a RES previously stored in ES. In the case when all the investment costs in a RES are covered by the prosumer, without any external support, the control should be performed with due regard to the best economical effect.

# 2 AVAILABLE TECHNOLOGY OVERVIEW

The optimal topology of a prosumer system for Polish conditions requires specific elements. There are available some market-ready applications which can operate alone, but their coordination within one common system is often impossible or does not permit anticipated functionality. Recognition of their properties and judgment of their usefulness constitute the first step in composing an optimal prosumer solution with several major functions like optimal RES energy utilization, energy storage ability and power flow control.

The technologies providing these functions can be divided into three groups: RES and interfaces, measurement and monitoring devices, energy management systems.

Presently in Poland all of the above mentioned technologies are available or are in a developmental or testing stage.



## 2.1 RES and Interfaces

There are three major types of renewable energy sources with the potential for commercial implementation in Polish prosumer systems: photovoltaic systems (1 MWh/m$^2$), small wind power systems (0,5 – 1 MWh/m$^2$) and biomass (biogas) fired micro cogeneration systems (energy potential dependent on biomass type).

Two first sources due to their unpredictable and unstable character, being mostly dependent on

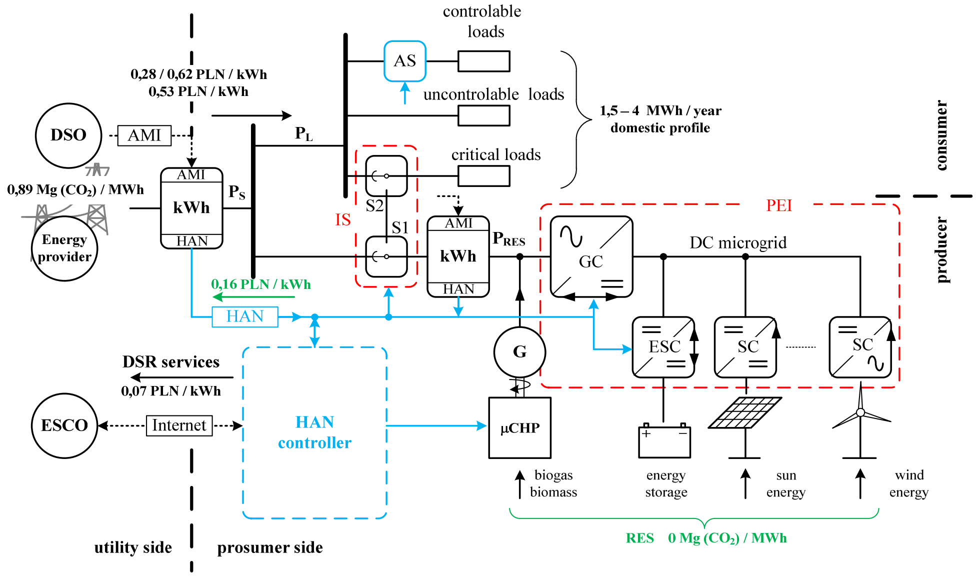


Figure 1: Unified and simplified schema of prosumer system with energy management technologies.

primary energy variations, need to be supported by interfaces based on two-stage power electronic converters with energy storage ability, although systems without ES are commonly used because of their lower prices. Micro cogeneration systems are treated as a stable source. The primary energy (biomass or biogas) in such systems is easily stored and can be more readily controlled than wind or sun. Moreover primary energy control can be used for stabilization of the output voltage characteristic or for output power management. The stable output voltage parameters of rotating generators allow the connection of a micro cogeneration system directly to the distribution system without power electronic converters. Of course, in some cases, for example in systems with a gas fired micro turbine, a frequency converter is required.

Today there are three types of RES interfaces available on the Polish market, the implementation of which is allowed for in the electrical distribution system (Benysek, G., Jarnut, M., 2013): Off Grid (islanded, autonomous), Grid Tied (On Grid, grid connected) and Hybrid. These applications have different functionalities and different abilities for energy management, but all of them can be implemented in prosumer systems.

#### 2.1.1 Off Grid Systems

The main rule of working in Off Grid systems is the creation of local islanded circuits in prosumer systems, where the sectioned circuits are supplied by an Off Grid inverter using energy generated in RES and stored in ES. The interfaces in an Off Grid topology consist of four major parts: source-side converter (SC in Fig.1), energy storage devices, grid-side converters (GSC in Fig.1 being Off Grid inverter) and by-pass switch (islanding switch – IS in Fig.1). Such a topology allows for a power balance creation inside prosumer installations using energy source switching for sectioned circuit only, so the summary utility power ($P_S$) changes will be visible as step changes and will be strictly dependent on the actual load of the sectioned circuit. This limits the flexibility of power flow control and there are no possibilities in this structure for energy reversing to the distribution grid. Although this may sometimes be treated as a disadvantage, in the Polish electrical power system, where the yearly voltage interruptions last ten times longer than, for example, in Germany, such a topology allows for the possibility of uninterruptible power supply of critical circuits.

#### 2.1.2 Grid Tied Systems

Grid Tied systems have a parallel connection in relation to the distribution grid, with their grid-side converters working in current mode, so they can be seen as controlled current sources. The typical structure of Grid Tied systems contain: source-side converter (SC), grid-side converter (GSC) and islanding protection switch (IS).

In prosumer installations with Grid Tied systems, in contrast to those with Off Grid systems, the power balance is created continuously. Unfortunately, because of the lack of an energy storage function, this process can’t be intentionally controlled and is rather directed to optimal RES energy utilization. In the case of the Polish version of FIT tariffs and taking into account the daily load profile of prosumer installations it can lead to non-optimal energy costs and to relatively high power variations in the distribution system (including $P_S$ power value as well as the power direction).

#### 2.1.3 Hybrid Systems

Hybrid systems combine the advantages of Grid Tied and Off Grid systems in one topology controlled in a specific way (Jarnut, M., 2012). Under normal conditions in a distribution network this means that when the utility voltage remains inside the permissible range, the grid-side converter works in current mode, shaping the sinusoidal output current magnitude according to the determined power flow control strategy. This strategy, in contrast to the Grid Tied or Off Grid solution, can be flexibly programmed for cost optimal control. It is worth noting that grid-side power balance control can be provided independently on the source-side power balance. This is possible with the implementation of a separated individual, bidirectional DC/DC converter (ESC in Fig.1) in the energy storage leg and an MPPT controlled DC/DC converter (SC in Fig.1) in the source leg. Once the distribution system fails, the grid-side converter is switched to voltage mode, shaping the sinusoidal voltage on the islanded circuit and performing a UPS function. In the hybrid solution, the islanding switch (IS in Fig.1) has both a functionality typical for a by-pass switch (Off Grid systems) and an anti islanding switch (Grid Tied systems).

### 2.2 Energy Measurement and Monitoring Systems

Optimal energy management in prosumer systems requires real-time information about power flow in both major circuits of the electrical installation: in the load circuit as well as in the source circuit. Moreover according to Polish Energy Law (Parliament of the Republic of Poland, 2013) the energy generated in licensed RES being subsidized by green certificates should be measured directly at source terminals or in a place of common coupling (PCC) of the source interface and utility grid. This means that in each Polish prosumer system there should be installed two independent meters. Presently in Poland public, commercial and industrial customers have installed advanced electronic meters allowing the recording and transmission of measurement data. In the last two years distribution system operators (DSO) have begun to implement widely the use of smart energy meters also for domestic customers with a connection power limit below 40 kW. Simultaneously they are developing an Advanced Metering Infrastructure (AMI) for remote data reading and meter management. According to the required structure, accepted by the Polish Energy Regulatory Office (Energy Regulatory Office of Poland, 2011), an AMI system consists of several major parts: smart meters, hubs and balancing meters, data transmission system and SCADA based data acquisition system.

In their target functionality AMI systems should be able to provide bidirectional communication of measurement data reading, as well as for commercial data transfer to the customer areas through smart meters equipped with additional interfaces to the Home Area Networks (HAN).

### 2.3 Energy Management Systems

The Polish Energy Regulatory Office, together with the requirements of the AMI infrastructure, prescribes the expectations of other Smart Grid components to assure their interoperability within one system. Some requirements have also been defined for customer-side energy management systems such as HAN (AT Kearney, 2012). HAN systems can cooperate with the AMI infrastructure through smart meter reception of technical and commercial information from DSO which can be used for optimal power balance control, matched for economy of use. The AMI infrastructure in Poland today is still in its developmental stage. The signals for commercial power control (reduction for peak power shaving or growth for valley filling at night) can also be transmitted using an alternative communication channel, for example, by the Internet, and can be provided by Energy Services Companies (ESCO). HAN infrastructure is not only a communication system, it is also a control system, which allows the control of instantaneous power balance. The HAN controller manages appliances according to programmed algorithms and according to research results could bring energy savings of between 4% and 15% (AT Kearney, 2012).

## 3 OPTIMAL CONFIGURATION OF PROSUMER SYSTEMS

The above described technologies due to their interoperability could be flexible combined to work together within one optimized energy management system. Choosing the optimal structure and control algorithms in the case of Polish prosumer systems and in accordance with the specific economic conditions is especially important in reducing investment costs (due to the lack of subsidy programs), but a choice which should also consider capacity for flexible energy management functions, such as load shifting or RES energy shifting, to match load and generation curves. To evaluate the costs and profits in different configurations and with different tariffs, the prosumer system with a standard daily load profile (domestic type, $P_L$ in Fig. 2) and PV based RES source ($P_{RES}$ in Fig.2) has been considered. Moreover the power of the PV system has been determined on the assumption of an ideal daily energy balance between energy consumed in loads (about 10 kWh) and energy generated in RES. To simplify analysis a day in the summer season has been chosen. Additionally the yearly irradiance variation has been ignored, so payback period has been evaluated in months (an assumption of constant irradiance during the summer season has been made). Illustrations of power management in the selected configuration of the prosumer system are shown in Figure 2. As can be seen the mismatch of power profiles of load and RES could cause a bidirectional energy transfer between utility grid and prosumer ($P_S > 0$ or $P_S < 0$) in Grid Tied systems. In systems such as Off Grid and Hybrid, controlled with an internal power balance strategy ($P_S = 0$) the energy storage devices store energy when $P_{RES} > P_L$ and supply load when $P_{RES} < P_L$ (through a grid-side inverter).

Depending on energy prices in different tariff programs and taking into account possible extra benefits in the case of providing ancillary services (DSR in Fig. 2a), the payback time of investment in

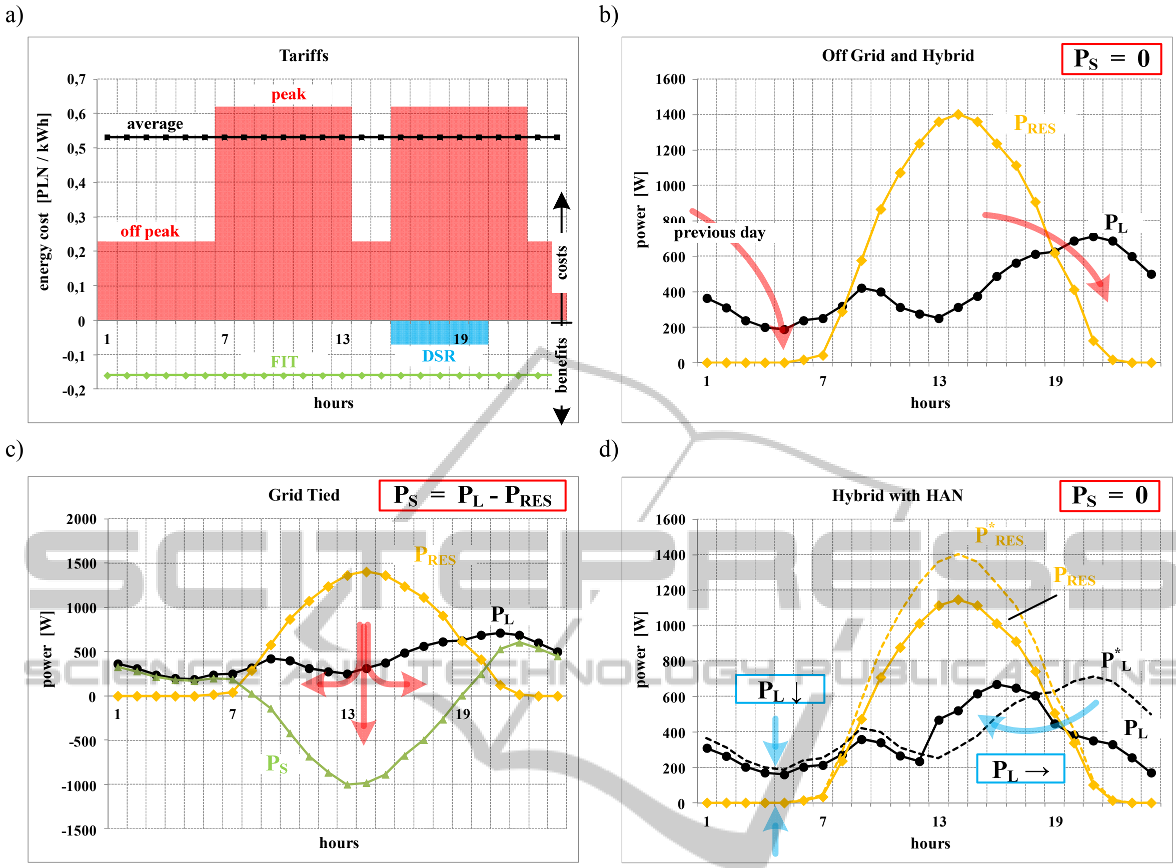


Figure 2: Illustration of power management in selected configuration of prosumer system: a) considered tariffs programs; b) Off Grid and Hybrid; c) Grid Tied; d) Hybrid with HAN based load management.



prosumer systems, working in specific configurations will be different. The overall cost of a solution is strictly dependent on the system configuration and is much higher in all solutions employing energy storage devices compared with those without batteries (almost three times higher). Thus the required capacity of energy storage devices should be minimized. This is possible using load management systems like HAN, working with strategy based on shifting operating time of programmable devices such as dish washers, washing machines, dryers, electric heaters, etc., to periods of day where the power of RES ($P_{RES}$) is higher than the power demand of the load circuit ($P_L$). This strategy has been indicated in Figure 2 as $P_L\rightarrow$. Using this strategy as well as the second one based on load power reduction ($P_L\downarrow$) it is possible to modify the load power profile ($P_L$ instead of $P^*_L$ in Fig. 2d) and to reduce the required battery capacity by 30% and 15% of required RES power ($P_{RES}$ instead of $P^*_{RES}$, see Fig. 2d). Although this results in decreasing proportional energy storage and PV costs, additional investment is needed in the HAN system, consisting, at least, of a central HAN controller and a several active sockets (AS). The proposed Off Grid and Hybrid configurations controlled using the strategy of internal power balance ($P_S$ = 0) give more cost optimal energy management than the Grid Tied configuration where the surplus energy is reversed into the utility grid ($P_S$ < 0 in Fig.2c) at a price much lower (FIT = 0,16 PLN / kWh in Fig.2a) than the energy taken from the grid (average = 0,53 PLN / kWh; peak = 0,62 and off peak = 0,28 PLN / kWh), but the benefits of the former come with higher investment costs (for more details see data in Table 1).

# 4 CONCLUSIONS

Consideration of the results presented in this paper show very clearly that in spite of the decreasing investment costs of RES technology in small scale applications investors would not gain any

Table 1: Properties of selected configurations of prosumer system.

| structure of solution | tariff program | power control strategy | estimated cost of solution [PLN] | utility energy daily transfer [kWh] from | to | monthly energy cost without RES utilization [PLN] | monthly benefits of RES energy utilization [PLN] | simple payback period [months] |
|---|---|---|---|---|---|---|---|---|
| PV+Off Grid | averaged | $P_S = 0$ | 18.750 | 0 | 0 | 158 | 158 | 119 |
| | peak / off peak | | | | | 145 | 145 | 130 |
| | peak / off peak + DSR | | | | | 145 | 151 | 125 |
| PV+Grid Tied | averaged | unavailable | 6.750 | 4,4 | 7,12 | 158 | 122 | 56 |
| | peak / off peak | | | | | 145 | 129 | 53 |
| | peak / off peak + DSR | | | | | 145 | 137 | 50 |
| PV+Hybrid | averaged | $P_S = 0$ | 17.750 | 0 | 0 | 158 | 158 | 113 |
| | peak / off peak | | | | | 145 | 145 | 123 |
| | peak / off peak + DSR | | | | | 145 | 151 | 118 |
| PV+Hybrid +HAN | averaged | $P_S = 0$ $P_L \rightarrow$ $P_L \downarrow$ | 17.000 | 0 | 0 | 134 | 134 | 127 |
| | peak / off peak | | | | | 123 | 123 | 139 |
| | peak / off peak + DSR | | | | | 123 | 129 | 132 |

power control strategies: $P_S = 0$ – internal power balance; $P_L \rightarrow$ – load power shift; $P_L \downarrow$ – load power reduction



satisfactory economic gains without any supporting programs. In Poland, the simplest prosumer systems based on the Grid Tied configuration and having effortless energy exchange between the utility grid and prosumer installations have to transfer the surplus energy at discouraging prices. Better in this field are systems with Off Grid and Hybrid configurations, which are functionally better suited for more cost effective energy management, but they need energy storage devices in their structure which increases investment costs. On the other hand one of these solutions – the Hybrid, has the flexibility which gives the prosumer the ability to control the power flow inside and outside of his installations The function of load curve modification (with or without HAN), especially in peak hours, will be the main trump of Hybrid solutions in the near future when the risk of a power deficit can occur in the Polish electrical power system with the disconnection of coal fired, outdated and relatively heavily polluting power plants. Freedom from utility grid outages is another advantage of the Hybrid solution as well as the ability for RES energy optimal utilization in this case. The small scale RES market in Poland is today still in its infancy, hence the results presented in this paper will be extended when more data becomes available.

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