Optimization of on-grid PV/battery system

Badralddin Nasher (19012916), *YTU*, Muaz Elbadri (18012149) *YTU*

Abstract— Today, the transition to renewable energy is almost inevitable with many countries across world regulating laws and giving incentives to speed up the process to avoid climate change and reduce greenhouse gas (GHG) emissions. Solar energy is among the most used widely used methods due to the large amount of excess sunlight that is available in many regions of the earth. Photovoltaic system is the most common solar technology and it requires optimization in various dimensions. This study presents the analysis and results of the performance and optimization of a decentralized grid connected PV and battery power system for a household during a whole day.

Keywords**:**
Solar energy
Optimization
Photovoltaic system
On-grid photovoltaic system

I. INTRODUCTION

Over the years, the main source of energy has been non-renewable energy resources such as fossil fuels and with the increase of demand on energy, governments had to take actions to encourage the use of renewable energy systems (RES). Wind, solar, water, etc., are all sources of renewable energy with solar energy being very important due to the large quantities of solar energy available. Photovoltaic (PV) systems use the solar energy to produce electricity have become an alternative solution implemented worldwide.[1]

With the increasing spread and use of photovoltaic systems, their cost has declined and allowed the development of more efficient PV. Although the cost of installing the photovoltaic system is high, it is a good investment in the long run, as it reduces the consumption of non-renewable resources. [2].

Grid connected (GCPV) and standalone systems (SAPV) are two types of PV power systems. Grid connected photovoltaic systems utilize the electricity grid network and the generated power can be sold to the utility while the standalone photovoltaic systems are off-grid not connected to the grid therefore the generated power is not sold to the utility.[3]

A very important problem regarding renewable energy is the storage of generated power, using a battery might solve the problem. There are some cases were using a battery alone might be inefficient and this is where a widely preferable energy generation systems the on-grid or grid connected can be used. On-grid photovoltaic system is used in various countries to supply grid power through energy obtained from PV. [4]

There are two types of on-grid PV systems; building integrated PV systems (BiPV) and distribution generation PV (DGPV) systems. BiPV systems feed a defined load while the excess energy generated goes to the grid. On the other hand, DGPV systems deliver all the produced energy to the grid without supplying any load. The grid connected system might consist of only PV arrays or might contain another energy sources such as wind turbine, diesel system or storage units. [5]

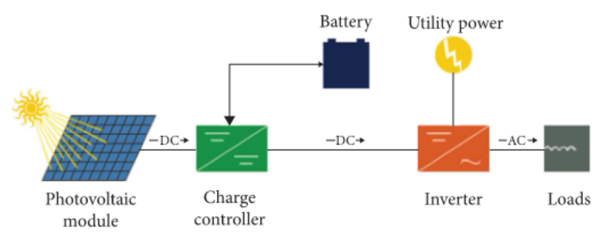

Figure (1) : Schematic of the On-grid power system [6]

This study will cover the optimization of a PV and battery system of a household that is connected to the grid to reduce the daily cost of electricity consumption by using linear programming (LP) in Python programming language.

Nomenclature

Abbreviations

RES	Renewable energy systems
PV	Photovoltaic
GCPV	Grid connected Photovoltaic system
SAPV	Standalone Photovoltaic system
BiPV	Building integrated Photovoltaic system
DGPV	Distribution generation Photovoltaic system
LP	Linear Programming

Sets

t	set of time

Parameters

ΔT	Time granularity
$\lambda_{1,t}$	Price of buying electricity in period t
λ_2	Price of selling electricity
DE	Battery discharge efficiency
CE	Battery charge efficiency
$SOE_{bat,max}$	Maximum state of energy of battery

$SOE_{bat,min}$	Minimum state of energy of battery
$P_{load,t}$	Load of the house
P_{pv}	Sum of PV generation

Variables

$P_{grid,t}$	Power used from grid
SOE	State of energy in battery
C	Total cost
P_{dis}	Battery discharge power
P_{ch}	Battery charge power
P_{pvsell}	Amount of Power sold to the gird
$P_{pv\text{-}load}$	Power generated from PV supplies load
U	Binary variable

II. METHODOLOGY

A household has a daily load 13.25 kWh shown in fig 2, and it costs more than 7.15 $ a day (due to the 3-period price). Therefore, the objective of this paper is to reduce the daily cost of the electricity consumption, the decision is to install 3-kW solar system to the household and keep it connected to the grid. And for more economical solution storage system will be used (3 Batteries 12 V 150 Ah).

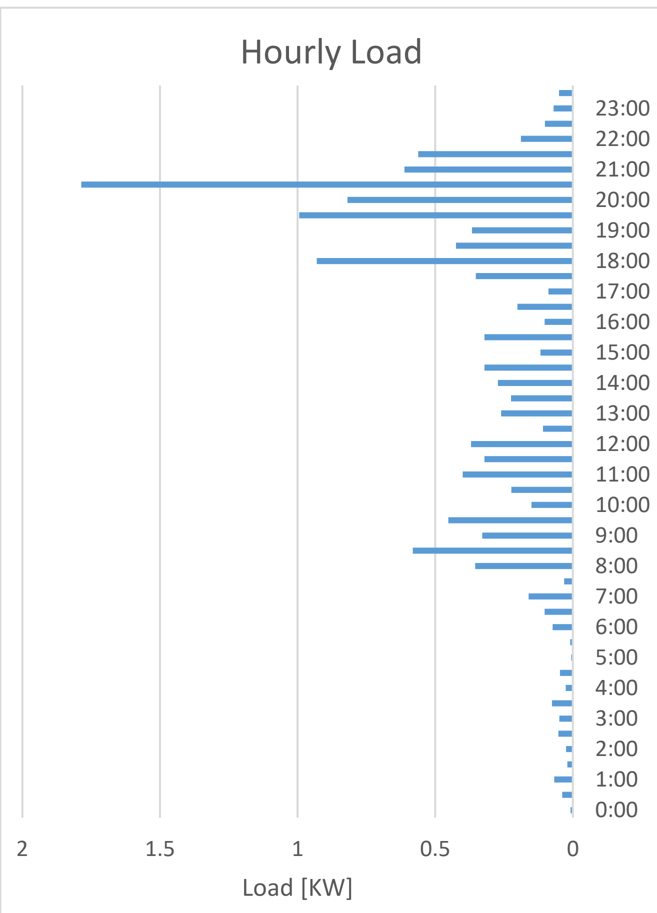

Figure (2): Hourly load of the household

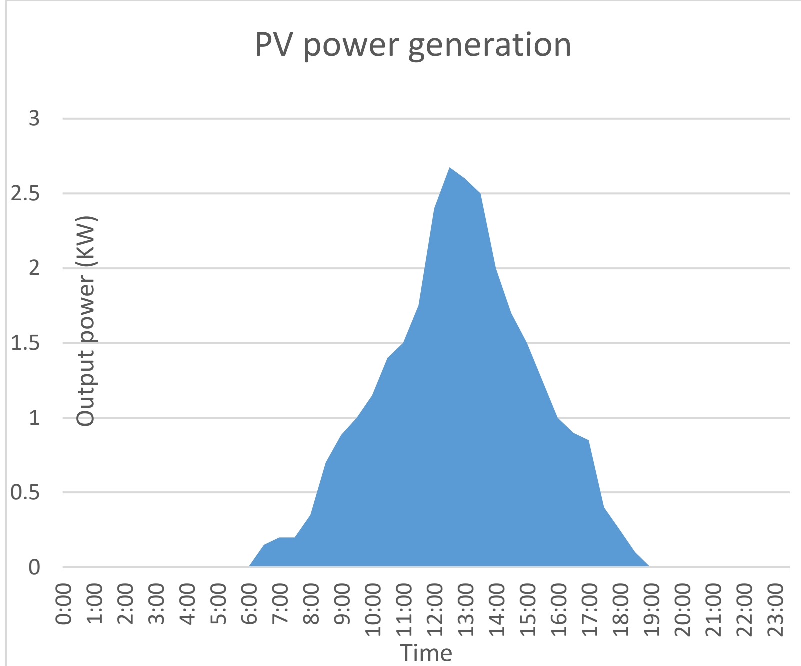

Figure (3): PV generated power in a day

The 3-kW solar system is assumed to produce the maximum power in 4 hours daily and the hourly generation of PV system is shown figure 3.

III. MATHEMATICAL MODEL OPTIMIZATION

Objective function

Minimize

$$C = \sum_t (\lambda_{1,t} * P_{grid,t} - \lambda_2 * P_{pvsell,t})\, \Delta T \quad (1)$$

$$P_{load,t} = P_{grid,t} + P_{pv\rightarrow Load,t} + P_{dis,t}\,, \forall t \quad (2)$$

$$P_{pv,t} = P_{pvsell,t} + P_{pv\rightarrow load,t} + P_{ch,t}\,, \forall t \quad (3)$$

$$P_{grid,t} \le N * U_{1,t}\,, \forall t \quad (4)$$

$$P_{pvsell,t} \le N * (1 - U_{1,t}), \forall t \quad (5)$$

$$SOE_{bat,t} = SOE_{bat,t-1} + P_{ch,t} * \Delta T * CE - \frac{P_{dis,t}\, \Delta T}{DE} \quad (6)$$

$$P_{ch,t} \le SOE_{bat,max} * U_{2,t}\,, \forall t \quad (7)$$

$$P_{dis,t} \le SOE_{bat,max} * (1 - U_{2,t})\,, \forall t \quad (8)$$

$$SOE_{bat,1} = SOE_{bat,ini} \quad (9)$$

$$SOE_{bat,min} \le SOE_{bat,t} \le SOE_{bat,max} \quad (10)$$

The objective function of the defined optimization problem is given in eq (1). It aims to minimize the total cost of the system. The power balance of the system is represented by eq (2). Eq (3) states that the total power generated by PV panels is, sold to the grid, directly supplies the load, or charges the battery. Eq (4,5) states that either use the grid or sell to the battery. Eq (4,5) states that either use the grid or sell to the grid. The state of energy is of the battery is calculated in by eq (6). The battery cannot charge and discharge simultaneously is given in eq (7,8). The state of the battery is noted in eq (9). Eq (10) states the min and max state of energy of the battery.

IV. RESULTS AND DISSCUSSIONS

In this section, the analysis of the PV/battery system is shown in that table below. The results of the PV/battery system are compared with PV on-grid and a system without PV for better comparison.

	Daily cost ($)	**Installation cost ($)**	**Lifetime (years)**
System without PV	7.15	0	0
PV on-grid	1.91	13,000	6.8 Years
PV/Battery on-grid	-2.424	19,600	5.6 Years

Gekko library has been used for calculation in python programming language. Note that the program in a period of 30 min for one day, thus there will be 48 periods.

The load in figure (2), PV power generation in figure (3), buying at the 3 different prices daytime, peak and night, at 0.48, 0.83, 0.21 $/kWh respectively and selling price at 0.25 $/kWh.

Results

As shown in figure 4 the result of the optimization the total cost is -2.424 $. This means the PV system generated more power than used and sold the rest to the grid making a profit of 2.424$ in one day.

The table shows the total cost for the same load in a day cost 7.15 $ without the PV system and 1.91 $ with PV only.

The PV/battery system costs about 19,600 $ thus in 5.6 years the system cost will be compensated.

```
--------------------------------------------------
Solver         :  APOPT (v1.0)
Solution time  :  0.18779999999999997 sec
Objective      :  -2.42394624007527
Successful solution
--------------------------------------------------
```

Figure (4): The result of the optimization program

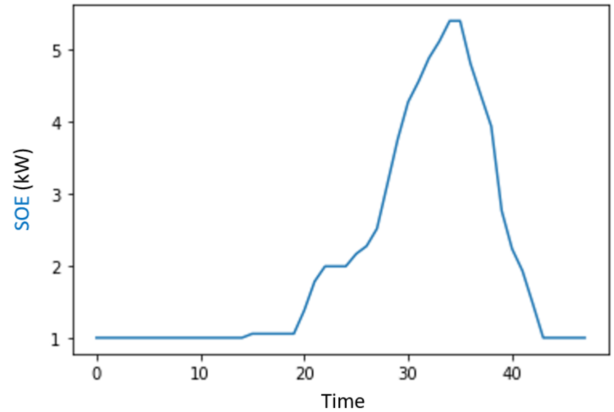

Figure (5): Diagram of the SOE (state of charge)

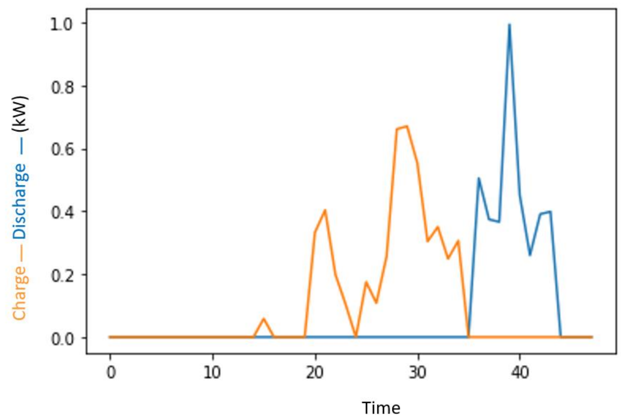

Figure (6): Diagram of the charging and discharging periods

V. CONCLUSION

In this study the optimization of a grid connected PV/battery system was performed. The optimization analysis showed that by the installation of the system the total daily cost was reduced by 2.424 $ and the system will be compensated in 5.6 years.

REFERENCES

[1] Vinay Anand Tikkiwal, Sajai Vir Singh & Hari Om Gupta (2021) Multi-objective optimisation of a grid-connected hybrid PV-battery system considering battery degradation, International Journal of Sustainable Engineering, 14:6, 17691779, DOI: 10.1080/19397038.2021.1982064

[2] Adjei, Bernard & Donkoh, Elvis & Otoo, Dominic & Owusu-Ansah, Emmanuel & Owusu-Ansah, Johnson & Mahama, Francois & Karthick, K. (2019). Optimization Of A Grid-Connected Photovoltaic System In A Densely Populated Residential Community. Journal of Advances in Mathematics and Computer Science. 33. 1-16. 10.9734/JAMCS/2019/v33i230175.

[3] Alsadi, S.; Khatib, T. Photovoltaic Power Systems Optimization Research Status: A Review of Criteria, Constrains, Models, Techniques, and Software Tools. *Appl. Sci.* **2018**, *8*, 1761. https://doi.org/10.3390/app8101761

[4] Alayi, R.; Mohkam, M.; Seyednouri, S.R.; Ahmadi, M.H.; Sharifpur, M. Energy/Economic Analysis and Optimization of On-Grid Photovoltaic System Using CPSO Algorithm. Sustainability 2021, 13, 12420. https://doi.org/10.3390/su132212420

[5] Tamer Khatib, Azah Mohamed, K. Sopian, A review of photovoltaic systems size optimization techniques, Renewable and Sustainable Energy Reviews, Volume 22, 2013, Pages 454-465, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2013.02.023.

[6] Habtemariam Aberie Kefale, Elias Mandefro Getie, Kassaye Gizaw Eshetie, "Optimal Design of Grid-Connected Solar Photovoltaic System Using Selective Particle Swarm Optimization", International Journal of Photoenergy, vol. 2021, Article ID 6632859, 9 pages, 2021. https://doi.org/10.1155/2021/6632859