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Design and Analysis of PV Hybrid System for Isolated Household Electrification

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Abstract: This paper describes a design method and construction of a PV hybrid system for household electrification in remote area which has typical important electrical loads for daily life such as television, refrigerator, electric fan, coffee maker, and radio. The paper presents the design method which is a short and correct method for the PV Hybrid system design. The result of the proposed design method is finally simulated by Homer software to optimize and prove the result. From the simulation, the output shows that the proposed method is proper for using to design the sizing of PV hybrid system. After the design, a PV hybrid system is constructed accordingly to the system design. A PV hybrid prototype is constructed as a small house which is specially constructed for demonstration of the proposed system. The PV hybrid system therefore has the size of PV 1.8 kWp, battery 20 kWh, and diesel generator 3 kW. After a long implementation of the system, the results of monitored data show that the designed PV hybrid system can deliver the power to the house continually 24 hours as it is originally designed. This can ensure that the proposed method of PV hybrid system design is correct and can be used for design the PV hybrid system for electrical utility in the remote area where has no an electric grid.

Key words: PV Hybrid, monitoring system, homer simulation.

1. Introduction

Energy is considered as an essential mechanism in order to development a country, but presently we are facing energy shortage. High cost of energy affects the development of country adversely. Alternative energy from various sources has been investigated in order to find a substitution for energy from main energy source such as energy from the sun or the wind. There are some research projects showing the failure of Solar Home System in many developing countries [1, 2] and PV-Diesel Hybrid System is proposed for Isolated Household because it is considerably enhance operating economy and reliability of system [2]. Hybrid System has more reliability and low cost of energy than stand-alone system because of it combines PV and conventional energy sources [3].

In Germany they have AREP (Autonomous Renewable Energy Project) under the direction from Prof. Dr.-Ing. Jurgen Schmid [4]. As the alternative energy is not available all the time, to ensure continually power deliver, the right design and right construction of a hybrid system is necessary.

The paper presents a proposed design method and the construction of a proposed PV hybrid system for household electrification in remote areas. The system is demonstrated at Rajamangala University of Technology Thanyaburi (RMUTT) accordingly to the proposed design method. The construction is also included a real-time monitoring system for data analysis. From the implantation, the demonstrated PV hybrid system has been working continuously to supply electric power to the loads without any energy shortage.

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2. Principal Designs

As mentioned, the PV hybrid system for isolated household electrification must be able to supply electricity to the loads continuously without interruption. The system must also use renewable energy as the main source of energy. In the design, the solar energy will be converted to electricity and supplied directly to loads and exceed energy is stored into batteries for the use during the night. There is also a real-time monitoring system to show whether the power production is working properly. Usually the monitoring system observes the production performance everyday and can give a report daily, monthly or annually. All the data are collected into a computer system for evaluation. The overall proposed PV hybrid system can be shown as in Fig. 1. The ac-bus system is selected for this implementation.

3. The Design

According to the design principle, the design must be able to cover all the power consumption of the designed system. Therefore to design the PV hybrid system, the most important factor is the consumption load profile. The load profile must be considered before the design. In this paper, load profile for typical household in remote areas is selected. The selected load profile is an example for this study which can be described as shown in Fig. 2. The total consumption demand is then calculated as 12 kWh/d. The consumption demand value is very important for the calculation. It must be indicated as kWh/d or kWh/a for this proposed method.

After having the load profile, the demand is considered and will be used for calculation to determine the capacity of the solar cell as P_{peak}, starting from the efficiency of the system as in Eq. (1), then the estimation in theory and in practice is calculated to find the energy obtained from sunlight (2) and (3), then the capacity of solar power is shown in Eq. (6).

$$Q=\frac{E_{el}}{E_{th}} \tag{1}$$

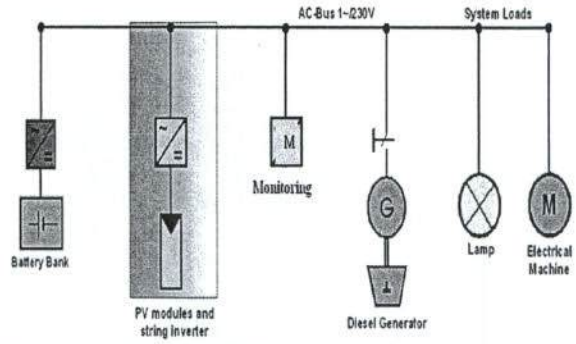


Fig. 1 Proposed PV hybrid system.

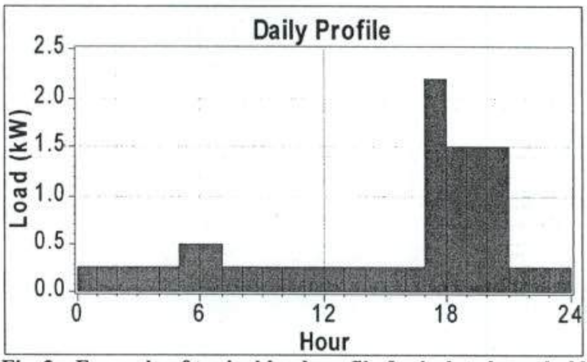


Fig. 2 Example of typical load profile for isolate household used for this design.

$$E_{th}=\eta\cdot E_{glob}\cdot A_{array} \tag{2}$$

$$P_{peak}=\eta\cdot I_{STC}\cdot A_{array} \tag{3}$$

$$E_{th}=P_{peak}\cdot\frac{E_{glob}}{I_{STC}} \tag{4}$$

$$Q=\frac{E_{el}}{E_{glob}\cdot P_{peak}}\cdot I_{STC} \tag{5}$$

$$P_{pea}=\frac{E_{el}\cdot I_{STC}}{E_{glob}\cdot Q} \tag{6}$$

when P_{peak} = PV peak power under STC [kWp]

Eel = real electric output [kWh/a]

$ISTC$ = radiation under STC [1 kW/m^2]

E_{glob} = global solar radiation [kWh/m^{2}a]

Q = quality factor of the system

Et_h = theoretical output energy of the system [kWh/a]

η = efficiency of the PV array [decimal]

A_{array} = area of the PV array [m^2]

Therefore Eq. (6) can be used for the design of the hybrid system. However to use Eq. (6), the quality factor, Q, must be used for calculation. Quality factor is a value which showing the efficiency of the system therefore this value is depending on the type of PV system. The quality factor values of the system are given in Table 1. In this study, the quality factor for PV hybrid system is used as 0.6.

After the calculation Eq. (6), we obtained the value of P_{peak}, then immediately we can use this value for the calculation to find the battery capacity which is very practical for the design by using the capacity of battery for 10 time of P_{peak} as in Eq. (7).

$$CB = 10 \times P_{peak} \quad (7)$$

When P_{pea} = PV peak power under STC [kWp]

CB = battery capacity [kWh]

Therefore the calculation can be done as following by having the E_{glob} in Thailand as 5 kWh/m^2/d.

$$P_{peak} = \frac{12kWh/d \times 1kW/m^2}{5kWh/m^2/d \times 0.6} = 4\ kW$$

Then we have the capacity of PV as 4 kWp. And therefore the battery capacity is then 40 kWh.

Once the capacity of the battery is obtained, the level of battery voltage can be selected depending on the level of load consumption. The proposed voltage level can be selected as shown in Table 2 accordingly to the demand. For the proposed system, voltage level of battery 48 volts is recommended.

Table 1 Quality factors of the system used in the calculation [5].

Component/System	Q
PV module(Crystalline)	0.85…0.95
PV array	0.80…0.90
PV system (Grid-connected)	0.60…0.75
PV system (Stand-alnoe)	0.10…0.40
Hybrid system (PV/Diesel)	0.40…0.60

Table 2 The level of battery voltage in comparison with average consumption of the system [6].

Mean daily energy consumption [kWh/d]	Peak power for minutes [kW]	Peak power for seconds [kW]	System voltage not below [V]
0…4	0.0…1.0	0.0…2.0	12
2…6	1.0…2.0	2.0…4.0	24
4…12	2.0…4.0	4.0…8.0	48
8 and more	4.0…8.0	8.0…16.0	96

After all mentioned values have been obtained, with this proposed method, we can use these values to begin the simulation for final decision. However, for this proposed method to design PV hybrid system, it is more flexible to reduce PV size because the conventional power supply such as a diesel generator can cover fractionally power to system. We can select the fraction of the solar energy and generator up to the decision. The diesel generator is considered obviously as the peak of load demand. From the selected load profile, the peak load is about 2.2 kW therefore we select the diesel generator 3 kW which is available in the market. After having all components, the values have to be optimized by a software simulation giving the performance decision to reduce and adjust the value of each component respectively then the final output will show the results of the selected system performance. As mentioned, the final decision will be considered on the component values which the PV system can be able to cover all demand. As the aim of this study, it must be noted that we will more consider on performance of energy supply, we will not consider for economics aspect decision.

It must be also noted that for the inverter selection, the appropriated inverter must work at the high efficiency. A typical inverter normally has high efficiency at the rated capacity, and then we choose the inverter rated the same as the PV capacity. We can also adjust the value of the inverter in simulation program to see the performance of the system. This is very useful if the selected inverter is not available in the market. Fig. 3 shows a typical efficiency of an inverter [7].

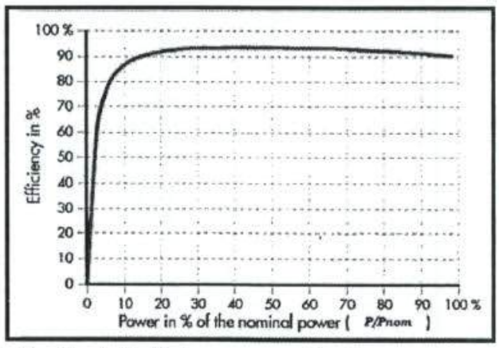


Fig. 3 Typical efficiency curve of an inverter.

The simulation of this designed hybrid system is the free well known software, Homer Simulation Program. We need to enter all parameters calculated in to the homer then simulate and adjust the values to find the best fit to optimize the system performance then we will consider the output simulation as a tool for the decision. As the homer has many aspects to optimize the system design. The proposed system under Homer is set up in the simulation as in Fig. 4. To prove the proposed method, we will begin to simulate the value which we obtained from the calculation as:

-PV = 4 kWp
-Diesel Generator = 3 kW
-Battery = 40 kWh
-Inverter = 4 kW

After all values have been set into the program, we can simulate the system performance. Fig. 5 shows the output result of the simulation, the output shows that the selected values were correctly calculated, the system cam deliver energy to loads without capacity shortage and the energy fraction of solar is 92%, this is a good design for such a PV hybrid system for remote areas.

From Fig. 5, the result shows that the design is properly calculated and we can use this calculation for implantation of hybrid system. This can prove that the proposed design method is correct and can be used for PV hybrid system design.

As PV hybrid system can be flexible for the decision of design, from the aim of this research, we decided to reduce the PV capacity in order to have a fraction of solar for 50% because we consider the system as a demonstrated PV hybrid system if the PV is high

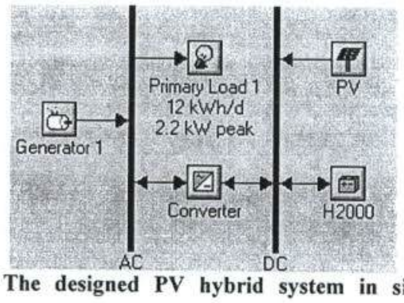
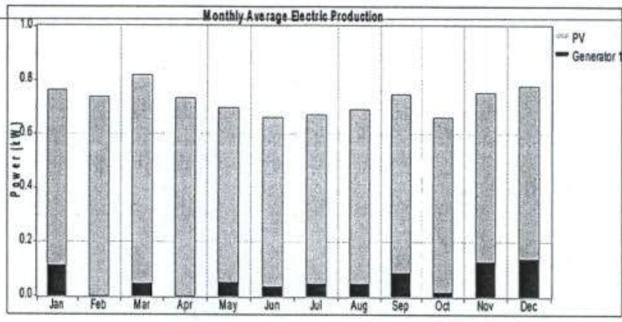


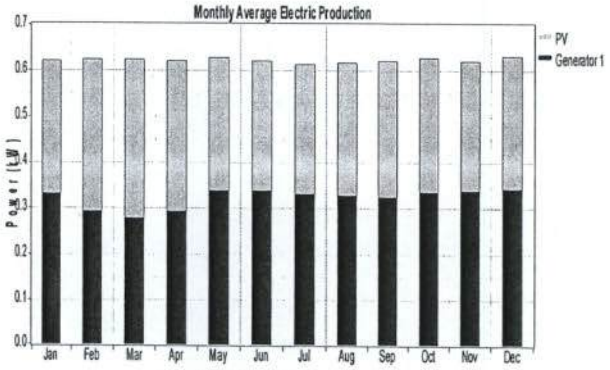
Fig. 4 The designed PV hybrid system in simulation program.



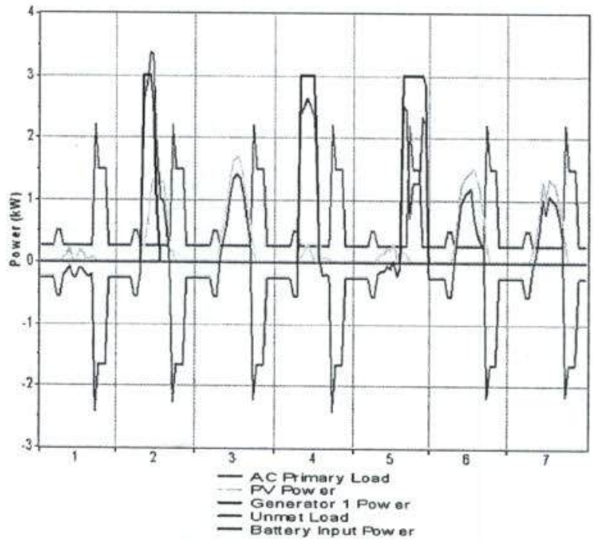
Production	kWh/yr	%
PV array	5,849	92
Generator 1	513	8
Total	6,362	100

Quantity	kWh/yr	%
Excess electricity	767	12.1
Unmet electric load	0.00000453	0.0
Capacity shortage	0.00	0.0

Fig. 5 The simulation results of the designed PV hybrid system.



(a) Monthly production



Production	kWh/yr	%
PV array	2,632	48
Generator 1	2,817	52
Total	5,449	100

Quantity	kWh/yr	%
Excess electricity	35.4	0.65
Unmet electric load	0.00000119	0.00
Capacity shortage	0.00	0.00

(b) Energy profile

Fig. 6 Simulation results for selected hybrid system.

capacity, the cost will also be high. After the simulation with various values, we selected the result of this demonstration PV hybrid system as followings:

-PV	= 1.8 kWp
-Diesel Generator	= 3 kW
-Battery	= 20 kWh
-PV inverter	= 1.5 kW
-Bi-directional inverter	= 3 kW

The results of the simulation show that the selected system can be able to supply energy to the load continuously as shown in Fig. 6 without any energy shortage and the fraction of solar is 48%.

From the simulation Fig. 6, it is found that during the day, PV can produce enough electricity to supply the loads and the surplus energy is stored into the battery and during the night when the solar cell cannot produce power, the stored energy in the battery is supplied to the load and if the battery is empty the energy generated by the diesel generator enabling the system to supply energy automatically therefore the PV hybrid system can ensure energy supply continuously and stably without power shortage or demand failure.

4. Implementation

Accordingly to the design method, now the PV hybrid system can be constructed to demonstrate the energy supply to households. Therefore the demonstrated house is then specially designed for the proposed PV hybrid system. The construction of energy house is located at RMUTT shown as in Fig. 7. The PV array is installed on the roof and faced to the south with tilt angle 15 degree accordingly to the location of the system in Thailand. Fig. 8 shows the electrical loads and system installation in the demonstrated house.

For a long experiment of the RMUTT energy hybrid house with manually turning on-off the daily loads, the results are shown as in Figs. 9 and 10. The designed monitoring system can collect the data of every 5 minute interval and will be recorded into the database to study and evaluate the efficiency of the system.

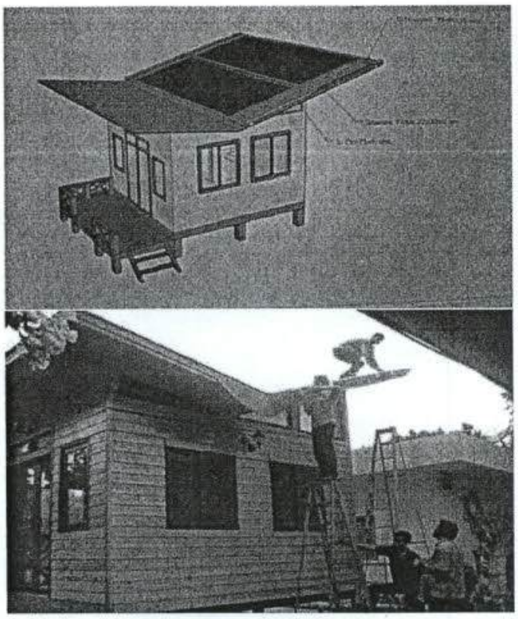


Fig. 7 The prototype of energy house.

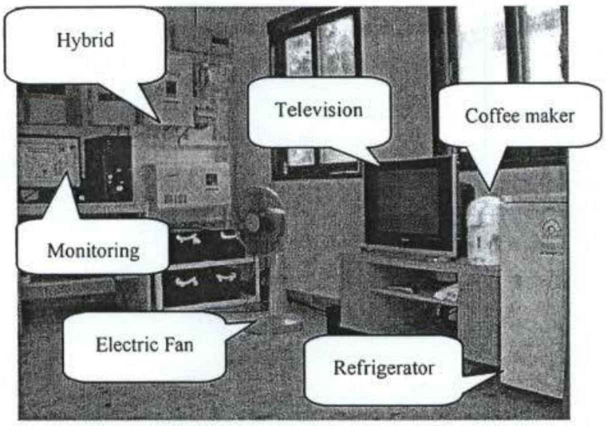


Fig. 8 The PV hybrid system and loads.

From the experiment, the designed system can supply electricity to the house stably.

From Figs. 9 and 10, they are the monitored data graphs showing the load profile and performance of the PV hybrid system. From the load profile, it is obvious that the demand is fluctuated almost during night, morning, and evening because the refrigerator is working as the normal on-off operation according to its temperature set-point. However during midday, the load profile is constant because the weather is warm at the day time in Thailand and the refrigerator has to work continuously to keep its temperature constant. From Fig. 10, it can be seen that PV can produce

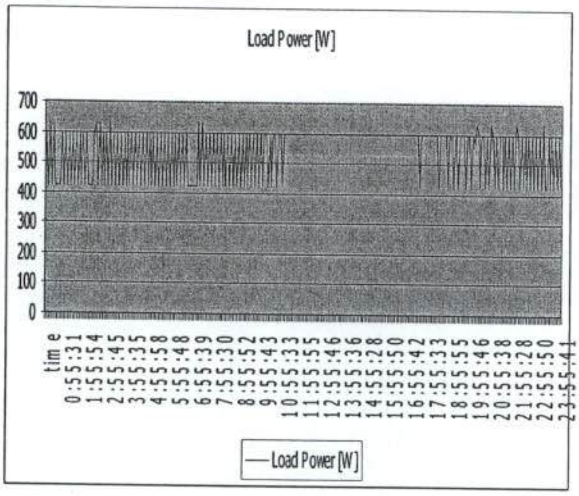


Fig. 9 Load profile of the house with a refrigerator.

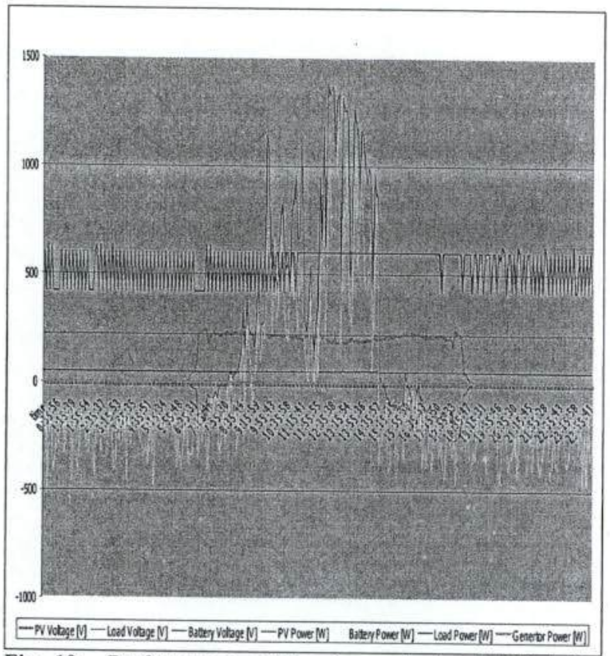


Fig. 10 Performance of the demonstrated PV hybrid system at RMUTT.

electricity for the loads from 8.00 a.m. to 16.00 p.m. The surplus energy will be stored in the battery for the night use. During the night the PV cannot produce electricity and then energy from the battery is in the minus range because the battery is supplied to the loads and the system will automatically start the generator when the battery voltage is lower than set-point which is 40% of SOC. At this 40%, the battery is going to be empty and it must be recharged otherwise battery will be damaged. However from the experiment, the designed PV hybrid system can supply to the loads continually without starting the diesel generator because there is enough energy during this experiment. This can be seen in Fig. 10 which shows that the energy from the generator is zero.

5. Conclusions

From the demonstrated PV hybrid system for household electrification in remote areas, the proposed design method is used to calculate the system components, all the values obtained from the design are optimize by the software program. From the simulation, it can prove that the proposed design method is correctly calculated. After the design, a real construction of the PV hybrid system is built accordingly to the design method. The construction includes daily load for typical households in remote areas. From the experiment, it is found that there is a spike of the load profile because of the refrigerator, it maintains the constant temperature of itself, during the day when the weather is warm, the refrigerator works almost all the time to keep its temperature. This is the typical function of refrigerators. From the monitored results, the designed hybrid system can supply enough energy to the load demand as it was designed. This can prove that the proposed method is correct for designing a PV hybrid system for household electrification. The system can work continuously and stably.

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