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Economic Analysis of a Building Integrated Photovoltaic System Without and With Energy Storage

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Abstract. A grid-connected solar photovoltaic (PV) system with energy storage can help in overcoming the intermittency as well as in reducing the peak demand on the network. It also benefits in electricity bills savings. In this context, it is significant to examine the appropriate use of local energy storage (i.e. battery) connected with PV for reducing the energy supply from the grid, and also its contribution in peak demand reduction with more emphasis on reduction in annual consumer electricity bill. In this paper, a techno-economic analysis of Building Integrated Photovoltaic (BIPV) system with energy storage has been presented. A typical South Norwegian house, installed with PV, has been considered for identifying annual electricity bill savings as well as economic indicators by deploying appropriate battery capacity. It has been observed that BIPV with energy storage can be beneficial to the consumer both economically and technically, providing incentives for both consumers and investors. The time-wise limits on electricity consumption from the grid supply can also help to make the BIPV house with energy storage more economically attractive as well as near zero energy building.

Keywords – Building Integrated Photovoltaic System, Energy Storage, Energy Economics

1. Introduction

It is recommended by the European Commission that all the new buildings should have near zero-emission by 2020, and it has also been incorporated by the Norwegian system. The economical design for electricity generation using hybrid energy source PV-Biomass for an agricultural farm, and a residential community has been reported in ref [1], but it has not considered the connection of energy community with grid and adequate details on energy economics. There are many studies [2, 3] on the off-grid hybrid energy system based on solar PV, but most of them have not considered the impact of grid extension as well as potential grid tariffs in the techno-economic analysis. In most of the countries, the building integrated photovoltaic (BIPV) system has been considered, and its penetration is increasing exponentially. BIPV with energy storage can be a more appropriate option for making the buildings near to zero emission, as well as net-zero energy building from the electrical energy point of view. Also, BIPV with energy storage can contribute to demand-side management as well as with appropriate power conditioning devices can operate as a dispatchable generator within the distributed network [4]. The grid interaction performance of the BIPV system for a typical zero energy building has been reported in ref [5], but it has not considered the integration of energy storage. The reported results in [5] have been used to estimate battery energy storage capacity considering the savings in the annual electricity bill [6]. In [5, 6], the operational, economic analysis of the BIPV house with energy storage using electricity tariff has not been sufficiently addressed. In a study [7], the ratio of the installed PV peak power to the useable capacity of the battery has been used for the analysis of self-consumption, self-reliance and economic efficiency of the system. In most of the studies [2-6], the BIPV production with load profiles have not been adequality explained with techno-economic benefits to the consumer.

The appropriate energy storage (i.e. lead-acid battery) sizing for a BIPV has been proposed in the ref [6] based on electricity bill minimization using flat-rate electricity tariff. The feasibility of replacing conventional energy storage technologies with hydrogen technologies is examined for Japan [8]. Ref. [9] has examined the effect of PV- battery penetration on the cost of energy and also on the operational hours of other distributed generators but has not significantly addressed the economic benefits to the consumer. Ref [10] has studied battery capacity estimation for BIPV under different geographical conditions for the lead-acid battery using flat-rate electricity tariff. Energy storage can enhance the profitability of the grid-connected BIPV system as well as can effectively contribute to demand-side management and for improving the local energy supply for making it self-sustainable and reliable as near zero energy building. To initiate the widespread use of energy storage integrated with a PV system, various government driven support schemes have been promoted. Most of the mentioned references [1-10] have not sufficiently addressed the techno-economic analysis of the BIPV system with energy storage considering real operational PV production and the load with appropriate electricity pricing. The levelized energy cost of the PV system and the discounted payback period of PV system with market penetration are explained in ref [11] and [12] respectively.

In this work, techno-economic analysis of BIPV system with energy storage has been studied for identifying annual electricity bill savings considering electricity energy pricing. The key objective of this work is to consider the real hourly PV output with corresponding load profile and battery energy throughput for analysing the annual electricity bill of the consumer based on market electricity tariff. An operational, economic assessment of BIPV system without and with battery energy storage is going to be analysed and will be useful for not only on certain policy implications but also to highlight the appropriate incentives for investing in the energy storage.

Apart from the introduction Section 1, Section 2 of the paper presents the operational results of a typical South Norwegian House with BIPV. Section 3 compares both the technical and economic benefits of integrating the battery of energy storage, and Section 4 concludes the study by providing some recommendations and further work.

2. BIPV System Description and Operational Results

In this work, a typical South Norwegian house with BIPV is considered with an area of 154 m^2 [5]. The usable area of the roof is 57.43 $m^{2,}$ and it is facing South-West. It is considered that the installed crystalline silicon PV panels (manufactured by Sunpower SPR 230NE-BLK-I) are covering area 39.9 m^2 of the roof. A considered typical BIPV system has a capacity of 7.4 kWp with fixed roof mount with the tilt angle of 32^0 and Azimuth 48^0 [5]. The electricity production and consumption have provided significant information to assess the energy profile of a typical South Norwegian house, built on zero energy building concept [5, 6].

2.1 PV Power Production and Load Profile

The annual PV generation and load profile of a typical South Norwegian House for the year 2016 are reported in Figs.1 and two respectively. The annual grid supply concerning the load and PV production in a particular time is reported in Fig. 3. The Figs. 1 to 3 is based on the results reported in ref [5, 6].

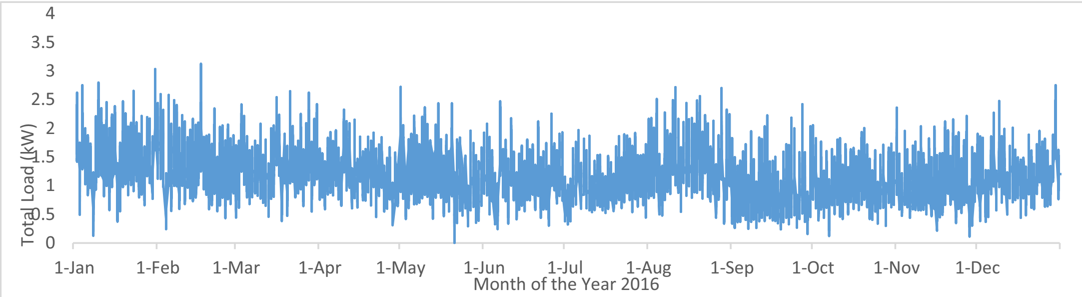

Figure 1: Annual PV production at a typical Southern Norway house

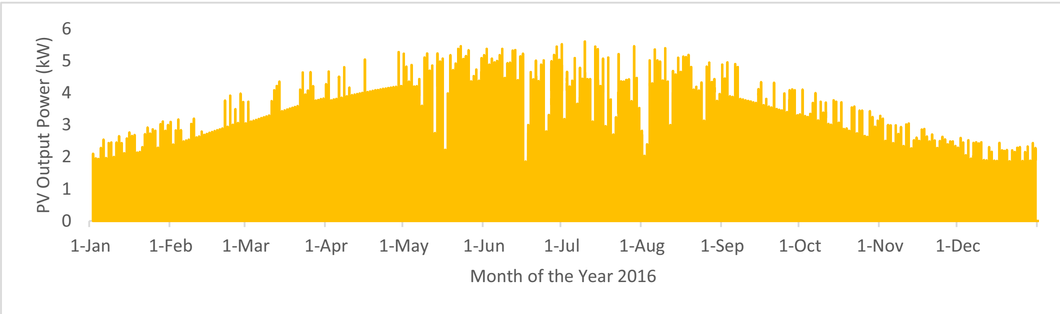

Figure 2: Annual load profile of a typical Southern Norway house

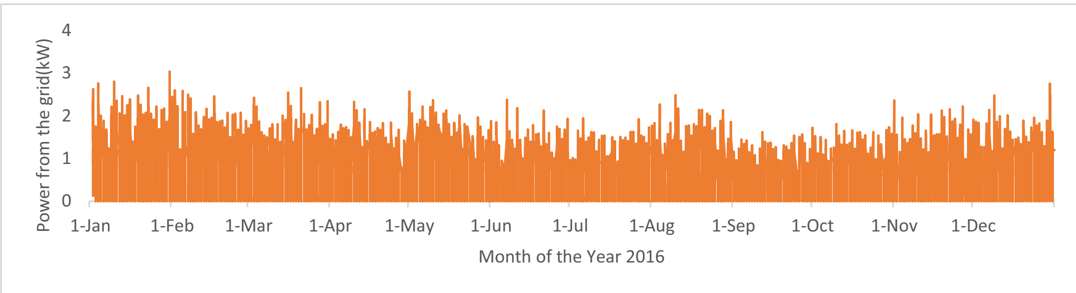

Figure 3: Annual Grid Supply to a typical Southern Norway house without energy storage

In terms of the electrical energy performance of a typical Southern Norway house, it is found that the capacity factor is 39.4%, and such BIPV system can generate out the energy of approximately 6400 kWh/yr. In the presented analysis, it is assumed that the PV system cost has been included in the housing price, and the consumer has not to pay any additional costs other than the regular mortgage of the house. Therefore, in the economic analysis, the capital cost of the BIPV system is not considered. In this work, the different purchase and sale price of electrical energy in different months of the year are considered and shown in Fig. 4. The grid purchasing price is based on ref [13], and the selling price is assumed lower than the buying price.

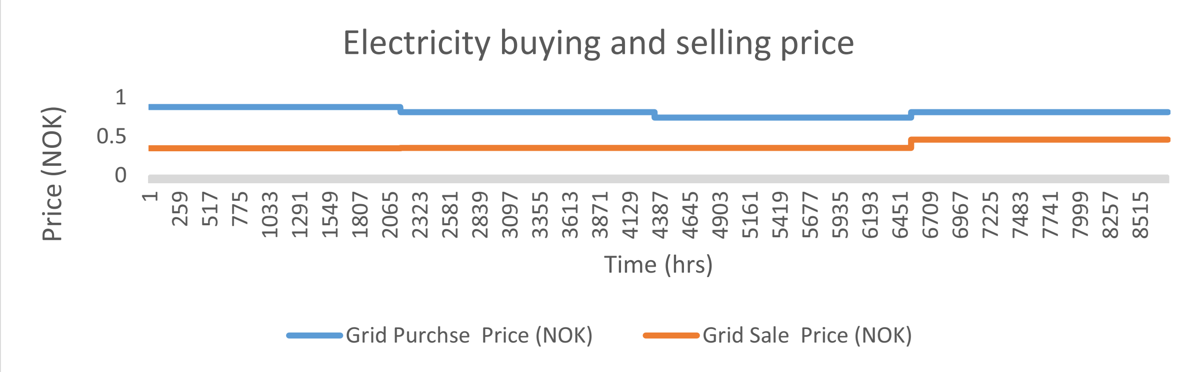

Figure 4: Grid purchase and sale price of electrical energy in the different months of a year

Through analysis, it is found that the primary load is 10308 kWh/year, with the PV production of 9860 kWh/year, and the grid electricity purchases are 6044 kWh/year, which is approximately 38%. The excess electricity of 3135 kWh/year is generated. Based on the assumptions and considered sale/purchase of electrical energy price and with consideration of remaining technical lifetime of the ten years, the net present value of BIPV system is estimated as NOK 49418, the calculated Levelized cost of energy is NOK 0.479 and the discounted payback period is 7.24 year. The levelized energy cost calculation is based on the ref [11] and the discounted payback period calculation is based on ref [12]. To reduce grid dependency and provide greater economic benefits, energy storage should be integrated with a PV system to evaluate greater economic feasibility and explore the viability of reducing grid dependency.

2.2 BIPV System with Energy Storage

The overall intermittency of the load, and also the PV production can be overcome through energy storage with BIPV system. Energy storage can also assist in demand-side management and help in strengthening the system stability. The work attempts to explore the various benefits for both economic and technical, which can be gained by integrating appropriate energy storage with BIPV. In this work, a battery energy storage (lead-acid type) of 21 kWh is considered, based on the previous work [6]. In this work, the BIPV system with lead-acid battery storage is analysed for the annual electricity bills saving, and the grid contributions are also examined. In this scenario, the annual electricity bill of the customer is reduced to 1175 NOK after integrating 21 kWh battery storage. The annual grid supply to the BIPV house with energy storage is given in Figure 5.

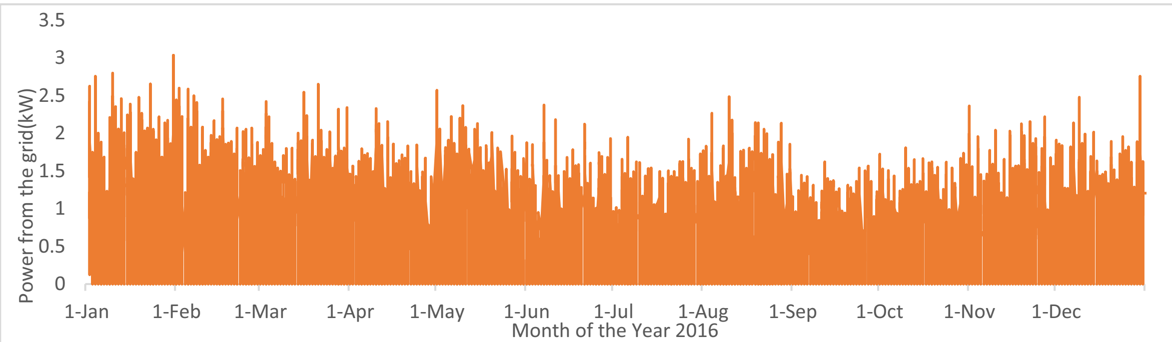

Figure 5: Annual grid supply of BIPV house with energy storage

It is evident from both Figure 3 and Figure 5, the peak load patterns (from the grid supply point of view) of the typical South Norwegian house are almost similar with and without battery energy storage. In this case, the grid purchase is 4764 kWh/year, and the battery energy throughput is 3063 kWh. The battery operating conditions have been considered with state-of-charge (SoC) from 100%

to depth-of-discharge (DoD) of 60%. The lifetime energy throughput of 1 kWh battery has been taken 840 kWh with roundtrip efficiency of 80%.

Based on the assumptions and considered sale/purchase of electrical energy price and with consideration of remaining technical lifetime of the ten years, the net present value of BIPV system with battery energy storage is estimated as NOK 38491, the calculated Levelized cost of energy is NOK 0.439 and the discounted payback period is 2.58 year. These economic indicators (Table 1) are calculated using references [11, 12].

3. Comparative Economic Evaluation of BIPV System

There are various economic indicators that can be adopted for carrying out an economic assessment of the BIPV system and battery energy storage performance [14]. In this section, the BIPV system without and with battery energy storage is evaluated economically by using certain economic assumptions. It is assumed that the BIPV system with and without energy storage has been already installed and their associated capital/installation costs are included in the mortgage of the building and not considered while computing the energy economic calculations from the consumer point of view. The considered electrical energy buying and selling prices are described in the previous section. The considered discount rate is 5.5%, and the inflation rate is 1.9% with the remaining project lifetime of 10 years. The relative comparisons of the economic indicators in both cases are given in Table 1.

Table 1. A comparison of economic indicators

Economic indicators	BIPV without energy storage	BIPV with energy storage
Net Present Cost	49418 NOK	38491 NOK
LCOE (per kWh)	0.479 NOK	0.439 NOK
Discounted payback (year)	7.24	2.69
Simple payback (year)	6.29	2.52

The annualized and operational costs (in NOK) of the BIPV system with and without energy storage are given in Fig.6.

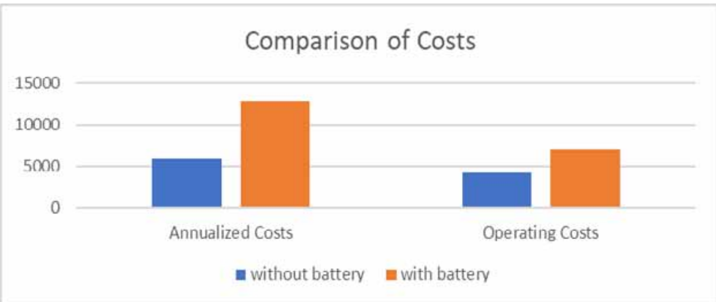

Figure 6: Comparison of capital and operating cost (in NOK) without and with energy storage

Levelized energy costs, discounted payback period etc. are good indicators of profitability of the BIPV system with energy storage, but more sensitivity analysis with economic parameters is needed concerning the battery replacements as well as operational cost analysis over the lifetime of the system. The discounted payback period is also 4.55 year less in case of BIPV system with energy storage, but more analysis is needed concerning the battery replacements as well as operational cost analysis over the lifetime of the system.

4. Conclusion

The BIPV with energy storage can play an important role not only for making a building near to net zero energy but also in demand side management considering the grid constraints as well as market electricity tariffs. In this work, a typical South Norwegian house with BIPV system is considered for potential application of energy storage. It has been observed that the BIPV system with energy storage can perform economically much better compared to its counterpart.

It is observed that a typical South Norwegian house with BIPV system with typical load profile and with considered battery capacity [6] can reduce the grid supply to 4764 kWh per year. The economic performance of BIPV with energy storage system mainly depends on the assumptions associated with PV and battery costs. In this work, it has been assumed that in both cases that the capital costs associated with PV and battery have been included in the building mortgage. Based on these assumptions, it is observed that the BIPV system with energy storage can perform economically much better compare to BIPV only system. Policies fostering investments in energy storage integrated BIPV system should be encouraged as the presented study highlights investments in BIPV system are not only beneficial for the household but also profitable for investors owing to the lower discounted payback period.

The annual electricity pricing mechanisms may change due to the load patterns as well as variation in generation scenario and also due to the introduction in the power pricing. Therefore, it is important to analyse the economic performance of the BIPV system through grid constraints and limits on-grid electrical energy purchase by the house. In further work, seasonal grid purchase limits with network constraints will be considered for doing the economic performance analysis of BIPV system with and without energy storage.

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