Optimization Modeling and Simulation Solar PV System Using PVsyst Software

CASE STUDY: GAS POWER PLANT IN NORTH BALI

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***Abstract* - This paper presents optimization and simulation of solar power plants as alternative energy sources and energy efficiency at gas power plants in northern Bali. Created 10 solar power plant designs based on variations in Photovoltaic technology, the number of parallel and series PV modules, the design results are simulated with the help of PVsyst software. Of the 10 designs made, three designs were chosen which met the technical optimal criteria to calculate the generation cost of each design. From the results of simulation research 7 was chosen as a technically feasible design because it has the highest output of 83,300 kWh / year and the smallest losses are 14,600 kWh / year and economically feasible because it has the lowest generation economic value of Rp.2,386 / kWh**

***Keywords – Technically, PVsyst, Photovoltaic, economically*.**

I. INTRODUCTION

Solar energy is one of the renewable energy sources that can become electrical energy using photovoltaic (PV). This time, PV is increasing using it as source of electrical energy, because it has advantages among environmental friendly, low maintenance costs, abundant energy and free[1-4]. Therefore, compared to conventional plants that use fossil fuels, the use of PV is more profitable for the long term as energy[5]. PV is one of the alternative energy in Indonesia because of the high availability of solar radiation containing the dry season[6].

The gas power plant in northern Bali is one of the available generating units or peaker that only operates when needed. Larger electricity generation units, which affect operational costs are high. Therefore, alternative energy is needed that can reduce operational costs of buildings and generating units.

In this paper will focus on the design and modeling of solar power plants that have optimal criteria technically and economically. The design uses the help of PVsyst software and several design models are carried out with the parameters of the type of PV technology, the PV manufactured, the watt peak of each module, and the number of modules installed. The selected design occupy optimal criteria technically and economically.

II. METHODOLOGY

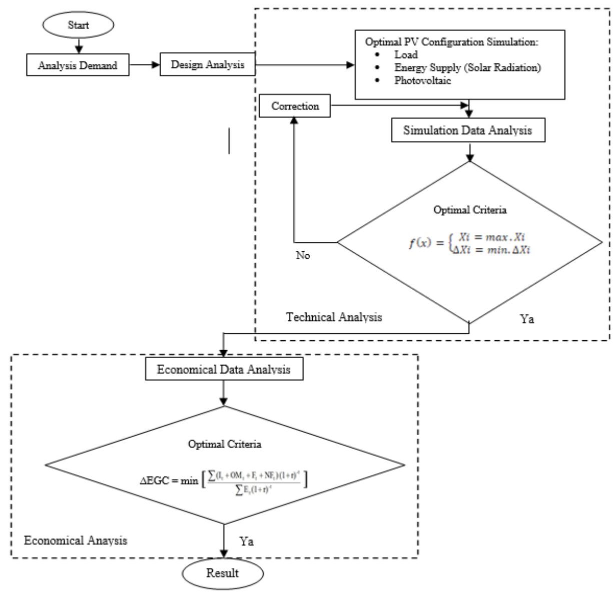

Fig. 1. Flowchart research

As per fig 1 in general this study consists of three stages. First, analyzing the electrical power needs of the building and the use of generating units. Second, designing and modeling solar power systems that are technically feasible to meet energy needs. Third, conduct generation economic analysis to assess whether the technically optimal design is also economically feasible

A. Analysis Demand

Electricity demand projections are carried out to find out how much average power must be supplied by solar power plants. In the case study, the load consists of the main building and the generator unit. Table I shows the details of the average load.

TABLE I. LOAD PROFILE

Name	Power (W)
Building	5,356.45
Unit Generation	44,560.38
Total	**49,916.83**

Table I shows the average power that solar power plants must provide at 49,916.83W and average become 50 kW. Because PV is designed to be grid connected without using batteries and PV only supplies energy during the day. So the reliability of supply for loads is not considered.

B. Solar Radiation

Solar radiation is one of the important parameters in solar power system. Because the size of solar radiation will affect the electricity produced by PV. Therefore, in Fig 2 shows the projection of average solar radiation per month for a year in northern Bali which originates from a meteonorm.

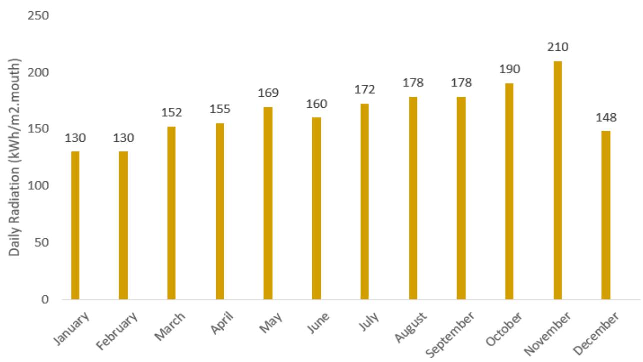

Fig. 2. Solar radiation

C. Photovoltaic

The size of a series of Photovoltaic modules arranged in series can be determined using equation 1 the following:

$$N_{ps} = \frac{N_v}{V_{pmax}} \quad (1)$$

Where Nps is number of series panels, V_N is nominal system voltage (V), and Vpmax is voltage of a PV module (V).

Calculate the number of parallel panels Npp is determined using equation 2 the following:

$$N_{pp} = \frac{I_{mmax}}{I_{pmax}} \quad (2)$$

Where is Npp is number of parallel PV module, Immax is maximum system current, and Ipmax is maximum current of a PV module.

the total number of panels can be calculated using equation 3 the following:

$$N_{total} = N_{ps} \; x \; N_{pp} \quad (3)$$

Where Ntotal is total number of panels, Nps is number of serial modules, and Npp is number of parallel modules.

To determine the total output power of the photovoltaic panel can use equation 4 the following:

$$P_{total} = P_{module} + N_{total} \quad (4)$$

Where Ptotal is total power output of PV (Wp), Pmodule is power output of module PV (Wp), and Ntotal is total number of module PV.

To determine the total output power of the photovoltaic panel can use 5 equation the following:

$$P_{mpp} = V_{mpp} + I_{mpp} \quad (5)$$

Where Pmpp is Power at Maximum Power Point (Wp), Vmpp is Voltage at Maximum Power Point (V), and Impp is Current at Maximum Power Point (A).

D. Efficiency Calculation

To calculate the efficiency value of the conversion of electrical energy from Photovoltaic can be determined using equation 6 the following:

$$\eta = V\,I\,/\,P\;x\;a \quad (6)$$

Where μ, V, I, P, A is respectively efficiency, voltage on solar cells, current of PV tight solar power on solar cells, area of solar power system.

Missing energy in the system can be calculated using 7 equation the following:

$$\Delta x = x` - x \quad (7)$$

Where Δx, x`, x is respectively missing energy in system, energy produced by solar power system, energy used by demand.

The percentage of energy lost in this system can be calculated by 8 equation the following:

$$\%\,\Delta x = \frac{x` - x}{x} \times 100\% \quad (8)$$

Where % Δx is percentage of missing energy in the solar system.

E. Simulation Data Analysis

Simulated alternative designs must meet optimal criteria technically and economically. This below is explained in detail each criterion.

1. Technical Criteria

to determine the optimal criteria the parameters used are the system produces small losses and the largest energy output.

$$f(x) = \begin{cases} xi = max.\,xi \\ \Delta xi = min.\,\Delta xi \end{cases} \quad (9)$$

Where xi and Δxi is respectively supply solar power plant, and losses solar power plant.

2. Economical Criteria

In the generation economy there are 4 components of costs that can usually be calculated, namely investment costs, fixed operating and maintenance costs, fuel costs, and variable operating and maintenance costs. These four components of cost can be calculated using two methods, namely leveling method and accounting calculation method. With these calculations it is expected that it will be known which components of the cost can be reduced in value, so that finally the electricity price is obtained which benefits all parties. Mathematical equations for determining the cost of the generator are addressed in the following equation 10.

$$EGC = \frac{\sum (I_t + OM_t + F_t + NF_t)(1+r)^{-t}}{\sum E_t (1+r)^{-t}} \quad (10)$$

Where EGC, I, OM, F, NF, E, t, r is respectively electricity generation cost, investment cost, operation maintenance cost, fuel cost, nonfuel cost, electricity production, time, and discount rate.

II. SIMULATION

Based on the results of the analysis of demand requirements, an electricity supply is needed for demand.

At this stage will be simulated. The design of alternative photovoltaics that meet the optimal criteria technically and economically. The initial simulation is done 10 times as shown in the Table II. From the results of 10 simulations, 3 simulations were taken which had smaller losses (Δx) and the largest energy supply. Simulations are carried out by varying the chosen photovoltaic technology, the number of series and parallel photovoltaic modules. Simulation results that meet the technical optimal criteria are shown in simulation 3, simulation 6, and simulation 7.

III. RESULT AND DISSCUSION

From the simulation results obtained three designs that meet the technical feasibility, then the economic price will be calculated for each design so that it is economically feasible.

In this stage, the economic feasibility calculation of the four components of the calculated costs is only two components to be used, namely the investment costs and operational and maintenance costs, with the consideration that the system is grid connected so that the generator is not supplied as a backup supply. So that the cost of fuel is not considered. The economic feasibility analysis for the three simulations that have been technically feasible is presented as follows:

- Simulation 3

This system uses Silicon polycrystalline (Si-poly) as a photovoltaic module with the number of 11 module photovoltaic modules in pairs of series and 15 parallel. The total number of modules used is 165 modules. The power per module unit is 300 Wp, 31V. The energy produced is 84600 kWp / year with losses of 14700kWp. The energy produced by photovoltaic does not remain 100% for 25 years of photovoltaic life, of course it will experience a decrease in capacity. So the assumption of energy produced by photovoltaic over a period of 25 years can be seen in the following Table III.

TABLE II. DATA OF SIMULATION

No.	Simulation	PV			Inverter		Missing Energy (Δx)		Energy Supply (year)
		Type	Capacity	Amount	Total Power	Operating Voltage	min. Δx (%)	min. Δx (kWh)	xi (kWh/m2)
1	Simulation 1	Si-Mono	300Wp 27V	12s 14p	50kW	300-600V	18,5	17300	81260
2	Simulation 2	Si-Poly	300Wp 33V	13s 11p	50kW	200-950V	15,4	14700	83300
3	Simulation 3	Si-Poly	300Wp 31V	11s 15p	50kW	305-600V	14,7	14300	84600
4	Simulation 4	CdTe	440Wp 156V	3s 38p	50kW	450-820V	17,5	16400	81400
5	Simulation 5	Si-Mono	370Wp 33V	17s 8p	48kW	200-1000V	15,4	14600	83100
6	Simulation 6	CdTe	120Wp 60V	8s 52p	50kW	200-950V	13,5	12800	84800
7	Simulation 7	Si-Mono	300Wp 28V	21s 8p	48kW	200-1000V	14,2	14600	83300
8	Simulation 8	Si-Mono	350Wp 33V	16s 9p	50kW	450-850V	19,3	18000	79800
9	Simulation 9	Si-Poly	330Wp 32V	19s 8p	50kW	200-950V	15,7	15100	83100
10	Simulation 10	Si-Mono	340Wp 32V	15s 10p	47kW	450-850V	17,9	17000	82000

TABLE III. ASSUMING OUTPUT ENERGY OF SOLAR POWER PLANT

Energy solar PV (kWh)	Assuming output of solar power plant	Amount	Output solar PV (kWh/year)
84600	Output (year 1 to 10)	90%	76140
84600	Output (year 11 to 20)	80%	60910
84600	Output (year 21 to 25)	75%	45680

Based on Table III the energy produced by photovoltaic per year is 8460 kWh. It is assumed that for 1 to 10 years the capacity has decreased by 90%, which is 7614 kWh / Year, at 11 to 20 years later it has decreased capacity by 80%, namely 6091 kWh / year and 20 to 25 years later has decreased by 75%, namely 4568 kWh / year.

1. Component cost A (Investment cost)

Details of the cost of component A (investment cost) simulation 3 can be seen in Table IV:

TABLE IV. ASSUMPTION OF COMPONENT COSTS A

Simulation 3		
Component	Amount	Total of Price
PV	165	Rp.813,044,001
Inverter	1	Rp.95,073,945
Total		Rp.908,117,946

Based on Table IV the total cost of component A simulation 3 is Rp.908,117,946. The above costs include shipping costs and using the dollar exchange rate has been added hedging.

2. Component cost B (Operation and maintenance cost)

Details of the cost assumption of component B can be seen in Table V:

TABLE V. ASSUMPTION OF COMPONENT COSTS B

component	price	amount	Total of price
depreciation of Solar Power Plant	Rp.813,044,001	25 year	Rp36,324,718
Maintenance of PV	Rp813,044,001	3%	Rp24,391,320
Maintenance of inverter	Rp95,073,945	3%	Rp2,852,218

On Table V the economic life of PLTS is 25 years therefore the depreciation of buildings and machinery for 25 years. Maintenance of PLTS a year is 3%.

3. Economic cost of Generation

Components of costs A and B are calculated within a certain time interval with r equal to 15.8% so that a fixed cost value will be obtained and each component of the cost will be leveled out like equation 10. The result is the generation cost for the three simulation based design is Rp.2,541 / kWh.

➢ Simulation 6

This system uses Cadmium telluride (CdTe) as a photovoltaic module with the number of 8 module photovoltaic modules in pairs of series and 52 parallel. The total number of modules used is 416 modules. The power per module unit is 300 Wp, 31V. The energy produced is 84800kWp / year with losses of 12800kWp. The energy produced by photovoltaic does not remain 100% for 25 years of photovoltaic life, of course it will experience a decrease in capacity. So the assumption of energy produced by photovoltaic over a period of 25 years can be seen in Table VI.

TABLE VI. ASSUMING OUTPUT ENERGY OF SOLAR POWER PLANT

Energy solar PV (kWh)	Assuming output of solar power plant	Amount	Output solar PV (kWh/year)
84800	Output (year 1 to 10)	90%	76320
84800	Output (year 11 to 20)	80%	61050
84800	Output (year 21 to 25)	75%	45790

Based on Table VI the energy produced by photovoltaic per year is 8460 kWh. It is assumed that for 1 to 10 years the capacity has decreased by 90%, which is 7632 kWh / Year, at 11 to 20 years later it has decreased capacity by 80%, namely 6105 kWh / year and 20 to 25 years later has decreased by 75%, namely 4579 kWh / year.

1. Component cost A (Investment cost)

Details of the cost of component A (investment cost) simulation 6 can be seen in Table VII:

TABLE VII. ASSUMPTION OF COMPONENT COSTS A

Simulation 6		
Component	Amount	Total of Price
PV	416	Rp.1,168,190,691
Inverter	1	Rp.77,551,440
Total		Rp.1,245,742,131

Based on Table VII the total cost of component A simulation 6 is Rp.1,245,742,131. The above costs include shipping costs and using the dollar exchange rate has been added hedging.

2. Component cost B (Operation and maintenance cost)

Details of the cost assumption of component B can be seen in Table VIII:

TABLE VIII. ASSUMPTION OF COMPONENT COSTS B

component	price	amount	Total of price
depreciation of Solar Power Plant	Rp1,245,742,131	25 year	Rp49,829,685
Maintenance of PV	Rp1,168,190,691	3%	Rp35,045,721
Maintenance of inverter	Rp95,073,945	3%	Rp2,852,218

On Table VIII the economic life of PLTS is 25 years therefore the depreciation of buildings and machinery for 25 years. Maintenance of PLTS a year is 3%.

3. Economic cost of Generation

Components of costs A and B are calculated within a certain time interval with r equal to 15.8% so that a fixed cost value will be obtained and each component of the cost will be leveled out like equation 10. The result is the generation cost for the three simulation based design is Rp.3,254 / kWh

- Simulation 7

This system uses Silicon Monocrystalline (Si-Mono) as a photovoltaic module with the number of 8 module photovoltaic modules in pairs of series and 52 parallel. The total number of modules used is 416 modules. The power per module unit is 300 Wp, 31V. The energy produced is 83300 kWp / year with losses of 14600 kWp. The energy produced by photovoltaic does not remain 100% for 25 years of photovoltaic life, of course it will experience a decrease in capacity. So the assumption of energy produced by photovoltaic over a period of 25 years can be seen in Table IX.

TABLE IX. ASSUMING OUTPUT ENERGY OF SOLAR POWER PLANT

Energy solar PV (kWh)	Assuming output of solar power plant	Amount	Output solar PV (kWh/year)
83300	Output (year 1 to 10)	90%	74940
83300	Output (year 11 to 20)	80%	59970
83300	Output (year 21 to 25)	75%	44980

Based on Table IX the energy produced by photovoltaic per year is 8460 kWh. It is assumed that for 1 to 10 years the capacity has decreased by 90%, which is 7494 kWh / Year, at 11 to 20 years later it has decreased capacity by 80%, namely 5997 kWh / year and 20 to 25 years later has decreased by 75%, namely 4498 kWh / year.

1. Component cost A (Investment cost)

Details of the cost of component A (investment cost) simulation 7 can be seen in the Table X:

TABLE X. ASSUMPTION OF COMPONENT COSTS A

Simulation 7		
Component	Amount	Total of Price
PV	168	Rp.718,486,188
Inverter	1	Rp.77,050,797
Total		Rp.795,536,985

Based on Table X the total cost of component A simulation 7 is Rp.795,536,985. The above costs include shipping costs and using the dollar exchange rate has been added hedging.

2. Component cost B (Operation and maintenance cost)

Details of the cost assumption of component B can be seen in Table XI:

TABLE XI. ASSUMPTION OF COMPONENT COSTS B

component	price	amount	Total of price
depreciation of Solar Power Plant	Rp795,536,985	25 year	Rp31,821,479
Maintenance of PV	Rp718,486,188	3%	Rp21,554,586
Maintenance of inverter	Rp95,073,945	3%	Rp2,852,218

On Table XI the economic life of PLTS is 25 years therefore the depreciation of buildings and machinery for 25 years. Maintenance of PLTS a year is 3%.

3. Economic cost of Generation

Components of costs A and B are calculated within a certain time interval with r equal to 15,8% so that a fixed cost value will be obtained and each component of the cost will be leveled out like equation 10. The result is the generation cost for the three simulation based design is Rp. 2,386/ kWh

Simulations that meet the requirements and basics are simultaneous which allows greater costs than others. The comparison frees in the following figure 3:

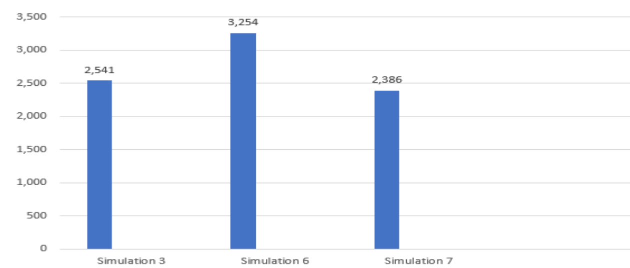

Fig. 3. Cost comparison chart between simulations

Based on figure 3 simulation 6 has the lowest generation economic value. Then from the results of the study, the simulation design 6 meets the optimal criteria technically and economically.

IV. CONCLUSION

In this study, Solar Power Plant was designed to meet the electricity needs in North Bali. The design is made with parameters that have optimal technical and economic aspects. In order to get great energy at a relatively cheap price. The design was carried out as many as 10 projects using the help of PVsyst software to get technically optimal results. After 10 simulations have been carried out, it is desirable to determine the appropriate cost to calculate the cost of the generation. From the most optimalresearch results based on: The energy produced is 83,300 kWh / year, the percentage of energy system lost is 14.2% or 14,600 kWh / year, and the cost of generating electricity is Rp.2,386 kWh.

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