Feasibility analysis of autonomous hybrid solar-wind system for household consumption: a case study

T I Pehlivanova and A K Atanasov
Trakia University of Stara Zagora, Faculty of Technics and Technologies of Yambol, Department of Electrical engineering, electronics and automatics
38 Graf Ignatiev str. Yambol, Bulgaria
e-mail: tanya.pehlivanova@trakia-uni.bg

Abstract. The constant increase of electricity prices from the power grid, rising fossil fuel prices and environmental motives make people look for opportunities to supply their homes with renewable energy independently from the grid. The easy technical feasibility of the projects and the climatic features of Bulgaria determine the solar and wind energy as the most suitable for the households. The variability of solar and wind energy predetermines their shared use in hybrid systems. Feasibility analysis of autonomous hybrid solar-wind system for household consumption was made in the article. The calculations were made for a residential building located in the village of Okop, Yambol District, Bulgaria. It has been verified if the levelized cost of energy (LCOE) of the domestic solar-wind hybrid system is in parity with the final cost of the grid electricity. Different variants of system configurations and different ways of financing were considered. The results show that for the considered place, the prices of electricity produced by autonomous hybrid systems are higher than the prices of electricity for household customers connected to the power grid. The use of standalone hybrid systems is only justified when there is no power supply from the grid. Lower average prices than those of the power grid are obtained only when building a photovoltaic plant connected to the grid.

1. Introduction
The EU Directive [1] sets a target at least 32% of the gross final electricity consumption in the EU by 2030 to be produced by renewable energy sources (RES). The geographical and climatic conditions in Bulgaria determine as one of the leading sources of renewable energy, the sun and wind. Solar and wind power are clean, inexhaustible and environmentally friendly. However, they have some disadvantages. Wind and solar sources are dependent on unpredictable factors such as weather and climatic conditions. Due to the complementary nature of the two sources, some of the weaknesses of the one source can be overcome with the strengths of the other. For this reason, these two sources are used in combination and form a hybrid solar-wind system.

In the recent years, the share of solar and wind electricity, mainly from power plants connected to the grid, has increased. Power systems for households with RES in Bulgaria are rarely built because their investments are too large.

The tendency is for the prices of photovoltaic (PV) and wind technologies to decrease. At the same time, the retail price of electricity in Bulgaria is constantly increasing. In addition, distributed generation eliminates the need for an expensive transmission system and minimizes transmission and distribution losses, which represent approximately 30% of the energy delivered. It is approaching the stage when the final cost of electricity from the grid will equalize with the levelized cost of energy (LCOE) produced
by RES systems and the households will begin to use autonomous electrical systems as an alternative to electricity supply.

There are various approaches in the literature to evaluate the technical and economic feasibility of energy systems.

Techno-economic analysis of the applicability of a 5kWp household's PV system connected to the grid was made in [2]. It has been proven that photovoltaics for home use, installed on the free rooftops and plots of consumers, are in grid parity in Bulgaria.

With the help of machine learning, using satellite and statistical data sources, the technical potential for electricity generation from solar systems located on the roofs of buildings for all EU countries was evaluated in [3]. Economically competitive systems were determined by comparing LCOEs, calculated with country-specific parameters, with the latest household electricity prices. The results show that EU rooftops could produce 24.4% of current EU electricity consumption, two thirds of which, at a cost lower than current tariffs. In Western European countries (Germany, Spain, Italy and France), PV energy is cheaper than grid electricity. In the Eastern EU countries (Bulgaria, Hungary, Romania and Estonia), grid parity is currently not possible due to low retail electricity prices. The results for Bulgaria, Romania and Croatia are surprising as they have a favorable solar resource.

Reference [4] presents a method for quantifying the economic viability of an autonomous system including photovoltaics, batteries and cogeneration systems by calculating the LCOE, which is compared to the cost of electricity from the centralized grid. The analysis does not include the additional value of heat from the cogeneration unit. The results of case study show that with reasonable investments and current costs, PV/battery/CHP systems already can provide lower energy prices to customers leaving the grid.

The feasibility of a hybrid power generation system using multiple energy sources to satisfy the electric demand of a residential community was explored in [5]. System performance was measured against capital investment, electricity costs (COE), CO2 emissions and net present cost. The study finds that the hybrid systems could replace total grid dependency.

In other publications on the subject was made system optimization based on the costs incurred.

In [6], the HOMER (Hybrid Optimization Model for Electric Renewable) software was used in combination with MATLAB / Simulink to perform a feasibility study of the proposed hybrid system with RES. In [7], the PV / Wind / battery hybrid system used in India was optimized using HOMER software. The price of energy produced was selected as the criterion for optimization. In [8], HOMER simulates the system based on an estimate of installation costs, replacement costs, operating and maintenance costs, fuel and interest.

The aim of the paper is to make a feasibility analysis of autonomous hybrid solar-wind energy system. It is verified if grid parity has been reached - the final cost of grid electricity, including transmission, distribution, charges and taxes, is in parity with the cost of energy produced by the hybrid solar-wind energy system.

2. Methods

A case study for a typical consumer of electricity for residential use in the village of Okop, Yambol District, Bulgaria is presented to demonstrate the methodology.

Studies and detailed assessments of wind and solar potential for the selected object have been carried out in advance. Based on the results obtained, 4 variants of system configurations were defined that meet the load requirements. One of them only includes photovoltaic panels, without wind generators. This variant was found to be optimal, but due to the limited roof area of the surveyed object and to avoid mounting solar panels on agricultural land, a configuration with 2 wind generators and 13 solar panels was chosen.

The feasibility of the investment was evaluated using the levelized cost of energy (LCOE) parameter. LCOE is a measure that allows comparison of different methods of electricity generation and different power sources. It is equal of the average total cost to build and operate a power-generating system over its lifetime divided by the total energy production of the system over its lifetime (1) [9].
\[ LCOE = \frac{I + O&M}{E} \]  

where  
I is the investment cost;  
O&M are the operational and maintenance costs;  
E is total energy production for the lifespan of the hybrid installation.

The life expectancy of the hybrid system is assumed to be 20 years. For this period, the total cost of the system is calculated, consisting of the cost of the investment and the costs of operation and maintenance.

For the same period, the average energy price for households is calculated. It is foreseen annual percentage increase in energy and transmission costs.

Since the hybrid system is autonomous and consumers use only a fraction of the energy produced, only the energy consumed is involved in the LCOE calculation. The calculated LCOE is compared to the final energy cost of the power grid.

3. Results

3.1. Defining energy prices for household’s during the lifetime of the solar-wind system

The object of research is located in the village of Okop, Yambol region, Bulgaria. The electricity provider for the region is Elektrorazpredelenie Yug EAD (EVN Bulgaria).

Household energy prices in Bulgaria are regulated by the Energy and Water Regulatory Commission EWRC. They consist of energy component, grid component and tax.

Energy prices for households in Bulgaria are defined in EWRC’s Decision C-19/1.07.2019 [10].

The energy price for Elektrorazpredelenie Yug EAD (EVN Bulgaria) is used as a base price and it is determined estimated cost for the next 20 years, which is the lifetime of the hybrid system. Accurate evaluation of the price of electricity from the grid is difficult to be made. Regulated prices consist of day and night tariff. The average daily household price is used as a basis. It is used that the night tariff is 8 hours and the daily - 16 hours. An annual price increase of 1.4% is foreseen over the 20-year period [2].

The price of the grid is also a regulated price. It includes the cost of transmission, distribution and access for the households. Advances in technology require continuous grid upgrades and major investments. For our study, linear 2.0% annual price increase for the first 10y period and linear 1.8% increase for the remaining 10y period was used [2, 11].

The results of the energy and grid price calculations for a 20-year period are shown in table 1. In Bulgaria, regulated prices are subject to 20% VAT. The average final energy price for households for the considered period with VAT is \( C_{av} = 0.115255 \) €/kWh.

3.2. Determination of the investment costs for the building of the hybrid solar-wind system and operating and maintenance costs

The defined as optimal standalone hybrid solar-wind system consists of two wind generators, thirteen solar panels, sixteen rechargeable batteries, one inverter and one controller. Parameters of the elements are shown in table 2.

The price of one photovoltaic panel of the selected type is 131,9 €. The total price, including costs for design, delivery, installation, constructions, cabling, etc. is 4002.4 €. The operation and maintenance costs O&M were accepted 5% of the investment for the whole period.

The cost of one wind generator of the selected type with installation is 1789.5 €. O&M were accepted 12% of the investment costs for the whole period.
Table 1. Final electricity prices for households for a period of 20 years.

| Year | Electricity price, €/kWh | Grid price, €/kWh | Total price, €/kWh | Total price with VAT, €/kWh |
|------|--------------------------|-------------------|-------------------|-----------------------------|
| 2020 | 0.055296 | 0.027113 | 0.082409 | 0.098891 |
| 2021 | 0.056070 | 0.027655 | 0.083725 | 0.100471 |
| 2022 | 0.056855 | 0.028208 | 0.085064 | 0.102076 |
| 2023 | 0.057651 | 0.028773 | 0.086424 | 0.103708 |
| 2024 | 0.058458 | 0.029348 | 0.087806 | 0.105367 |
| 2025 | 0.059277 | 0.029935 | 0.089212 | 0.107054 |
| 2026 | 0.060106 | 0.030534 | 0.090640 | 0.108768 |
| 2027 | 0.060948 | 0.031144 | 0.092092 | 0.110511 |
| 2028 | 0.061801 | 0.031767 | 0.093569 | 0.112282 |
| 2029 | 0.062666 | 0.032403 | 0.095069 | 0.114083 |
| 2030 | 0.063544 | 0.032986 | 0.096530 | 0.115836 |
| 2031 | 0.064433 | 0.033580 | 0.098013 | 0.117616 |
| 2032 | 0.065335 | 0.034184 | 0.099520 | 0.119423 |
| 2033 | 0.066250 | 0.034799 | 0.101050 | 0.121259 |
| 2034 | 0.067178 | 0.035426 | 0.102603 | 0.123124 |
| 2035 | 0.068118 | 0.036063 | 0.104182 | 0.125018 |
| 2036 | 0.069072 | 0.036713 | 0.105784 | 0.126941 |
| 2037 | 0.070039 | 0.037373 | 0.107412 | 0.128895 |
| 2038 | 0.071019 | 0.038046 | 0.109065 | 0.130879 |
| 2039 | 0.072014 | 0.038731 | 0.110745 | 0.132893 |

Table 2. Parameters of the elements of the system.

| Elements of the system     | Parameters       |
|----------------------------|------------------|
| Wind generators            | 2000 W           |
| Solar panels               | 500 W            |
| Rechargeable batteries     | 12V, 100Ah       |
| Inverter                   | 48V, 5000VA      |
| Controller                 | 48V, 440A        |

An inverter with 95% efficiency and 15 years maximum life is selected. Its cost is 1994 €. During the life of the system, one replacement will be required, so funds were planned for two inverters. The controller required for the system is with price 766.9 €.

The cost of one rechargeable battery of the selected type is 167.2 €. The maximum life of the rechargeable batteries is 10 years so one replacement was planned. The price of O&M was estimated to be 5.1 € per year for each battery.

3.3. Calculation of LCOE and comparison with the cost of energy from the power grid

Calculations were made using own funds for the investment and using consumer credit. A consumer loan for a 10-year period was selected. Interest is 5.6% and yearly percentage costs are 6.24%.

The results for the four possible system configurations are shown in table 3.
Table 3. Levelized cost of energy LCOE.

| Number WG and PV | Cost of energy consumed with credit (€/kWh) | Cost of energy consumed without credit (€/kWh) | Cost when using all the energy produced with credit (€/kWh) | Cost when using all the energy produced without credit (€/kWh) |
|------------------|---------------------------------------------|-----------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------|
| 1 WG 16 PV       | 0.240                                       | 0.092                                         | 0.123                                                     |                                                              |
| 2 WG 13 PV       | 0.257                                       | 0.110                                         | 0.149                                                     |                                                              |
| 3 WG 9 PV        | 0.273                                       | 0.145                                         | 0.195                                                     |                                                              |
| 19 PV            | 0.220                                       | 0.076                                         | 0.089                                                     |                                                              |

When the system is autonomous, only a part of the energy produced is used. For comparison, calculations were made for the cost of 1 kWh electricity if all the energy produced from the sources for a period of 20 years is used. The calculations take into account that the energy produced each year is different because the production of the solar panels decreases by 0.2% every year [2].

Comparison of the results obtained with the average energy cost over the 20-year period $C_{av} = 0.115255$ €/kWh shows that for the autonomous hybrid systems the stage of grid parity has not yet come. Despite the use of the buildings roofs and free parcels, the prices received are more than twice higher than grid energy prices. The use of such systems is economically justified only in the absence of the ability to connect to the grid.

4. Conclusions

The article assesses the feasibility of a small standalone hybrid PV/wind system for household consumption. The calculations were made for a residential building located in the village of Okop, Yambol District, Bulgaria. Variants with one, two and three wind generators and the corresponding number of solar panels and variant with photovoltaic only were evaluated.

The results show that the average cost of the energy produced by an autonomous hybrid electrical system over a 20-year period is more than twice as large the average cost of the energy from the grid. When using consumer credit for the investment, the difference becomes even greater. The reason for this is that in order to ensure autonomy in the months with worst conditions, the system contains a large number of sources and much of the energy produced remains unused. Autonomous hybrid systems are only feasible when there is no power supply from the grid.

For the investigated place, even when using all the energy produced, prices remain higher than those of the power grid. Only when building a photovoltaic power plant connected to the grid lower prices can be obtained.

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