Experimental Evaluation of a Building Integrated Photovoltaic System for Peak Load Reduction Potential

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Abstract— **In this paper, the effect of the Building Integrated Photovoltaic (BIPV) system on the building energy demand from the grid is investigated. The main load of the building is due to the Heating, Ventilation and Air-Conditioning (HVAC) equipment, and its load is highly correlated with the ambient temperature. Similarly, the BIPV system output is also dependent on the ambient conditions, and increases with higher solar irradiation but tends to reduce as temperatures decrease when all other factors are constant. BIPV systems, thus, have the potential to help building owners and operators, both from energy production and load reduction/shifting aspects. In this paper, we utilize a 12-month operational data from the BIPV system at Yasar University, and assess its performance from energy generation and demand reduction perspectives.**

Keywords: **Building Integrated Photovoltaics, Power Grid, HVAC, Load Reduction, Energy Efficiency, Demand Response**

I. INTRODUCTION

According to the International Energy Agency [1], buildings are responsible for about 40% of the global energy consumption, and about 50% of the energy used in a building is accounted for by the heating, ventilation and air conditioning (HVAC) system. Thus, improving operational efficiency of HVAC systems will results in large savings in the energy consumption. Moreover, buildings present a unique opportunity as flexible loads that can be controlled to provide ancillary services to the electric power grid, and thus enable high penetration of renewables. The high thermal capacity of large commercial buildings allows real-time control of their HVAC systems to regulate electricity demand as required for grid stability, without effecting the quality of service in the building significantly.

Recent advancements in communication and control capabilities of the power grid enabled demand side to provide high-quality ancillary services at various time scales [2]. Several approaches [3-5] for managing flexible loads depend on priority based scheduling of loads modeled as a stochastic battery. Both Europe [6] and the US [7] are putting significant effort for large scale adaptation of building flexible loads as reliable contributors in the ancillary services market.

The European Directive on the energy performance of buildings (EPBD) encourages the European Union member states to approve energy policies that promote the implementation of very low and even close to zero energy buildings [8, 9]. Solar energy seems to be one of the environmentally compatible sources of renewable energy. Integrating photovoltaic (PV) solar components into building façade represents a significant step forward. Photovoltaic (PV) solar collectors represent not only a renewable source of electricity, but also a source of collected heat for building heating and cooling by natural or forced convection.

In this context, Building-Integrated PV (BIPV) is proving to be the most rapidly emerging technology within the solar industry globally and its capacity growth is estimated to be about 50% or more from 2011 to 2017 [10, 11]. BIPV systems are multi-functional building elements that combine electricity generation with other functions of the building envelope. They are considered to be a promising strategy to help in achieving the ambitious goals set by the European energy policies, as for the nearly-zero energy buildings (nZEB) foreseen in the energy performance of buildings directive (EPBD) [12].

The effect of the BIPV system on the building energy demand from the grid is investigated. The main load of the building is the HVAC equipment, and its load is highly correlated with the ambient temperature. Similarly, the BIPV system output is also dependent on the ambient conditions, and increases with higher solar irradiation but tends to reduce as temperatures decrease when all other factors are constant. During peak load hours, the utilities typically charge a different tariff to their customers, and this can have significant impact on the building electric bill. BIPV systems, thus, have the potential to help building owners and operators, both from energy production and load reduction/shifting aspects. In this paper, we utilize a 12-month operational data from the BIPV system at Yasar University, and assess its performance from energy generation and demand reduction perspectives.

II. SYSTEM DESCRIPTION

The demo building Y is a 6-floor multi-use building (classrooms, offices and labs) with 8100 m^2 net internal area. The building is served by 11 AHUs (35kW-45kW) and 1 chiller, and has peak cooling load of 420kW and peak heating load of 872kW (natural gas). See Figure 1 for the heating/cooling system diagram. The BIPV system installed at Yasar University, Izmir, Turkey has a total peak power of 7.44 kW and consists of a total of 48 Crystalline Silicon (c-Si) modules in 4 rows and 12 columns, with a gap of 150 mm between the modules and the wall, as illustrated in Fig. 1 and Fig. 2. Each PV module has 12.9% module efficiency with 18.54% cell efficiency (i.e. 30% transparency). There are shading effects that were considered, as the southeast façade lies on the lower part of the building. The façade area is totally 57.6 m^2 with a cell area of 42.8 m^2 while the total peak installed power is 7.44 kW with a peak power per PV unit of 155 Wp. AC output power is connected to the existing building UPS equipment. The energy performance of the BIPV system is monitored online through a SMA Cluster Controller device and SMA Sunny Portal website.

The electricity generation by the experimental BIPV system is monitored for a 12-month period. Fig. 3 summarizes the monthly production in kWh. We then use the observations and the results from this experimental system and model a larger BIPV system covering the entire southeast facing façade of the building. We assume that the existing windows are replaced by 30% transparent photovoltaic glass and the walls are covered with opaque PV panels for increased capacity. The resulting system covers a total of 936 m2 with a peak capacity of 114 kWp. We then modeled this system in PVSOL and PVGIS, and calculated the monthly electricity generation as presented in Figure 4. Estimated losses due to temperature and low irradiance are taken as 9.3% (using local ambient temperature), estimated loss due to angular reflectance effects are 4.6%, other losses (cables, inverter etc.) are 14.0%, finally combined PV system losses: 25.6%. The average PV surface and ambient air temperatures as well as the solar irradiation are presented in Figs. 5 and Fig. 6, whereas montly average experimental cell efficiency values are shown in Fig. 7.

Figure 1. Building Y, with southeast façade with pointed arrows

Figure 2. Experimental BIPV system installed on the southeast facade of building Y

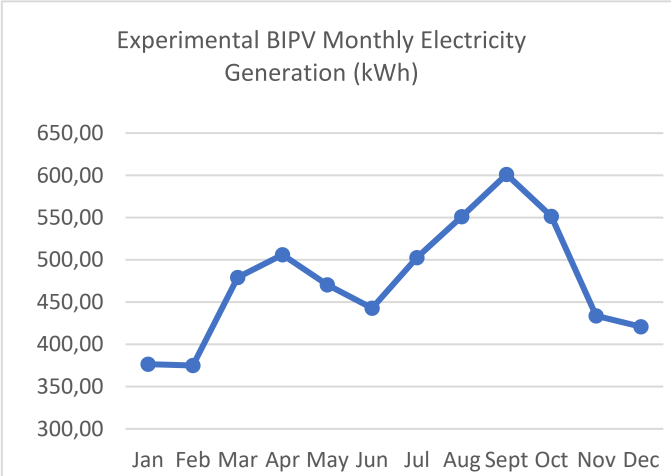

Figure 3. Experimental BIPV Monthly Electricity Generation (kWh)

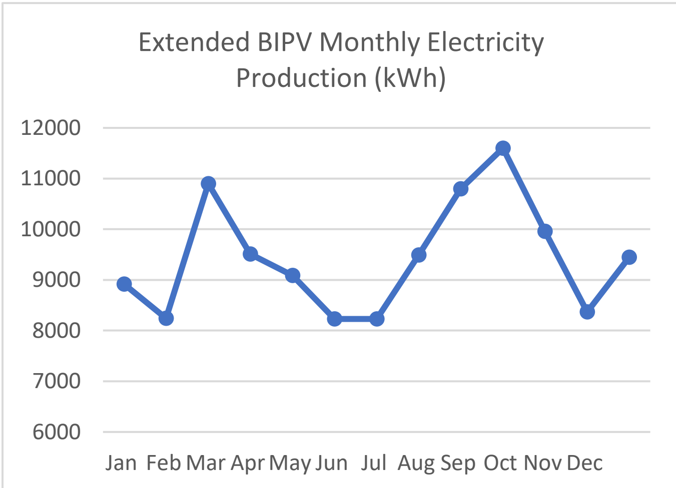

Figure 4. Extended BIPV Monthly Electricity Production (kWh)

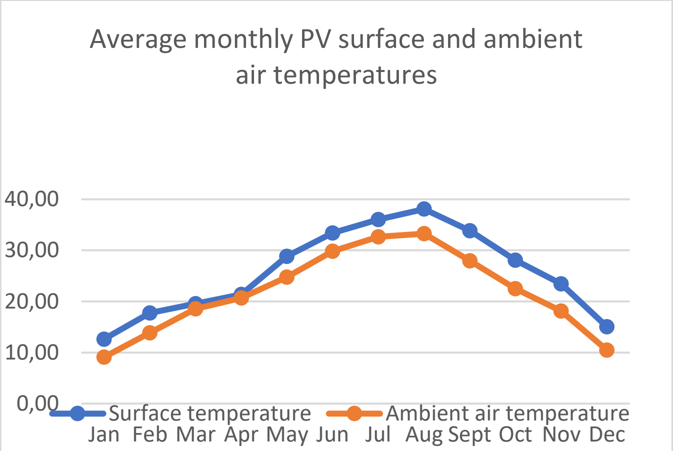

Figure 5. Average monthly PV surface and ambient air temperatures

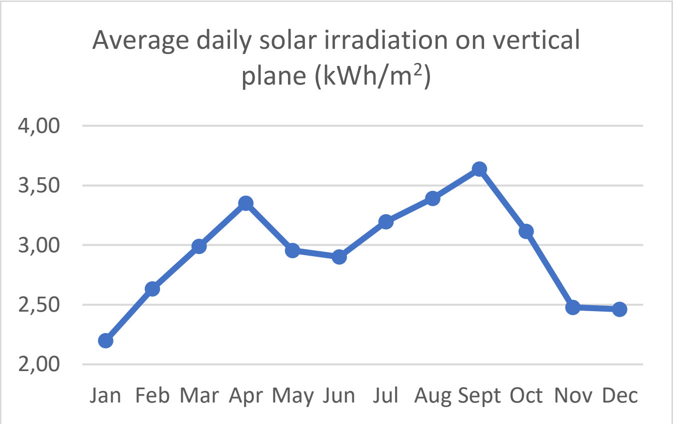

Figure 6. Average daily solar irradiation on vertical plane (kWh)

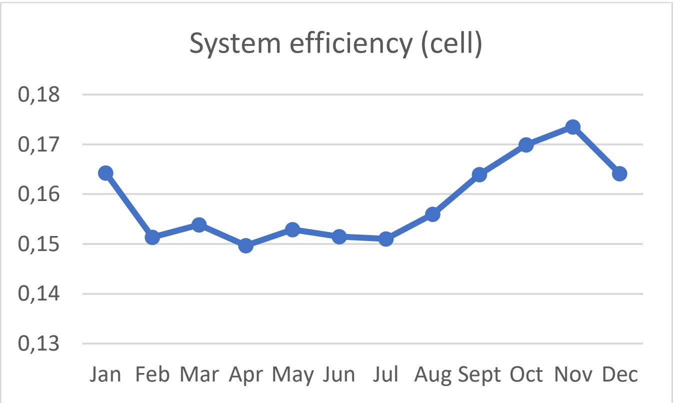

Figure 7. Monthly system (cell) efficiency - experimental

We next obtained the chiller and fan demand from the facility services department. The monthly chiller and fan electricity consumption is given in Fig. 8. As expected, peak chiller load is attained in summer months, with the maximum of 92000 kWh/month in August, and is highly correlated woth the ambient temperature shown in Fig. 5

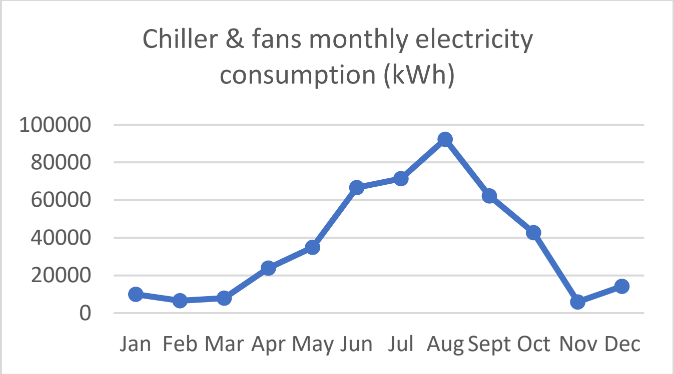

Figure 8. Chiller monthly electricity consumption (kWh)

III. RESULTS AND DISCUSSION

When the chiller and fan load is compared with the BIPV generation, we can see in Fig. 9 that the BIPV system can serve roughly 10% of the chiller demand in summer (when highest absolute load is demanded).

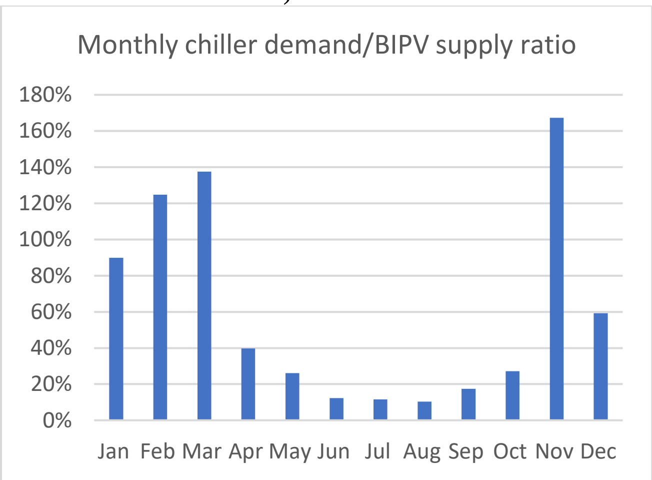

Figure 9. Monthly chiller demand/BIPV supply ratio

The current electricity price paid by the university is 13 ¢/kWh. In addition, there is an up to 30 ¢/kW incentive for participating in the demand response program by using the building HVAC equipment as a flexible load. Therefore, the BIPV system contributes not only by reduced electricity purchase from the grid, but also enables the building HVAC chiller to be flexible with more than 10% load reduction. This capability would bring additional income to the facilities management by reducing chiller load at utility peak times.

Fig. 10 shows the expected monthly reduction in the utility bill due to both reduced energy purchase and participation in the demand response without negatively impacting thermal comfort in the building. HVAC electricity bill of the building is reduced roughly 1000 USD (10%) in summer by deferred power purchase from the utility thanks to the BIPV energy generation. The additional 2500-3000 USD (~25%) reduction is obtained by using the HVAC load as a flexible source (demand response) in the ancillary services market.

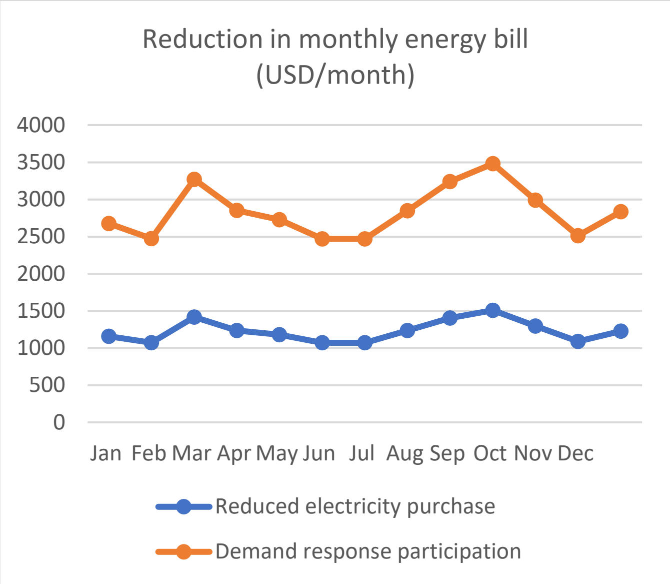

Figure 10. Reduction in monthly energy bill

IV. CONCLUDING REMARKS

In this study, we considered a BIPV system installed at Yasar University, Izmir, Turkey. We used experimental data to extend the existing BIPV system to the entire southeast façade of the building, and then evaluated the performance of this system using PVSOL and PVGIS. The generated electricity is used to serve the building chiller and fans, and provides load flexibility when the building participates in a demand response program.

Some concluding remarks we have drawn from the results of the present study may be summarized as follows:

a) The BIPV system can satisfy more than 10% of the building HVAC (chiller + fans) load in summer

b) The BIPV system provides load flexibility, and thus enables the building's participation in a demand response program.

c) The building can reduce its HVAC electricity bill by 10% in summer, thanks to the BIPV energy generation only. Another 25% reduction can be achieved by reducing HVAC load in utility peak times as an ancillary service with high incentives.

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