An Evaluation of Energy Saving and Peak Shaving in a Warehouse by Homer Grid

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Abstract: This paper presents an evaluation the optimal sizes of solar energy system and battery energy storage system for reducing the electricity units purchased from the grid and meanwhile shaving peak demand of a general warehouse where its location is in Chonburi, Thailand. The method of this study was to exploit the load profiles from January to December 2019 due to its normal operation before the COVID-19 pandemic and HOMER Grid Software for simulation of the economical and optimal renewable project. Furthermore, data analysis of the demand time and duration when the peaks of the working days are always started from 06:00 p.m. to 10:00 p.m., and input analyzed data to Demand Response program with selected setting of optimize demand reduction. From the simulation, the results have shown that the 1st winning system architecture was only PV-282 kW which can give the lowest Net Present Cost (NPC) and the Levelized Cost of Energy (COE) at 43.12 M฿ and 2.77 ฿ /kWh, respectively. Other interesting setting of Demand goals at 250, 152.5 and 136 kW were simulated and suggested to install PV-265 kW, 50 kW inverter and 28 units of 2.4 kWh Li-Ion for the lowest NPC and COE at 45.44 M฿ and 3.03 ฿/kWh, PV-294 kW, 140 kW inverter and 92 units of 2.4 kWh Li-Ion for the lowest NPC and COE at 50.29 M฿ and 3.36 ฿/kWh and PV-289 kW, 160 kW inverter and 100 units of 2.4 kWh Li-Ion for the lowest NPC and COE at 51.46 M฿ and 3.47 ฿ /kWh respectively.

Keywords**—**energy warehouse, energy saving, peak shaving, homer grid.

I. Introduction

Nowadays, air pollution and Greenhouse effect come from the massive carbon emission, which was occurred by the rapid growth of transportation, construction industry and increase of industrial energy consumption can lead to global climate change. In account to save the environment and sustain global energy, the Renewable Energy Sources (RES) with Battery Energy Storage System (BESS) integrated are one of potential solution to manage and optimize the energy utilization, while maintaining energy security, mitigating the emission as well as avoiding the intermittent nature of RES [1].

In Thailand, environmental concern is addressed and became the most concerning issue, therefore the carbon market is designed to be one of the Thai government's key tackles under this Global Climate Change as to promote green economy and reduce Greenhouse Gas (GHG). Based on its website, carbon market is established to align with Kyoto Protocol, the objective of carbon market is to mitigate GHG [2] by selling and purchasing carbon as a product. To quantify the benefits of GHG emission reduction, from Carbon Market website, the average price in 2021 was around 34.34 ฿ /tonCO_2 [3], which means for each ton of carbon released into the environment, will cost at 34.34 ฿ in minimum of the atmospheric pollution, the wastewater, the human health, and the property damage. With reference to the cost, it would be an additional financial benefit to calculate after receiving the result from simulation.

As reported by our world in data [4], in 2016, global greenhouse gas emission around 73.2% came from energy sector, and energy uses in buildings like residential and commercial buildings are taken about 17.5% in this sector. Although this study is focusing on reducing energy consumption and power demand from grid, the greenhouse gas reduction is considered as the aftermath from the project in term of the positive environmental impact.

Nowadays for serving sufficient power demand to buildings or energy user, the power plants must run more turbines, and this will consume more fuels, regardless they are coal, gas, or oil. The consumption of fuels would produce more GHG. To manage this uncertain load, the peak load shaving will assist for the power management and benefit both grid and energy user, consequently, reduce the emission of carbon dioxide which is the primary GHG [5].

To reduce the electricity cost by cutting both the energy units and peak demand, it is necessary to have the sufficient data for analyzing and a suitable software to calculate and evaluate the economic optimization of the renewable

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energy system. There are various methods and software to solve this proposed problem. HOMER Grid software is one of the interesting software for solving the optimization of component sizing of the system and the economic analysis.

Homer software can generally simulate and analyze a hybrid power system, which is combined between the different technologies, for instance, generators, cogeneration, solar photovoltaic, batteries, turbine, wind, hydropower, fuel cells and biomass to produce and supply power. Moreover, the software is able to analyze the energy supply hourly, therefore 8,760 hours in one year, and compare with the electric demand. The software will review and evaluate the cost of all input components, tariffs, and load data for the project feasibility whether is cost efficient solution. [6]

As Homer Grid software is right for behind-the meter systems with a need for peak shaving and optimizing all aspects of grid connected system [7]. In addition, the software will determine the system which can present the lowest of Net Present Cost (NPC) that consider the demand of load profile of consumer and represent more economical decision [8]. Due to its optimization and demand response program, which can evaluate many possible system configurations, especially we can specify the peak period of time with many options of optimize demand reduction, demand reduction and demand goal.

Therefore, this study uses the HOMER Grid to manipulate monthly load data of the warehouse from January to December 2019, and optimize the energy saving and peak shaving. The ways to save electric energy and shave the peak demand of warehouse will be calculated by choosing Solar PV, Lithium-Ion batteries, and inverters to be the components in software.

This paper is organized as follows: Section 2 shows load profile of the warehouse, the system configuration, utility, photovoltaic panels, energy storage, inverter, demand respond, economics and controller. In Section 3, the simulation will be performed, and the results will be presented. Last Section will be a conclusion of this study.

II. Methodology

According to the Homer Grid Software Design, configuration steps are taken as follows:

A. Set up location

The interested warehouse is located in Si Racha (or Sriracha), Chonburi, Thailand. The exact location of the warehouse must be pinned to receive the renewable energy resource data, as per Fig.1. The location was received the database from Solar Resource, the National Renewable Energy Laboratory.

Fig.1 Location of Project

B. Annual Load Profile Analysis

The retrieved load profiles of warehouse in the peak day from AMR (Automatic Meter Reading) have shown the highest wattage consumption are always in the evening period, 06:00 p.m. - 10:00 p.m. The sample of load profiles in January, July and December 2019 were presented in Fig. 2.1-2.3.

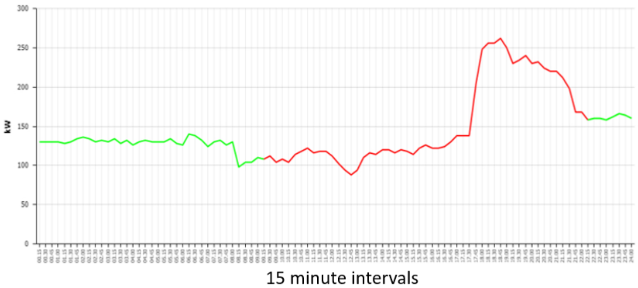

Fig. 2.1 January 2019

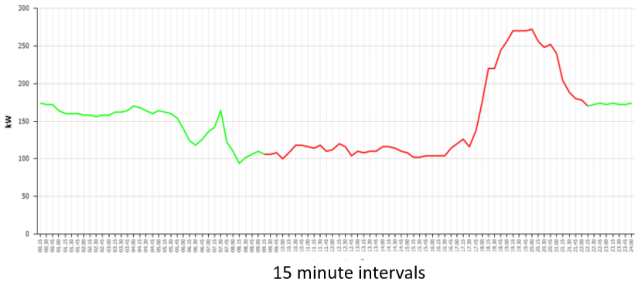

Fig. 2.2 July 2019

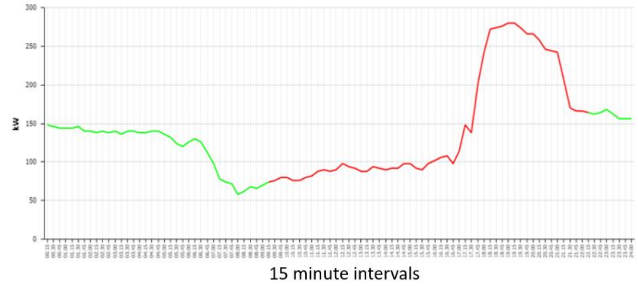

Fig. 2.3 December 2019

To evaluate the potential of electricity saving, the load factor as a useful method was applied for calculation in equation (1). Normally, if the load factor percentage is low, there will be higher cost of electric bills and vice versa the great possibility of energy saving and shaving the peak demand.

$$\text{Load factor \%} = \frac{\text{Average real power}}{\text{Maximum real power}} \quad (1)$$

After calculating, the peak demand date, time, peak wattages, and the calculated load factors of warehouse can be summarized as per Table 1. The average of monthly load factor equals to 43%, indicated an opportunity of demand shaving [9].

TABLE I
Peak Demand Date, Time, Peak Power, and Load factors of the warehouse

Peak Demand Date	Time	Peak Power (kW)	Load factor(%)
4-Jan-19	18:45	262	44%
13-Feb-19	19:30	250	44%
5-Mar-19	19:00	270	41%
25-Apr-19	20:45	272	40%
22-May-19	19:45	272	51%
5-Jun-19	19:45	280	63%
11-Jul-19	20:00	272	41%
7-Aug-19	21:30	278	35%
24-Sep-19	21:00	292	36%
24-Oct-19	19:30	294	52%
1-Nov-19	19:15	294	41%
3-Dec-19	19:15	280	32%

C. Electric Load Input

The load profile in those peak days that represented monthly data, were input to the HOMER Grid, and can be visualized as shown in Fig.3. The annual electric energy consumption was around 1,206.2 MWh while the daily load consumed was 3,304.6kWh/day.

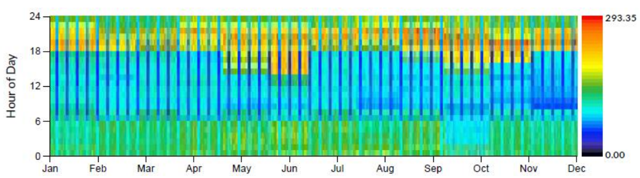

Fig.3 Yearly Profile of the warehouse

D. Utility

Since HOMER Grid does not originally provide Thai Tariff, therefore simple tariff was set as follows; 1. Unit rate, 2. Demand rate, and 3. A monthly fixed rate following to Schedule 3.1.2 at voltage level 22-33kV [10] of PEA tariff. In normal rate at mentioned voltage level, Demand, Energy unit and Service Charges are 196.26 ฿/kW, 3.1471 ฿/kWh and 312.24 ฿/Month, respectively.

For user's clear visualization, the monthly tariff bills were plotted as bar chart as shown in Fig.4.

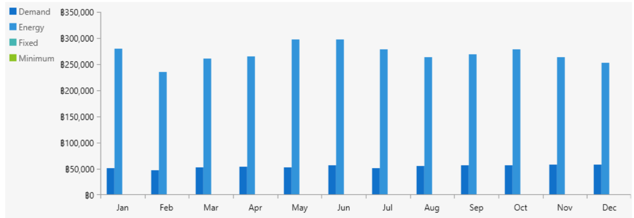

Fig.4 January to December tariff bills

E. Photovoltaic Panels

To simplify our selection with Thai currency, we selected the 330 Watts poly crystalline solar panel, Gammo brand, which costs 2,750 ฿ per panel [11] and created it in the HOMER Librarian (Grid). The cost of selected PV in the AC side was added up the cost of grid-connected inverter Huawei Model SUN2000-100KTL-M1, size 100 kW, 241,000 ฿ [12], installation cost and accessory costs for solar panel, all total went up 50% approximately.

From the optimization tool in HOMER [13], the power output of PV is calculated as equation (2).

$$P_{pv} = \delta_{pv}\Gamma_{pv}\frac{I_T}{I_s} \quad (2)$$

Where: P_{pv} = Power output from PV array,
δ_{pv} = Factor of degradation,
Γ_{pv} = Capacity of PV unit,
I_T = The irradiance on the panel concerning time,
I_s = The standard solar irradiance

Power from the Solar PV will be supplied to load and charge the battery during daytime.

F. Energy Storage

Related to our load profile analysis, duration of peak demand is 4 hours, (06:00 p.m. - 10:00 p.m.), to select between the several energy storage technologies, BESS is suitable for mid-term time scale (less than 5 hours) to shave the peak load demand [5].

From the fact that, the Battery Energy Storage System is required to be charged and discharged many times in its cycle life, thus the Lithium Battery is the best option because of their high efficiency (over 95%), long life, high cycle of more than 3000 cycles at 80% depth of discharge and high energy density. However, this type of battery still demands the protection of the circuit to prevent a surge of thermal instability as causing battery stress and fast degradation when the system reach high temperature during operation or when stored in high voltage [14,15].

Typically there are 5 types of Li-Ion, 1) Lithium cobalt oxide ($LiCoO_2$) its characteristic of low thermal stability causes short life span, 2) Lithium manganese oxide ($LinMn_2O_4$): high thermal stability but the cycle and calendar life are limited, 3) Lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$ or NMC): it was the best cathode combination of nickel-manganese-cobalt in Li-ion systems, these systems can be custom-made to serve as energy cells or power cells, 4) Lithium iron phosphate

(LiFePO4): this type was selected in this study, besides its good balance of temperature, also it provides a high current rating, feasible extended cycle life, more safety, and tolerance if misapplied and 5) Lithium titanate ($Li_4Ti_5O_{12}$): it is safe and has excellent low-temperature discharge characteristics [15].

In this study, the chosen 48V Meritsun Lithium-Ion batteries, LiFePO4, with 2 different current rates, 50 and 100 Ah, cost 20,000 and 31,000 ฿, respectively [11], were input to Homer Librarian (Grid) for design selection.

The basic routine of the battery is to convert the electrical energy into chemical energy and re-convert the chemical energy to electrical energy for final use or during the demand period [9]. In Homer, the Storage Capacity (SC) of the battery is calculated by using the equation (3):

$$SC = \frac{\text{no. of days x E}}{\eta_{battery} \text{ x } \eta_{inverter} \text{ x DoD}} \quad (3)$$

Where: E = No Load Voltage,
$\eta_{battery}$ = Battery Yield,
$\eta_{inverter}$ = Inverter Yield,
DoD = Depth of Discharge

The SOC (State of Charge) of battery changes between no load and load [16].

G. Converter

The connecting between the AC and DC section of the system architecture is the converter, which specified chosen size of the inverter must be as its rated power and should be equal to or greater than the peak load. In this paper we will mention the converter as the inverter.

Following the battery energy storage system was integrated in the system, a bidirectional inverter would help in recharging from grid or solar energy, during the times when demand was at a low rate or derived energy from any renewable energy sources and can serve the required load needed in the peak period. Such application would require rectifier with integrated DC conditioning capabilities to supply the battery during the charging time and in the opposite way it would be discharged when the battery require to supply to the loads [17].

The Homer optimizer will select the best size of inverter according to the system specification and constraints, referred to equation (2) whereby P_{pv} is the DC power generated from Solar Panels and will be an input power to the inverter, P_{in} and AC output power from the inverter, P_{out}. Both can be related to the inverter efficiency, η_{inv} as in equation (4) [18]:

$$\eta_{inv} = \frac{P_{out}}{P_{pv}} \quad (4)$$

Since an inverter is used to provide AC power from DC component or vice-versa, a provided inverter in complete catalogue was bidirectional type, in Thai market a Leonics Apollo S-219C 5kVA/5kW Pure Sine Wave inverter costs 115,700 ฿ [19]. The sizing of the inverter was stepped 5-kW size of inverter from 5 to 250 kW.

H. Program: Demand Response (DR)

Under the Generic Demand Response, in Thailand, PEA Electricity Tariff has no benefit of the demand reduction incentive, thus we selected optimize demand reduction as an option as shown in Fig.5. Random dates start from 1 Jan to 31 Dec, Number of random events 260 based on (5 working days/week and 52 weeks/year) and according to table (1), random start time range was set at 06:00 p.m. to 10:00 p.m. and one hour event duration.

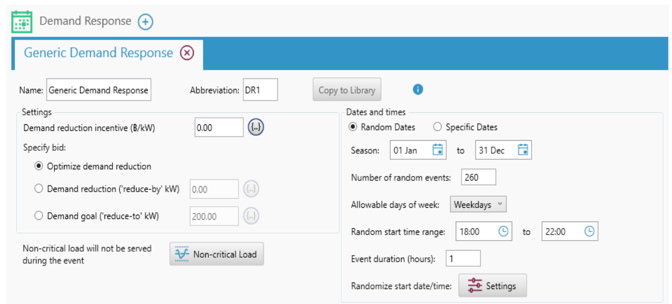

Fig.5 Optimize demand reduction

When considered the lowest of peak demand in 2019 was at 250kW in February which is determined to be another option of setting demand goal, as shown in Fig.6.

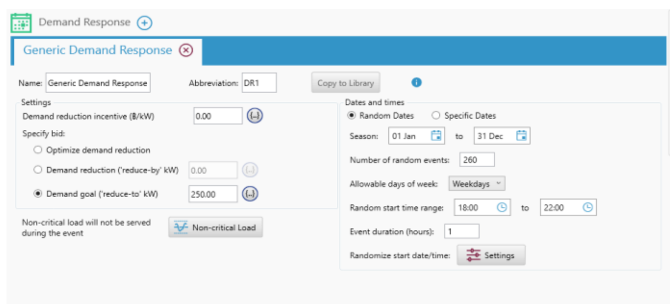

Fig.6 Demand gold at 250kW

I. Project: Economics and Controller

Most of parameters in Economics remain unchanged except the currency was changed to Thai as shown in Fig. 7 and the controller is Homer Peak Shaving with 25 years Project lifetime as shown in Fig. 8.

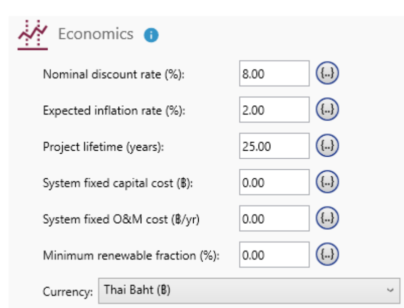

Fig.7 Project: Economics

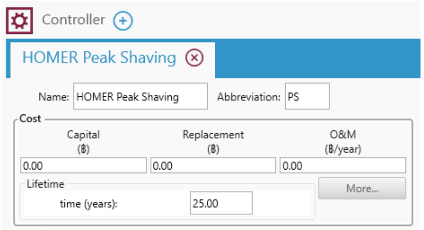

Fig.8 Project: Controller

The design schematic with all above input data is shown in Fig.9.

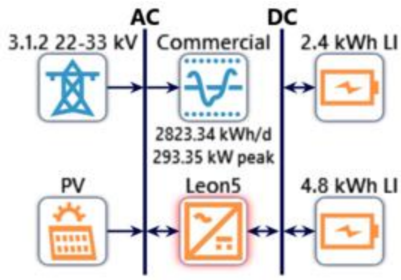

Fig.9 The designed schematic in HOMER Grid

III. RESULT AND DISCUSSION

A. DR setting: Optimize demand reduction

The wining system architecture solution obtained by HOMER Grid was shown in Fig.10. It was seen that only 282 kW PV with grid (3.1.2) met the optimal and economical solution which provided the lowest NPC compared to the base case architecture is only grid (3.1.2).

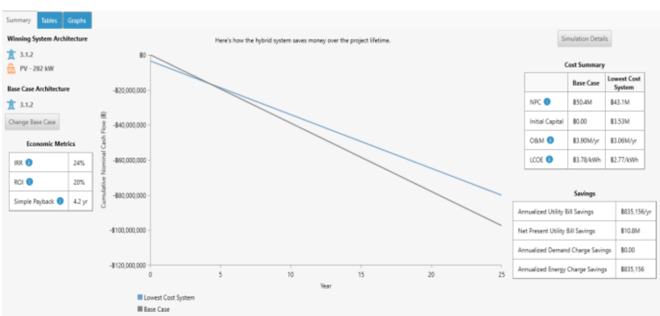

Fig.10 Simulation result of optimize demand reduction

The considered NPC value in Homer Grid combines the present value of all costs and costs of buying power from grid included any revenues happened between in the project as a main considerable factor of simulation result in Renewable Energy project investment, payback time, the estimated profitability of this potential investment, and percent of Internal Rate of Return (IRR%). Therefore, the best optimized solution for HOMER Grid is not considered the COE [7].

- 1st System

The winning system architecture was consisted of only 282 kW PV, which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 43.12 M฿, 4.23 years, 3.53 M฿, 2.77 ฿/kWh and 0.84 M฿ per year.

- 2nd System

The 2nd winning system architecture was consisted of 262 kW PV, 3 units of 2.4kWh Li-Ion battery and a 5kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 43.37 M฿, 4.18 years, 3.45 M฿, 2.85 ฿/kWh and 0.83 M฿ per year.

- 3rd System

The 3rd winning system architecture was consisted of 294 kW PV, 2 units of 4.8 kWh Li-Ion battery and a 5kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 43.48 M฿, 4.56 years, 3.85 M฿, 2.76 ฿/kWh and 0.86 M฿ per year.

The results have shown that, the 3rd system saved the highest annual electric bill, this is because the PV and battery sizes are bigger than other systems and be the most expensive initial capital. However, all these systems mostly help in energy saving because of the low energy charge rate (3.1.2) and the demand response setting with optimize demand reduction.

B. DR setting: Demand goal at 250kW

The lowest of peak load was 250kW in February 2019 and selected to be the trial maximum demand goal. After the simulation, the wining system architecture solution was shown in Fig.11 and consisted of the 265 kW PV, 28 units of 2.4 kWh Li-Ion battery and 50 kW inverter with grid (3.1.2) met the optimal and economical solution which provided the lowest NPC compared to the base case architecture of grid (3.1.2) with 13 units of 4.8 kWh Li-Ion battery and 50 kW inverter.

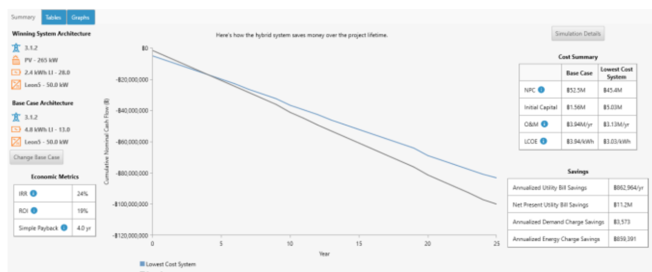

Fig.11 Simulation result of demand goal at 250kW

- 1st System

The winning system architecture was consisted of 265 kW PV, 28 units of 2.4 kWh Li-Ion battery and 50 kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 45.44 M฿, 4.04 years, 5.03 M฿, 3.03 ฿/kWh and 0.86 M฿ per year.

- 2nd System

The 2nd winning system architecture was consisted of 262 kW PV, 12 units of 4.8 kWh Li-Ion battery and 50 kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 45.84 M฿, 4.27 years, 4.81 M฿, 3.05 ฿/kWh and 0.85 M฿ per year.

The results have shown that, the 1st system saved the highest annual electric bill and was the only one system that cut the demand cost up to 3,573 ฿ per year compared to the base case.

C. DR setting: Demand goal at 152.5kW

In the interest of finding the right demand goal setting that can be achieved both with and without PV components, we calculated the average value of hourly power demand in the peak day of January-December and found the mean was 152.5 kW and set this value as the new demand goal. After the simulation, the wining system architecture solution was shown in Fig.12 and consisted of the 294 kW PV, 92 units of 2.4 kWh Li-Ion battery and 140 kW inverter with grid (3.1.2) met the optimal and economical solution which provided the lowest NPC compared to the base case architecture of grid (3.1.2) with 44 units of 4.8 kWh battery and 140 kW inverter.

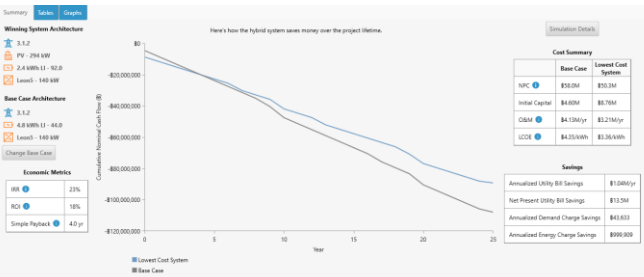

Fig.12 Simulation result of demand goal at 152.5kW

- 1st System

The winning system architecture was consisted of 294 kW PV, 92 units of 2.4 kWh Li-Ion batteries and 140 kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 50.30 M฿, 4.04 years, 8.76 M฿, 3.36 ฿/kWh and 1.04 M฿ per year.

- 2nd System

The 2nd winning system architecture was consisted of 256 kW PV, 40 units of 4.8 kWh Li-Ion battery and 140 kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 51.80 M฿, 4.55 years, 7.68 M฿, 3.58 ฿/kWh and 0.95 M฿ per year.

- 3rd System

The 3rd winning system architecture was consisted of 80 units of 2.4 kWh Li-Ion battery and 140 kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 57.80 M฿, 8.19 years, 4.84 M฿, 4.34 ฿/kWh and 8,551.94 ฿ per year.

The results have shown that, though the 1st system (Solar PV plus BESS) provided the highest annual electric bill but without Solar PV, the 3rd system still can save the annual electric cost and return the investment in 8 years.

D. DR setting: Demand goal at 136kW

An additional setpoint from the mean of the 12-month average power demands on peak days that except the demand period at 6:00-10:00 pm., was 136kW and selected to be the additional new demand goal. After the simulation, the wining system architecture solution was shown in Fig.13 and consisted of the 289 kW PV, 100 units of 2.4 kWh Li-Ion battery and 160 kW inverter with grid (3.1.2) meet the optimal and economical solution which can give the lowest NPC compared to the base case architecture of grid (3.1.2) with 48 units of 4.8 kWh Li-Ion battery and 160 kW inverter.

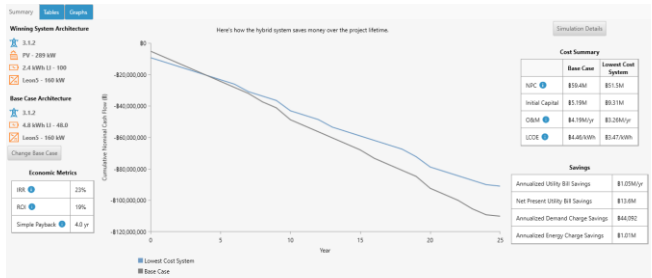

Fig.13 Simulation result of demand goal at 136kW

- 1st System

The winning system architecture was consisted of 289 kW PV, 100 units of 2.4 kWh Li-Ion batteries and 160 kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 51.46 M฿, 3.98 years, 9.31 M฿, 3.47 ฿/kWh and 1.05 M฿ per year.

- 2nd System

The 2nd winning system architecture was consisted of 236 kW PV, 45 units of 4.8 kWh Li-Ion battery and 160 kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 53.21 M฿, 4.54 years, 8.04 M฿, 3.76 ฿/kWh and 0.94 M฿ per year.

- 3rd System

The 3rd winning system architecture was consisted of 92 units of 2.4 kWh Li-Ion battery and 160 kW inverter which its NPC, Simple payback time, initial capital, COE and annual utility bill saving were 58.98 M฿, 7.23 years, 5.54 M฿, 4.43 ฿/kWh and 16,889.19 ฿ per year.

The results have shown that the 3rd system without Solar PV provided the small amount of annual electric cost saving and total return was around 7 years due to compared to the base case.

E. Comparison of results

In this study, we are only interested in the winning system of each option. Among all systems, the NPC, initial capital, and COE of the 1st system of optimize demand reduction are the lowest value because the solar energy system has no BESS to manage the power demand of the user load. Yet from all simulations, the optimal and economical solutions for this study is to implement only 282 kW Solar energy, even though its annual utility bill saving is at 835,156.30 ฿ per year. Besides the lowest annual saving of the optimize demand reduction, the investment of this system as mentioned is the lowest, thus the return of investment is around 4.23 years, means that the money will be converted into cash before 51 months and lowered the risk of loss.

Usually, the project lifetime in Homer Grid is set to 25 years in case of the solar energy implementation and after completing the depreciation, some of the components are remained book values such as Li-Ion battery (12 years) and inverter (10 years). For that reason, the salvage values of these components will be calculated as to decrease the net present cost (NPC) of the project, however the optimize demand reduction will still be the optimum solution as it is unrequired the replacement of the battery and inverter in every 10 years.

The example of peak day PV and grid purchases in January is shown in Fig.14 optimize demand reduction. The results shown that the only PV panels without grid can generate the power to load since 9.00a.m.-3.00p.m. It is summarized that this system only can reduce the electricity units purchased from the grid.

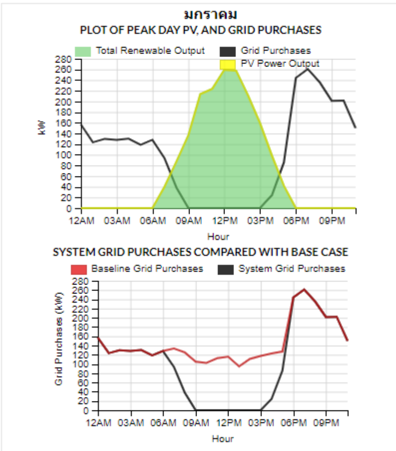

Fig. 14 peak day PV and grid purchases in January: optimize demand reduction

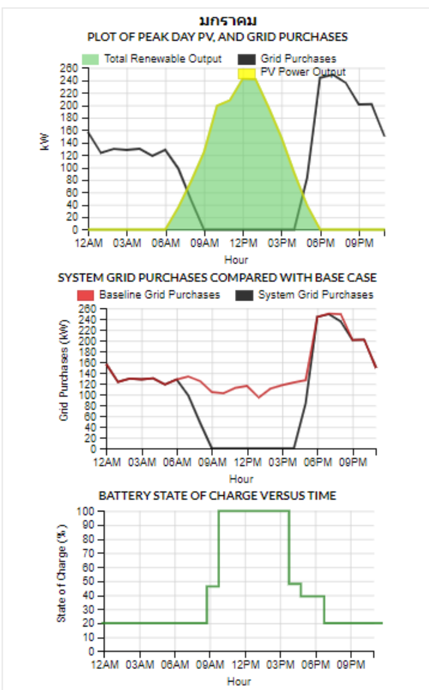

Fig. 15 peak day PV and grid purchases in January: 250kW demand goal

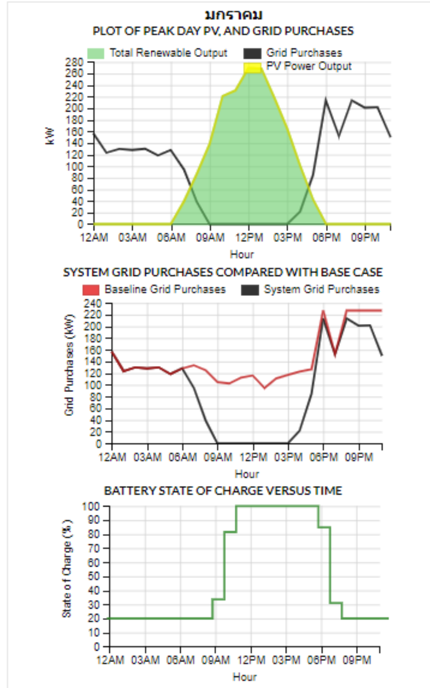

Fig. 16 peak day PV and grid purchases in January: 152.5kW demand goal

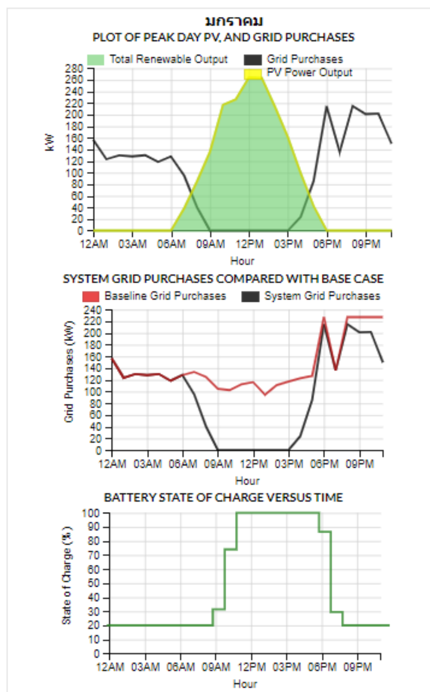

Fig. 17 peak day PV and grid purchases in January: 136kW demand goal

Comparison of the result of 250 kW, 152.5kW and 136kW demand goal in Fig.15, 16 and 17, are shown that the peak power demand was successfully controlled as per setting goal by BESS, which was charged by solar energy during daytime and discharged during the high demand period. Though the effectiveness of BESS, the NPC and initial capital of these solution are more expensive than the optimize demand reduction.

To consider the environmental impact, the base case of all options will emit 651-654 tonCO_2/year. To compare individually the 1st simulated results of optimize demand reduction (only Solar PV energy) can reduce the carbon emission to 483 tonCO_2/year and demand goal at 250kW, 152.5kW and 136kW (Solar PV plus BESS) can reduce the carbon emission to 479, 453 and 452 tonCO_2/year respectively. Regard to the impact on the environment, Solar PV plus BESS will be more supportive to the green economy and additionally 136 kW demand goal can earn the highest carbon credit around 7,000 ฿/year from Thai Carbon Market. Though the amount of carbon credit is considered no impact to the investment and profit return, but the highest percentage of carbon emission was reduced 31%. The significant impact to our environment will be if we implement the huge size project, we can expect the more reduction of carbon emission.

IV. CONCLUSION

Based on the simulation result of the optimize demand reduction, the 1st system of only Solar PV can assist well in energy saving, by reducing NPC and payback time of the project and optimizing profit return, however this will depend on many factors, for instance, load profile and characteristic, utility cost, component costs, lifetime, demand response program setup, incentive etc. However, the small size of BESS in the 2nd and 3rd system of optimize demand reduction are still able to save the demand charge around 5,000 ฿/year, thus the solutions of all the demand goal settings might not assist in financial benefit as not a cost-effective solution.

Due to the limited lifetime and the expensive cost of storage and inverter components that made NPC of demand goal options are less attractive, in the future we believe that trend of Li-Ion battery exploiting will be widespread and when it becomes high demand, its price will be more reasonable for the huge volume buy, especially for the entrepreneurs and investors. Through the potentially financial and environmental saving from the BESS will be one of the suitable energy management solution and alleviating emission at the customer's side, it has many great impacts on the Grid's side or EGAT (Electricity Generating Authority of Thailand) and PEA as well, not only reduce the need of turbine engine starting, also reducing the purchasing energy cost from outside country during these high demand periods. Finally, when the renewable energy plus energy storage is marketable in Thailand, PEA/EGAT infrastructure's investment plan can be rescheduled and extended as in UK [20].

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