FEASIBILITY ANALYSIS OF A GRID-CONNECTED PV SYSTEM FOR HOME APPLICATION

by I Made Arsawan

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ABSTRACT

The objective of the present study is to provide technical and economical analyses of a grid-connected PV system for a small house located in Bukit Jimbaran, Bali. The peak load of the house during observation was 390 watt and the daily electricity consumption is about 4.7 kWh. HOMER, a renewable energy system software developed by National Renewable Energy Laboratory (NREL), was utilized for simulation and optimization. The house will be installed with a grid-connected PV system which includes PV arrays, converters, and batteries (optional). The investment cost of the PV arrays is 3000 USD/kW and their lifetime, derating factor, and ground reflectance are 20 years, 90%, and 20%, respectively. The PV sizes to consider are 0.5, 1, 1.5, and 2 kilowatts. The grid applies a flat rate of about 0.1 USD/kWh. The surplus energy of the PV system will be fed into the grid with a net metering system in which the meter run backward when the excess energy is being fed into the grid. However, the sellback price is zero if energy sales exceed purchases. The converter costs 1000 USD per kilowatt. The economic inputs required by HOMER are the annual real interest rate and the lifetime of the project, which are 7% and 20 years, respectively. Results show that the proposed grid-connected PV system is technically viable. However, the grid-only system is still the most cost effective choice based on the net present cost (NPC) with the current price of 0.1 USD per kWh. The cheapest choice for the grid-connected PV system is when the PV and converter sizes are both 0.5 kW. The NPC of the PV system is 3,823 USD and its related cost of electricity (COE) is 0.209 USD/kWh. The renewable fraction of the system is 38%. Sensitivity analysis were also conducted with some scenarios such as reduction in PV prices, electricity price increases, and CO_2 penalties.

Keywords: Renewable energy; grid-connected PV system; HOMER; feasibility analysis; home application.

INTRODUCTION

According to Antara (the news agency of Indonesia), 26,800 new customers of PLN (the state electricity company) Bali was on the waiting list due to power shortage [1]. With the installed capacity and the highest peak load of 850 MW and 781 MW, respectively, PLN Bali cannot serve new installments. To solve the problem, some measures have been taken, such as building a new power plant at Celukan Bawang and reducing demand by encouraging costumers to turn off appliances during peak hours.

Another important measure is to encourage costumers to apply renewable energy systems, which are not so popular in Indonesia. Amid cheap electricity and fuel prices, renewable energy systems are not the most cost effective choices to power houses.

The objective of the present study is to provide technical and economical analyses of a grid-connected PV system for a small house located in Bukit Jimbaran, Bali. The house is a typical two bedrooms house with a small kitchen and a bathroom. Four people live in the house which peak load during a 24-hour observation was 390 watt and the daily electricity consumption is about 4.7 kWh.

HOMER, a renewable energy system (RES) software developed by National Renewable Energy Laboratory (NREL), was utilized for simulation and optimization. HOMER has been widely used by renewable energy experts in different contexts, such as houses, schools, hotels, and villages [2]. HOMER compares many different RES based on their technical and economical attributes [3].

LITERATURE REVIEW

There are different ways of reducing energy load and protecting the environment, such as behavioral changes [4,5], demand side management [6,7], and renewable energy application.

Energy conservation through behavioral changes can be done, for example, by encouraging hotel guests to reuse linens and towels [8] or by changing light bulbs with energy efficient ones. Demand side management is usually applied by utilities when demand shifts from peak hours to off peak hours are expected.

HOMER SOFTWARE

HOMER can answer questions that come up when installing renewable energy systems, *e.g.*: is it cost effective to add PV panels to the grid-connected house, can the new system serve if the load is growing, or what should be the electricity price for the PV system to be cost effective? HOMER has been used as a tool to calculate technical feasibility and economical viability of renewable energy system in different fields, for examples, in large and small hotels [9,10,11], a university building [12], and remote area and stand alone systems [13,14].

For a system to be technically feasible, the hourly energy production (from generation and grid purchases) should be able to satisfy the hourly load and constraints determined by the user [2,3]. Loads and energy production over a one-year period is calculated and if there is energy surplus or deficit, HOMER decides what to do with it. The surplus can be thermally/electrically stored or sold to the grid. The deficit can be resolved by purchasing energy from the grid or discharging the stored energy.

For a system to be economically viable, HOMER estimates the life-cycle costs of the system by calculating its net present value (NPC). The net present value can be defined as the present value of the total cost and revenue incurred over the lifetime of the project. HOMER uses the equation below to calculate NPC:

$$NPC = \frac{TAC}{CRF} \qquad (1)$$

where TAC is the total annualized cost including capital costs, replacement costs, operation and maintenance costs, fuel costs, electricity purchased, and revenues from selling excess electricity and the salvage value of the components and CRF is the capital recovery factor:

$$CRF = \frac{i(1+1)^N}{i(1+1)^N - 1} \qquad (2)$$

where N is the project lifetime and i is the annual real interest rate, given by the following equation:

$$i = \frac{i' - f}{1 + f} \qquad (3)$$

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

HOMER calculates the levelized cost of energy (COE) using the following equation:

$$COE = \frac{TAC}{E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales}} \qquad (4)$$

where TAC is the total annualized cost, $E_{prim,AC}$ is the total amount of AC primary load served per year, $E_{prim,DC}$ is the total amount of DC primary load served per year, E_{def} is the total amount of deferrable load served per year, and $E_{grid,sales}$ is the total grid sales per year.

METHODS

Before HOMER simulates and optimizes the system, we are required to input data. Those inputs are the electric load, equipment to consider, resources (solar resource in our case), economics, system control, emissions (if applicable), and constraints.

Load

Load inputs are collected from hourly load observation of the house over a 24-hour period. Data were taken in May 2015. Figure-1 shows the hourly load profile of the house in a day. The peak load of the house during observation was less then 400 watt and the daily electricity consumption is about 4.7 kWh.

HOMER synthesizes the data to estimate the hourly load profile over a year. To do so, HOMER asks for day-to-day and time-step-to-time-step random variability, which are 15% and 20%, respectively. Figure-2 shows HOMER estimation of the seasonal load profile of the house. The estimated peak load is now 658 watt.

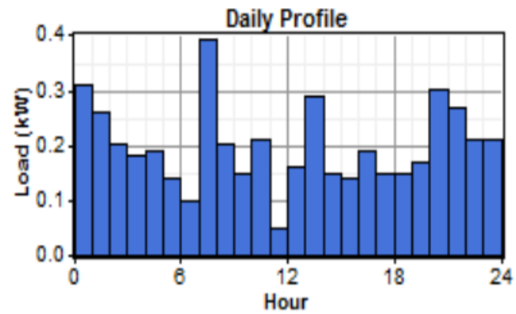

Figure-1. Hourly load profile of the house

Equipment to consider

The house will be installed with a grid-connected PV system which includes PV arrays, converters, and batteries (optional). The grid provides alternating current (AC) and serves the load directly. PV panels and batteries are connected to direct current (DC) bus and converted to AC by a converter.

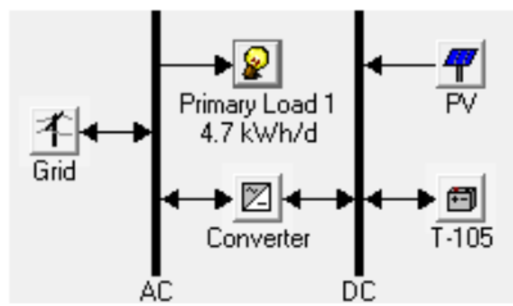

Figure-3. The proposed grid-connected PV system

The grid sells electricity at a flat rate of 0.1 USD/kWh. The house will use net metering with the net purchases calculated monthly. The surplus energy of the PV system will be fed into the grid with a net metering system in which the meter run backward when the excess energy is being fed into the grid. However, the sellback price is zero if the energy sales exceed the purchases.

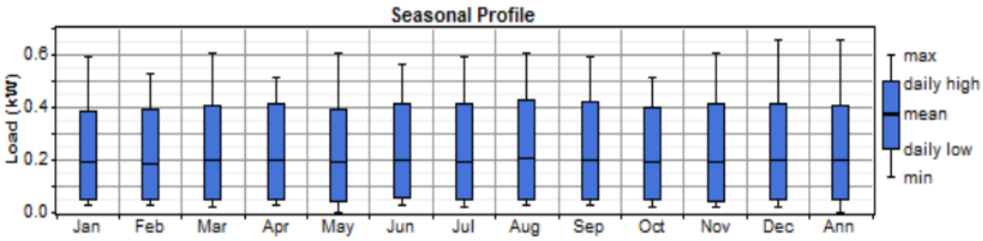

Figure-2. Estimation of the seasonal load profile

The chosen PV panels, which have no tracking system, are expected to operate for 20 years with derating factor, slope, azimuth, and ground reflectance of 90%, 8°, 180°, and 20%, respectively. The investment and replacement costs of the system are the same: 3000 USD/kW [15]. The sizes to consider are 0.5 kW, 1 kW, 2 kW, and 3 kW.

The batteries are Trojan T-105 with the nominal voltage of 6 volt, the nominal capacity of 225 Ah (1.35 kWh), and the lifetime throughput of 845 kWh. The investment cost and replacement cost are estimated to be 125 USD and its related O/M cost is 5 USD. The sizes of the batteries to consider are 0, 1, 2, and 3 batteries.

The converter costs 1000 USD/kW. Its lifetime is expected to be 15 years and its efficiency is 90%. When it converts AC to DC, the efficiency is estimated to be 85%. We consider converters of 0.5 kW, 1 kW, 2, kW, and 3 kW.

Resources Inputs

Since we propose a PV system, HOMER requires solar resource input to calculate hourly PV power production over the year. The data were collected from NASA. Figure-4 shows Global horizontal solar radiation near the site.

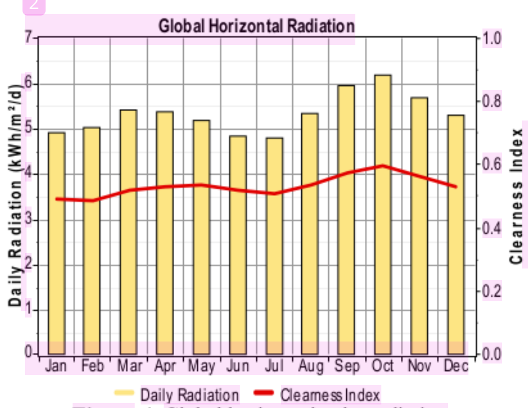

Figure-4. Global horizontal solar radiation

Economic Inputs

The economic inputs required by HOMER are the annual real interest rate and the lifetime of the project, which are 7% [16] and 20 years, respectively. The annual real interest rate is difference between the nominal interest rate and the inflation rate [17].

Constraints

We allow the maximal capacity shortage of 5%. We also set that the operating reserve should be at least 10% of the hourly load, 25% of solar power output, an 50% of wind power output.

RESULTS

When all inputs are provided, HOMER is ready for simulation an optimization of the system configurations that are specified previously. HOMER calculates load and the available resources and discards any configurations that cannot satisfy the load given constraints that were specified previously. This infeasible configurations are not shown in optimization and sensitivity results.

Figure-5 shows the optimization results of each configuration. The grid-only system is still the cheapest choice based on the net present cost (NPC) with the current electricity price of 0.1 USD per kWh. The grid-only system NPC is 1,829 USD. The total net present cost of the grid-connected PV system is 3,823 USD and its cost of electricity (COE) is 0.209 USD/kWh. Its renewable fraction is 38%. Grid with 0.5 kW PV panels and 0.5 kW converter is the optimal configuration for the grid-connected PV system. Bigger capacities of PV panels or converter or adding batteries lead to higher NPC and capital cost. With the current prices of electricity and PV system, grid-connected PV system is not the most cost effective choice.

Results in Figure-5 also mean that all the possible configuration is technically feasible. Technical characteristics of the grid-connected PV system are shown in Table-1 to Table-3. Table-1 shows that 62% of the load is estimated to be served by the grid and only 38% by the PV arrays. Table-2 shows that most of the electricity (86%) is to serve the load and only 14% is sold to the grid.

Table-1. Electricity production of the Grid/PV system

Production	kWh/yr	%
PV array	885	38
Grid purchases	1,420	62
Total	2,305	100

Table-2. Electricity consumption of the Grid/PV system

Consumption	**kWh/yr**	**%**
AC primary load	1,726	86
Grid sales	289	14
Total	2,016	100

PV (kW)	T-105	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
			2	$ 0	173	$ 1,829	0.100	0.00	0.00
	1	0.5	2	$ 625	243	$ 3,195	0.175	0.00	0.00
0.5		0.5	2	$ 2,000	172	$ 3,823	0.209	0.38	0.00
0.5	1	0.5	2	$ 2,125	168	$ 3,902	0.213	0.42	0.00

Figure-5. Optimization results

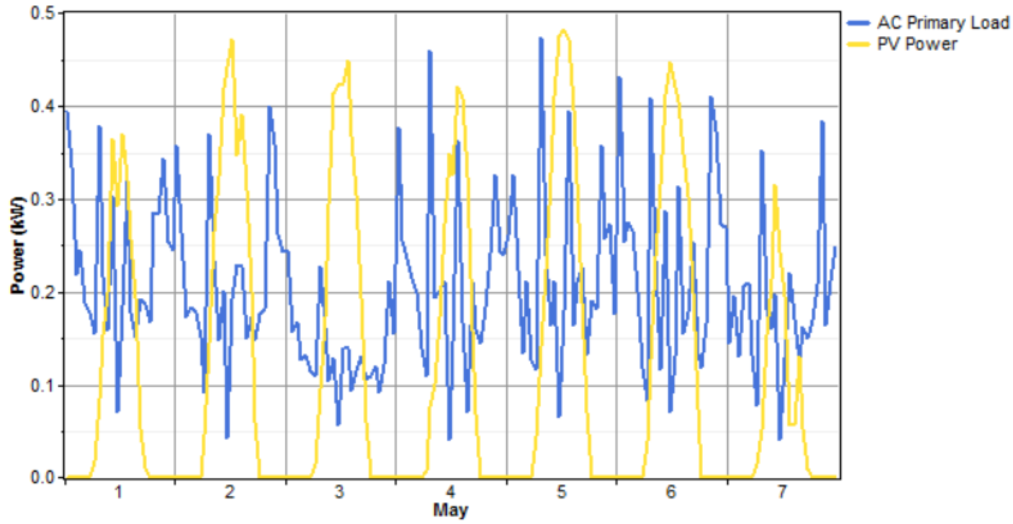

Figure-6. Hourly profiles of load and PV electricity production on the first week of May

Table-3 shows the performance of PV arrays. Its mean output is predicted to be 0.1 kW or 2.42 kWh/day. It has 20% capacity factor and 51% penetration. Total electricity production is 885 kWh/year. The system operates 4,384 hour/year to produce electricity.

Table-3. PV arrays performance

Quantity	**Value**	**Units**
Rated capacity	0.5	kW
Mean output	0.10	kW
Mean output	2.42	kWh/d
Maximum output	0.54	kW
Capacity factor	20.2	%
PV penetration	51.3	%
Total production	885	kWh/yr
Hours of operation	4,384	hr/yr

The comparison of hourly profiles of load and PV electricity production is shown in Figure-6. The figure shows that PV electricity production during the day can satisfy load. During the night, however, the grid should serve the load.

Sensitivity analysis

The present study performs sensitivity analysis with the following scenarios: PV panel price reduction to 50%, 25%, and 10% of the current price, electricity price increase from 0.1 USD to 0.15, 0.2, and 0.25 USD, and CO_2 penalties of 10 USD/ton CO_2, 25 USD/ton CO_2, and 50 USD/ton CO_2. The main purpose of sensitivity analysis are to find out in which scenarios the grid-connected PV system is more cost effective than the grid-only system.

Figure-7 shows optimal systems for different PV capitals and electricity prices. CO_2 penalty is not applicable. The figure shows that, with the current prices, the grid-only system is still the most cost effective choice. Even when the PV capital is reduced to half its current price and the electricity price increases by 50% (0.15 USD/kWh), the grid-only system is still superior to the other options. If the PV capital drops to 20% its current price, the Grid/PV system is the best choice.

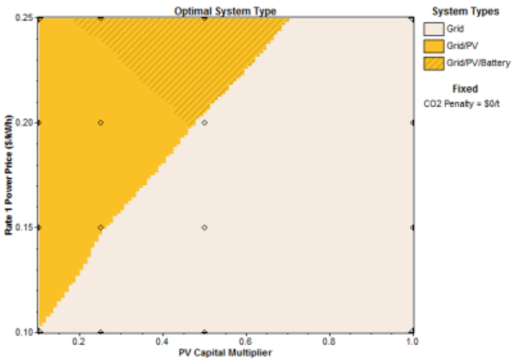

Figure-7. Optimal systems for different PV capitals and electricity prices. No CO_2 penalty.

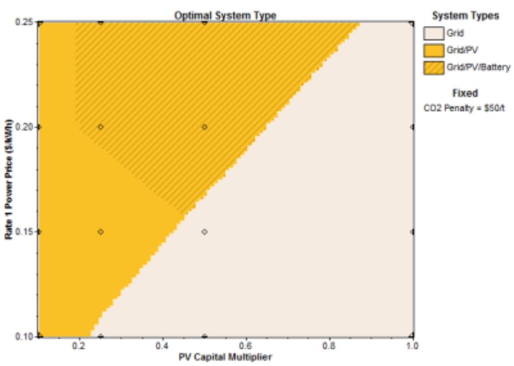

Figure-8. Optimal systems for different PV capitals and electricity prices. CO_2 penalty is 50 USD/ton CO_2

In a more extreme case in which the CO_2 penalty is 50 USD/ton CO_2, similar patterns exist (see Figure-8). Only when the PV capital is reduced to half its current price and the electricity price doubled to 0.2 USD/kWh do we have the Grid/PV/Battery system to be more cost effective than the grid-only system.

In another extreme case, in which the PV capital is 25% its current price, the Grid/PV system is the most cost effective when the electricity price increases by 50%. Figure-9 shows the scenario.

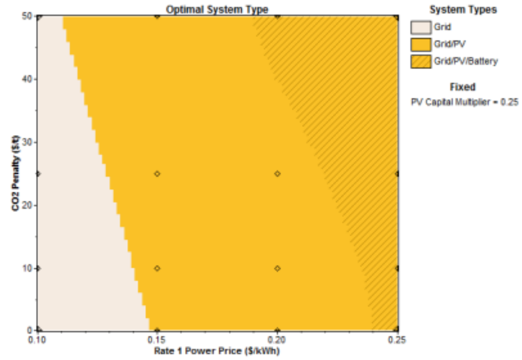

Figure-9. Optimal systems for different electricity prices and CO_2 penalties.

CONCLUSIONS

The present study provides technical and economical analyses of a grid-connected PV system for a small house located in Bukit Jimbaran, Bali. The present study is supposed to answer two main questions: is it cost effective to add PV panels to the grid-connected house? or what should be the electricity price for the PV system to be cost effective?

Results shows that each configuration is technically feasible. They can satisfy load and constraints set by the user. However, HOMER shows that, at the current electricity and PV panel prices, the grid-only system is much more cost effective than the grid-connected PV system. The NPC and COE of the grid-connected PV system are 3,823 USD and 0.209 USD/kWh, respectively, which are much higher than those of grid-only system (NPC = 1,829 USD and COE = 0.1 USD/kWh). They are about twice as much as those of grid-only system.

Sensitivity analysis shows that a CO_2 penalty policy alone does not have strong impact on promoting the grid-connected PV system to be more cost effective than the grid-only system at the current electricity price. The same conclusion is true for the scenario of electricity price increase only or PV capital reduction only. Only when all scenarios are applied simultaneously are the grid-connected PV system more cost effective than the grid-only system.

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