# Suitable Energy Management Strategy for the Large Factory in Thailand Using Practical Load Profile

Mongkol Treekijjanon, Nitikorn Junhuathon, Uthen Leeton, and Thanatchai Kulworawanichpong*

***Abstract—*** *Nowadays, many large factories use much electricity in the world. Therefore, a suitable energy management strategy to reduce the Cost of Energy (COE) of the large factory was interested in. In this paper, the PCS Machine group holding limited company factory was selected to test system because this factory had the policy to reduce the cost of energy the same as the interesting topics. The factory is located in Mueang District, Nakhon Ratchasima Province. The PV solar roof 8 MW already has installed in this factory. The average load of PCS is 198,740.64 kWh/day, and peak load is 15,852.35 kW. The strategies have proposed in 3 way included (1) installing the optimal size solar rooftop (2) installing the optimal size solar rooftop and batteries (3) installing the solar rooftop and batteries with the size that can work in islanding mode. The simulation results showed COE of the base case and strategy 1 to 3 are 2.97 THB/kWh, 2.77 THB/kWh, 2.76 THB/kWh, and 6.25 THB/kWh, respectively. The first strategy that installed the optimal size solar rooftop on the PCS factory can reduce COE from base case down to 0.2 THB/kWh. The second strategy that installed optimal size solar rooftop and BESS on the PCS factory can reduce COE from the strategy 1 just 0.01 THB/kWh but have high capital cost and longer payback period. Therefore, the second strategy that installed optimal size solar rooftop is the most suitable in the present.*

***Keywords—*** **Energy management strategy, solar roof, cost optimization.**

## 1. INTRODUCTION

Nowadays, there are many factories using much energy cause of high energy costs. In addition, the most energy that produced carbon-dioxide from coal and natural gas cause of global warming. thus, the concept of using renewable energy to reduce COE and pollution is interesting [15-16].

Renewable Energy Resources (RERs) are gained more global attention due to global warming and high energy consumption cause RERs are interested in managing energy for home office and factory in various area. From the comparing result of the COE between conventional resources and RERs, the COE of RERs are less than conventional energy [1].

The installing investment of renewable energy are increased continuously in developed countries such as United States, China, Japan cause many researchers are researching to develop a renewable energy system that can reduce COE and have not an adverse badly effect on the environment [2]

The integration of RERs especially solar rooftop system has been commonly used on commercial buildings to reduce COE and to improve clean energy [3]. From the survey, many factories have much free space on a rooftop cause the solar rooftop is interested in using for reducing COE of the factories. Thus, the solar rooftop is the most appropriate renewable energy resource to use with factories [4-5].

The current renewable energy system design has various method such as using PVsyst, Using artificial intelligent and HOMER, etc. In this research, the design is proposed using a HOMER program because it has many renewable energy sources and component such as wind energy, solar energy, and battery, etc. In addition, this program can analyze both electrical parameter and economic parameters. for a decade, the program has been used widely to design many renewable energy systems such as analyzing wind-solar hybrid power system cost using HOMER for Statesboro, designing optimum standalone hybrid renewable energy system using HOMER for a small community of Portland, designing optimization and operation of a renewable energy based PV using homer [12-14] cause the HOMER program is reliable to design renewable energy systems.

This paper proposed a suitable strategy to reduce COE of the factories base on renewable energy system installation using HOMER program to design the optimal size of the component. The organization of this paper is as follows: Section II is system description. The methodology is introduced in Section III. In Section IV, Energy management strategies are introduced. Simulation results are discussed in Section V. Section VI concludes the paper.

## 2. SYSTEM DESCRIPTION

### *Load profile*

In this paper, The PCS factory was analyzed to reduce COE because this factory had high electricity price and interested to use RERs to reduce COE. The average load

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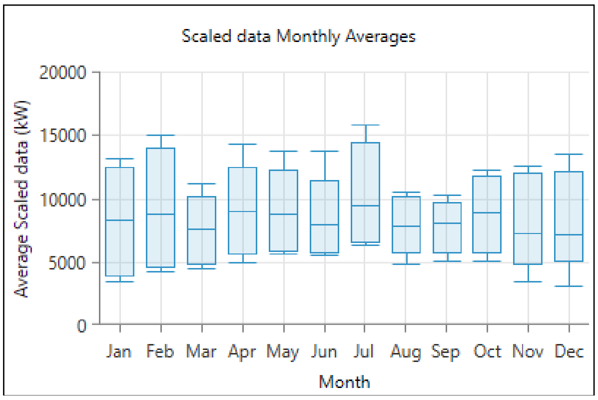
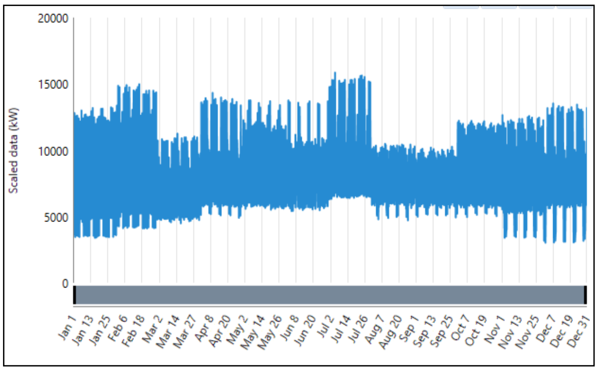
of the factory is 198.74 MWh/day, and peak load is 15.85 MW. Following Fig. 1.




(a)




(b)

**Fig. 1. (a) Scale data monthly averages load; (b) Scale data load profile in a year**

### *Price of Component*

In this paper, the actual price of the component was used to analysis following TABLE 1.

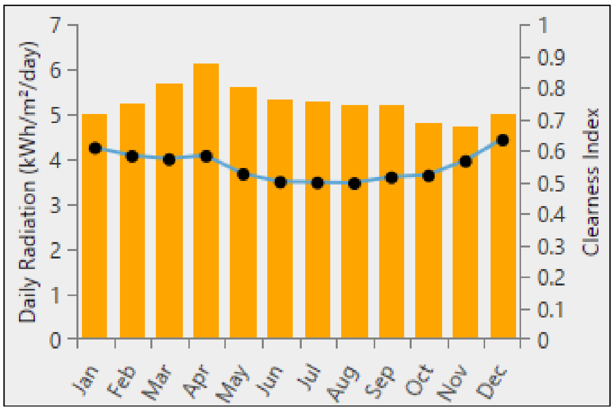
**Table 1. Price of component**

| Component | Capital Cost (THB/MW) | Operation & Maintenance cost (THB/Year) | Life Time (Years) |
|---|---|---|---|
| PV Solar roof (Jinko JKM320) | 21,500,000 | 300,000 | 25 |
| Inverter (SMA25) | 1,500,000 | - | 15 |
| Battery MWh | 6,652,000 | 100,000 | 10 |

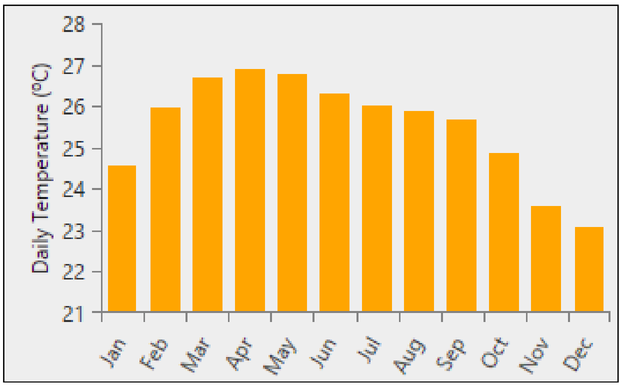
**THB=Thai Bath*

### *Solar radiation and Temperature*

The resources in this simulation can be taken from actual information. Monthly average solar irradiation is 5.27 kWh/m2/day, and the annual average temperature on the solar roof is 25.53 °C. The latitude and longitude coordinates are 14°54.7'N 101ₒ56.5'E, respectively. following Fig. 2.




(a)




(b)

**Fig. 2. (a) Solar irradiation resource; (b) Temperature resource.**

## 3. METHODOLOGY

### *HOMER*

Homer is the global tool for optimizing microgrid design in all sectors, from village power and islanding mode to grid-connected campuses and military bases. Homer Pro, or HOMER (Hybrid Optimization of Multiple Electric Renewables), simplifies the task of evaluating designs for both off-grid and grid-connected power systems.

There are much research using HOMER to the optimal size of a component such as designed and optimize cost, designed suitable hybrid system [6-10], etc., al. Thus, this paper use HOMER to find a suitable strategy for large industry base on RERs installation.

### *The implementation of HOMER*

The first step to designing a renewable energy system is defining the scope of the project included discount rate, inflation rate, annual capacity shortage, and lifetime project following Fig. 3. The second step is improving the grid in AC bus and defining electrical price following rate of governor following Fig. 4. The third step is improving load per hour in a year in the AC bus following Fig. 5.

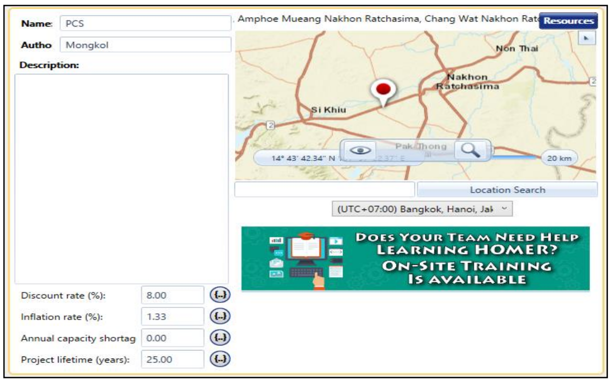



Fig. 3. Scope of the project.

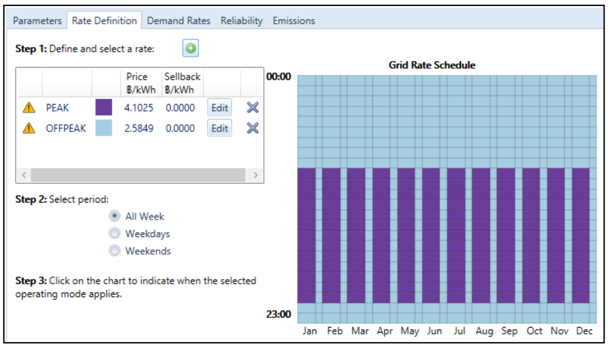



Fig. 4. Electrical price following rate of the governor

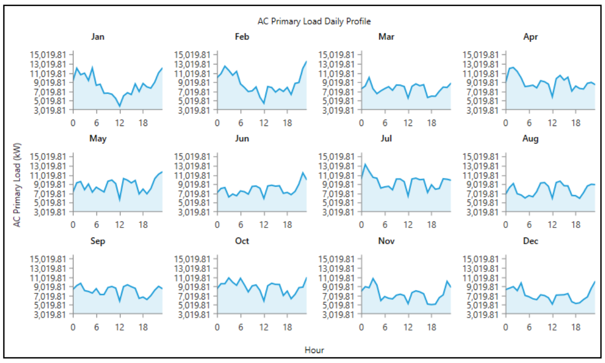



Fig. 5. AC primary load profile.

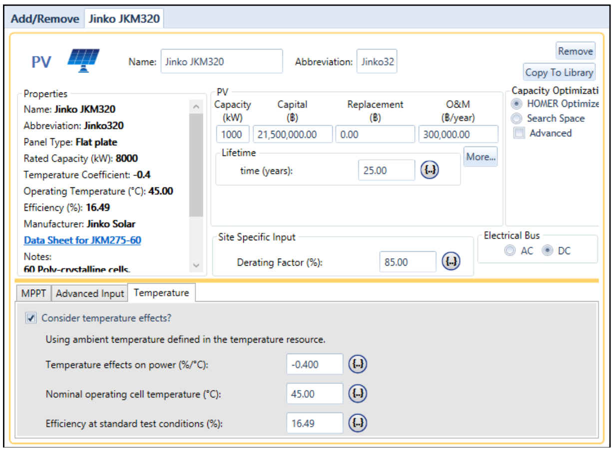



Fig. 6. Data of the solar cell.

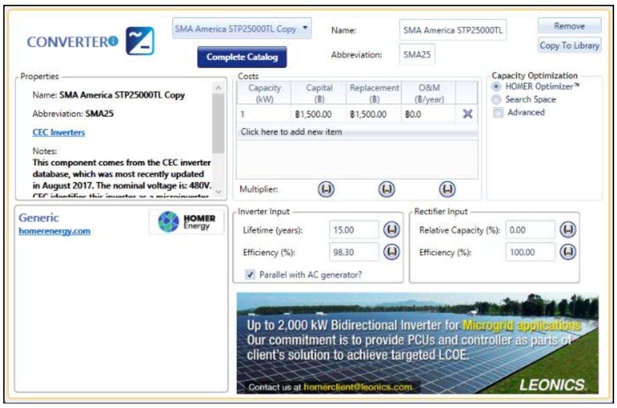



Fig. 7. Data of the inverter.

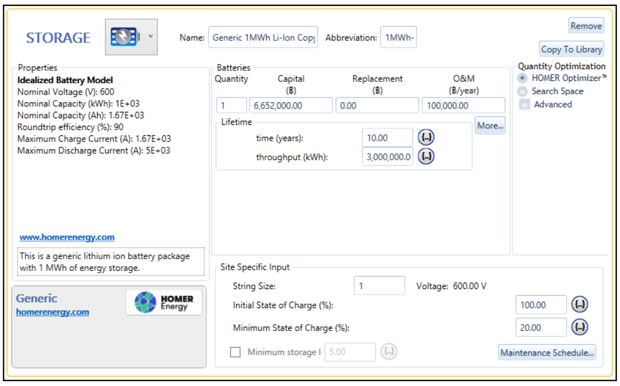



Fig. 8. Data of the energy storage.

The fourth step is improving solar cell in DC bus and defining data of the solar cell following Fig. 6. The fifth step is improving inverter to convert generated power from DC bus to AC bus following Fig. 7. The sixth is improving battery in DC bus following Fig. 8, and the last step is analysis all parameter following Fig. and show results by HOMER program.

### *Cost Analysis Procedure in Homer*

Net present cost (NPC) is the installation cost and the operating cost of the system throughout its lifetime following as [11]:

$$NPC = \frac{TAC}{CRF(i, R_{prj})} \tag{1}$$

where, *TAC* is the total annualized cost; *CRF* is a capital recovery factor; $i$ is the interest rate in percentage; and $R_{prj}$ is project lifetime in a year.

Total annualized cost (TAC) is the summation of the annualized costs of every equipment of the power system including capital and operation and maintenance cost. It also includes replacement and fuel cost [11]

Capital recovery factor (CRF) is a ratio that is used to calculate the present value of a series of equal annual cash flow [11]

$$CRF = \frac{i \times (1+i)^n}{(1+i)^{n-1}} \tag{2}$$

where $n$ is the number of years and $i$ is the annual real interest rate.

The annual real interest rate is a function of the nominal interest rate shown as [11]

$$i = \frac{i' - F}{1 + F} \tag{3}$$

where $i'$ is nominal interest rate and $F$ is the annual inflation rate.

Cost of energy (COE) is the average cost/kWh of useful electrical energy produced by the system.The COE is calculated as follows [11]:

$$COE = \frac{TAC}{L_{prim,AC} + L_{prim,DC}} \tag{4}$$

where $L_{prim,AC}$ is the AC primary load and $L_{prim,\,DC}$ is the DC primary load.

## 4. ENERGY MANAGEMENT STRATEGIES

In this thesis, the strategies are proposed in 3 cases and 1 base case included (1) Base case (2) strategy 1: Increasing to optimal size solar rooftop (3) strategy 2: Increasing to optimal size solar rooftop and BESS (4) strategy 3: Designing to the off-grid system following Fig. 9.

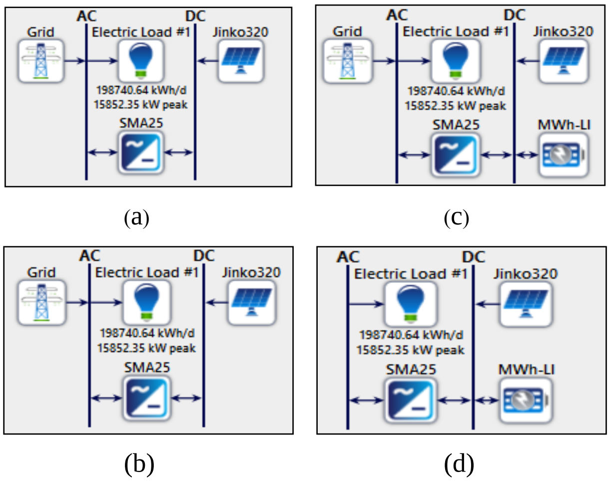



**Fig. 9. (a) Base case (b) strategy 1: Increasing to optimal size solar rooftop (c) strategy 2: Increasing to optimal size solar rooftop and BESS (d) strategy 3: Designing to an off-grid system.**

From all of the mentioned strategies, proposed strategies focus only the solar rooftop system because the much factories that were surveyed had a lot of space on the rooftop that can install solar rooftop but did not have suitable space for installing others RERs such as wind turbine. Therefore, this research focusses only solar rooftop from all of RERs. At present, battery price is constantly decreasing because battery is interested in using for storing and supply energy to reduce the COE. In addition, the strategy to design the factory as an off-grid system using solar rooftop and battery was proposed for the future. All of the Simulation results are shown in Section 5.

## 5. SIMULATION RESULTS AND DISCUSSION

After using all of the proposed strategies, the simulation results of the base case and strategies 1 to 3 are shown in Fig. 10. to Fig. 13 and table 2., respectively. For the base case that installed solar rooftop 8 MW, generated energy by solar rooftop is 12,521,131 kWh/year or 17.1% of annual load. The COE is 2.97 THB/kWh, the operation cost is 200 MTHB/year, and the initial capital is 181 MTHB. For the first strategy that improved the optimal size solar rooftop on the factory, generated energy by solar rooftop is 28,189,609 kWh/year or 35.9% of annual load. The COE is 2.77 THB/kWh, the operation cost is 168 MTHB/year, and the initial capital is 402 MTHB. The PBP is 5.55 year. The COE of the first strategy reduces from base case down to 0.2 THB/kWh and more PBP than base case just 0.9 years. For the second strategy that improved the optimal size solar rooftop and BESS on the factory, generated energy by solar rooftop is 28,189,760 kWh/year or 36.5% of annual load and the COE is 2.76 THB/kWh, operation cost is 163 MTHB/year, and the initial capital is 449 MTHB. The PBP is 9.92 year. The COE of the second strategy reduces from base case down to 0.21 THB/kWh and more PBP than base case 4.37 year. For the third strategy is designing PCS Machine group holding company limited to the off-grid system; the results show the optimal size solar rooftop producing enough to all load is 111.729 MW cause the capital cost of this strategy is too much, and the COE is 6.25 THB/kWh, the operation cost is 67.9 MTHB/year, and the initial capital is 4,670 MTHB. The PBP is over the life project.

**TABLE 2 Simulations results**

| Strategy | NPC (THB) | COE (THB/kWh) | Capital cost (THB) | IRR (%) | PBP (year) |
|---|---|---|---|---|---|
| base | 2.61B | 2.97 | 181M | 21.3 | 4.65 |
| 1 | 2.44B | 2.77 | 402M | 17.7 | 5.55 |
| 2 | 2.43B | 2.76 | 449M | 8.9 | 9.92 |
| 3 | 5.49B | 6.25 | 4.67B | - | - |

| Architecture | | | | | | | | Cost | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Jinko320 (kW) | Grid (kW) | SMA25 (kW) | Dispatch | NPC (฿) | COE (฿) | Operating cost (฿/yr) | Initial capital (฿) |
| | | | | 8,000 | 50,000 | 6,192 | CC | ฿2.61B | ฿2.97 | ฿200M | ฿181M |

(a)

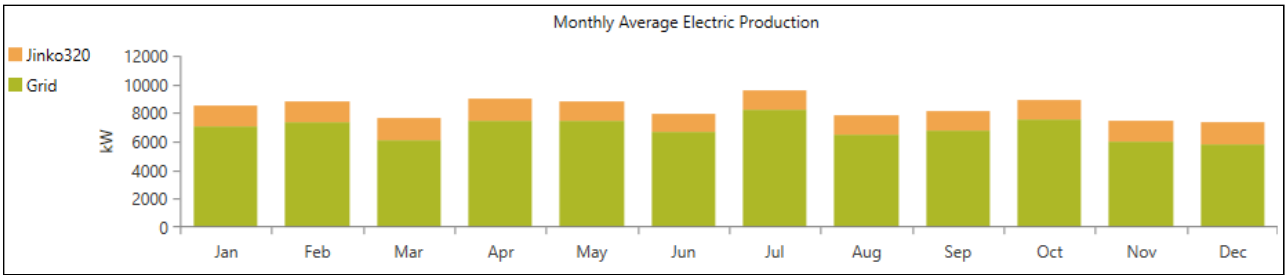
| Production | kWh/yr | % |
|---|---|---|
| Jinko JKM320 | 12,521,131 | 17.1 |
| Grid Purchases | 60,503,745 | 82.9 |
| Total | 73,024,876 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 72,533,801 | 100 |
| DC Primary Load | 0 | 0 |
| Deferrable Load | 0 | 0 |
| Total | 72,533,801 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 283,027 | 0.388 |
| Unmet Electric Load | 6,533 | 0.00900 |
| Capacity Shortage | 9,476 | 0.0131 |

| Quantity | Value | Units |
|---|---|---|
| Renewable Fraction | 16.6 | % |
| Max. Renew. Penetration | 213 | % |

(b)




(c)

**Fig. 10. Base case (a) architecture and cost; (b) energy production and consumption; (c) Monthly average electric production**

| Architecture | | | | | | | | Cost | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Jinko320 (kW) | Grid (kW) | SMA25 (kW) | Dispatch | NPC (฿) | COE (฿) | Operating cost (฿/yr) | Initial capital (฿) |
| | | | | 18,011 | 50,000 | 10,156 | CC | ฿2.44B | ฿2.77 | ฿168M | ฿402M |

(a)

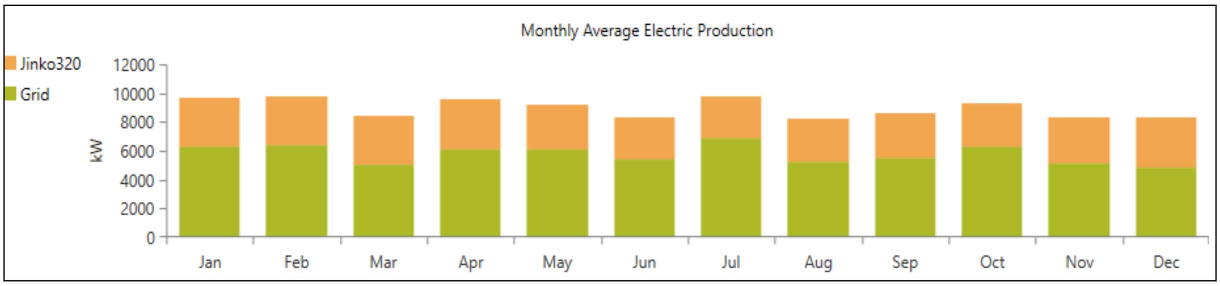
| Production | kWh/yr | % |
|---|---|---|
| Jinko JKM320 | 28,189,609 | 35.9 |
| Grid Purchases | 50,431,409 | 64.1 |
| Total | 78,621,018 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 72,536,986 | 100 |
| DC Primary Load | 0 | 0 |
| Deferrable Load | 0 | 0 |
| Total | 72,536,986 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 5,701,738 | 7.25 |
| Unmet Electric Load | 3,348 | 0.00460 |
| Capacity Shortage | 8,839 | 0.0122 |

| Quantity | Value | Units |
|---|---|---|
| Renewable Fraction | 30.5 | % |
| Max. Renew. Penetration | 479 | % |

(b)




(c)

**Fig. 11. Results of the first strategy (Increasing PV to a suitable size for PCS); (a) architecture and cost; (b) energy production and consumption; (c) Monthly average electric production.**

| Architecture | | | | | Cost | | | |
|---|---|---|---|---|---|---|---|---|
| Jinko320 (kW) | MWh-LI | Grid (kW) | SMA25 (kW) | Dispatch | NPC (฿) | COE (฿) | Operating cost (฿/yr) | Initial capital (฿) |
| 18,011 | 7 | 50,000 | 10,156 | CC | ฿2.43B | ฿2.76 | ฿163M | ฿449M |

(a)

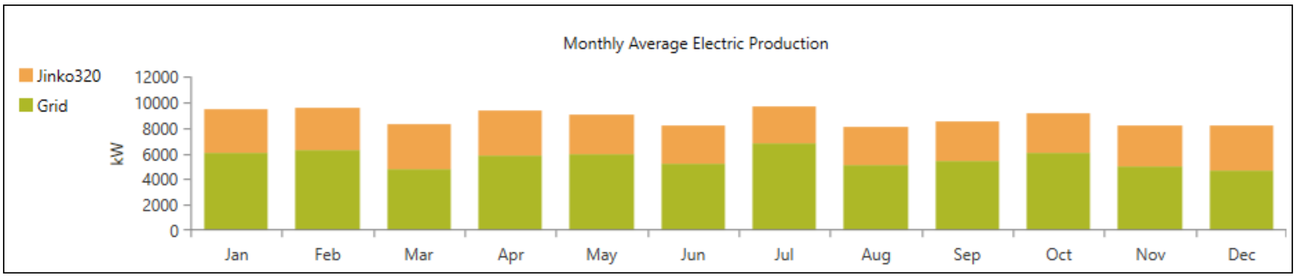
| Production | kWh/yr | % |
|---|---|---|
| Jinko JKM320 | 28,189,760 | 36.5 |
| Grid Purchases | 48,952,273 | 63.5 |
| Total | 77,142,033 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 72,536,986 | 100 |
| DC Primary Load | 0 | 0 |
| Deferrable Load | 0 | 0 |
| Total | 72,536,986 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 4,035,892 | 5.23 |
| Unmet Electric Load | 3,348 | 0.00460 |
| Capacity Shortage | 8,839 | 0.0122 |

| Quantity | Value | Units |
|---|---|---|
| Renewable Fraction | 32.5 | % |
| Max. Renew. Penetration | 479 | % |

(b)




(c)

**Fig. 12. Results of the second strategy (Improving suitable size BESS for PCS that using suitable size PV); (a) architecture and cost; (b) energy production and consumption; (c) Monthly average electric production.**

| Architecture | | | | Cost | | | | System | |
|---|---|---|---|---|---|---|---|---|---|
| Jinko320 (kW) | MWh-LI | SMA25 (kW) | Dispatch | NPC (฿) | COE (฿) | Operating cost (฿/yr) | Initial capital (฿) | Ren Frac (%) | Total Fuel (L/yr) |
| 111,729 | 336 | 19,076 | CC | ฿5.49B | ฿6.25 | ฿67.9M | ฿4.67B | 100 | 0 |

(a)

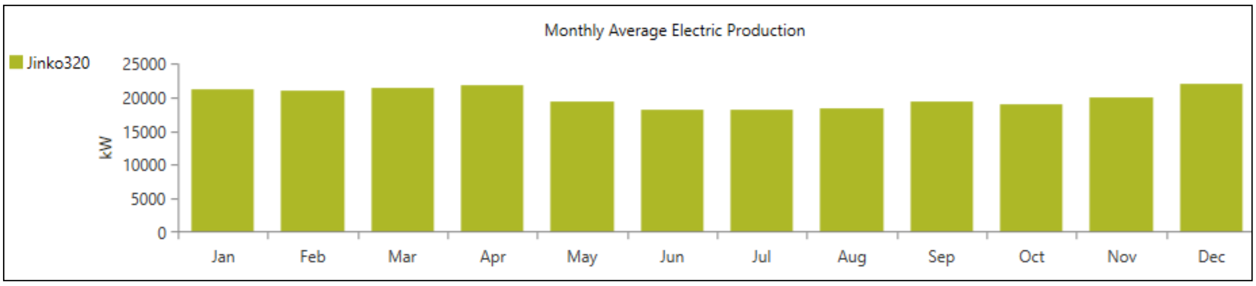
| Production | kWh/yr | % |
|---|---|---|
| Jinko JKM320 | 174,872,217 | 100 |
| Total | 174,872,217 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 72,486,521 | 100 |
| DC Primary Load | 0 | 0 |
| Deferrable Load | 0 | 0 |
| Total | 72,486,521 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 96,665,510 | 55.3 |
| Unmet Electric Load | 53,813 | 0.0742 |
| Capacity Shortage | 72,534 | 0.100 |

| Quantity | Value | Units |
|---|---|---|
| Renewable Fraction | 100 | % |
| Max. Renew. Penetration | 2,972 | % |

(b)




(c)

**Fig. 13. Results of the third strategy (design off-grid system for PCS); (a) architecture and cost; (b) energy production and consumption (c) Monthly average electric production.**

From strategy 1 to 3, The simulation results showed the optimal size solar rooftop that was 18.011 MW, and the optimal size of BESS was 7 MWh. In this paper, The COE , Internal Rate of Return (IRR) and Payback Period (PBP) were considered to choose the suitable strategy. The results showed the first strategy is the most suitable strategy to reduce COE of PCS Machine group holding company limited because the first strategy has low IRR PBP and COE. Although the second strategy that has less COE than other strategies but has so long PBP cause the second is not suitable to use at present. For the third strategy, The investing with Off-grid system is not worth because of a component of RERs system too expensive at present. If the price of a component decrease in the future, this strategy will be interesting in reducing COE of any factories.

## 6. CONCLUSION

In this paper, PV solar roof is focused because many large factories have much space on a roof that is not used for any benefit and there is not enough space on the ground for installing a wind turbine. From the simulation results, the first strategy that installed suitable size of PV solar roof on the PCS factory having PBP is 5.55 years, not too long, and low COE is 2.77 THB/kWh nearly the second strategy that having lowest COE is 2.76 THB/kWh, but the second strategy has long PBP. The second strategy has long PBP because the capital cost of BESS is high, at present, but causing the energy price decreased from the third strategy only 0.01 THB/kWh. For the third strategy, Off-grid system is an investment that is not worth at present. Therefore, the first strategy that installing PV solar roof with the appropriate size producing electric power is the most suitable strategy. However, if the battery has a lower price in the future, the third strategy will be interesting.

## ACKNOWLEDGMENT

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## APPENDIX

The grid purchases daily profile and solar roof output daily profile of the optimal strategy that installed optimal size solar rooftop were shown in Fig. 14 and 15.

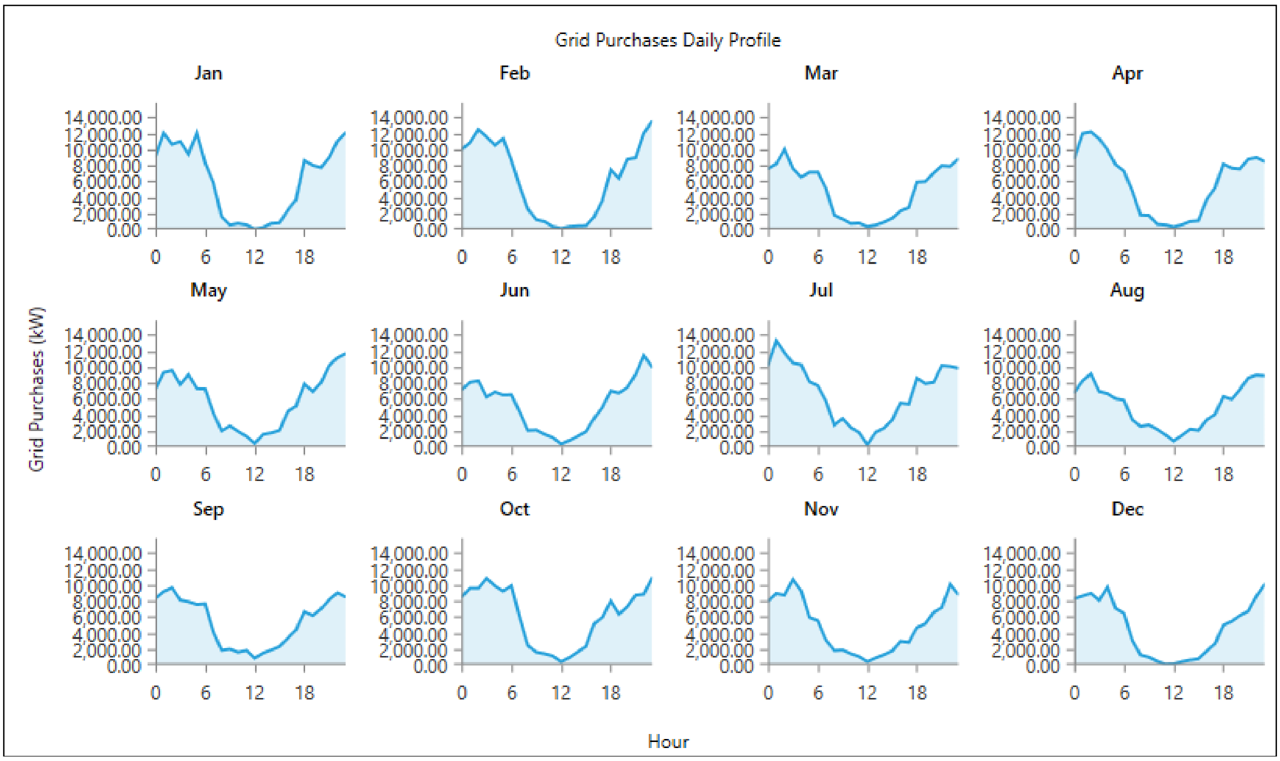


**Fig. 14. Grid purchases daily profile**.

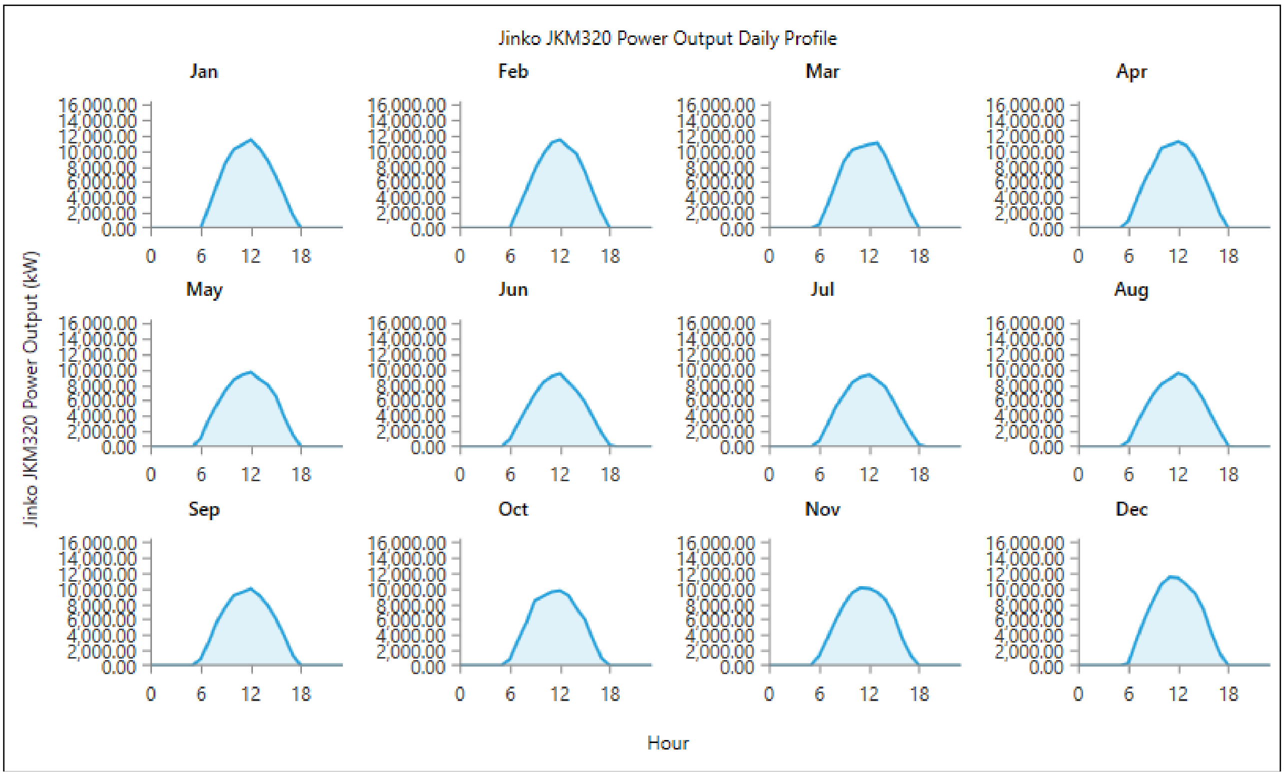


**Fig. 15. solar roof output daily profile**