Prosumer-Based Optimization of Educational Building Grid Connected with Plug-in Electric Vehicle Integration using Modified Firefly Algorithm

Yusdiar Sandy
Departement of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
yusdiar.206022@mhs.its.ac.id

Ardyono Priyadi
Departement of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
priyadi@ee.its.ac.id

Vita Lystianingrum
Departement of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
vita@ee.its.ac.id

Isa Hafidz
Departement of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia

***Abstract*— Educational buildings have the potential to support government programs in efforts to reduce carbon emissions. Installing photovoltaics and providing charging stations can reduce the use of fossil fuels and increase the number of electric vehicle users. This paper aims to optimize educational buildings when implementing a prosumer scheme and integrating Plug-in Electric Vehicles (PEV) to meet building electricity demands. Optimization is conducted through two case studies, namely the application of a prosumer scheme with independent photovoltaic generators with and without PEV integration. The optimization process uses the Modified Firefly Algorithm. The results obtained by applying the prosumer scheme to educational buildings, the two case studies can produce LCOE cheaper than just buying electricity from the grid. Optimizing results show that photovoltaic installation and charging stations in educational buildings can be beneficial when implementing a prosumer scheme.**

***Keywords*— grid connected, modified firefly algorithm, optimization, prosumer, plug-in electric vehicle**

I. INTRODUCTION

The Government of Indonesia determines the Economic Value of Carbon to reduce the country's carbon emissions in 2030 [1]. Currently, the largest carbon emissions come from steam power plants and combustion vehicles. Using environmental-friendly energy can assist the government in realizing the program. Combustion vehicles are slowly being replaced by electric vehicles, with renewable energy sources such as photovoltaic. In addition to electric vehicles, photovoltaics can also be installed in large-roofed offices and educational buildings.

Another potential for a building that has an independent source of electrical energy is being able to implement a prosumer scheme. This means that the building can be a producer and consumer to meet the demand for electrical energy. This scheme can reduce the cost of building electrical energy consumption. The vehicle parking area can also be used as a charging station for electric vehicles. Thus, buying and selling of electrical energy can occur between buildings and grid or buildings with electric vehicles. Plug-in Electric Vehicle (PEV) is a type of electric vehicle that can support the prosumer scheme because it has a facility for charging and discharging.

Opportunities for actualizing educational buildings as prosumers can be analyzed at the optimal capacity of each required component. Optimization aims to determine the optimal capacity of the components needed and the amount of profit that can be obtained. Several optimization studies have been carried out to obtain optimal capacity for the use of renewable energy sources [2][3][4]. Optimization is carried out to minimize the Levelized Cost of Energy (LCOE). The algorithms used for optimization include Grasshopper Optimization Algorithm (GOA), Harris Hawks Optimization (HHO), and Particle Swarm Optimization (PSO). PEV optimization is carried out to minimize the annual cost of photovoltaic components, wind turbines, and batteries in a smart house [5].

This paper aims to optimize educational buildings by implementing a prosumer scheme integrated with PEV to perceive how to minimize the costs. This optimization is the first step to realizing the opportunity for education buildings as prosumers. The optimization process used is the Modified Firefly Algorithm (MFA). The choice of this method is its ability to solve optimization problems used on economic dispatch problems with the most optimal results and fastest iteration times [6].

Optimization is carried out in two cases; the first is applying photovoltaic in grid-connected buildings and running a prosumer scheme; the second is applying photovoltaic in grid-connected buildings and PEV integration. This research contributes to modeling the prosumer scheme in lecture building with land area limitation for photovoltaic installation, parking area capacity, time of PEV existence, and modeling of load profile obtained from sampling and modeled according to the academic and national calendar.

 How to cite: Sandy, Y., Priyadi, A., Lystianingrum, V., Hafidz, I. (2023). Prosumer-Based Optimization of Educational Building Grid Connected with Plug-in Electric Vehicle Integration using Modified Firefly Algorithm. *JAREE (Journal on Advanced Research in Electrical Engineering), 7(1).*

This article is arranged sequentially, with the research methods described in section II, the results and discussion of the optimization process in section III, and the conclusion in section IV.

II. METHODS

The optimization process is performed by modeling the system in mathematical form. The data obtained is then used as input for the optimization process. LCOE is the objective function of this optimization problem.

A. Prosumer Modeling

Modeling of educational buildings as a prosumer is shown in Fig. 1 refers to [7]. The educational building chosen in this study is Building B of Electrical Engineering at the Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. The building is four floors high, consisting of lecture halls, lecturer workspaces, and laboratory rooms. The peak load of this building is quite large, approximately 90 kW. A rooftop area of 800 m^2 can be used to install photovoltaics and a parking space with a capacity of 14 vehicles. The electricity import rates follow the price from PT PLN group P-3/TR which is \$0.11 per kWh; exports are 65% of the import rate. Meanwhile, PEV exports and imports are set at a flat rate of \$0.11 per kWh [8][9].

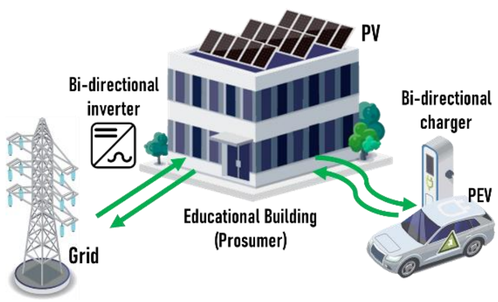

Fig. 1. Educational Building Prosumer Model

The components of the educational building as a prosumer include photovoltaic, inverter, grid, charging station, and PEV. Shortage or surplus of electrical energy from the buildings will meet by import or export to the grid or PEV by considering the most profitable cost and PEV existence. The cost of a prosumer scheme is counted using equations (1)(2)(3).

$$PR_{\text{Cost}} = Grid_{Cost} + PEV_{Cost} \quad (1)$$

$$Grid_{Cost} = \left(\sum P_{imp} \times C_{imp}\right) - \left(\sum P_{\exp} \times C_{\exp}\right) \quad (2)$$

$$PEV_{Cost} = \left(\sum P_{EV\_imp} \times C_{EV\_imp}\right) - \left(\sum P_{EV\_\exp} \times C_{EV\_\exp}\right) \quad (3)$$

where, PR_{Cost} is the prosumer cost (\$), $Grid_{Cost}$ is the grid transaction cost (\$), PEV_{Cost} is the PEV transaction cost (\$), T_{amb} and $P_{\exp}$ is the total import and export energy to grid (kWh), P_{EV_imp} and $P_{EV\_\exp}$ is the total import and export energy to PEV (kWh), and C_{imp}, $C_{\exp}$, C_{EV_imp}, $C_{EV\_\exp}$ is the import and export cost of grid and PEV (\$/kWh).

B. Components Modeling

Components optimized in this study include photovoltaic, inverter, grid, and PEV modeled into a mathematical form to perform optimal sizing.

1) Photovoltaic

Photovoltaics generate electrical energy by converting light energy into electrical energy. The amount of light intensity and ambient temperature affect the resulting power output, according to [10], which is modeled in (4). Meanwhile, the parameters needed in the optimization process are shown in Table I.

$$P_{pv\_out}(t) = P_{pv\_r} \times \left(\frac{G_t(t)}{1000}\right) \times \left[1 + \alpha_t\left(T_{amb}(t) + (0,0256 \times G_t) - T_{c\_stc}\right)\right] \quad (4)$$

where, $P_{\text{pv\_out}}$ is the output power (kW) of the photovoltaic module, G_t is solar irradiance (Wh/m^2), P_{pv_r} is photovoltaic rate power (kW), α_t is temperature coefficient $(-3,7 \times 10^{-3})$, T_{c_stc} is cell temperature at standard test condition (°C), and T_{amb} is the ambient temperature (°C).

2) Inverter

This optimization model uses an on-grid-inverter according to the needs of implementing a prosumer scheme. This type of inverter is responsible for equalizing the voltage and frequency so that the excess electrical energy from the photovoltaic can be exported to the grid. Inverter capacity is 20% larger than photovoltaic capacity [11]. The goal is that the full power output from the photovoltaic can be sent to the grid. The economic and technical parameters of the on-grid-inverter are presented in Table I.

3) Plug-in Electric Vehicle (PEV)

PEV is a type of electric vehicle that has a charge and discharge feature [12]. This advantage can be used to optimize educational buildings in running a prosumer scheme. The export and import of electrical energy are carried out on the grid and the PEV. Utilization of PEV to be able to connect with educational buildings requires a bidirectional charging station. The specifications of the PEV and charging station are shown in Table I. The presence of PEVs that are not always in buildings is modeled in discrete data according to the national calendar shown in Fig. 2.

The parameter of PEV is part of the optimization constraint because there are parameters attached to the presence of PEV in the building. These parameters are arrival time (T_{arrive}^{PEV}), departure time (T_{dep}^{PEV}), SOC (state of charge); arrival-SOC (SOC_{arrive}^{PEV}), and departure-SOC (SOC_{dep}^{PEV}). PEV arrival and departure times are adjusted to office hours by following the normal distribution function and SOC [5]. Arrival and departure times with an average of 8 and 16 with a standard deviation of 2 hours. Arrival-SOC values are determined based on daily traffic data [13] and mileage/kWh of PEV [14]. Arrival-SOC is determined with an average of 80% and a standard deviation of 20%. Minimum departure-SOC is maintained at least 80%. The conditions of the above parameters are summarized in equations (5)(6)(7)(8).

$$T_{arrive}^{PEV} \sim N(\mu_{PEVa}, \sigma_{PEVa}) \quad (5)$$

where $\mu_{PEVa} = 8, \sigma_{PEVa} = 2$ and $7 \le T_{arrive}^{PEV} \le 12$

$$T_{dep}^{PEV} \sim N(\mu_{PEVd}, \sigma_{PEVd}) \quad (6)$$

where $\mu_{PEVd} = 16, \sigma_{PEVd} = 2$ and $12 \le T_{dep}^{PEV} \le 18$

$$SOC_{arrive}^{PEV} \sim N(\mu_{SOCa}, \sigma_{SOCa}) \quad (7)$$

where $\mu_{SOCa} = 80, \sigma_{SOCa} = 20$ and $60 \le SOC_{arrive}^{PEV} \le 90$

$$SOC_{dep}^{PEV} \ge 80\% \quad (8)$$

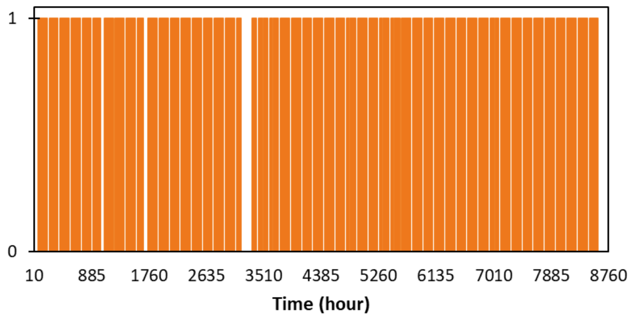

Fig. 2. Annual time of PEV existence

TABLE I. TECHNICAL & ECONOMIC SPECIFICATION OF THE COMPONENTS

Device	Parameter	Values	Units
A. Photovoltaic	Type	BiHiKu7	-
	Rate Capacity	0,65	kWp
	Price/module	208	$
	Lifetime	30	Years
	Rate Temperature	41 ± 3	°C
	Dimensions	1,3 × 2,4	m^2
	OM Cost	1	%
B. Inverter	Type	GW50KN-MT	-
	Rate Capacity	50	kW
	Price/Modul	4155,64	$
	Lifetime	10	Years
	OM Cost	3	%
	Efficiency	98,7	%
C. Charging Station	Rate Capacity	30	kW
	Price/Modul	3000	$
D. Grid	Import Price	0,11	$/kWh
	Export Price	0,0715	$/kWh
E. PEV	Battery Capacity	40	kWh
	Import Price	0,11	$/kWh
	Export Price	0,11	$/kWh

C. Economic Analysis

Economic analysis is the main part of optimization in this study. Data processing involves the cost parameters of all optimization components.

1) Levelized cost of energy

LCOE is the price per unit of electrical energy produced, determined according to the total investment costs and the total production of electrical energy used [15]. The unit of LCOE is dollars per kilowatt hour. In general, LCOE is formulated in equation (9).

$$LCOE = \frac{TNPC \times CRF}{\sum_{t=1}^{t=8760} P_{load}(t)} \quad (9)$$

where TNPC is the total net present cost ($) and CRF is the capital recovery factor in percentage units. CRF is determined using the equation (10).

$$CRF = \frac{r.(1+r)^n}{(1+r)^n - 1} \quad (10)$$

where, r is the interest rate (%) and n is the project lifetime (years). The value of r is determined according to the optimization location, which refers to [16], which is the average data for 2021 of 2.7% (percent).

2) Total net present cost

Total net present cost (TNPC) or life cycle cost is the cost incurred during the lifetime of the projects [17]. The calculation is by subtracting the results of the addition of initial costs, replacement costs, operation and maintenance costs, and prosumer costs with the salvage value. TNPC is formulated in equation (11).

$$TNPC = I_c + OM_c + R_c + (PR_{\text{Cost}} \times Lf_{prj}) - SV \quad (11)$$

Initial cost (I_c) includes the initial cost of the photovoltaic, inverter, and charging station ($). Operational and maintenance cost (OM_c) is applied to photovoltaic and inverter ($). Replacement cost (R_c) and salvage value (SV) only on the inverter because the calculation is according to the component lifetime ($). Prosumer cost (PR_{Cost}) according to the energy export and import transactions multiplied by the project lifetime (Lf_{prj}).

D. Optimization Data

Optimization is carried out to meet the electricity load demand of educational buildings. Based on the selected building, the building load profile is obtained through hourly sampling on holidays, weekdays without lecture activity, and active lecture days. The data is compiled into an annual load profile according to the academic and national calendar. The average daily profile and annual electrical load demand of B Building Electrical Engineering, Institut Teknologi Sepuluh Nopember in Fig. 3 and Fig. 4. Meteorological data is needed in the optimization process to calculate the output power of photovoltaic. Meteorological data, namely solar radiation and ambient temperature, were obtained from [18] according to the location of the building at the coordinates, latitude: -7.285° and longitude: 112.796°. The distribution of solar radiation and ambient temperature data every hour in one year is presented in Fig. 5 and Fig. 6.

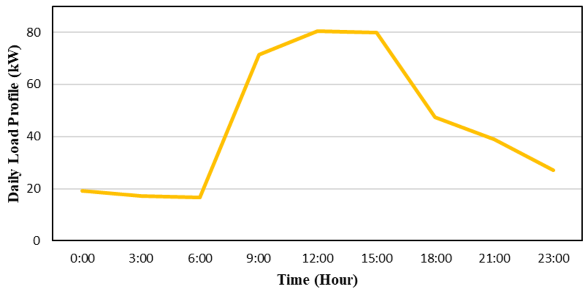

Fig. 3. Average Daily Load Profile

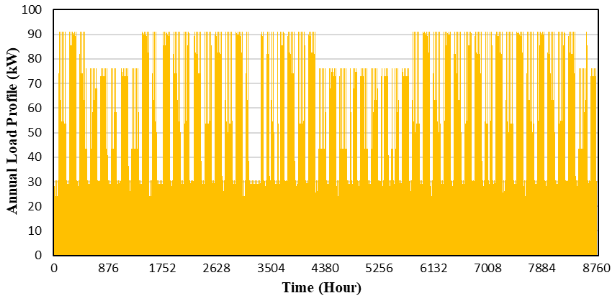

Fig. 4. Annual Load Profile

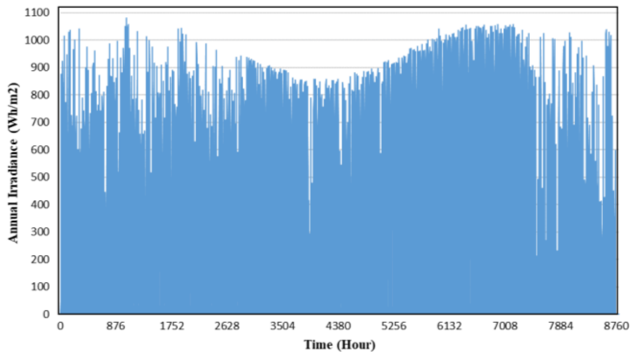

Fig. 5. Annual Irradiance Profile

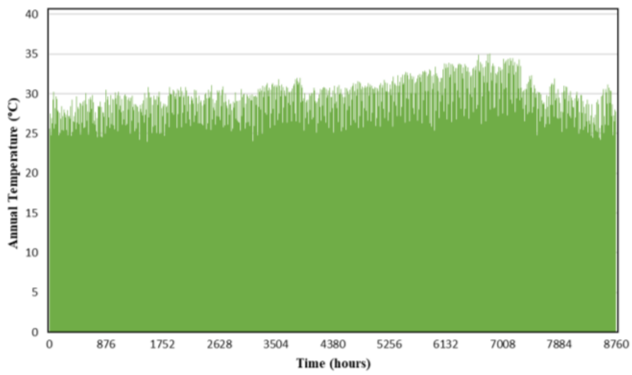

Fig. 6. Annual Ambient Temperature Profile

E. Modified Firefly Algorithm for System Optimization

The optimization case study in this paper applies the modified firefly algorithm (MFA). Several modifications to the firefly algorithm aim to improve the performance of the basic firefly algorithm, either from the completion time or the accuracy of the optimization process [6][19]. MFA performance on MATLAB R2022a on AMD A8-7410 APU 2.2-2.5 GHz Quad Core 12 GB RAM and SSD 240GB (500MB/s). The selected MFA refers to [20], with modification in the form of decreasing the value of α (alpha) for each iteration. The goal is to improve the randomness of fireflies due to the exploration of the optimal solution so that convergence is achieved more quickly.

F. Optimization Formulation

Optimizing educational buildings as a prosumer is an economic analysis but must meet technical requirements. The economic analysis combines all costs to obtain the minimum Levelized Cost of Energy (LCOE). The technical requirements are the fulfillment of electric load demand by existing energy sources with the ability limits of each component. Optimization is calculated with a project lifetime of 25 years.

1) Case 1

In case one, optimizing a grid-connected educational building has an independent energy source from photovoltaics by implementing a prosumer scheme. The objective function of the optimization problem is according to (12). The TNPC equation component that is prosumer cost according to (13).

$$\min f(pv) = [\mathrm{LCOE}] \tag{12}$$

$$PR_{\mathrm{Cost}} = Grid_{\mathrm{Cost}} \tag{13}$$

The results of the optimization are not only the minimum LCOE value, but the size of the component capacity must meet the maximum roof capacity limit that can be installed with photovoltaic and meet the electricity load requirements of the building. Fulfillment of electrical load demand is calculated by equations (14) and (15), and the maximum photovoltaic capacity according to equation (16).

$$P_{imp} = P_{load} - P_{pv\_out} \tag{14}$$

$$P_{\exp} = P_{pv\_out} - P_{load} \tag{15}$$

$$P_{pv\_r} \le \frac{W_a}{W_{m\_pv}} \tag{16}$$

where, W_a is the wide area of building rooftop (m^2) and W_{m_pv} is the wide of photovoltaic module (m^2). Techno-economic analysis in case 1 is carried out according to the flowchart of Fig. 7.

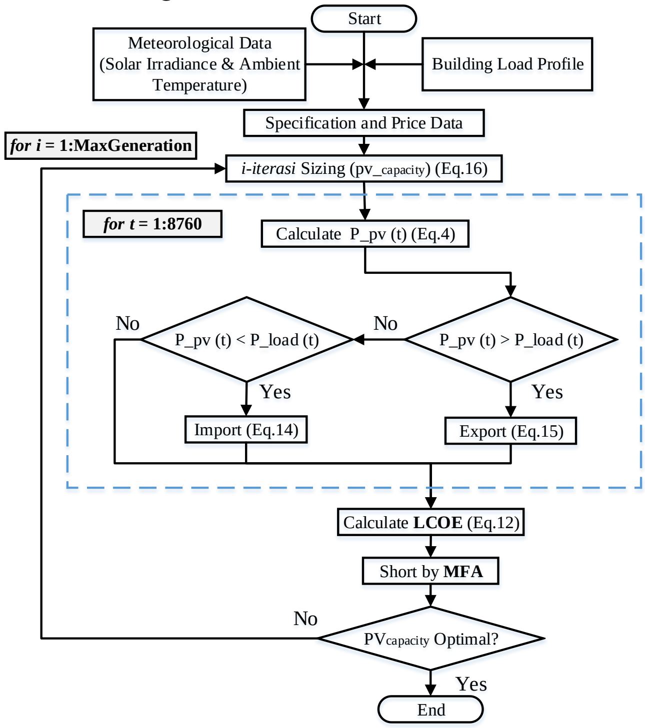

Fig. 7. Algorithm for the optimization of Case 1

2) Case 2

In case 2, optimizing a grid-connected educational building with an independent energy source from photovoltaics by implementing a prosumer scheme and PEV integration. The objective function in this optimization problem is according to (17).

$$\min f(pv, n\_PEV) = [\text{LCOE}] \quad (17)$$

TNPC in case 2 is modified in the initial cost section by adding the initial cost of the charging station according to the optimal number of PEVs.

The constraint function of case 2 consists of the load balancing that is met through import power (18) and if the electricity production exceeds the load demand, power can be exported (19), the maximum photovoltaic capacity (16), the maximum number of PEVs (20), and the power availability of PEV according to (5)(6)(7)(8).

$$P_{pv\_out} + P_{imp} + P_{PEV\_imp} \geq P_{load} \quad (18)$$

$$P_{pv\_out} - P_{PEV\_exp} - P_{exp} \geq P_{load} \quad (19)$$

$$n\_PEV \leq 14 \quad (20)$$

Techno-economic analysis in case 2 is carried out according to the flowchart of Fig. 12, on the appendix.

III. Results and Discussion

Optimal sizing of two cases has been carried out in grid-connected educational buildings with a prosumer scheme. Using MFA, the optimal system configuration is determined by minimizing LCOE. The parameters of the MFA are adjusted as follows: population size (N) = 20, $\alpha = 1$, $\beta = 0.2$, $\gamma = 1$, and maximum iteration number = 100. MFA's performance in solving cases 1 and 2 is presented in Table 2.

A. Optimal Sizing Analysis

Prosumers system optimal sizes of educational building for case 1 and case 2 are shown in Table 2. The optimal capacity of components is determined based on load supply, building area limits for photovoltaic installation, and parking area with minimum LCOE. The minimum photovoltaic size in case 1 and 2 is the same. The limitation of the roof area of the building as an installation area causes the capacity of the two cases to be similar. The optimal number of PEVs in case 2 is seven units from the maximum number that can be parked is 14 units. The number of charging stations follows the optimal number of PEVs.

TABLE II. OPTIMIZATION RESULT

	Case 1	Case 2	Units
Optimal Sizing			
PV	156	156	kWp
Inverter	200	200	kW
Σ PEV	-	7	Unit
Σ Charging Station	-	7	Unit
Economic Result			
TNPC	388,142.75	380,686.77	$
Annual Cost	21,551.72	21,137.73	$
LCOE	0.0472	0.0455	$
Power Aggregation			
Load Demand	356,392.24	356,392.24	kWh/year
PV Output Power	287,031.92	287,031.92	kWh/year
Grid Import	173,787.73	168,567.19	kWh/year
Grid Export	99,733.28	93,280.95	kWh/year
PEV Import	-	5,238.35	kWh/year
PEV Export	-	14,559.46	kWh/year
MFA Performance			
Iteration	100	100	
Elapsed time	12.9	310	second

B. Economic Analysis

Table 2 shows the LCOE, TNPC, Annual Cost, and annual power for case 1 and case 2. Comparison of the optimal LCOE of case 1 and case 2 that integrates PEV, case 2 produces LCOE 3.6% cheaper than Case 1. If it is break down, in terms of Annual Cost and TNPC, Case 2 is 1.9% smaller than case 1. Annual power generation from photovoltaic in both cases are the same. The difference lies in the allocation of export and import power, prosumers price scheme, and additional charging station investment costs in case 2. In case 1, 100% of the educational buildings power surplus and shortage are imported and exported to the grid. In Case 2, 97% import power is obtained from the grid and 3% from the PEV. Meanwhile, the export power is sent to the grid at 86.6% and 13.5% to PEV. The optimization results by applying the prosumers scheme show that with an expected project lifetime of 25 years, case 1 can save LCOE by 57%, and case 2 can save LCOE by 58.6% of grid electricity prices. This is in line with [21] that PEV integration with optimal calculations of each component can obtain profitable electricity costs.

C. Power Flow Analysis

The power flow from both cases is analyzed to show that the power distribution follows the load demand and the power generated. One week sample power flow from cases 1 and 2 that includes load demand, photovoltaic output power, and export and import of electrical energy shown in Figures 8 to 11. Sample semester dates are taken in the second week, whereas sample vacation dates are taken in the fourth week of January 2021. This month represents the rainy season, where the irradiance intensity's is certainly not at its maximum.

1) Case 1

In Fig. 8, which represents semester dates, photovoltaic power output on weekdays rarely exceeds load demand, meaning that limited power can be exported. Power exports tend to be bigger on weekends because load demand is small. In Fig. 9, power export takes place every day on vacation dates. Import power from the grid takes place when the photovoltaic output power cannot meet the load demand, whereas the amount is always according to the load requirements.

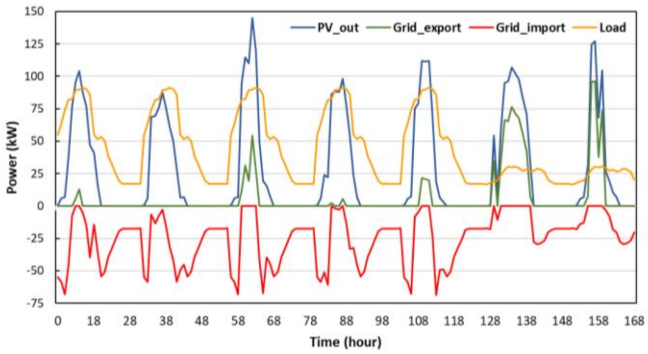

Fig. 8. One Week Sample of Semester Dates (Case 1)

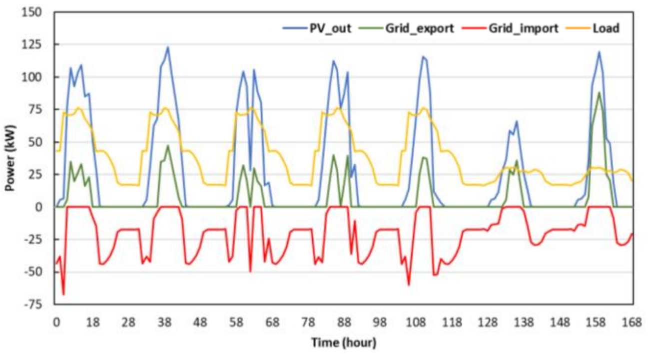

Fig. 9. One Week Sample of Vacation Dates (Case 1)

2) Case 2

Fig. 10 and Fig. 11 show the power flow in case 2. The two figures illustrate that the difference between case 2 and case 1 is that power exports are allocated to the grid and PEV. The main power export to PEV is because there is a minimum power departure constraint and the export price of power at PEV is more profitable. However, the power export to PEV can only be done on weekdays when PEV is available. Import power also prioritizes from PEV, whereas the power shortage will be imported from the grid. As shown in Fig. 11, the export allocation is more varied on vacation dates because PEV is still available on vacation dates, and load demand is not as big as on semester dates.

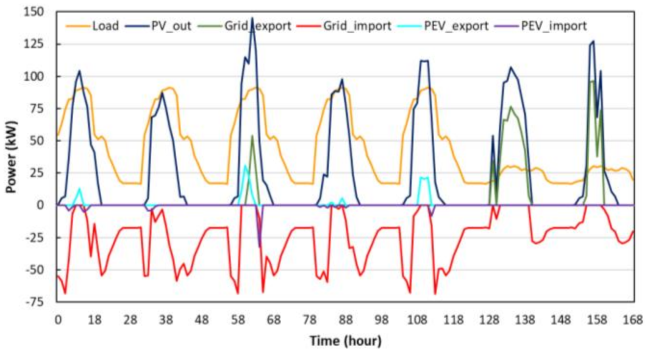

Fig. 10. One Week Sample of Semester Dates (Case2)

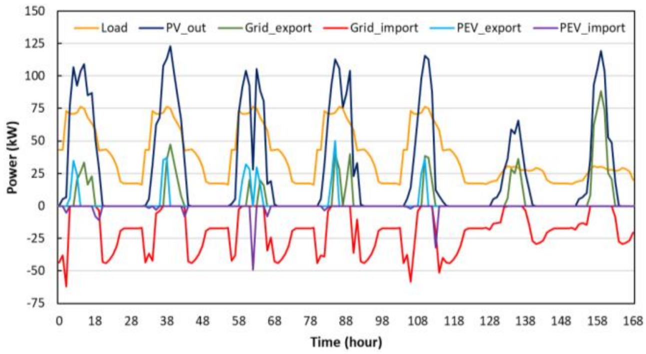

Fig. 11. One Week Sample of Vacation Dates (Case 2)

IV. CONCLUSION

This paper optimizes educational building opportunities in implementing prosumer schemes when installing solar panels and PEV integration. The optimal results obtained are in the form of 2 configurations, namely: (a) photovoltaic installation and applying the prosumer scheme and (b) photovoltaic installation and PEV integration using the prosumer scheme. The most optimal results from the two configurations are photovoltaic installation and PEV integration by implementing a prosumer scheme because, with an expected project lifetime of 25 years, this configuration can reduce the cost of purchasing electrical energy (LCOE) by 58.6% compared to only buying electricity from the grid. These results underlie that the application of the prosumer model can reduce the cost of electrical energy for an educational building, even with certain characteristics of the educational building's load demand, limited building space for photovoltaic installation, and limited number of PEVs. The challenge faced in implementing this scheme is that requires a big initial investment and regulation from the government regarding the implementation of the prosumer scheme, especially in Indonesia.

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Appendix

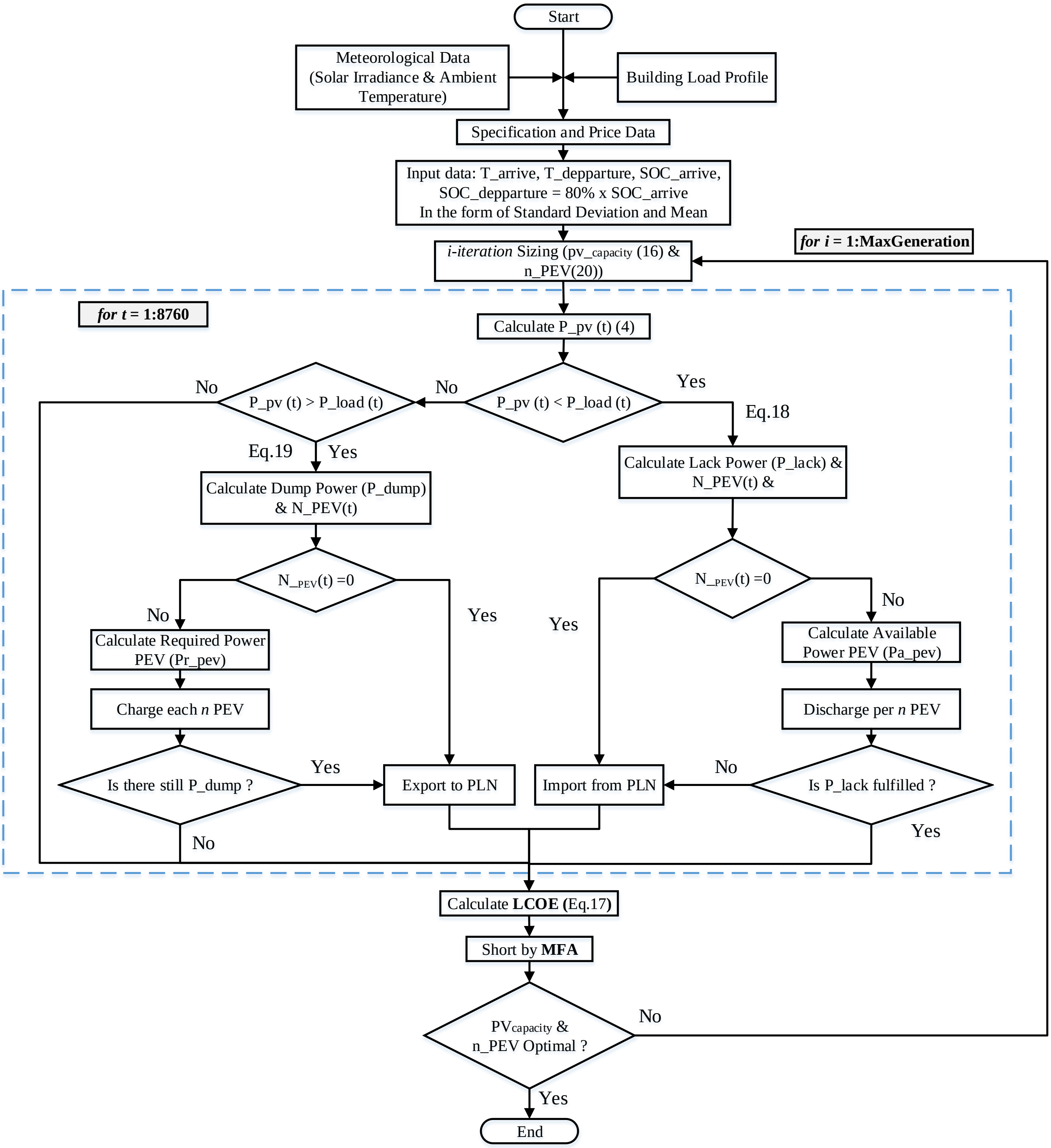

Fig. 12. Algorithm for the optimization of Case 2