Building the Economic Efficiency Assessment Model of the Grid-Tied Rooftop Solar Power with Storage Project

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Abstract. According to Decision No. 13/2020/QD-TTg dated April 6, 2020 by the Prime Minister on the mechanism to encourage the development of rooftop solar power in Vietnam will expire after December 31, 2020. To harmonize the interests of households and the Electricity of Vietnam (EVN), a grid-connected rooftop solar power system with storage will be a solution worthy of attention. This paper builds a grid-tied solar power model with storage system. The model will ensure to storage of excess electricity from the solar power system and will not use grid electricity for the storage system. From there, evaluate the impact of the rooftop solar power system with the storage system on the household's load demand in two cases of cost optimization and grid operation optimization. In addition, the paper will evaluate in detail the investment efficiency of this type of rooftop solar power from the perspective of households. The results show that the grid-connected rooftop solar power system with storage system brings many benefits in terms of grid operation such as: no pressure on the power grid, reduced peak demand for households, increased energy efficiency, and increased energy efficiency. Flat load graph, reducing the demand for electricity at peak hours. But in economic terms, the interests of households and those of EVN are opposite.

Keywords: Storage system · grid-tied rooftop solar power · solar power

1 Introduction

The enormous potential and economic efficiency when using energy storage technologies have been clearly demonstrated through reports and research by Vietnamese experts (Nguyen Huy Hoach, 2021). Developing energy storage systems when electricity from renewable energy increases is an inevitable trend to ensure stable and safe operation of the power system. The view of Vietnam's power system development in the coming years is to develop a balance of power sources by regions on the basis of local consumption demand, which will reduce inter-regional transmission demand, reduce losses and increase the efficiency of the power system. However, in Vietnam, only storage hydropower projects are being invested, built and developed. When it comes to battery technology to store energy (BESS), currently Vietnam has not had a policy for this type. Meanwhile, the new generation of BESS technology has increasingly higher

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energy efficiency, simultaneously contributing to improving the economy and reliability of renewable energy sources. At the same time, the cost of BESS technology is forecasted to continuously decline over the next 10 years (Morteza Zare Oskouei et al., 2021, 18–19). If the Government offers a reasonable subsidy policy, sets the price according to the fixed plan for the entire project life, or adjusts it annually in accordance with the adjustment of the average electricity selling price that the economy and users are willing to pay. With the use of withstandable electricity, and at the same time, ensuring that the investor of the BESS project can recover the investment costs and make a reasonable profit, the BESS system will certainly be born quickly, suitable for the development of power sources from our country's renewable energy. And to achieve the goal of reducing net carbon emissions to zero by 2050 (Decision No. 896/QD-TTg dated July 26, 2022), energy policy needs to promote different economic sectors to participate in investment. Energy storage systems on both large, small and microscale. On a micro scale, for rooftop solar power, we have already had a fairly large amount of capacity that can be integrated with an energy storage system. Until December 31, 2021, there were 101,029 rooftop solar power projects (STMs) connected to the power system with a total installed capacity of nearly 9,296 MW, the output generated to the grid is more than 3.57 billion. MWh (EVN, 2021). And most of the rooftop solar power is owned by residential households – causing the largest load fluctuations when focusing on electricity use at peak hours. With the rapid increase of rooftop solar power and no storage system, all the excess solar power sold to the grid causes overload for the grid system. As a result, EVN stopped signing rooftop solar power purchase contracts after December 31, 2020 (EVN, 2021). To solve this problem, integrating the storage system with rooftop solar is a very effective method. This system was previously available and used by only a few customers. However, this system is used randomly without any strings attached, and the Government does not have a policy for this system to operate effectively. Therefore, this system does not provide the benefits that an energy storage system can provide. The question is whether the rooftop solar PV system will operate optimally for the grid and how the households will be affected. And what will be the economic and financial efficiency of this type of solar power with storage? To address these questions, the paper will build a model of a grid-tied rooftop solar power system with storage system. The paper includes: Sect. 2 builds the theoretical basis for the model of grid-tied rooftop solar power system with storage, Sect. 3 demonstrates a method to evaluate the economic efficiency of a grid-tied rooftop solar power project with storage, Sect. 4 simulates grid-connected rooftop electrical system with storage and evaluates economic efficiency and Sect. 5 gives conclusions and also recommendations.

2 Introduction

When considering any points of time, the grid-tied rooftop solar power system with storage will operate according to the following diagram (Fig. 1)

Nomenclature:

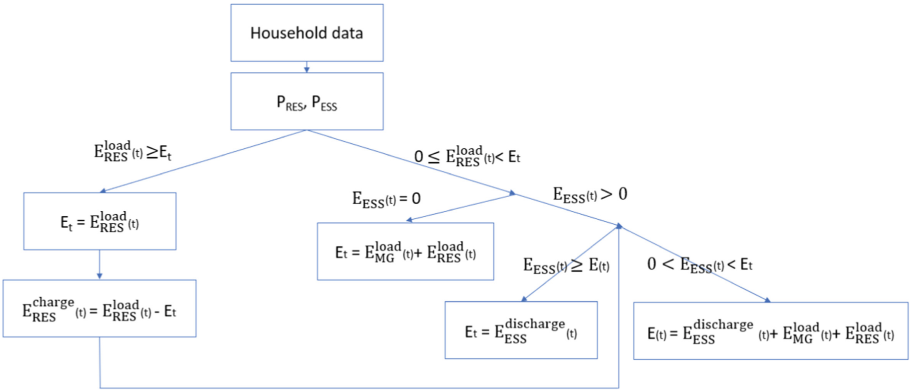

Fig. 1. Operation diagram of grid-tied rooftop solar power system with storage

P_{RES}:	Capacity of rooftop solar power system (kWp)	E^{load}_{RES}:	The amount of electricity from the solar power system used directly (kWh)
P_{ESS}:	Capacity of storage system (kW)	E^{load}_{MG}:	The amount of electricity directly used from the national grid (kWh)
E_t:	Demand for electricity (kWh)	E^{charge}_{RES}:	The amount of electricity from the solar power system used to store (kWh)
E_{ESS}:	The amount of electricity in the storage system (kWh)	$E^{discharge}_{ESS}$:	The amount of discharge electricity from the energy storage system (kWh)

Case 1: If the amount of solar electricityis larger than the household's demand: $E^{load}_{RES}\ (t) > E_t$.

Solar power will meet the needs of households:

$$E_t = E^{load}_{RES}\ (t)$$

Excess electricity will be used to charge the storage system:

$$E^{charge}_{RES}\ (t) = E^{load}_{RES}\ (t) - E_t$$

This excess electricity will be used when solar power does not meet the needs of the household.

Case 2: If the amount of solar electricity is smaller than the household's demand: $E^{load}_{RES}\ (t) < E\ t$

Case 2.1: The storage system is empty ($E_{ESS(t)} = 0$), the household will use the entire grid:

$$E_t = E^{load}_{MG}\ (t) + E^{load}_{RES}\ (t)$$

Case 2.2: The storage system has electricity ($E_{ESS\ (t)} > 0$), this case is divided into 2 cases.

Case 2.2.1. The storage system is larger than the demand ($E_{ESS\ (t)} > 0$), the household will use all the electricity discharged from the storage system:

$$E_t = E_{ESS\ (t)}^{discharge}$$

Case 2.2.2: The storage system is smaller than the demand and greater than 0 ($0 < E_{ESS(t)} < E_t$), the household use electricity from the storage system first and then to use electricity from the grid:

$$E_t = E_{ESS\ (t)}^{discharge} + E_{MG\ (t)}^{load} + E_{RES\ (t)}^{load}$$

3 Modeling Evaluates Economic and Financial Efficiency

3.1 Cost

The investment capital for a grid-tied rooftop solar power project with storage will include installation costs for the solar power system and the storage system. And the installation cost of both systems depends on the installed capacity.

Investment capital = Solar power system capacity * unit price + Storage system capacity * unit price

Determine the Capacity of the Rooftop Solar Power System

First, from household data, we determine the amount of electricity produced by the rooftop solar power system (kWh) calculated by the formula:

$$E_{RES} = S * H * B * PR * f$$

E_{RES}: The amount of electricity produced by the rooftop solar power system (kWh)

S: Installation area (m2)

B: Radiation intensity (kWh/m2)

PR: Efficiency degradation factor of solar panels over time (%)

H: PV panel efficiency (%)

f: is the loss coefficient

From there we can determine the investment capacity:

$$P_{RES} = \frac{E_{RES}\text{(total 20 years)}}{30 * 12 * \text{Number of hours of sunshine in a day} * 0,8 * 20}$$

Note: Explain the factor 0.8 in the above formula. Since there are many factors that affect the peak capacity of the panels (tilt, efficiency direction of the inverter,...) So when calculating we estimate the efficiency will be about 80% (Givasolar, 2020).

Determine the Capacity of the Storage System

Since the excess electricity from the energy storage system cannot be sold to the national grid, the storage system must store all the excess electricity. In order to save investment costs of the storage system, we will consider energy storage and use in a day. Considering 1 day, the capacity of the storage system must ensure to store the largest amount of solar electricity that can be generated minus the household's demand for use in the sunshine duration of the day: ERES max – Et.

3.2 Benefit

Electricity produced from the solar power system will be used for home and ESS charging.

$$E_{RES} = E_{RES}^{load} + E_{RES}^{charge}$$

Because the rooftop solar power system can only produce in the sunshine duration of the day, this electricity will be used directly by the family, and the rest is used to charge the storage system. (n: electricity consumed at night/all day).

$$E_{RES}^{charge} = ERES - nE$$

(if $E_{RES} < nE$ at all times: the household consumes all the electricity generated by the rooftop solar system, so there is no need to use the storage system).

However, in this simulation, the storage system is only enough to store and be used for 1 day. The amount of electricity in the storage system is not large for the amount of electricity that households use at night.

$$E_{RES}^{charge} < (1 - n)E$$

Because the storage system has a utilization factor of efficiency and depth (η: utilization factor of the storage system):

$$E_{RES}^{discharge} = \eta E_{RES}^{charge}$$

The amount of grid electricity a household must buy after installing a rooftop solar power system with storage is

$$E(s) = E(t) - E_{RES}^{load} + E_{RES}^{discharge}$$

Therefore, the benefit of the project is the amount of electricity saved from the grid after installing a rooftop solar power system with storage.

4 Simulation of a Grid-Tied Rooftop Solar Power System with Storage System

4.1 Scale of Simulation

Fixed Data

In the simulation using data on national grid prices according to Decision 648/QD-BCT dated 20/3/2019. From the data on the annual change of grid electricity price in

Table 1. .

Period	Demand (kWh)	Period	Demand (kWh)	Period	Demand (kWh)
0–1	0.2	8–9	0.6	16–17	0.3
1–2	0.2	9–10	0.3	17–18	1
2–3	0.2	10–11	0.6	18–19	1.4
3–4	0.2	11–12	1.3	19–20	1.5
4–5	0.2	12–13	1.4	20–21	1.4
5–6	0.3	13–14	1	21–22	0.8
6–7	0.6	14–15	0.8	22–23	0.6
7–8	0.8	15–16	0.3	23–24	0.2

the period (2009–2021), the simulation will use the average increase in grid price of 5%/year. Simultaneously, the simulation uses the uniform depreciation method and the discount rate of 10% for the project. And the project life cycle time is 20 years.

Household Data

Considering the size of households in Ninh Thuan, the average monthly electricity consumption is about 550 kWh/month. The proportion of daytime consumption will account for about 60% of total daily consumption. The household wishes to install a solar power system with an area of about 18 m^2.

For use in analyzing the effects of grid-tied rooftop solar power storage systems with storage, the typical household demand usage simulation in a day is as shown in Table 1.

Solar Panel System Data

The cost for 1 kWp of solar power is about 15 million (Dat solar, 2022). In which the cost includes: Solar panel, Inverter hybrid, Junction box, DC, AC electrical cabinets and other accessories, Construction, installation, Survey, Equipment Design, Warranty service, after-sales, Truss brackets,…And some technical parameters about the solar power system:

PR: Convention is 1%/year (Nguyen Hoang Lan, 2021)

H: About 20% on average (Nguyen Hoang Lan, 2021)

f: is the loss coefficient due to conversion from DC to AC when passing through the inverter, losses on power lines, due to dust, weather, etc. This coefficient is from 0.5 to 0.9 and is usually taken as 0.75.

Storage System Data

The simulation will use the storage system as a Lithium Battery (LiFePo4 technology). These batteries provide a very long cycle life of about 6000 to 8000 cycles. This number of cycles is enough for a 20-year lifecycle of a rooftop solar power system with an operating cycle of as little as one day. With high discharge and recharge rates and up to 95%–98% round trip efficiency. Combined with the deep charge (DoD), the utilization

Table 2. The amount of solar electricity in hourly simulation

Period (hour)	The amount of solar electricity (kWh)	Period (hour)	The amount of solar electricity (kWh)
0–1	0	12–13	1.772
1–2	0	13–14	1.584
2–3	0	14–15	1.267
3–4	0	15–16	0.842
4–5	0	16–17	0.439
5–6	0.001	17–18	0.079
6–7	0.257	18–19	0
7–8	0.736	19–20	0
8–9	1.208	20–21	0
9–10	1.564	21–22	0
10–11	1.775	22–23	0
11–12	1.835	23–24	0

factor of the storage system is $\eta = 0.9$. The current cost of lithium electricity storage batteries is quite high, about 26 to 30 million for a capacity of 5.12 kW (GIGAWATT, 2022). However, the minimum capacity of this battery type is 2.56 kW and there are other capacities such as 5.12 kW or 10.24 kW. So when installing the storage system will install to the nearest capacity level.

4.2 Simulation of Grid-Tied Rooftop Solar Power System with Storage System

The model will simulate the use of a rooftop solar system with integrated grid-tied storage for one day. Periods will be divided into 24 h. This simulation can show the influence of the system on the change in electricity demand of the household. Using the data of households in Sect. 3, the preliminary calculation model of the system scale is to use a solar cell system with a capacity of 3 kWp and a storage system with a capacity of 7.68 kW. The simulation uses solar radiation data taken from a day in July (Global Solar Atlas, 2022) and calculates the hourly amount of solar electricity as shown in Table 2.

The Case of Cost Optimization

In the case of cost optimization, households will prioritize using solar power, and the excess will be charged to the storage system. Electricity in the storage system will be used as soon as solar power does not meet the needs of the household and will be used until it runs out. Only then will households use electricity from the national grid. In this way, households will have to buy the minimum amount of electricity purchased from EVN and avoid high electricity prices. From the data and calculation results, the simulation of using the grid-tied storage system with storage is as shown in Table 3.

Table 3. The results of the simulation in the case of cost optimization

A	B	C	D	E	F
0–1	0	0.2	0	0	0
1–2	0	0.2	0	0	0
2–3	0	0.2	0	0	0
3–4	0	0.2	0	0	0
4–5	0	0.2	0	0	0
5–6	0.01	0.29	0	0	0
6–7	0.257	0.343	0	0	0
7–8	0.736	0.064	0	0	0
8–9	0.6	0	0.608	0.608	0
9–10	0.3	0	1.264	1.872	0
10–11	0.6	0	1.175	3.047	0
11–12	1.3	0	0.535	3.582	0
12–13	1.4	0	0.372	3.954	0
13–14	1	0	0.584	4.538	0
14–15	0.8	0	0.467	5.006	0
15–16	0.3	0	0.542	5.547	0
16–18	0.3	0	0.139	5.686	0
17–18	0.079	0	0	4.663	1.023
18–19	0	0	0	3.107	1.555
19–20	0	0	0	1.441	1.666
20–21	0	0.1035	0	0	1.441
21–22	0	0.8	0	0	0
22–23	0	0.6	0	0	0
23–24	0	0.2	0	0	0

Note: A: Period (hour)
B: The amount of electricity used from solar electricity ((kWh)
C: The amount of electricity purchased from the grid after system installation (kWh)
D: The amount of stored electricity (kWh)
E: The amount of stored electricity in the storage system (kWh)
F: The amount of discharge from the storage system (kWh)

From the table of results, we can clearly see that the amount of electricity that households buy from the national grid has decreased significantly (Fig. 2).

To compare the amount of electricity that households buy from the national grid before and after installing a grid-connected rooftop solar power system with storage, we have the following chart (Fig. 3).

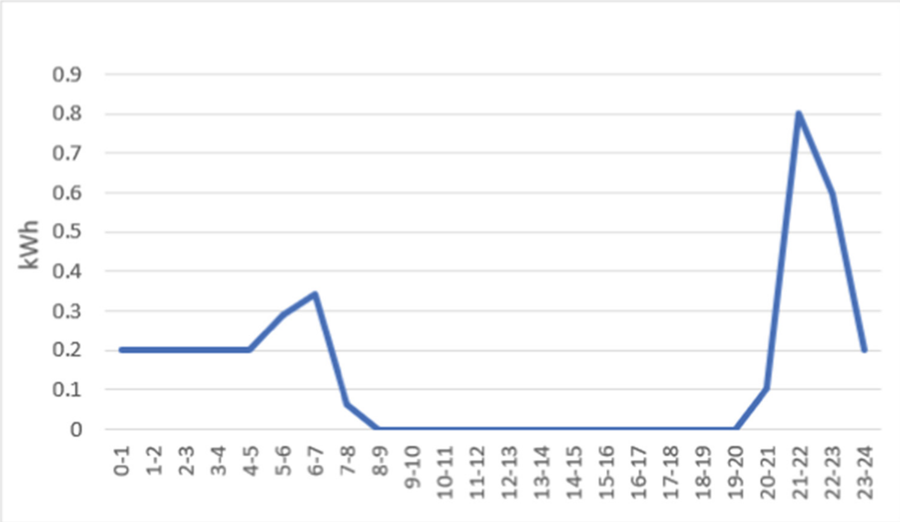

Fig. 2. Household electricity graph purchased from the grid after system installation

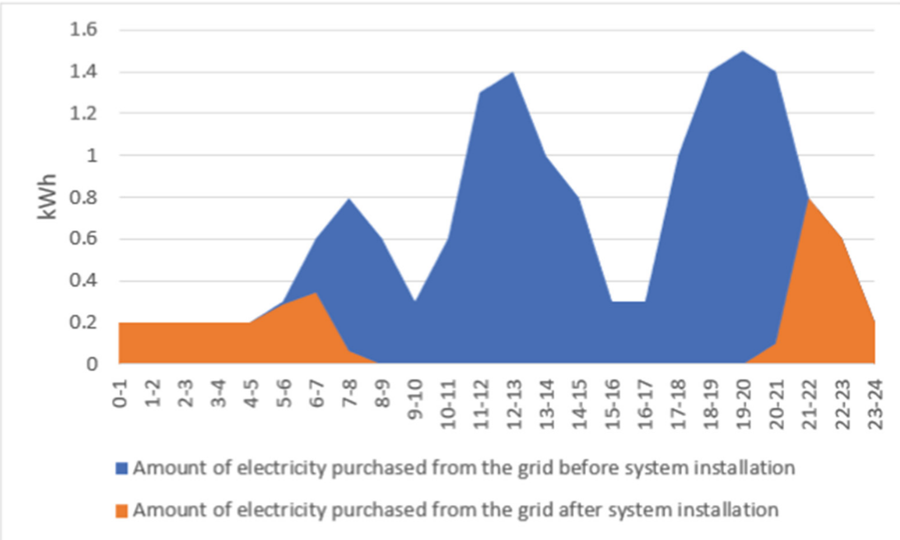

Fig. 3. Comparison graph between before and after installation of the system

From the results, we can calculate the PAR coefficient (PAR: the ratio between peak load demand and average load demand in a day, from t = 1 to t = 24).

$$PAR = \frac{\max\left(E_{LD(t)}\right)}{\frac{1}{T}\sum_{t=1}^{T} E_{LD(t)}} = 5.646$$

In addition, from the results table, we analyze the influence of the rooftop solar power system with storage on the consumption needs of households as follows:

From 5 to 8 o'clock:

$$E_t = E^{load}_{MG\ (t)} + E^{load}_{RES\ (t)}\ (t = 5 - 8)$$

From 8 to 17 o'clock:

$$E_t = E^{load}_{RES\ (t)}\ (t = 8 - 17)$$

From 17 to 18 o'clock:

$$E_t = E^{discharge}_{ESS\ (t)} + E^{load}_{RES\ (t)}\ (t = 17 - 18)$$

From 18 to 20 o'clock:

$$E_t = E^{discharge}_{ESS\ (t)}\ (t = 18 - 20)$$

From 20 to 21 o'clock:

$$E_t = E^{discharge}_{ESS\ (t)} + E^{load}_{MG\ (t)}\ (t = 20 - 21)$$

From 21 to 5 o'clock:

$$E_t = E^{load}_{MG\ (t)}\ (t = 21 - 5)$$

From the results and analysis, I draw the following conclusions:

- The characteristics of household use at some times during the sunny hour are quite low, such as the period from 8 am to 10 am or 1 pm to 5 pm. During this period, solar power is quite large despite the small installed capacity. It is advisable to let the demand for use be smaller than the amount of solar electricity generated, requiring a very small installed capacity of solar power or increasing electricity use at those times. These two problems are difficult to solve when installing a small roof solar power system that will not bring many economic benefits, while increasing electricity use causes trouble for households. Therefore, it is very difficult to install a solar power capacity smaller than the demand in all the sunshine duration of the day.
- Because the excess electricity is stored and used as soon as solar power does not meet the demand and does not sell electricity to the national grid, it does not put pressure on the national grid.
- The amount of electricity purchased from the national grid has been reduced from 16.2 kWh to 3.4 kWh. This helps households save money on electricity. Especially when Vietnam's grid electricity price is a ladder price, when households reduce the amount of electricity purchased from the grid, they will reduce their high electricity bills at high consumption levels.
- Peak household demand decreased from 1.5 kWh to 0.8 kWh. But PAR is still quite high at 5.64 because the difference between hourly electricity demand is still high.

– The amount of electricity used during peak hours has been significantly reduced. Especially during peak hours from 9 am to12 am. Due to the storage system, the amount of electricity used during the afternoon rush hour has decreased significantly.

The Case of Grid Operation Optimization

In this section, we will simulate so that the amount of electricity purchased from the national grid by the household in each hour has the lowest difference or the lowest PAR possible and the total amount of electricity used in the day is unchanged. In this simulation, we consider the storage system to be ideal with a discharge efficiency of 100% and base the calculation from when the electricity from the solar system is greater than the household demand. From there, we calculate the average hourly amount of electricity that households will have to buy from the national grid.

$$E^{load}_{MG-TB\ (t)} = \frac{\sum_{24}^{1}(E_t - E^{charge}_{RES})}{24} = 0.118(\text{kWh})$$

From there the following Table 4 of results:

From the results, we can calculate the coefficient PAR (Fig. 4):

$$PAR = \frac{\max(E_{LD(t)})}{\frac{1}{T}\sum_{t=1}^{T} E_{LD(t)}} = 1.45$$

In addition, from the results table, we analyze the influence of the rooftop solar power system with storage on the consumption needs of households as follows:

From 8 to 17 o'clock:

$$E_t = E^{load}_{MG-TB\ (t)} + E^{load}_{RES\ (t)}\ (t = 8 - 17)$$

From 17 to 18 o'clock:

$$E_t = E^{load}_{MG-TB\ (t)} + E^{load}_{RES\ (t)} + E^{discharge}_{ESS\ (t)}\ (t = 17 - 18)$$

From 5 to 8 o'clock:

$$E_t = E^{load}_{MG-TB\ (t)} + E^{discharge}_{ESS\ (t)}\ (t = 5 - 8)$$

From 5 to 6 o'clock:

$$E_t = E^{load}_{MG-TB\ (t)} + E^{load}_{RES\ (t)} + E^{discharge}_{ESS\ (t)}\ (t = 5 - 6)$$

From 6 to 7 o'clock:

$$E_t = E^{load}_{MG-TB\ (t)} + E^{load}_{MG\ (t)} + E^{load}_{RES\ (t)} + E^{discharge}_{ESS\ (t)}$$
$$(t = 6 - 7)$$

From 7 to 8 o'clock:

$$E_t = +E^{load}_{MG\ (t)} + E^{load}_{RES\ (t)}\ (t = 7 - 8)$$

From the results and analysis, we draw the following conclusions:

Table 4. The results of the simulation in the case of optimization of grid operation

A	B	C	D	E	F
8–9	0.482	0.118	0.726	0.726	0
9–10	0.182	0.118	1.382	2.108	0
10–11	0.482	0.118	1.293	3.401	0
11–12	1.182	0.118	0.653	4.054	0
12–13	1.282	0.118	0.490	4.544	0
13–14	0.882	0.118	0.702	5.246	0
14–15	0.682	0.118	0.585	5.831	0
15–16	0.182	0.118	0.659	6.491	0
16–17	0.182	0.118	0.257	6.748	0
17–18	0.079	0.118	0	5.945	0.803
18–19	0	0.118	0	4.663	1.282
19–20	0	0.118	0	3.281	1.382
20–21	0	0.118	0	1.999	1.282
21–22	0	0.118	0	1.317	0.682
22–23	0	0.118	0	0.835	0.482
23–24	0	0.118	0	0.753	0.082
0–1	0	0.118	0	0.671	0.082
1–2	0	0.118	0	0.589	0.082
2–3	0	0.118	0	0.507	0.082
3–4	0	0.118	0	0.425	0.082
4–5	0	0.118	0	0.343	0.082
5–6	0.010	0.118	0	0.171	0.172
6–7	0.257	0.172	0	0	0.171
7–8	0.736	0.064	0	0	0

Note: A: Period (hour)
B: The amount of electricity used from solar electricity (kWh)
C: The amount of electricity purchased from the grid after system installation (kWh)
D: The amount of stored electricity (kWh)
E: The amount of stored electricity in the storage system (kWh)
F: The amount of discharge from the storage system (kWh)

– The amount of electricity saved by the household is still guaranteed. The household load graph has been relatively flat and greatly reduced consumption during peak hours. However, the capacity of the storage system increased significantly when the largest amount of stored electricity increased from 5,686 kW to 6,748 kW. This can increase investment costs and make it less economically efficient.

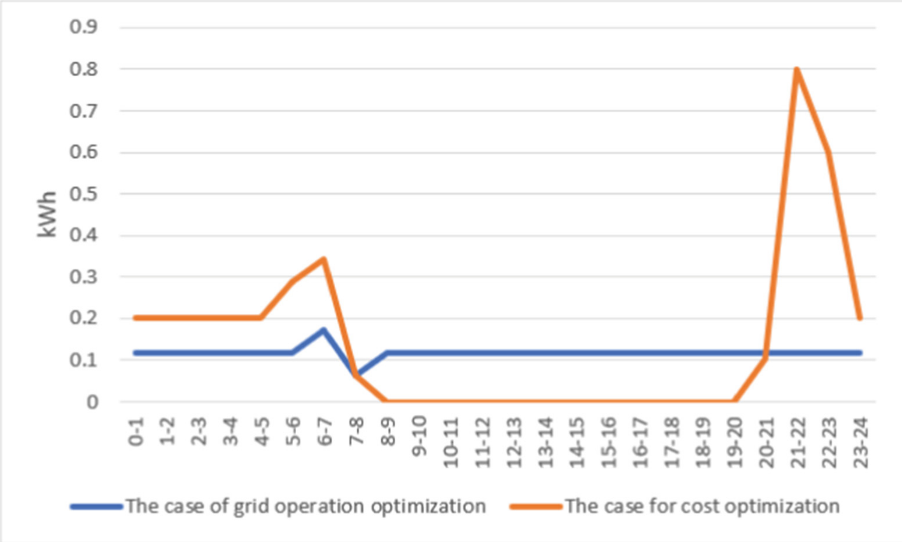

Fig. 4. Comparison graph of grid operation optimization and cost optimization

- The amount of electricity purchased from the national grid is much more stable than in the case of cost optimization. PAR index lowered from 5.64 to 1.45.
- Because to ensure the savings of the household, it is not possible to buy more electricity from the grid to store it in the storage system. So when the electricity stored from solar power runs out, the system will be less flexible.
- Because to ensure the durability of the storage system, when a charge-discharge cycle expires in a day, the storage system will no longer support efficient operation.

4.3 Evaluation of the Economic and Financial Efficiency of the Grid-Tied Rooftop Solar Power System with Storage System

Analyze the Economic and Financial Efficiency of the Simulation

The simulation will calculate the monthly benefits of the project. Then sum it up year by year over the project's 20-year lifecycle.

Consider the first month of the first year of the project lifecycle:

Amount of solar electricity: S * H * B * PR * f = 18 * 142.1 * 100% * 20% * 0.75 = 383.67 (kWh)

The amount of electricity used in the sunshine duration of the month: 550 * 60% = 330 (kWh) < 383.67 (kWh)

Therefore, the household will use the entire amount of solar electricity corresponding to 300 kWh.

The amount of electricity charged into the storage system = The amount of solar electricity – The amount of electricity used by households in the sunshine duration = 383.67 – 330 = 53.67 (kWh).

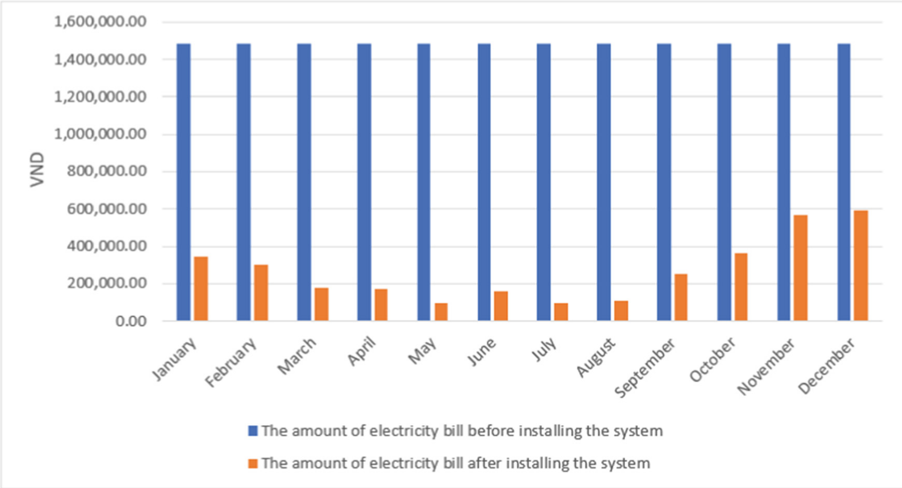

Fig. 5. Comparison chart of electricity bills before and after system installation in the first year

Because the system stores the amount of electricity there will be losses. Amount of electricity discharged from the storage system = 53.67 * 90% = 48.3 (kWh).

The amount of electricity the household needs to buy from the grid in a month = Monthly electricity consumption – The amount of solar electricity used by the household – The amount of electricity discharged from the storage system = 550 – 300 – 48.3 = 171.7 (kWh).

The amount to be paid by the household after installing the system = 171.7 * electricity price = 346.497.53 (VND).

The benefit of the project is the difference between the electricity bill that households have to pay before and after installing the system = 1,482,855 - 346,497.53 = 1,136,357.47 (VND).

Similar to other months in the first year, model will calculate the details of each month of the year. From monthly calculated data, the model aggregates data year by year to build a benefit stream for the project (Fig. 5).

The system has helped households reduce a lot of electricity bills purchased from the national grid, especially in the summer months with lots of sunshine from April to September. In the following years, due to the decline in efficiency of solar panels over time (about 1%/year), so the amount of solar electricity generated will be less than in the first year. However, because the annual electricity price will change with an upward trend (about 5%), it will help the amount of money that households save more money to buy from the grid.

From the above data, the model calculates the capacity of the solar power system and the capacity of the storage system as follows:

The installed household solar power system capacity is:

$$P_{RES} = \frac{93,477.66}{30 * 12 * 0.8 * 5.5 * 20} \approx 3(\text{kWp})$$

The capacity of the storage system will have to ensure that it can store the largest amount of electricity between the amount of solar electricity and the household's electricity demand during the day. In this simulation, the biggest difference will be in July, the month with the largest amount of solar electricity generated. In July, the average amount of electricity stored per day is:

$$\frac{514.89 - 330}{30} = 6.163(\text{kWh})$$

Since the minimum capacity of the storage system is 2.56 kW, and to ensure that the entire amount of electricity is stored even in the event of a sudden spike in solar radiation, the nearest power level is 7.68 kW is selected.

Investment capital for the project is:

Investment capital = Cost of rooftop solar power system + Cost of storage system ≈ 89,260,253.64

Annual O&M cost = Investment capital * 1% = 89,260,253.64 * 1% = 892,602.54

From the cost and benefit data of the project, the model analyzes the investment efficiency and gives the following results:

Payback period = 8.66 (years)

NPV = 69,898,848.39 (VND) > 0

IRR = 18.58% > 10%

B/C = 1.72 > 1.

Overall, all the economic indicators obtained show that the project is economically viable. In addition, the project helps to reduce CO_2 emissions into the environment. However, the payback period is still quite large compared to the type of rooftop solar power without storage. The grid-tied rooftop solar power system with storage system is undeniably efficient in terms of grid operation, but it is not attractive because the efficiency level of the project is not high. However, the development of science and technology as well as the Government's policies, we expect future investment costs will decrease and economic efficiency will be higher and higher.

Scenario Analysis in Case of Area Change

With the same data on households and installed area, the model will evaluate the effect when the area of the household changes (Table 5).

The efficiency level of each area varies considerably. The difference is substantial due to the increase in investment capital as the capacity of the storage system differs in each region. Due to the same scale of installation:

In areas with good radiation such as Ninh Thuan, Binh Thuan,… a large amount of electricity solar helps households save more electricity, but the cost of the storage system will increase while the electricity savings cannot compensate all expenses.

In areas with moderate radiation such as Saigon, Tien Giang,.. having amount of electricity solar is moderate, the cost of the storage system can be offset by the amount of money saved.

In areas with low solar radiation such as Son La, Lai Chau,… having amount of electricity solar is low, so it does not cost much for the storage system and helps to save investment capital.

Table 5. Data sheet in case of area change

No.	Area	PRES (kWp)	PESS (kW)	Investment Capital (VND)	Payback period (years)
1	Ninh Thuan	2.95	7.68	89,260,253.64	8.66
2	Binh Thuan	3.06	7.68	90,906,074.88	8.51
3	Sai Gon	2.77	5.12	71,555,240.50	6.77
4	Tien Giang	2.70	5.12	70,428,539.68	6.83
5	Lai Chau	2.63	2.56	54,485,146.99	6.55
6	Son La	2.58	2.56	53,688,590.53	6.16

Table 6. Data sheet with the area of solar panels changes

S (m^2)	PRES (kWp)	PESS (kW)	Payback period (years)
15	2.46	5.12	7.09
16	2.62	5.12	6.97
17	2.79	7.68	8.82
18	2.95	7.68	8.67
19	3.11	7.68	8.56
20	3.28	10.24	10.35
21	3.44	10.24	10.19
22	3.61	10.24	10.05

From there, it can be seen that the optimal installation scale for each area is different. The optimal scale will greatly affect the investment efficiency of the project. Therefore, when installing, it is necessary to calculate to optimize both the solar power system and the storage system to bring the highest level of efficiency.

Scenario Analysis in Case the Area of Solar Panels Changes

To find the optimal system installation scale for simulation, the model will analyze the change of PV panel installation area. The reason is the fact that the capacity of the storage system will depend on the amount of solar electricity. Therefore when changing the installation area, the capacity of the storage system will change (Table 6).

From the results and analysis, we draw the following conclusions:

– For grid-tied rooftop solar power systems with storage systems, the smaller the scale is, the more efficient it is. The effectiveness of the project depends a lots on the capacity of the storage system or the difference of the maximum amount of solar electricity during the day and the amount of electricity consumed in the sun by the household.

The smaller the amount of electricity stored, the more economically efficient it is for the household. However, large scale is more efficient for grid operation.
– At different scales, the ratio of costs for the storage system to the total investment will change. However, because the cost of the storage system is still high, this rate can be from 30% to more than 50%.
– With the same capacity for the storage system, the larger the PV panel installation area, the higher the efficiency level. Due to the lack of variety in the storage system capacity market, there are only certain types of capacity levels. Therefore, with the same capacity of the storage system, it is advisable to install the scale of the solar power system so that it can be used optimally.

5 Conclusions and Recommendations

This paper has built a model to simulate a grid-tied solar power system with a storage system. At the same time, it has been applied this model to a typical project in Ninh Thuan with household objects in the cases of cost optimization, operation optimization and evaluation of the economic and financial efficiency of the project. From this application, it would be easy to analyze and make general assessments, problems of the grid-tied solar power system with storage in terms of both economic and technical aspects.

In terms of economic efficiency, the grid-tied rooftop solar power system has a lower storage system than non-storage one due to the additional investment costs for the storage system. The cost for the storage system accounts for a relatively high proportion from 30% to more than 50% of the total investment depending on the scale. However, the grid-tied rooftop solar power system with storage system still helps households reduce a great amount of electricity bills, and the level of economic efficiency is fairly good. According to studies, in the future, the cost of solar power systems and storage will both reduce by up to 50%, then the economic efficiency of this type will be considerably improved. The factor that has the most momentous influence on the economic efficiency of a grid-tied rooftop solar power system with a storage system is the largest amount of solar electricity generated during the day and the household's demand for consumption in the sunshine duration of the day. The difference between these two factors will determine the capacity of the storage system. The slighter the difference is, the smaller capacity of the storage system will be, which leads to a significant reduction in initial investment costs and vice versa.

In terms of grid operation, this type will bring obvious effects, for instance not putting pressure on the power grid, reducing the peak demand of households, flattening the load pattern, and reducing the demand for electricity at peak hours, etc. In the case of cost optimization, this model will help reduce the amount of electricity purchased from the grid in the morning at peak hours, while at the afternoon peak hours will not bring much impact. The difference between the ratio between the peak load demand and the average total load demand during the day is still quite high owing to the time not using grid electricity and the time using grid electricity during peak hours. In the case of grid operation optimization, the amount of electricity purchased from the national grid by households in each hour has the subtlest difference and still ensures the amount of money that households can save every month. Peak demand of households decreased significantly compared to the case of cost optimization, the amount of electricity purchased in both peak hours also decreased greatly. However, the capacity of the storage system must increase dramatically. This leads to the increasing of investment costs and also reduction of economic efficiency levels. Due to the guarantee that the electricity level and the amount of electricity purchased from the household's grid are constant, the storage system has not been able to promote its full regulatory capacity. From that, it can be seen that the interests of households and the interests of EVN are opposite. The larger the scale of the system, the more benefits EVN brings but reduces the benefits for households and vice versa.

Therefore, it is very prominent to optimize the use of grid-connected rooftop solar power systems with storage and balance the benefits between households and EVN. To do this, it is necessary to carefully calculate the size of the installation to maximize the use of the storage system and match the data of the household. In addition, on the government's side, to encourage initial projects, the Government promulgates regulations that the selling price of electricity from storage batteries is equivalent to the electricity price during peak hours of the system, or allows the selling price of electricity from projects with storage system be higher than normal projects or preferential policies or capital support,… For households, only with the binding condition that EVN have to operate the storage system and also ensure the interests of households., the model of investment coordination between households and EVN could be used.

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