Study on Performance of Rooftop Solar Power Generation Combined with Battery Storage at Office Building in Northeast Region, Vietnam

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Abstract: At present, renewable energy sources are considered to ensure energy security and combat climate change. Vietnam has a high potential for solar power development, especially in the central region and the southern region. However, the northeast region has the lowest solar radiation value, so it can cause difficulty for rooftop solar power investment. In this paper, the study results analyze the financial efficiency of the grid-tied rooftop solar power system with battery storage and compared it to the grid-tied rooftop solar power system without battery storage. The experimental data of a grid-tied solar power system with battery storage at an office building in the northeast region of Vietnam is collected to evaluate the system's operation performance in real conditions. The study results present that the financial efficiency of rooftop grid-tied power project with and without storage is viable since the benefit-cost ratio (B–C) is larger than one, and internal rate of return (IRR) and net present value (NPV) are positive. However, the grid-tied rooftop solar power system with storage is not quite feasible in case of changing the electricity selling price and investment cost even though the grid-tied solar power system using the storage device can operate more flexibly. The payback period of the grid-tied solar power system with storage is 6.2 years longer and the total profit is nearly 1.9 times lower than the solar power system without battery storage due to the difference in the price of the inverters and the battery. In contrast, the grid-tied solar power system without battery storage shows better financial efficiency but strongly depends on the operation of the utility grid.

Keywords: solar energy; rooftop solar power; hybrid inverter; battery storage system

1. Introduction

Recently, the world has been exploiting renewable energy [1,2] to meet electricity usage expectations and minimize environmental pollution. Solar power is playing a crucial role in the power supply system to develop the economy of countries in the world [3–5].

In 2020, the installed capacity of renewable energy sources around the world was still growing in the effects of the Covid-19 epidemic [6,7]. The total cumulative installation capacity of solar power till the end of 2020 reached 760.4 GW [8], accounting for 27.1% of all renewable energy. In comparison, the total cumulative solar power capacity in 2019 was 621.1 GW [8], so the growth in solar power in 2020 increased by nearly 139.3 GW [8].
This data presents that the countries around the world are being heavily affected by the Covid-19 epidemic but the installed solar power capacity is still growing.

Grid-tied rooftop solar power can reduce the pressure on the power grid load at noon rush hours and decrease the burden of investment in the power system. However, development of PV rooftop power depends on regional characteristics [9]. Many grid-tied solar power system projects have been implemented to evaluate the technical economic efficiency. Razali Thaib et al. [10] presented that the investment efficiency of a 3 MW solar power station was feasible with an electricity cost of 11.7 cents/kWh for the University of Samudra campus with the help of System Advisor Model (SAM) software. The economic efficiency of rooftop solar power for different areas in Thailand using the PSIM software was researched by Suntiti Yoomak et al. [11], and the study results showed that the central region of Thailand was suitable for rooftop solar power system installation. Ahmed F. Bendary et al. [12] suggested an optimum fault-finding solution for solar array by using an adaptive neuro-fuzzy inference system to improve the efficiency of the solar power system. According to a study of JunHan et al. [13], the outdoor performance of photovoltaic (PV) compared to normal glass when fitted to the building surface by a small-scale test system, measured data showing that the maximum indoor air temperature for normal glass was close to 34 °C, while it was only 29 °C for PV in the same summer weather condition. The efficiency of rooftop PV systems in electricity generation and building cooling of five major cities in India were studied by Y. Kotak’s [14] research group. Their simulation results demonstrated that the PV system reduced the energy for roof cooling loads from 73 to 90%. Furthermore, the performance and benefits of grid-tied rooftop solar power projects combined with storage systems were also studied. The novel control strategy of Dina Emara et al. [15] could control the voltage stability of the DC bus in the microgrid with solar power and energy storage system. The optimum configuration of rooftop PV with storage batteries for all kinds of residential buildings (villas, traditional houses, and apartments) in the city of Neom, Saudi Arabia, was designed by Alqahtani et al. [16]. A method of using storage for PV systems of Pietari Puranen et al. [17] was researched to improve the self-load consumption of an ordinary household in Finland.

Before creating support policies for the development of grid-connected solar power, solar power applications using batteries in Vietnam were mainly off-grid solar power projects in rural areas, border areas, and islands [18]. Some demonstration grid-connected solar power projects in the city during this time did not use batteries to connect directly to the inverter in the solar power system. The batteries, if used, were connected directly to the solar panel by a separated charge controller, and these storage devices could connect to priority load by using another power conversion system in the building.

Thanks to the Vietnamese government’s policies [19,20] for promoting grid-tied solar power, this technology has just been developed in recent years and is considered to be a solution to ensure energy security and combat climate change. Despite the Covid-19 pandemic, solar power in Vietnam was still growing rapidly in 2020. The installed solar power capacity in the period from 2018 to 2019 reached 4793 MW while the total installed capacity of solar power in the period from 2019 to 2020 increased 2.28 times; it raised the total solar power capacity in Vietnam to 16,504 MW [8]. As a result, Vietnam moved up to third place in the top ten nations with the highest solar power capacity in the world in 2020 [8].

Besides, investors also aggressively constructed rooftop solar power projects starting in 2017 and increased the total rooftop solar power capacity in Vietnam up to 9580 MWp by the end of 2020 [21]. Many studies have been conducted in Vietnam to assess the performance of rooftop solar systems. Phap et al. [22,23] determined the rooftop solar power potential and installation efficiency of grid-tied solar power projects in Hanoi. The power and efficiency of a photovoltaic (PV) system for a residence in Thu Dau Mot, Vietnam were studied by Thanh et al. [24]. Lan et al. [25] calculated the economic statistics of rooftop solar power with the effects of retail electricity prices in the central highlands of Vietnam. The potential of rooftop solar power in Hau Giang province was evaluated by Tan
et al. [26]. In the study of Nguyen et al. [27], the efficiency of utilizing solar panels instead of glass for buildings in Vietnam was analyzed.

In 2021, the old support mechanism for the development of grid-tied solar power projects in Vietnam was expired, and Vietnamese government has not yet issued a new support policy. As a result, the development of grid-tied rooftop solar power stations is stalled, and new rooftop solar power projects in 2021 are not yet permitted to connect to the local utility grid and install the bi-directional meters [28]. Therefore, business companies in Vietnam’s solar power industry have offered a solution to incorporate energy storage equipment in grid-tied rooftop solar power stations so as to allow clients to continue to install grid-tied rooftop solar power. The battery can be connected directly to the grid-tied rooftop solar power system by using the hybrid inverter and allows for the storing of excess solar power that cannot be sold to the utility grid. This excess electricity will be used for home loads at an appropriate time of day. However, Vietnam currently does not yet have any research to evaluate in detail the financial efficiency and working performance of grid-tied rooftop solar power systems with battery storage, especially in the area with the lowest solar power potential such as the Northeast region of Vietnam.

Therefore, the content of this research focuses on analyzing the financial efficiency of the grid-tied rooftop solar power system with battery storage for the office building and compare it with the grid-tied rooftop solar power system without battery storage. Experimental data of a 3 kWp grid-tied solar power station with the storage device in an office building in Hanoi city in the Northeastern region of Vietnam are also collected to evaluate the system’s performance in real world conditions. The study results will also contribute to providing appropriate criteria for the investment decision of rooftop solar power technology at office buildings in Vietnam.

The paper includes six sections with the first section serving as the introduction. The second section describes the operation principles of grid-tied rooftop solar power systems with and without battery storage being deployed in Vietnam to show the difference between the two operational principle configurations. The materials and methods are shown in the third section. In the fourth section, the selected site case study is introduced. The fifth section describes the study results and discussion, and the last section presents the conclusions.

2. Grid-tied Rooftop Solar Power Technologies

2.1. Grid-tied Rooftop Solar Power without Battery Storage

The schematic diagram of the grid-tied solar power system is shown in Figure 1.

![Figure 1. Schematic diagram of grid-tied rooftop solar power system without battery storage.](image)

During the day when the weather conditions are favorable, the PV panels will absorb energy from sunlight and convert solar energy into direct current. The grid-tied inverter plays a very important role in the solar power system, and the inverter is responsible for converting direct current into alternating current of the same phase, frequency, and
voltage with the national power grid, by which the electricity from the solar power station will be transmitted to the local utility grid. There are four possible cases with electricity produced from the solar power system and consumed by the load equipment as below:

Firstly, when the electricity generated from the solar panel system is lower than the amount of electricity consumed by the load, the national utility grid will automatically compensate to provide enough power for the load equipment to avoid the lack of electricity affecting the equipment.

Secondly, when the electricity generated from the solar panel system is equal to the amount of electricity consumed by the load being used, the solar energy system will give priority to the load equipment using electricity from solar panels, and at the same time not using and consuming the national grid power source.

Thirdly, when the electricity generated from the solar panel system is greater than the amount of electricity consumed by the load being used, the excess electricity will be transmitted to the national grid, the bi-directional meter allows one to measure the amount of electricity of the solar panel system that the householder sells or buys from the local power company.

Fourthly, when the electricity from the solar power system cannot generate enough electricity for the loads due to weather or at night, the loads will prioritize using electricity from the national utility grid.

The disadvantage of a grid-tied solar power system without battery storage is that in the case of the absence of sunlight (bad weather) or at night, the solar panel cannot absorb solar energy to convert it into electricity and the national utility grid has problems with the power supply. The power outages will be maintained in the home and affect the use of electrical equipment, especially important loads.

2.2. Grid-tied Rooftop Solar Power with Battery Storage

In general, the operation principle of a grid-tied solar power system combined with a power storage device as shown in Figure 2 is the same as a grid-tied solar power system, but it overcomes the disadvantages of a grid-tied solar power system without battery storage by using a hybrid inverter. This inverter has the function of simultaneously connecting both the power grid and the battery instead of the conventional grid-tied inverter. In the case when solar cells cannot generate electricity and the national grid has a problem, the electricity from the storage device will then be used through the hybrid inverter to supply to prioritized and important load devices. Storage systems using batteries will also be charged from the solar system and/or the utility grid with the help of the hybrid inverter.

![Figure 2: Schematic diagram of grid-tied rooftop solar power system with battery storage.](image)

3. Methodology

In this study, the electricity generated from the rooftop grid-tied solar power system can be calculated by the PVSYST software. The yield factor and performance ratio in PVSYST program [23] are determined as below:
PV array yield ($Y_a$):

$$Y_a = \frac{E_a}{P_0}$$  \hspace{1cm} (1)

where: $P_0$ is the power of PV array [kWp]; $E_a$ is output PV array yield [kWh]; $Y_a$ (Array Yield) is the PV array daily output energy, referred to the nominal power [kWh/kWp/day].

Reference system yield ($Y_r$) is calculated by the equation:

$$Y_r = \frac{H_r}{G_0}$$  \hspace{1cm} (2)

where: $Y_r$ (Reference system yield) is numerically equal to the incident energy in the PV array plane [kWh/m²/day]. $H_r$ is the total horizontal irradiance on PV array [kWh/m²] and $G_0$ is the global irradiance at standard condition (STC) at $25^\circ C$.

The system yield ($Y_f$) equation is as below:

$$Y_f = \frac{E_{AC_{out}}}{P_{max}}$$  \hspace{1cm} (3)

where: $Y_f$ (System Yield) is the system daily useful energy, referred to the nominal power [kWh/kWp/day]; $E_{AC_{out}}$ is the amount of electrical energy generated by the PV power system; $P_{max, STC}$ is the total installed power of the PV array at standard test condition (STC).

The results of the financial efficiency analysis of grid-tied solar power systems with and without storage are carried out using Retscreen software [29,30]. This software is used around the world to evaluate the energy production and associated savings, cycle costs, GHG emissions reductions, financial feasibility, and risks for renewable energy production or different energy efficiency technologies.

The financial feasibility indicators of the PV project are cash flow [31], payback period, and internal rate of return [29]. The profitability, quality, and efficiency of a project are estimated from the internal rate of return (IRR), net present value (NPV), and benefit-cost ratio (B–C). The investment in a renewable power project has financial feasibility when the B–C is larger than 1, the IRR, and NPV are positive.

The internal rate of return IRR [29] is the discount rate causing the Net Present Value (NPV) of the project to be zero.

$$0 = \sum_{n=0}^{N} \frac{\bar{C}_n}{(1 + IRR)^n}$$  \hspace{1cm} (4)

where $N$ is the project life in years, and $\bar{C}_n$ is the cash flow for year $n$.

The net present value NPV [29] of a project is the value of all future cash flows, discounted at the discount rate, in today’s currency.

$$NPV = \sum_{n=0}^{N} \frac{\bar{C}_n}{(1 + r)^n}$$  \hspace{1cm} (5)

where $r$ is the discount rate, and $\bar{C}_n$ is the after-tax cash flow in year $n$.

The benefit-cost ratio, B–C, [29] presents the relative profitability of the project.

$$B - C = \frac{NPV + (1 - f_d)C}{(1 - f_d)C}$$  \hspace{1cm} (6)

where $C$ is the total initial cost of the project, $f_d$ is the debt ratio.

The annual average reduction of CO₂ uses the following formula:

$$\Delta t \text{CO}_2 = E_{\text{grid}} \times EF_{\text{grid}}$$  \hspace{1cm} (7)

where: $E_{\text{grid}}$ is the average annual generation electricity from the solar power station (MWh), EFgrid is the CO₂ emission factor of the Vietnamese power grid.
4. Site Selection

4.1. Solar Energy Potential

Vietnam has possible potential for solar power development with the average total solar irradiance of the country of from 4 kWh/m² per day to 5 kWh/m² per day and the average number of sunny hours of from 1600 h per year to 2600 h per year [18]. The regions of the Central and the South in Vietnam have the highest solar irradiance between 4.5 kWh/m² per day and 5 kWh/m² per day while the Northeast region has the lowest potential with total solar irradiance below 4 kWh/m² per day [18], so it can cause difficulty for rooftop solar power investment in the provinces of the Northeast area.

The cities and provinces in the Northeast region have a tropical monsoon climate and the weather consists of the rainy season and the dry season [32]. The weather data in simulation programs shows that Hanoi city has a fairly average solar power potential with an average annual total solar radiation of about 3.96 kWh/m² per day as shown in Figure 3. The months with the lowest solar radiation are from December to March, while the months from May to September have the highest solar radiation. June has the largest average temperature of about 30°C while January has the smallest average temperature of nearly 18°C.

![Climate data](image)

**Figure 3.** Daily solar radiation in Hanoi city.

4.2. Location

The office building in Hanoi city with an approximate height of 25 m and a roof area of 152 m², the roof direction is North-South. The corrugated iron roof of the building in Figure 4 is a sloping roof on both sides, and there is no ventilation pipe between the roofs. The roof area is open, spacious, and unobstructed by trees, so the roof surface is suitable for installing a solar panel system. Solar panels will be installed on the South-facing iron roof with an inclination angle of 7°.
Actual survey result in the office building shows that the building load mainly includes equipment such as lights, fans, air conditioners, computers, printers, and server systems. The average monthly electricity consumption is about 2850 kWh per month.

4.3. The Experimental Rooftop Solar Power System with Battery Storage of Case Study

In Figure 5; Figure 6, eight LPW-385M-72H (385 Wp, Loop Inc, Tokyo, Japan) monocrystalline solar panels are connected in series to form a string with a total capacity of 3080 kWp. When the weather condition is favorable in the day, the solar panels can absorb energy from sunlight and convert it into electricity (direct current). The SPH3000 (3 kW, Shenzhen Growatt New Energy Co., Ltd., Shenzhen, China) single phase hybrid inverter plays an important role in this solar power system, and it is responsible for converting direct current into alternating current of the same phase, frequency, and voltage with the national power grid, thereby the electricity generated from the solar power station will be fed into the local power grid. Direct current (DC) is charged into the battery storage system by the hybrid inverter, four 100 Ah Sealed Lead Acid–AGM–VRLAM (Vision Technology Joint Stock Company, Hanoi, Vietnam) batteries are connected in series to form a storage system with a voltage of 48V. Batteries in this real PV power system are selected to meet minimum energy storage requirements and back-up for the prioritized electric loads in the absence of solar or grid power to minimize total investment cost. The hybrid inverter will control the charging process of the battery to avoid overcharging or running out of battery power. In case of bad weather without sunlight or at night and the utility grid loses power, the hybrid inverter will use power from the battery system to supply to the prioritized electric loads in the office building.
5. Results and Discussion

5.1. Technical Result

The electricity generation performance of the grid-tied rooftop solar power system is determined by comparison results between simulation and experiment. The generated electricity of the 3 kWp solar power system is simulated by using the PVSYST specialized software for the solar power system as shown in Figure 7. The average annual amount of electricity produced from the solar array is about 3679 kWh per year or 306.5 kWh per month. The period from May to September is the highest solar power production, while December, January, and February are the lowest solar power generation months of the year.
According to the actual survey at the office building, the average monthly electricity consumption load is about 2850 kWh/month. Thus, after installing the solar panel system, the office building will save about 10.7% of the electric load consumption since solar electricity mainly serves the building’s load and does not generate any excess electricity to the distribution power grid. Electric loads in the building will not use the amount of electricity from the utility grid, which is equal to the amount of generated solar power. Therefore, the price of solar electricity is equal to the electricity price that the Vietnam Electricity Company (EVN) sells to the office building.

The real operation of a 3 kWp grid-tied solar power station with battery storage on a typical day is shown in Figure 8. The amount of electricity generated by the solar panels depends on the weather, the solar array produces more electricity on sunny times while generating less electricity on rainy and cloudy times. In the real grid-tied rooftop solar power station with battery storage, the electric loads can be served from the solar panel and/or power grid. When the power grid fails, the prioritized electric load such as the server system can be charged from the backup battery system.
months from April to July. The difference in power output from the solar power system occurs since the actual operation of the solar power station can be greatly affected by the maintenance time, dust, weather, and loss in the system. Therefore, the power output in the real condition is a little lower than the simulation design.

**Table 1.** Comparison of experimental result and simulation result.

| Month  | April | May  | June | July |
|--------|-------|------|------|------|
| Simulation (kWh) | 275   | 371  | 382  | 408  |
| Experiment (kWh)  | 192.7 | 337.2| 353.2| 378.5|
| Difference (kWh)  | 82.3  | 33.8 | 28.8 | 29.5 |

5.2. Financial Efficiency Calculation

The financial efficiency of the grid-connected solar power projects can be determined by financial feasibility indicators of the internal rate of return (IRR), net present value (NPV), and benefit-cost ratio (B–C). In this study, the financial efficiency analysis results of grid-tied rooftop solar power systems with and without storage are presented to have a basis to recommend investment decisions for office buildings in Vietnam. The project investment cost in Table 2 is consistent with the actual price of the solar power market in Vietnam. The price of the inverters and the battery causes a large difference in the total investment cost of the grid-tied solar power systems with storage and without storage. The price of the hybrid inverter for a solar power system with storage is about three times larger than the price of a grid-tied inverter of the rooftop PV system without storage. Besides, the investment cost of a solar power system with storage also increased due to batteries 100 Ah with a price of $870. Thus, the investment cost difference of 3 kW grid-tied solar power systems with storage and without storage is about $2030.

**Table 2.** Investment cost of grid-tied solar power systems

| Content                                      | Grid-Connected Solar Power System with Storage ($) | Grid-Connected Solar Power System without Storage ($) |
|----------------------------------------------|---------------------------------------------------|-----------------------------------------------------|
| 385 Wp solar panels                          | 1202                                              | 1202                                                |
| 3 kW hybrid inverter                          | 1404                                              | -                                                   |
| 3 kW grid-tied Inverter                       | -                                                 | 429                                                 |
| 100 Ah batteries                              | 870                                               | -                                                   |
| Mini rail array                               | 22                                                | 22                                                  |
| Middle battery clip                           | 11                                                | 11                                                  |
| Marginal battery clip                         | 3                                                 | 3                                                   |
| DC/AC electrical cabinets for safety current breaker, wires, jack MC4 | 343                                               | 343                                                 |
| Transportation, installation, user manual, handover | 258                                              | 258                                                 |
| Total cost before VAT tax                     | 4113                                              | 2268                                                |
| **Total cost after 10% VAT tax**              | **4525**                                          | **2495**                                            |

The input data of the financial efficiency calculation of grid-tied rooftop solar power systems with and without battery storage are shown in Table 3. In which, total operation and maintenance (O&M) cost includes the inverters, battery replacement cost, and O&M cost.
Table 3. Input data for financial calculation in Retscreen program.

| Specifications                                      | Grid-Tied Rooftop Solar Power with Battery Storage | Grid-Tied Rooftop Solar Power without Battery Storage |
|-----------------------------------------------------|----------------------------------------------------|------------------------------------------------------|
| Solar power station capacity (kWp)                  | 3                                                  |                                                      |
| Power generation (kWh/year)                         | 3679                                               |                                                      |
| Total investment cost ($)                            | 4525                                               | 2495                                                 |
| Total O&M cost ($)                                   | 3060                                               | 1500                                                 |
| The electricity selling price of EVN for office buildings ($/kWh) | 0.085 $/kWh and will increase by 6%/year on average |                                                      |
| Project life cycle (years)                           | 20                                                 |                                                      |
| Discount rate (%)                                    | 5                                                  |                                                      |
| Solar panel capacity loss coefficient according to manufacturer | 2.5% in the first year and 0.7% for the following years |                                                      |

The calculation results of the payback time and cumulative cash flow of grid-connected rooftop solar power stations with and without battery storage are shown in Figure 9; Figure 10, respectively. In general, the construction of rooftop solar power stations can save monthly electricity costs for the owners.

![Cumulative cash flows](image)

**Figure 9.** The payback time and cumulative cash flow of grid-tied rooftop solar power system with battery storage.
Study results show that the grid-tied solar power system with battery storage has a total investment cost of about $4525. The profit of this solar power system is not high, so the payback period is about 13.8 years. The period from the 14th year to the 20th year is the period collecting profits for using solar power with a profit value of about $4267.

In contrast, the calculation results show that the grid-tied solar power system without battery storage has a total investment cost of about $2495, and the payback period is about 7.6 years. The system’s profit collection period time will be from the 8th year to the 20th year with a profit value of about $8032.

The financial feasibility indicators of NPV, IRR, and B–C of grid-tied rooftop solar power systems are shown in Table 4. In general, the investment of rooftop grid-tied power project with and without storage is viable since the B–C is larger than one and the IRR and NPV are positive. However, the financial feasibility indicators of grid-tied rooftop solar power system without storage are higher than these indicators of the PV system with storage. Therefore, the payback period of grid-tied solar power system with storage is 6.2 years longer and financial efficiency is also lower than the solar power system without battery storage. The total profit of the grid-tied rooftop solar power without battery storage is nearly 1.9 times greater than the grid-tied rooftop PV system with storage.

Table 4. Comparison of the financial efficiency between grid-tied solar power systems

| Data              | Grid-Tied Solar Power with Battery Storage | Grid-Tied Solar Power without Battery Storage |
|-------------------|-------------------------------------------|---------------------------------------------|
| NPV ($)           | 308                                       | 3402                                        |
| IRR (%)           | 5.6                                       | 14.8                                        |
| B–C ratio         | 1.1                                       | 2.4                                         |
| Payback time (year) | 13.8                                      | 7.6                                         |
| Total profit ($)  | 4267                                      | 8032                                        |
The sensitivity of the grid-tied rooftop solar power system with and without the storage is analyzed by considering the impact of variable input parameters as investment cost and electricity selling price to the important value as NPV since NPV is used to determine whether a power project having a net profit or a loss. The variable range of the input parameters is 0, ±5%, ±10%.

The analysis results present that the change of electricity selling price and investment cost will affect the NPV value of both systems as shown in Figure 11, Figure 12. However, only the grid-tied rooftop solar power system with storage is not feasible when the variable range of investment cost is 0, ±5%, ±10% and the variable range of electricity selling price is 0, –5, –10%. Thus, the grid-tied rooftop solar power system with storage is not quite feasible in the case of adjusting the input parameters.

In addition, the electricity price is increasing in Vietnam, so the installation of rooftop grid-tied solar power systems can contribute to protect the environment and counteract global climate change by reducing the amount of CO₂ emitted into the environment. In Vietnam, the emission factor of the Vietnamese electrical grid is 0.9130 (tCO₂/MWh) according to the regulation of the Ministry of Natural Resources and Environment [33], so investment of a rooftop solar power system with a capacity of 3 kWp can reduce about 3.3 tons of CO₂ per year.

6. Conclusions

The basic operation of a grid-tied solar power system with energy storage equipment is the same as the grid-tied solar power system. However, it overcomes the disadvantage of a grid-tied solar power system without storage by using a hybrid inverter instead of a
conventional grid-tied inverter to have the simultaneous connection function for both the power grid and the battery. When the power grid fails, the prioritized electric load such as the server system can be charged from the backup battery system by using the hybrid inverter. The solar power system in actual operation is greatly affected by external factors such as dirt and unusual weather changes, so the power output is a little smaller than the simulation design.

Study results show that the investment of rooftop grid-tied power project with and without storage is viable since the B–C is larger than one and IRR and NPV are positive. However, the grid-tied rooftop solar power system with storage is not quite feasible in the case of changing the electricity selling price and investment cost. The payback period of the grid-tied solar power system with storage is 6.2 years longer and the total profit is nearly 1.9 times lower than the solar power system without battery storage due to the difference in the price of the inverters and the battery. The grid-tied solar power system without battery storage has a better financial efficiency but it highly depends on the operation conditions of the power grid. Thus, office buildings in Vietnam can consider choosing the suitable grid-tied rooftop solar power technology for practical use.

The Northeast region, including Hanoi city, has the lowest solar energy potential in Vietnam but the study result shows that the financial efficiency of the grid-tied rooftop solar power system with battery storage in the northeast region can be achieved. Thus, the payback time of the rooftop solar power system with battery storage at other regions in Vietnam having higher solar energy potential can be faster and the financial efficiency will be better than in the Northeast region. In general, the investment of rooftop solar power projects with battery storage in the office buildings in Vietnam can be accepted in the coming time, especially buildings that need to ensure uninterrupted power for priority loads. However, the investment cost of grid-tied rooftop PV systems using battery storage in Vietnam is still high, so it needs a new support policy and specific feed-in tariff from the government to ensure feasibility financial efficiency for all regions in Vietnam. This could represent an additional study topic in the future.

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