



Feasibility Study of Grid-Connected PV System for Peak Demand Reduction of a Residential Building in Tehran, Iran

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ABSTRACT

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The use of fossil fuels for energy demand is overgrowing, leading to a higher CO₂ emission. Besides, these resources have fluctuating prices and have higher operating costs. Thus, the integration of renewable energy (RE) sources has been increasing throughout the years to reduce the dependency on fossil fuel generation. However, RE generations have high initial costs and intermittent resources. Therefore, it is crucial to conduct technical and economic analysis before the installation of any hybrid energy systems. This study proposes the installation of a PV system for a residential building in Tehran, Iran. The goal of the system is to have a PV system for peak demand reduction. Moreover, the input data also includes economic parameters such as costs of PV, battery, and grid purchases alongside interest rates. Sensitivity analysis also conducted in this study to investigate the variation of load profiles on the optimal system configuration. The simulation results show a 422-kW grid-connected PV system with battery storage is the most optimal system for the selected location. The system has a lower Net Present Cost (NPC) and initial capital compared to other configurations. Moreover, the system also has a higher RE generation and lower energy import from the grid.

1. INTRODUCTION

Due to the need to use clean energy sources, the use of renewable is increasing over the years [1-3]. Previous works have shown that the integration of RE, such as solar PV, the small hydro, wind, geothermal, and hydrogen, will reduce greenhouse gasses such as CO₂. Also, fossil fuels, such as oil, gas, and coal, have variable prices and costly to operate [4, 5]. Hence, many countries take more serious action into the use of alternative energy sources such as RE [5-8]. The use of RE generations such as solar energy, wind, geothermal, hydrogen, and biomass requires technical and economic studies before installation to have an optimal configuration leading to a more efficient system [9]. RE is the most promising solution for developing countries and areas with limited access to electricity. Therefore, many programs and policies have been developed to increase RE into their country energy mix [10-12]. However, the adaptation of these energy sources to the current conventional energy generations has still been overwhelmed with problems such as higher costs and intermittent resources.

There have been many works related to feasibility study RE and hybrid system installation. For example, Shaahid et al. have conducted a study of techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia [13]. Meanwhile, Al-Masri et al. perform a feasibility investigation of a hybrid on-grid wind photovoltaic retrofitting system [14]. Ahmed et al. have conducted work related to a stand-alone hybrid

generation system that combines solar photovoltaic and wind turbine with maximum power point tracking control [15].

In addition, Al-Sharafi et al. worked on techno-economic analysis and optimization of solar and wind energy systems for power generation and hydrogen production in Saudi Arabia [16]. Baghdadi et al. have conducted a feasibility study and energy conversion analysis of stand-alone hybrid RE systems [17]. Khalili et al. investigate the optimal hybrid system comprises of a grid-connected PV system in Ardabil city [18]. Alayi et al. have provided conducted work on the optimization and evaluation of wind, solar, and fuel cell hybrid system to meet the load demand in a remote area [19]. Kazem and et al study the effect of environmental variables on photovoltaic performance-based on experimental studies [20]. Moreover, Maatallah et al. explore the assessment viability for hybrid energy systems (PV/wind/diesel) with storage in the northernmost city in Africa, Bizerte, Tunisia [21]. Vassel et al. conducted a study on the effect of wind direction on the performance of solar PV plants [22]. Yu et al. perform a study on the sizing of hybrid energy systems [23]. Moreover, M.R.B Khan et al. conducted feasibility studies for hybrid PV and micro-hydro systems for a resort island in Malaysia based on seasonal load demand [24-26].

In this study, the feasibility analysis of PV system installation for a residential building has been conducted based on the techno-economic analysis. It is crucial to conduct technical and economic analysis before the installation of any hybrid energy systems. This study proposes the installation of a PV system for a residential building in Tehran, Iran. The goal

of the system is to have a PV system for peak demand reduction. Moreover, the input data also includes economic parameters such as costs of PV, battery, and grid purchases alongside interest rates. Sensitivity analysis also conducted in this study to investigate the variation of load profiles on the optimal system configuration the rest of the papers are structured as follows: Section 2 described the data collected for this study. Meanwhile, Section 3 presents the technical and economic analysis that includes the system model and design. Section 4 demonstrates the results obtained, such as optimal configurations and sensitivity analysis. Finally, Section 5 summarizes the work and findings.

2. DATA COLLECTION

The selected location for this study is a 40-story residential building located in Mehrabad, Tehran, Iran, at 36.7°N and 51.4°E. The location of the case study is shown in Figure 1.



Figure 1. Location of Mehrabad, Tehran [Source: edited from Google Maps]

2.1 Load profile

The load profile was obtained based on the modeled building in TRNSYS. The building characteristics are as follow:

- 40 story building with two units on each floor with an area of 130 m²
- Each unit has an average of three occupants
- Each unit has two bedrooms and a kitchen with an area of 12m² and 15m², respectively.

The average daily load profile for the residential building is shown in Figure 2. Meanwhile, the seasonal load demand throughout the year is shown in Figure 3. Each unit has an estimated average of 860 kWh of energy consumption per month. The building has an average load of 50.8 kW with a peak of up to 286 kW.

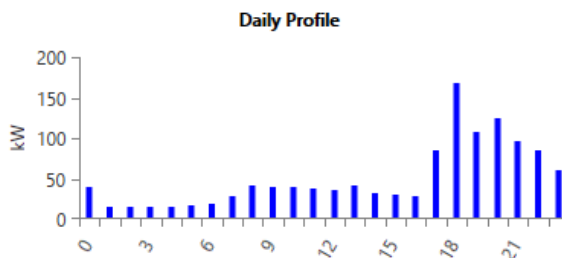


Figure 2. Daily load profile

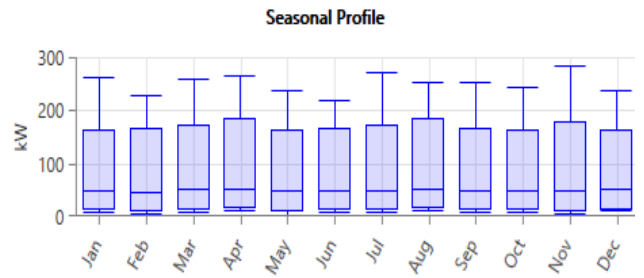


Figure 3. Seasonal load profile

2.2 Solar radiation

In this study, the solar radiation data in Mehrabad was collected from the NASA POWER database. Solar radiation data is crucial to determine the potential generation from PV systems at the location. The amount of average solar radiation in this area is 4.89 kWh/m²/d. The solar radiation profile is illustrated in Figure 4.

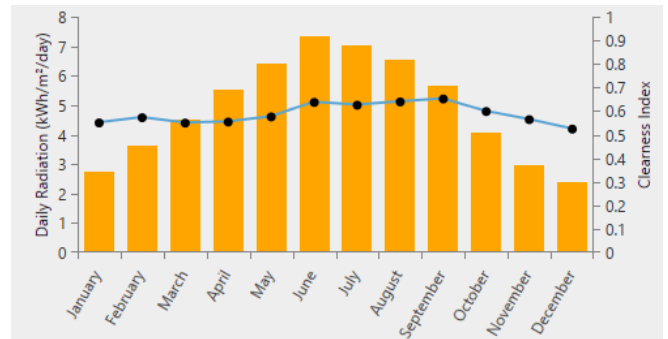


Figure 4. Average monthly solar radiation in Mehrabad, Tehran

2.3 System model

HOMER was used to determine the feasibility of PV system installation on-site. The software tool is expected to show the technical and economic parameters for the optimal system configurations. The system modeled comprises of PV, battery, converter, and grid. The HOMER model is presented in Figures 5 and 6. Both PV and battery storage systems are connected to the DC bus. The inverter system is used to convert the DC output from PV and battery to the AC linked grid and load. The systems' technical and economic parameters are presented in Table 1.

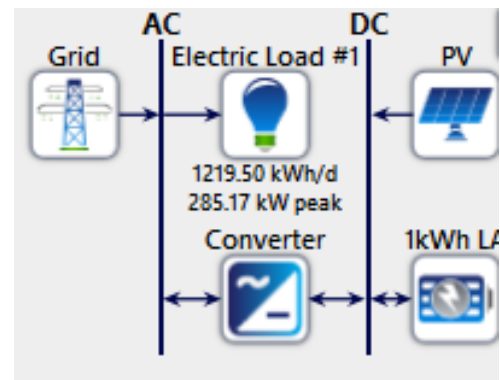


Figure 5. Hybrid System Model in HOMER scenario 1

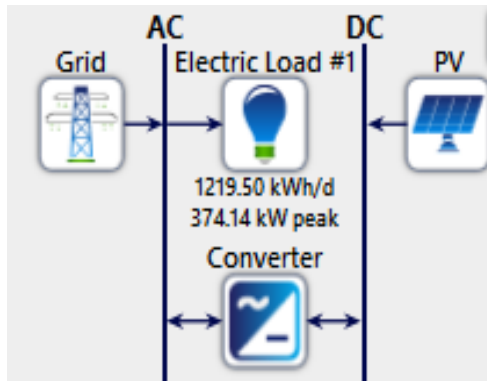


Figure 6. Hybrid System Model in HOMER scenario 2

Table 1. Technical and economic parameters [23, 24]

| No | Components | Specifications |
|--|--|----------------------------------|
| 1 | PV System | |
| | Size considered (kW) | 0 to 700 kW with 20 kW step size |
| | Capital cost (\$/W) | 3.64 |
| | Replacement cost (\$/W) | 3.64 |
| | Operation and maintenance cost (\$/year) | 329 |
| 2 | Inverter | |
| | Size considered (kW) | 0 to 700 kW with 20 kW step size |
| | Capital cost (\$/W) | 1.05 |
| | Replacement cost (\$/W) | 1.05 |
| | Operation and maintenance cost (\$) | 10,500 |
| 3 | Batteries | |
| | Model | Generic |
| | Batteries per string | 100 |
| | Sizes considered | Up to 2,000 kWh |
| | Capital cost (\$/battery) | 1,200 |
| | Replacement cost (\$/battery) | 1,200 |
| Operation and maintenance cost (\$/year) | 10 | |

3. SECTION HEADINGS TECHNICAL AND ECONOMIC ANALYSIS

3.1 PV system

The PV system modeled with sizes varied from 0 to 700 kW with a step size of 20 kW. This building-integrated PV (BIPV) system is limited to 700 kW only due to limited space and area of installation. The cost considered also comprises of Balance of System (BOS) as well.

3.2 Battery storage system

The battery storage system modeled with sizes varies from 0 to 700 kW with a step size of 20 kW. A generic battery model was used to simulate the battery storage system.

3.3 Grid

Grid is the primary source to meet the load demand. The grid rate in Tehran, Iran, is 0.7 cents/kWh price with 0.05\$/kWh sellback.

3.4 Energy management system

Both Load Following (LF) and Cycle Charging (CC) were considered for the system controls. HOMER will perform decision making based on the best control method that produces higher RE generations with lower cost.

4. RESULTS

4.1 Optimization results

The optimization results are presented in Table 2. The results indicate PV-battery-grid system is the most optimal configuration followed by PV-grid and grid the only system. Only PV-battery-grid and PV-grid system will be compared and discussed since the goal of this work are to determine the optimal configuration and sizing of a grid-connected PV system for the building.

Although, the initial capital of the PV-battery-grid system is 1.07\$M, which is 56% higher than the PV-grid system. The PV-battery-grid configurations have the lowest NPC at 2.16\$M (million) followed by PV-grid and grid only with NPC of 2.30\$M and 2.88\$M, respectively. Additionally, the Cost of Energy (COE) for the PV-battery-grid system is 0.257\$/kWh, which is lower compared to the PV-grid system. Moreover, the operation cost for the PV-battery-grid system is lower than the PV-grid system at 84,372\$ and 141\$, 421\$, respectively. The optimal system has an LF control strategy.

Meanwhile, other configurations used CC as the control strategy. LF energy management is where the generator only produces sufficient power to meet the demand. Whereas in CC strategy, the generator will operate at full capacity, and the excess generation will be used to charge the battery storage system.

The PV-battery-grid system also has higher RE penetration with 90% PV generation. However, the PV-grid system has only 53% RE generation due to a lack of storage system. The electricity production of each system is shown in Figure 7.

4.2 Sensitivity analysis

The sensitivity variable chosen is load profile growth. The load profile growth effect on the optimal system sizing and configuration was simulated in HOMER. The sensitivity analysis results are shown in Table 3. The results show the system configuration varies as the load profile increases. The PV and battery sizes needed to become more substantial as the load becomes bigger. However, the system will import more energy from the grid contributing to lesser RE penetration as the load profile grows.

Table 2. Optimization results

| Rank | PV (kW) | Battery (kWh) | Conv. (kW) | Grid (kW) | Dispatch Strategy | Initial capital (\$) | NPC (\$) | COE (\$/kWh) | RF |
|------|---------|---------------|------------|-----------|-------------------|----------------------|----------|--------------|-------|
| 1 | 422 | 1,603 | 270 | 1000 | LF | 1.07M | 2.16M | 0.257 | 0.901 |
| 2 | 237 | - | 193 | 1000 | CC | 468,776 | 2.30M | 0.263 | 0.530 |
| 3 | - | - | - | 1000 | CC | 0 | 2.88M | 0.500 | 0.000 |

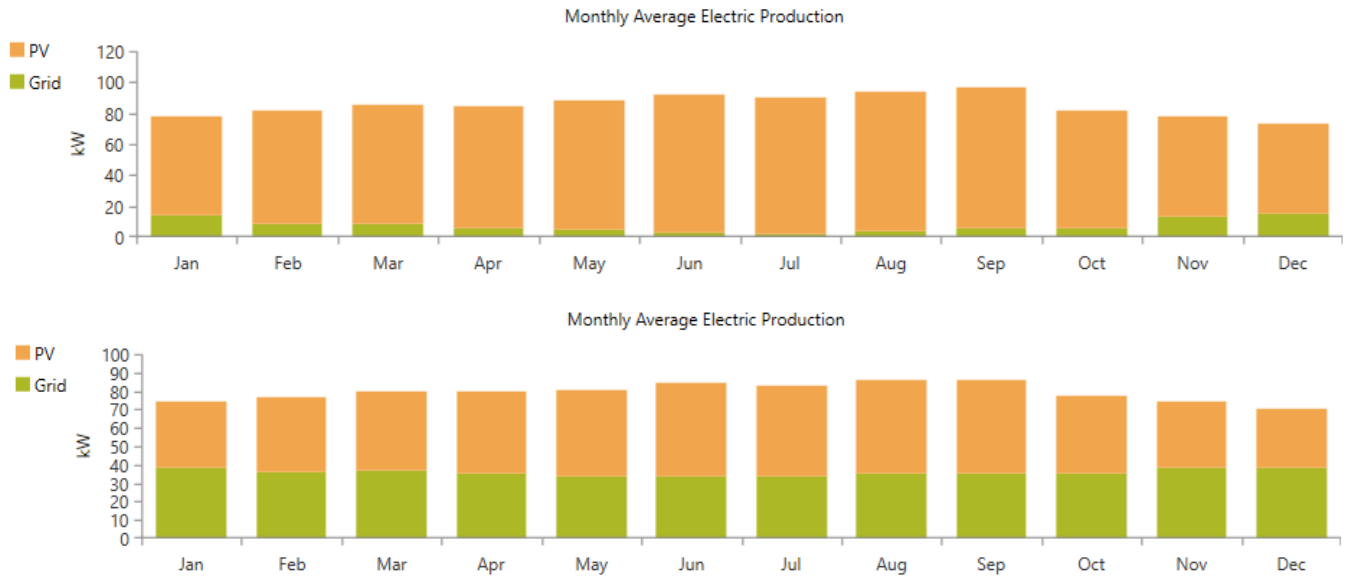


Figure 7. Monthly average electricity production a) PV-battery-grid system b) PV-battery system

Table 3. Sensitivity analysis results

| Load (kWh/d) | PV (kW) | Battery (kWh) | Conv. (kW) | Grid (kW) | Dispatch Strategy | Initial capital (\$) | NPC (\$) | COE (\$/kWh) | RF |
|--------------|---------|---------------|------------|-----------|-------------------|----------------------|----------|--------------|-------|
| 1,220 | 422 | 1,603 | 270 | 1000 | LF | 1.07M | 2.16M | 0.257 | 0.901 |
| 1,320 | 448 | 1,734 | 283 | 1000 | LF | 1.14M | 2.34M | 0.261 | 0.897 |
| 1,440 | 486 | 1,892 | 309 | 1000 | LF | 1.24M | 2.55M | 0.262 | 0.896 |
| 1,600 | 551 | 2,083 | 351 | 1000 | LF | 1.39M | 2.83M | 0.257 | 0.898 |

5. CONCLUSIONS

This work goal is to determine the optimal configuration of a grid-connected PV system to lower the peak demand for a residential building. HOMER software was used to model and simulate the system. The results show grid-connected 422 kW PV with battery storage is the most optimal configuration for the selected location. The system has an NPC of 2.16\$M and initial capital of 1.07 \$M, which is 6% lower than other configurations. Moreover, the system also has a lower COE with 0.2547\$/kWh.

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