Technical Design and Financial Feasibility Analysis of Off-Grid Photovoltaic Power Supply System for Residential Load

Muhammad Imran Hamid¹, Afifah²

¹Electrical Engineering Dept. Andalas University - Indonesia
²Business Administration Dept. Politeknik Negeri Padang - Indonesia

Abstract. Due to intensive promotion to use renewable energy, by the various benefits obtained by utilizing, and then supported by advances in generation technology: causing various parties to divert the type of fuel for their energy use activities. The same thing happens to residential electricity consumers, driven by the advantages of electricity power generation that can be done on the consumer side, independent operation, reliability and quality of power, many consumers try to install renewable energy based generation such as photovoltaic system for their electricity supply. However, looking at the tariff of utility electricity and considering the investment needed: building a photovoltaic-based supply system is not necessarily the right choice. This paper presents a technical design for electricity supply of a residential load through an off-grid photovoltaic system. The technical basis for designing and the capacity of its constituent components is explained, as well as the analytical techniques carried out to assess the financial aspects of the development and operation of the system. The results of this analysis can be used for deciding whether it is appropriate to divert the source of electrical energy to the photovoltaic system. To show the steps of the analysis, a case study was carried out by designing an off-grid photovoltaic system for a residential load characterized by its daily load curve. The capacity and costs were calculated and financial analysis is carried out by looking at the extent to which the designed system can provide comparable benefits if the power is supplied from the utility at the prevailing price, as well as how long the system must be operated to obtain a breakeven return on investment. Based on the daily load curve in this case study, it is known the total daily energy consumption of the load is 6.885 kWh. This amount of energy must be provided from photovoltaic module with 5 hour effective per day, so the minimum capacity of PV-module is 1463.65 W. For an autonomy time of 1 day, a minimum energy storage capacity of 8.965 kWh is required. Investment costs which include the cost of procurement, system development, and the tax are Rp. 150,008,037. The financial benefits are calculated based on prices of the PLN 2016 non-subsidized tariff. It was assumed that the energy used that should be supplied from PLN, is substituted by photovoltaic generation system. NPV analysis and Payback period shows that the off-grid photovoltaic generation system will be feasible if the electricity price is 2.3 times the current price, and the discount factor (DF) for construction is 2.5%, in such electricity prices and DF factor, the payback period is reached if generation system is operated at least until the end of the 25th year. Financial analysis showed the inability of the off-grid electricity supply scheme based on the designed photovoltaic generation for current conditions.
1. Introduction

The need for energy today continues to increase along with the civilization development, economic, and population growth. Unfortunately at this time, energy consumption is still dependent on the non-renewed fossil energy. According to Energy Economic Statistics of Indonesia 2016, the three main sources of energy supply in Indonesia are still held by fossil energy such as petroleum, coal, natural gas and their products. The coal supplies around 24.8%, petroleum 30.2% and 19.03% by natural gas [1]. Meanwhile, fossil energy reserves in Indonesia are increasingly depleting. Based on the 2014 Reserve/Production (R/P), if it is assumed that no new reserves of fossil energy found in Indonesia, it was predicted that the petroleum will run out in 12 years, natural gas 37 years, and coal 70 years [2]. Thus it is very necessary to change the dependency of fossil to the renewable energy. It is reasonable, considering that renewable sources such as wind power, hydropower, geothermal, sea water waves, solar power, bio-energy, and others renewable sources are very promising in Indonesia.

Encouraged by the above conditions, various parties devoted attention to efforts in the context of diverting energy sources. Various studies have been carried out by researchers to find new energy sources, optimize the exploration of existing renewable energy and try to create efficient technologies for energy consumption. Likewise, various sectors of energy use try to divert their energy use from initially relying on fossil-based fuels to fuels from renewable sources. On the side of policy makers, it is seen that many government in various countries around the world emphasize the use of renewable energy in their policy.

Utilization of energy is carried out in a variety of human activities: household, transportation, industry and also to produce or convert to other form of energy such as electrical energy. In the household sector, the diverting of energy use can be seen as the replacement of fuel from the use of kerosene to gas and electricity, as well as in transportation and industry, the diverting of energy is carried out in the form of using bio-fuel as previously using diesel.

Specifically for electrical energy, in addition to the diverting at the generation-side level -where energy for generating the electricity is diverted from coal and petroleum to renewable energy such as water, wind, photovoltaic (PV), and other renewable sources- diverting is also done at the consumer-side level. This can be done by utilizes the advantage of electrical energy that is, it can be generated at the consumer installations. In electricity user installations, in addition to being connected with electrical loads, it can also be connected to electric power generation devices. This can be found as in home-based photovoltaic generation applications. This is inseparable from the progress in the field of electric power generation technology which is achieved today.

Electric energy conversion technology using photovoltaic systems has enabled the electric generation can be carried out on the side of consumers. The capacity of energy that can be generated stretches from hundreds to several kilowatts. This technology also increases the reliability of energy supply for consumers because it can be used as a back-up power supply. Even with certain schemes, consumers not only consume electricity but can also supply the generated electricity by selling it to the utility grid. Furthermore, with the off-grid system, consumers can provide, regulate, plan electricity consumption independently. Consumers are also protected or isolated from various problems of fault, interruptions as well as electrical power quality problems that often occur in the electricity grid.

The reliability, security and independence of electricity supply made possible by using the photovoltaic system caused many parties and consumers interested and decided to realize and install it on their electricity supply system. However, realizing a photovoltaic system requires no small investment, considering the components used in this system are still relatively expensive due to some factors. In this regard, a number of questions have not been fully answered, is it more efficient to use electricity from own photovoltaic generation than from utility? Maybe in a certain country this is efficient because it is supported by various factors such as high electricity utility prices and the renewable generation energy incentives, however in other countries it is not profitable related to subsidies and other factors.
This paper presents the financial analysis of photovoltaic generation system applied to residential applications. The components that make up the system and its functions are described, as well as the patterns of electricity usage that result in the design of the photovoltaic system. Based on the design, the initial investment value of the system is calculated. Financial assessment is done based on investment criteria such as net present value (NPV) and payback period (PBP). The energy produced is assessed by the price of electricity sold by state electric company. This is done with the assumption that the energy generated is used as a substitution when the energy needed by the load must be supplied from state electric company. A residential load with the characteristics of electricity usage in form of load curve is used as a case study.

2. Methodology

2.1 Residential Photovoltaic System Design

The design of a photovoltaic generation system in a location, including for residential use, is aimed basically to adapt the designed system to specific energetic and geographical condition, as well as to energy behavior of the load. In addition to the feasibility of the geographical position in relation to the availability and fluctuations of photovoltaic energy sources, several things related to operation need to be determined from the beginning, because this will result in the selection of components and technology used. Whether the system will be operated off-grid or on-grid, whether the system will be built in single or three-phase system [3], and whether the coupling component is done in DC or AC side and others considerations.

The **off-grid or stand-alone system**, is completely isolated from the existing electricity system (grid). To be able to meet the availability of electricity supply for a full day, in the absence of solar energy sources at night, the presence of energy storage components such as batteries is absolutely necessary. While the **on-grid system** is a system built using components that allow energy generated in consumer installations to be connected to the grid. Power-supply for consumer installations can be done from two directions, from own photovoltaic system, and in the absence of a solar energy at night; the power-supply for the load is taken from the grid. In the condition that the energy generated exceeds consumer consumption, the excess energy can be fed into the grid. In such a system, the consumer and grid must continue to be connected because the inverter component uses the grid voltage as a reference for generating power. This causes the reliability of consumer supply decreases and is affected by the condition of the utility grid. To improve system reliability and prevent the system from being affected by the distribution system in the event of a fault and poor power quality, on-grid systems can be equipped with energy storage components (**hybrid system**). When the grid supplied are is disconnected and in the absence of solar energy, the power-supply of consumer installations can be taken from the storage unit. Such a system requires that the inverter used has the ability to work on-grid or off-grid by having its own voltage reference for power generation. **Figure 1** describes the systems.

![Figure 1. Structure of PV system for residential. Stand-alone (left), grid-tied (middle), hybrid (right).](image-url)
Related to geographical location, the data needed is the amount of irradiance at the location where the PV system will be built. To get this data, direct measurements followed by statistical analysis must be carried out. The data can also be obtained through data provided by various institutions related to atmospheric conditions and irradiation monitoring. These institutions provide specific data on the amount of irradiation at a location, and also provide a database on the amount of radiation for a certain time.

The PV system design for a residential load begins by recognizing the characteristics of the load to be supplied. This is shown in the form of load curves describes the variation of consumed energy in full day duration (24 hours). From the curve, load parameters such as average, maximum and minimum load and when they occur, load and loss factors, and also the amount of energy used for one day can be calculated. The information is then used to determine the photovoltaic system capacity and the amount of battery capacity related to the planned autonomy time duration. Autonomy time is the time for which the storage device will support and ensure the load still supplied by the electrical power. The next step is determining the capacity and features of each component that makes up the photovoltaic system. Considering the operating patterns (on-grid or off-grid) of the system must be involved. The following is an overview of the planning of each component making up photovoltaic system for residential:

2.2 Photovoltaic Module

This component functions to change the amount of photon energy contained in solar sun into DC electricity in its terminals. In addition to the level of irradiation and temperature, a number factors influence the amount of power that can be generated, in general the relation of these factors to the output power -presented by DC current- is written by the following relation [4]:

\[ I_{pv} = I_{ph} - I_d - I_{sh} \]  

\[ I_{ph} = (I_{SCR} + K_1(T - 25)) - \frac{G_a}{100} \]  

\[ I_d = I_o \left[ e^{\frac{q(V_{pv} + I_{pv}R_{se})}{A_o k T}} - 1 \right] \]  

\[ I_{sh} = \frac{(V_{pv} - R_{sh})}{R_{sh}} \]  

\[ I_o = I_{or} \left[ \frac{T}{T_r} \right]^{3} \exp \left[ \frac{qE_{GO}}{A_o k T_r} \left( \frac{1}{T} - \frac{1}{T_r} \right) \right] \]

Where:
- \( I_{pv}, V_{pv} \): current and voltage of the PV cell.
- \( I_{ph} \): light generating current.
- \( I_o \): diode dark saturation current.
- \( K_1 \): short circuit temperature coefficient at ISCR.
- \( T \) and \( G_a \): cell temperature and irradiance on cell surface.
- \( I_{or} \): cell saturation current at reference temperature \( T_r \).
- \( E_{GO} \): band gap energy.
- \( k \) and \( q \): Boltzmann cons. = 1.3807 \times 10^{-23} \text{ JK}^{-1} \) and electric charge = 1.6022x \times 10^{-19} \text{ C}.
- \( R_{se} \) and \( R_{sh} \): parasitic series and shunt resistances, associated with cells in operation condition.
- \( A_o \): diode ideality (quality) factor; its value is taken between 1 and 2.
- \( I_{SCR} \): short circuit current of the cell on 1000 W/m² and 25°C of temperature.
In the market, PV modules are available in the form of modules which are series and parallel configuration of PV cell. The important thing for each module is the availability of the relationship $v_i$-curve which shows the conditions of the output voltage and current for various levels of test irradiance and temperature. From this curve, the condition of short-circuit current and no-load voltage, and the point where the maximum power operation happened (MPP) can be known. Other important aspects of PV modules are lifetime and efficiency. Referring to the glass as the basic material of PV modules, theoretically the life time of PV module is predicted to be up to 50 years. Over time, the performance of PV modules decreases [5]; in general the manufactures provide a guarantee of operation for up to 25 years for their module will still within the permissible level of performance [6]. From the aspect of efficiency, studies shown that mono-crystalline and concentrated photovoltaic are photovoltaic module with good efficiency [7]. Table 1 shows the performance comparison of several types of PV modules available on the market.

### Table 1. Characteristic of Some PV-Module Types

| Solar Cell Type                  | Efficiency-Rate | Advantages                                    | Disadvantages                     |
|----------------------------------|-----------------|-----------------------------------------------|-----------------------------------|
| Monocrystalline Solar Panels (Mono-SI) | ~20%            | High efficiency rate; optimized for commercial use; high life-time value | Expensive                         |
| Polycrystalline Solar Panels (p-Si) | ~15%            | Lower price                                   | Sensitive to high temperatures; lower lifespan & slightly less space efficiency |
| Thin-Film: Amorphous Silicon Solar Panels (A-SI) | ~7-10% | Relatively low costs; easy to produce & flexible | Shorter warranties & lifespan     |
| Concentrated PV Cell (CVP)       | ~41%            | Very high performance & efficiency rate        | Solar tracker & cooling system needed (to reach high efficiency rate) |

#### 2.3 Photovoltaic Inverter

PV-Inverters are characterized by the number of phases and their capacity in kilowatt, working voltage, frequency, and efficiency. In the market, single-phase inverters are available in small capacities, usually in transformer-less topologies while three-phase inverters are designed in a higher power rating and use a topology with a transformer (multi-stage inverter). Voltage rating, frequency of the inverter is usually determined and ordered before the purchase is made. A number of manufacturers produce PV inverters specifically for off-grid and on-grid use, but other manufacturers distinguish these functions only on the software and hardware settings. The efficiency of a PV inverter is defined as:

$$ \eta_{\text{inv}} = \frac{P_{\text{AC}}}{P_{\text{DC}}} = \frac{P_{\text{DC}} - P_{\text{loss}}}{P_{\text{DC}}} $$

Where:
- $P_{\text{DC}}$: instantaneous DC power
- $P_{\text{AC}}$: instantaneous AC power
- $P_{\text{loss}}$: power losses

The efficiency values of inverter products from various manufacturers on the market vary from 94 - 98% [8]. Each inverter has efficiency level as function of its load factor, and presented as efficiency curves. Generally efficiency of the inverter shows a different value at each level of power conversion, higher efficiency is shown when operating below 50% of its rating. Due to the varying conditions of this efficiency, to assess the overall efficiency of an inverter, European Central Climate, arrange the formula as:
\[ \eta_{\text{euro}} = 0.03 \eta_{5}\% + 0.06 \eta_{10}\% + 0.13 \eta_{20}\% + 0.10 \eta_{100}\% + 0.48 \eta_{50}\% + 0.2 \eta_{100}\% \]  

(3)

The level of inverter capacity for an installation can be calculated energetically by knowing the total energy to be consumed in one year (annual) and deriving the equation of the inverter efficiency curve available from manufacturer [8]. Furthermore, by using equations (4) and (5), the optimum capacity can be obtained by differentiate the energy equation respect to inverters power rating and equate it with zero:

\[ \frac{dE}{dP_{\text{inv,N}}} = 0 , \]

Then, for \( P_{\text{inv,N}} > P_{\text{max}} \):

\[ P_{\text{inv,N}}^{\text{opt}} = P_{\text{max}} \sqrt{\frac{B}{3C}} \]  

(4)

and for \( P_{\text{inv,N}} \leq P_{\text{max}} \):

\[ P_{\text{inv,N}}^{\text{opt}} = P_{\text{max}} \frac{A+B+C}{A+2B} \]  

(5)

Where:

- \( P_{\text{max}} \): Maximum DC power from the installed PV module
- \( A, B \) and \( C \): A number obtained by modeling (making the function of efficiency vs. load factor) the characteristics of the inverter efficiency.

The equation for optimum inverter capacity for a certain PV plant is arranged with two conditions: the condition when the \( P \) inverter is made larger and smaller than the module capacity. Designing a PV inverter smaller than a PV module will cause most of the operating time, the inverter will work at a 100% rating and vice versa, this working mode will affect the inverter's life time. Optimum size of an inverter for a given installation can vary from 1.11 to 2.02. [9].

2.4 Battery

In a photovoltaic-based and other intermittent energy supply systems, energy storage is very important. This is even more important if the supply system is off grid, it will function as a main supply in the absence of energy sources. In the on-grid system, energy storage functions as a useful back-up in the case of grid supply are interrupted or experiencing a fault. The most practical form of energy storage today is the battery storage. The battery is characterized by its output voltage and capacity measured in Ah or kWh.

In general applications, there are a number of battery types that can be used, but the selection of batteries must take into account the price, capacity, voltage and cycle-life. Cycle life needs to be considered because it involves battery capacity in terms of the number of discharge/charge cycles the battery can provide before capacity drops to a specified percentage of rated capacity. Batteries are considered to be at the end of their lifespan when 20% of their original capacity is gone. The selection must also consider what is called a deep-cycle, i.e. how far the battery can be discharged relative to its capacity [10]. A comparison of several types of batteries is shown in Table 2. Note that two types of batteries dominate the use in photovoltaic systems, namely Lead-Acid based batteries and Lithium-Ion based batteries.
The amount of battery storage is designed based on the energy usage that can be derived from the load curve. After the amount of energy is known, the next step is to determine the days of autonomy, i.e. how many days are worth of energy to be stored in the battery bank. And the next is to choose the type of battery by considering the output voltage of the solar panel, the rate of discharge, the depth of discharge we need, and the operation temperature. According to following formula:

$$Ah_a = \frac{Ah_d \times TC \times DA \times DM}{DoD}$$  \hspace{1cm} (6)

Where:

- $Ah_a$: Ampere-hours adjusted
- $Ah_d$: Ampere-hours day
- $TC$: temperature correction factor, according to type of battery
- $DA$: autonomy time (day, 1 – 4 days)
- $DM$: design factor, 1 – 1.25
- $DoD$: depth of discharge, 0.2 – 0.8

Battery storage capacity can also be designed based on the total energy (kWh) that must be stored. Noted that Ah value in formula (6) is the total energy needed by the load, to calculate how many batteries are needed, a datasheet from the battery manufacturer is needed which shows the output voltage, the capacity of the unit so that the battery configuration can be arranged according to the current and operating voltage of the system.

### Table 2. Characteristic of some Battery Storage Types

| Battery Type | Advantage | Disadvantage |
|--------------|-----------|--------------|
| Lead-Acid,  |
| - VRLA/SLA (Valve regulated LA, Sealed LA) consist of AbsGlasMat and Gel |
| - Flooded LA |
| 1 kW to 10 MW Application | Better in subtropical (low temperature) operation, relative ECO friendly | low specific energy, Limited Cycle Life 400-500 cycles, 50 - 55% DoD, low charge rate, 80-85% efficiency, |
| NiCd (Nickel Cadmium) | NiCd batteries have superior performance characteristic to lead-acid with respect to their tolerance of full charge and discharge | lower energy density, present some environmental hazards |
| 1 kW to 0.5 MW | | |
| NIFE (Nickel Iron),  |
| 1 kW to 1 MW. | Better energy density, | high self-discharge rate |
| Lithium-Ion,  |
| - Iron phosphate |
| - Nickel, Cobalt, Manganese | Low discharge rate, high energy density (lighter and smaller), 80 - 100% DoD, ECO friendly, no maintenance or venting, higher charge rate (refilled much faster), 95% efficient, life cycle: 2000 to 5000 cycles, better operate in tropical (hot temperature) | The internal resistance can heat, thus causing failure of the battery; Higher cost. |
| 1 kW to 1 MW | | Contain many hazardous elements, operate at high temperatures of approximately 270°C–350°C, cycles 250 |
| Sodium–Sulfur (NaS) Battery, 0.8 to more than 10 MW | High power density, high efficiency, up to 90% and long lifetime (over 10 years) | when a VRB is deactivated, the membrane can be highly acidic or alkaline requiring special measures of disposal. |
| Flow Batteries (FBs); VRB, Iron–chromium (FeCr), zinc–bromine (ZnBr2), Zinc–air. 10 kW to more than 10 MW | Cost and storage of the electrolyte more convenient, the electrolyte does not degrade with time, and so, the life of VRB can theoretically reach ten years. | |
| Sodium–Nickel–Chloride (NaNiCl2) Batteries, 100 kW to less than 10MW | Wide range operating temperature | Operate at high temperatures of approximately 270°C–350°C |
2.5 Charge Controller
Charge controller is used to protect batteries from overcharging and/or excessive discharge. This is achieved by regulating the current for charging to the battery, avoiding overcharging and overvoltage, regulating the current released/taken from the battery so that the battery does not over-charged, and monitor battery temperature. Charge controllers are characterized by their working voltage, amperage, full charge level and low voltage cut.

2.6 Financial Analysis of Residential PV System
Internal Rate of Return (IRR) and Pay Back Period (PBP) are the indicators used to assess the feasibility and profitability of an engineering project. In this method, a cash flow analysis using the NPV is carried out to be able to evaluate the indicators. NPV is used based on the present value of cash inflows and outflows over a period of time, from this, the Internal Rate of Return (IRR) which the discount rate that makes the NPV of the project equal to zero can be found. NPV is written as [11]:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$  \hspace{1cm} (7)

Where:
- $C_t$: net cash inflow for the period
- $C_o$: initial investment
- $r$: discount rate
- $t$: number of period

Cash outflows consist of maintenance and replacement costs of the project, while cash inflow typically consists of financial benefits by selling the energy produced by the PV plant. Capital investments ($C_o$) are the initial costs incurred for investment projects carried out. They are calculated considering the cost of all the components that make up the PV system, including the cost of procuring solar modules, inverters, batteries, charge controllers, electrical cables and civil infrastructure. Information regarding the cost obtained from the supplier websites or from any literature.

In the Payback Period Analysis, we used the payback period to assess the feasibility and profitability of the project. Payback period is the period needed to return the investment expenditure (initial cash investment).

In this financial analysis, the financial benefits of the project are obtained from the amount of electricity generated, assessed by the tariff of electricity released by the electricity company, in this case, PT. Perusahaan Listrik Negara (PLN). This is done by assuming the energy generated is used as a substitute if the energy supply is fed from PLN. Thus, through the financial analysis conducted, it can be assessed whether it is better to realize/built the PV generation system for supplying the connected load or connect it to the PLN grid.

Electricity tariffs in Indonesia are built on the basis of two cost components: connection and electricity usage cost. By type of use, the tariff is divided into main groups: tariffs for social services, household, business, industrial, electricity tariffs for government offices and street lighting, tariff for traction purposes, for electricity power in the medium voltage, and tariffs for special services on low, medium and high voltage which are not included in the tariff groups mentioned previously [12]. Each main tariff group consists of several groups to form totally 12 tariff groups. In each of these groups there are groups that receive subsidies from the government. The payments for the tariffs can be made in prepaid or postpaid scheme. The tariffs for low voltage (single or three-phases) households are classified into three tariff groups: the tariff for small households with power up to 2200 VA, tariff for medium households with power 3500 - 5500VA, and tariff for large households with power up to 6600 VA or above. Subsidies for these household tariffs are only for small household with a maximum power connection of 900 VA. The electricity tariffs as mentioned above are generally dynamic, a tariff adjustments is made regularly to adapt the factors that affect the cost of electricity production.
3. Result and Discussion: The Case Study

This section will present a case study of a photovoltaic power plant design to supply a residential load with load-curve characteristic as illustrated in Figure 2 (a). For one year, energy consumption is obtained by multiplying the average daily energy consumption and number of days in a year. The power supply system for this load is designed as an off-grid photovoltaic system equipped with battery storage and charge controller with autonomy duration for one day. PV-inverter for this purpose is the type that has references for voltage generation independently (off-grid inverter). The scheme of the system is presented in Figure 2 (b).

![Load curve for the case study (upper); Schematic for the PV system (lower)](image)

From this daily load-curve, it is known that the peak load occurs at 19.30 pm of 690 Watt, while the lowest load occurs at 08.00 am at 155 Watt level. With further analysis, the average electricity consumption is 143.44 Watt with a total daily energy consumption of 6.885 kWh. This amount of energy must be provided from photovoltaic modules via inverter, it is assumed the inverters efficiency is 96%, so the input power to the inverter is 6.885/0.96 = 7.171 kWh. With this condition, and assuming that effective irradiance at the location is 5 hour, efficiency of wiring is 98%, then minimum capacity of the total photovoltaic module that must be provided is 7.171 kWh/0.98/5h = 1463.65 W. For this needs, taking into account the uneven variations in the sun's intensity for one day, 6 modules of Panasonic VBHN245SJ25 are chosen with a capacity of 245 Watt each. These modules are arranged in 3 series configuration (3×2) to obtain maximum 100 Volt voltage during no load condition on their terminals.
Based on the obtained daily energy consumption, then an energy storage component capacity with autonomy time of 1 day, depth of charge 80%, minimum energy storage capacity of (7.171kWh×1d)/0.8 = 8.965 kWh is required. The Lithium-Ion battery from LG Chem with capacity of 9.8 kWh was chosen for this purpose. To charge the battery for 5 hours duration in a DC bus voltage of 48 volts, a charge controller with a minimum current capability of 7.171 kWh/5h/48 Volts = 29.88 Amp is required. For this purpose, the Steca Solarix MPPT 5020 solar charge controller is chosen. The DC output of the charge controller is fed to fill the battery; other output can be used as supply for existing DC loads. To supply the AC loads, an inverter that with DC side connected to battery terminal/ DC output of charge controller is needed. Considering the maximum load at 650 W, the Steca XTS 1400-48 inverter with DC input range of 38 - 68 Volt, AC output of 230 Volt and power capacity of 900 VA is selected for this purpose.

The financial cash flow for this 9.8 kWh power supply and storage system is shown in the Table 3. The system is planned to operate in normal time of 25 years with three scenario of discount factor, they are 2.5%, 5%, and 7.5%. Investment costs which include the cost of procurement, system development, and the tax is Rp. 150,008,037. Operating and maintenance is planned to ensure no degradation on energy producing, the costs are taken at 1% of investment which is done every 5 years. The benefits obtained are ascribed to the production of energy produced, the price of which is calculated based on the non-subsidiary energy price of PLN: Rp. 1,467.26/kWh.

| Year | Capital Investment | Annual Return | Energy Price (Rp.) | Cost Flow (Rp.) | Discounted Factor, DF 2.5% | Discounted Factor, DF 5% | Discounted Factor, DF 7.5% |
|------|-------------------|---------------|-------------------|----------------|----------------------------|--------------------------|----------------------------|
| 0    | -150,008,037      | 0             | 0                 | -150,008,037   | -150,008,037               | -150,008,037              | -150,008,037               |
| 1    | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,597,636                  | 3,440,507                | 3,346,151                  |
| 2    | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,596,636                  | 3,440,507                | 3,346,151                  |
| 3    | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 4    | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 5    | -1,500,080        | 0             | 0                 | -150,008,037   | -150,008,037               | -150,008,037              | -150,008,037               |
| 6    | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 7    | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 8    | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 9    | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 10   | -1,500,080        | 0             | 0                 | -150,008,037   | -150,008,037               | -150,008,037              | -150,008,037               |
| 11   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 12   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 13   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 14   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 15   | -1,500,080        | 0             | 0                 | -150,008,037   | -150,008,037               | -150,008,037              | -150,008,037               |
| 16   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 17   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 18   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 19   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 20   | -1,500,080        | 0             | 0                 | -150,008,037   | -150,008,037               | -150,008,037              | -150,008,037               |
| 21   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 22   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 23   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 24   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |
| 25   | 2,513             | 1,467.28      | 3,687,311          | 3,687,311      | 3,687,311                  | 3,440,507                | 3,346,151                  |

| Total | -63,825,575 | -86,520,547 | -101,422,476 | -111,538,616 |

Financial analysis is carried out to determine at what level the price of PLN energy will provide favorable conditions for deciding to build an own energy supply installation from photovoltaic independently at a calculated cost. From the analysis conducted as in Table 3, at the current level of energy prices from PLN at Rp. 1467.28; there is no discount factor that gives a positive NPV. A positive NPV system is obtained when the PLN energy price is Rp. 3337.00 obtained at a 2.5% DF rate. This shows that financially, for the technical specifications and planned lifetime of the system, the development of an independent PV-based supply and storage system is only feasible if the PLN
power consumption of 143.44 watts, maximum power of 155 Watts and a daily energy usage of 4.

The payback period obtained from the payback period analysis for this condition is reached at the end of the 25th year, where the value of the discounted net cash flow starts to be positive, Table 4.

| Year | Capital Investment (Rp.) | Annual Return Energy Price (Rp.) | Cash Flow (Rp.) | Discounted Factor, DF 2.5% | Discounted Factor, DF 5% | Discounted Factor, DF 7.5% |
|------|-------------------------|---------------------------------|----------------|--------------------------|--------------------------|--------------------------|
| 0    | -150,008,037            | 0                               | 0              | -150,008,037             | -150,008,037             | -150,008,037             |
| 1    | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 8,181,429                | -141,826,608             |
| 2    | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 7,981,882                | -133,844,726             |
| 3    | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 7,787,302                | -126,057,523             |
| 4    | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 7,595,720                | -118,460,255             |
| 5    | -1,500,080              | 6,858,884                       | 6,855,884      | 6,086,118                | -112,374,137            | 5,395,270                |
| 6    | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 7,231,191                | -105,142,946             |
| 7    | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 7,054,820                | -98,088,136              |
| 8    | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 6,882,752                | -91,205,374              |
| 9    | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 6,714,880                | -84,490,494              |
| 10   | -1,500,080              | 6,858,884                       | 6,083,349      | 6,403,441                | -79,111,253              |
| 11   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 6,391,319                | -71,719,934              |
| 12   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 6,235,433                | -64,484,501              |
| 13   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 6,083,349                | -59,777,935              |
| 14   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 5,934,975                | -54,466,176              |
| 15   | -1,500,080              | 6,858,884                       | 5,794,948      | 6,391,319                | -79,111,253              |
| 16   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 5,648,995                | -72,719,934              |
| 17   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 5,511,214                | -65,281,954              |
| 18   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 5,376,795                | -58,749,713              |
| 19   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 5,245,653                | -52,147,903              |
| 20   | -1,500,080              | 6,858,884                       | 4,992,888      | 6,039,948                | -80,347,707              |
| 21   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 4,871,110                | -73,826,800              |
| 22   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 4,752,303                | -67,409,107              |
| 23   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 4,636,393                | -61,147,404              |
| 24   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 4,523,310                | -55,086,705              |
| 25   | 2,513                   | 3,337.00                        | 8,385,964      | 8,385,964                | 4,409,266                | -49,192,998              |
| Total| 53,640,752              | 49,206                          | -35,199,919    | -59,162,984              |

4. Conclusion
Design and financial analysis of an off-grid photovoltaic generation system for supplying a residential load have been presented. The load is characterized by a daily load curve that shows the average power consumption of 143.44 watts, maximum load power of 155 Watts and a daily energy usage of 6,885 kWh. To supply this load in an off-grid system with solar-based generation with autonomy time for one day, it requires a photovoltaic module with a total capacity of at least 1463.65 Watts, and a minimum battery storage capacity of 8,965 kWh which is controlled using a battery controller of 29.88 Amperes. The supply for AC loads is carried out through an off-grid inverter with a capacity of 900 VA, 230 V. For realization, it is necessary to optimize and adjust the capacity obtained from the design and availability of component capacities produced by the manufacturer in real conditions.

Financial analysis for this DC-Coupling off-grid system is carried out to assess the feasibility in the environment of the existence of other energy supply, i.e. state electrical company, PLN. For cash flow analysis, the investment cost consists of cost for component procurement and construction of facilities, including taxes, where prices are obtained from the website of the supplier/manufacturer. The financial benefits obtained are calculated based on electricity prices according to the non-subsidized electricity tariff of PLN 2016, which is done with the assumption that the energy used that should be supplied from PLN, is substituted with the energy generated through own photovoltaic generation system. NPV analysis and payback period that has been done shows that in supplying electricity through off-grid photovoltaic generation system it will be feasible if the electricity price is 2.3 times the current price, and the discount factor (DF) for construction (if assumed to be built using a loan) is 2.5%, in such a condition of electricity prices and DF factor, the payback period is reached if generation system is operated at least until the end of the 25th year.
Financial analysis carried out showed the inability operations of the independent electricity supply scheme based on the photovoltaic generation that have been designed for current conditions. This was due to the high investment that had to be provided because most of the photovoltaic generation system components were still imported equipment. A number of schemes can be carried out by policy makers to encourage the use of renewable energy, for example by incentive treatment, reduction of interest rates for the construction of renewable plants, reduction or elimination of import duty for renewable generation components and the most important is a policy to encourage the availability and production of renewable generation components domestically.

References

[1] Ministry of Energy and Mineral Resources Republic of Indonesia, “2016 - Handbook of Energy & Economic Statistics of Indonesia.,” vol. 45, no. 12. pp. 48–50, 2005.

[2] S. Nugraha, “Indonesia Energy Outlook 2010,” p. 139, 2016.

[3] M. Anwari, M. I. Hamid, and Taufik, “Photovoltaic energy conversion system using single-phase grid-tied inverter,” in INTELEC, *International Telecommunications Energy Conference (Proceedings)*, 2009.

[4] E. Koutroulis, K. Kalaitzakis, and N. C. Voulgaris, “Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System,” *IEEE Trans. Power Electron.*, vol. 16, no. 1, pp. 46–54, 2001.

[5] D. C. Jordan and S. R. Kurtz, “Photovoltaic degradation rates - An Analytical Review,” *Prog. Photovoltaics Res. Appl.*, vol. 21, no. 1, pp. 12–29, 2013.

[6] J. Weaver, “Solar module lifetime predictions are getting better. PV magazine -Photovoltaics Markets and Technology 2018 Available at: <https://www.pv-magazine.com/2018/12/10/solar-module-lifetimepredictions-are-getting-better/>,” p. 2018, 2018.

[7] M. F. Nayan, S. M. S. Ullah, and S. N. Saif, “Comparative analysis of PV module efficiency for different types of silicon materials considering the effects of environmental parameters,” *2016 3rd Int. Conf. Electr. Eng. Inf. Commun. Technol. iCEEiCT 2016*, no. De, 2017.

[8] T. Khatib, A. Yasin, A. A. Mohammad, and I. A. Ibrahim, “On the effectiveness of optimally sizing an inverter in a grid-connected photovoltaic power system,” in *2017 14th International Conference on Smart Cities: Improving Quality of Life Using ICT and IoT, HONET-ICT 2017*, 2017, vol. 2017-Janua, pp. 48–52.

[9] C. Demoulias, “A new simple analytical method for calculating the optimum inverter size in grid-connected PV plants,” *Electr. Power Syst. Res.*, vol. 80, no. 10, pp. 1197–1204, 2010.

[10] I. Alsaidan, A. Khodaei, and W. Gao, “Determination of optimal size and depth of discharge for battery energy storage in standalone microgrids,” *NAPS 2016 - 48th North Am. Power Symp. Proc.*, 2016.

[11] Gujari A. S, “A Technoeconomic Feasibility of Inverter Selection for MegaWatt(MW) Scale Grid Connected Solar Photovoltaic Power Plant,” in *International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS-2017)*, 2011, vol. 1, no. June, pp. 6–8.

[12] Ministry of Energy and Mineral Resources Republic of Indonesia, “Peraturan Menteri Energi dan Sumber Daya Mineral Republik Indonesia Nomor 28 Tahun 2016 tentang Tarif Tenaga Listrik yang Disediakan oleh PT Perusahaan Listrik Negara (Persero).” 2016.