Techno-economic evaluation of a grid-connected residential rooftop photovoltaic system with battery energy storage system: a Romanian case study

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***Abstract*— Solar energy is one of the most valuable renewable energy sources and, as the technologies advances, is expected to be an increasingly viable alternative to conventional energy sources. Battery energy storage systems represent a solution for solving the problem of solar resource intermittency and, at the same time, may decrease the electricity bill by supplementing the electricity self-consumption of residences. This paper is aiming to evaluate from a technical and economic point of view the viability of a grid-connected rooftop solar photovoltaic system combined with several battery energy storage systems for a residence in Romania. The results obtained indicated that mainly due to current costs of energy storage and photovoltaics, the installation of a battery energy storage system together with a photovoltaic system could be profitable only when upfront subsidies are granted.**

Keywords*— *Rooftop photovoltaic, Battery energy storage system, Feasibility analysis, Prosumer, Solar energy.

I. Introduction

Energy is considered one of the most important factors that plays a vital role in the sustainable economic growth and development [1]. The growing global energy needs are associated with population growth and economic development [2]. As global economies grow, the energy consumption is boosting, being mainly covered by conventional energy sources leading to gradual fossil fuels depletion and environmental pollution.

Energy security, alongside environmental concerns, is among the most significant threat to the sustainability of this century [3]. Among the most important problems the conventional power system is dealing nowadays are environmental pollution, the systematic diminishing of fossil fuels reserves and deficient energy efficiency [4-6]. Renewable energy sources are expected to gradually replace fossil energy sources for meeting the world's energy demand.

Although the solar energy has a massive potential to meet today's global energy demand [7], its contribution is still minor. Due to the intermittency of solar resource, the photovoltaic (PV) systems dispatchability is restricted, as opposed to combustion power plants [8].

Due to the increasing PV penetration level, technical problems may arise in power systems, predominantly linked with power quality [9]. The integration of battery energy storage system (BESS) with PV systems could prevent the technical issues.

The main advantages of an energy storage system like BESS refer to power quality enhancement [10], diminution of green power fluctuations [11], energy management and diminishing of peak demand [12], low self-discharge, high efficiency, very fast response time [13].

This study was carried out to assess the feasibility of three BESS with different capacities connected to a rooftop solar PV system for a residence in Romania, considering the released rebate scheme to promote the deployment of residential PV systems. To our knowledge, in no prior papers have been evaluated the viability of a BESS integrated with PV system in Romania after the proclaimed program that grants subsidies for solar prosumers.

The rest of this paper is organized in the following way: in the second section, the similar work presented in other papers is briefly highlighted. In the third section the methodology is described. The fourth section introduces the case study. The fifth section presents the results and the conclusions are revealed in the sixth section.

II. Related work

Because energy storage technologies cost is decreasing, there is a growing attention related to research dealing with the feasibility of integrating BESS and residential rooftop PV systems.

Reference [14] carried out a techno-economic evaluation of a grid-interactive PV battery-based system for a residential consumer located in South Africa. In [15], the economic viability regarding the integration of diverse BESSs in a grid-connected PV system has been investigated. The paper

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highlights that the solar PV installation and BESSs are not profitable for residences without supplementary subsidy.

In [16], the economic assessment of installing PV system together with BESS in households in Alberta, Canada was carried out. The results revealed that a PV installation with BESS is profitable in rural parts of Alberta. Reference [17] investigated the feasibility of an energy storage system in China and found that at the considered cost level the investment is not profitable.

III. Methodology

The residential PV system produce green electrical energy, that when is higher than the domestic energy consumption is leading to BESS charging until its capacity is reached and the surplus is exported to the network, usually during summer, while when is lower than the electricity demand leads to a deficit of electricity that is covered by BESS and the grid.

The PVSOL premium 2020 software was utilized for simulating the electricity generated by the PV installation taken into account in the examined case-study. A real load data was defined in the simulation software, followed by the PV system and BESS design. In the next step, shading simulations were carried out to obtain the electricity produced by the PV installation. The results were used to determine the profitability of the PV system with BESS.

The net present value (NPV) is the method that was chosen to assess the economic feasibility of the BESS with various capacities connected to a residential PV installation because is frequently used in the evaluation of investment projects. NPV determines the present value of all the cash flows from an investment project. NPV can be calculated as follows:

$$NPV = \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i} - CAPEX \quad (1)$$

where: *NPV* represents the Net Present Value; CF_i represents the cash flow from year i; r is the discount rate; *CAPEX* represents the capital expenditures; n is the investment lifetime.

The annual cashflows take into account the excess of electricity injected into the network, the savings accumulated on the electricity bill by installing BESS integrated with PV system and operation and maintenance costs.

If NPV is negative, then the investment should not be accepted and if NPV is positive, then the investment is favorable.

IV. Case Study Definition

In this study, we want to evaluate the feasibility of three BESS that are integrated in a residential rooftop PV installation of a dwelling, connected to grid, located in Cluj-Napoca, Romania: it is situated in the North-Western part of Romania, with latitude and longitude coordinates of 46.7712° N and 23.6236° E respectively.

In this paper, a real load profile from a residence was employed. The monthly electricity consumption data from the examined dwelling are presented in Fig. 1.

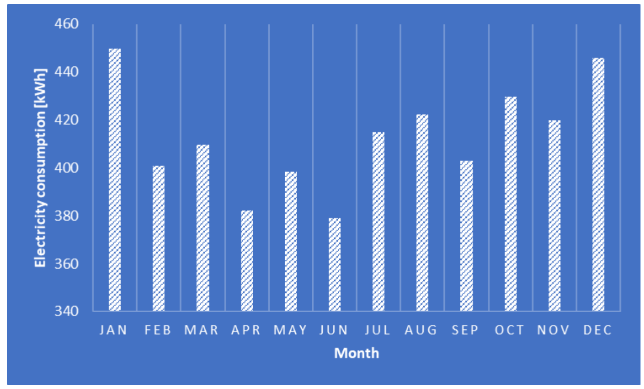

Fig. 1. The electricity consumption of the residence

A simplified layout of the grid-connected PV system with BESS is presented in Fig. 2. The electricity generated by the PV installation may be consumed in the residence, stored in BESS or fed into network.

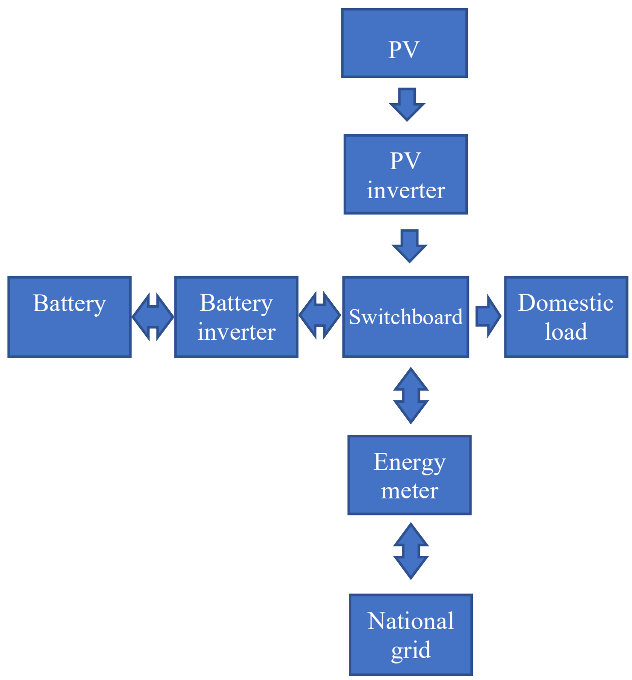

Fig. 2. Simplified layout of grid-connected PV-battery energy storage system [18-19]

The PV system examined in this paper was designed using PVSOL, to satisfy the residence annual electricity consumption of 4956 kWh. The PV installation consists of twenty polycrystalline modules with a capacity of 275 W each. In order to accomplish the planning of PV system, the adequate inverter was assigned for maximizing the production of electricity.

In this paper, the performance of the PV system was evaluated together with three different capacities batteries. In Table 1 are presented the main features of the investigated BESSs.

TABLE I. BESSS DESCRIPTION

Characteristics	BESS version		
	I	*II*	*III*
Total power [kW]	3.3	6.5	9.8
Usable energy [kWh]	2.9	5.9	8.8
Nominal capacity [Ah]	63	126	189
Nominal voltage [V]	51.8	51.8	51.8
Max. power [kW]	3	4.2	5
Efficiency [%]	95	95	95
Cycles	6000	6000	6000

All types of BESS are lithium-ion batteries with capacity ranging from 63 Ah to 189 Ah and the depth of discharge for each version is 95%.

The Romanian Parliament enacted Law no. 184/2018 that brought important changes, among the most significant being the "prosumer" term. The prosumer is the end-consumer owning a renewable energy system that can sell the energy in excess [20].

According to current legislation, the selling price of the electricity generated by the PV system owned by prosumer is determined based on average price on the Day-Ahead Market from previous year [21]. In 2020, for every kWh injected into the network, the prosumer receives around 0.0587 USD, while for the electricity purchased from the grid, the price is approximatively 0.1567 USD.

The Romanian Government, by Order no. 1287/2018 established a program for financing the installation of PV systems on residences. The prosumers can receive subsidies up to 90% of the total costs, but no more than approximatively 4680 USD [22].

The price of PV systems declined significantly in recent years. The installation cost for the proposed PV system is considered to be 1500 USD/W, summing a total of 8250 USD for the investment in the PV installation. The economic analysis takes into account an investment period of 25 years, a discount rate of 5 percent, while maintenance and operation costs equal 1 percent of the total investment [23].

The considered BESSs specific costs take into account the data collected from several suppliers. In this study, the costs for the BESS I, II and III are 3300 USD, 4900 USD and 6400 USD respectively. The price per kWh of usable energy rises as the BESS's usable energy reduces. Although the guaranteed minimum lifespan of the investigated BESSs is 10 years, a calendar lifetime of 20 years and 7000 full cycles was assumed in [24]. In this study, using a more cautious approach, 6000 equivalent full cycles and 13 years was assumed to be the calendar lifetime for BESSs. Thus, there is a need to substitute the BESSs after 13 years. The BESS cost is forecasted to decline at a rate of 5% annually to about 52% of the present price [25] when it needs to be replaced after 13 years of use.

V. RESULTS

The results present details regarding the investment opportunity in a solar power system together with one of the BESSs described in the precedent section. Fig. 3 shows the electricity generated by the PV system in the first year of operation.

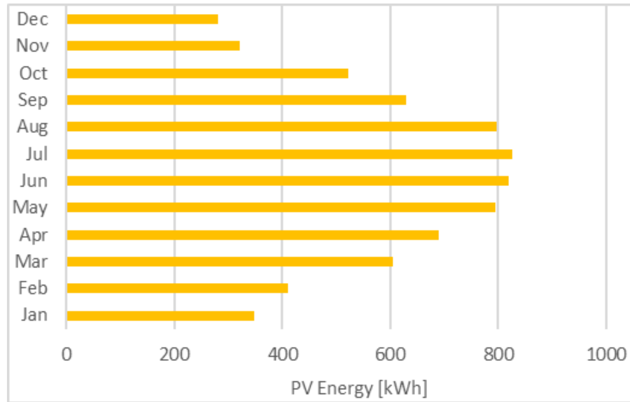

Fig. 3. PV electricity production

As can be noticed from Fig. 3, the electricity production is specific for the temperate continental climate with warm summers in which the PV system generates the largest amount of electric energy, as opposed to winter months when snow or frost covers the solar panels obstructing the PV process. Reference [26] reported that polycrystalline modules are among the most suitable for these climate conditions.

The monthly electric energy injected into the network by the PV installation together with the BESSs is presented in Fig. 4.

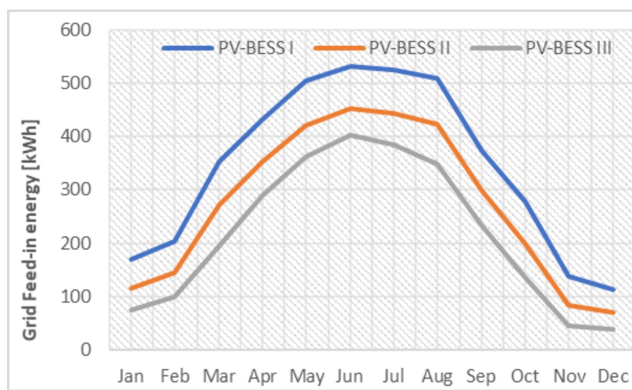

Fig. 4. Energy sold to the grid

Fig. 5 shows how the residential energy consumption is distributed (per month) when BESS I is integrated in the PV installation.

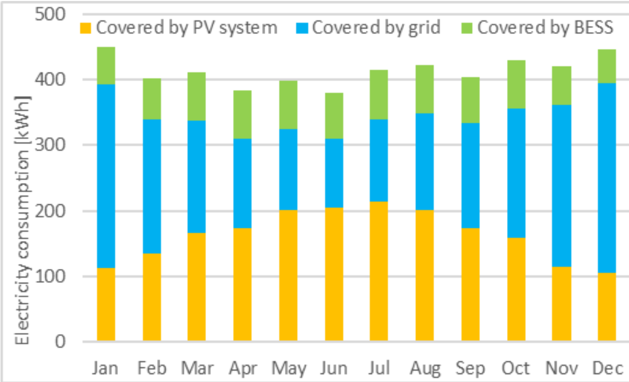

Fig. 5. Coverage of energy consumption for BESS I

The way in which electricity consumption is ensured when BESS II is integrated in the PV installation is presented in Fig. 6.

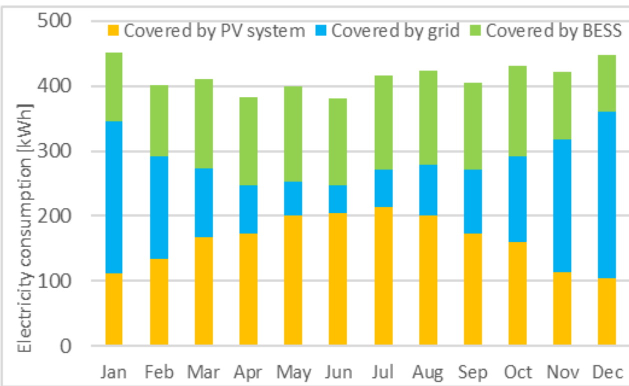

Fig. 6. Coverage of energy consumption for BESS II

Fig. 7 illustrates the coverage of electricity consumption when PV system is combined with BESS III.

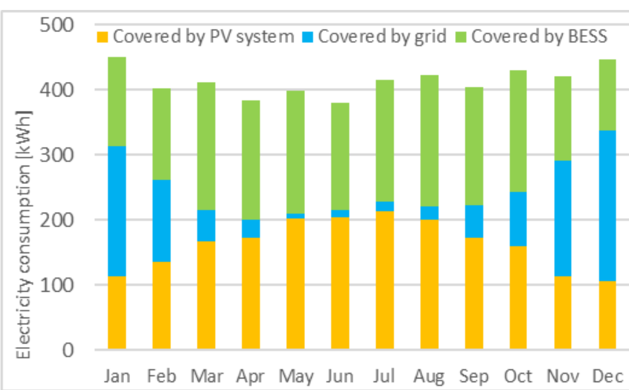

Fig. 7. Coverage of energy consumption for BESS III

It can be noticed that BESSs influence the manner in which total monthly energy consumption is covered. The higher their capacity is, the smaller the amount of energy purchased from the network.

The NPV for the PV system together with the BESSs is shown in Fig. 8.

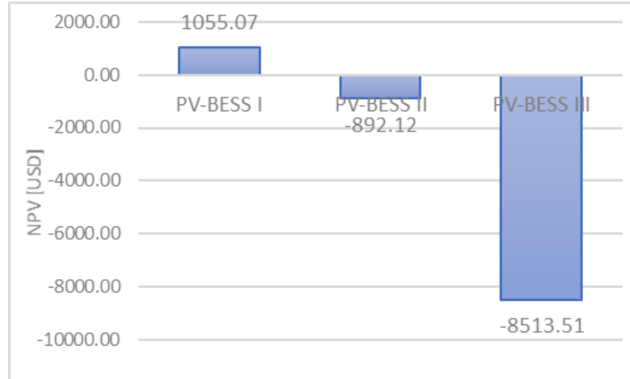

Fig. 8. NPV for PV system and BESSs

The results indicate that grid-connected residential PV system coupled to BESS II and BESS III are not economically feasible in the current Romanian context.

The only system configuration that is economically sustainable is that in which the PV installation is coupled with BESS I.

VI. Conclusions

This study presented a techno-economic assessment of a 5.5 kW grid-connected residential rooftop PV system coupled with three BESSs with usable energy ranging from 2.9 kWh to 8.8 kWh in the city of Cluj-Napoca, Romania.

In order to assess the feasibility of BESSs integrated with the solar system, simulations were carried out using PVSOL software. NPV was calculated to evaluate the profitability of the three system configurations.

BESS with a lower capacity have proven to be more profitable than those with a higher capacity. The results revealed that the PV system coupled with BESS having a nominal capacity of 63 Ah attained the best viability.

Although BESSs with usable energy of 5.9 kWh and 8.8 kWh are increasing the self-consumption of the household, especially during summer months, the present value of the costs is higher than the present value of the benefits. Therefore, the system configurations with these BESSs are not economically viable.

The results obtained in this paper lead to the conclusion that the system configurations using a high capacity BESS at residential scale are not economically feasible for the time being, mainly due to the high costs and relatively short BESS's lifespan.

Even though the PV and BESS technology has evolved significantly during recent years, the investment in PV installations coupled with BESSs without financial support is not profitable, at least under the specific conditions of the analyzed city. The techno-economic assessment carried out in this paper is not considering the electricity price evolution and the electric power quality functionalities evaluation. This will be investigated in future works.

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