Optimization of Renewable Energy Hybrid System by Minimizing Excess Capacity

Juhari Ab. Razak, Kamaruzzaman Sopian, Yusoff Ali,

Abstract**—**Optimization of renewable energy hybrid system looks into the process of selecting the best components and its sizing with appropriate operation strategy to provide cheap efficient, reliable and cost effective. The techno-economic analysis usually looks at the cheapest cost of energy produced by of system components while neglecting the excess capacity of the combination. This paper discusses the optimization of the hybrid system in context of minimizing the excess energy and cost of energy. The hybrid of pico hydro, solar, wind and generator and battery as back-up is the basis of assessment. The system configuration of the hybrid is derived based on a theoretical domestic load at a remote location and local solar radiation, wind and water flow rate data. Three demand loads are used in the simulation using HOMER to find the optimum combination and sizing of components. Another set of demand loads is used to investigate the effect of reducing the demand load against the dominant power provider of the system. The results show that the cost of energy can be reduced to about 50% if the demand load is increased to the maximum capacity. Reducing the load to the capacity of the dominant power provider will reduce the cost of energy by 90%.

Keywords**—**Optimization, Hybrid System, Renewable Energy, Techno-Economic, HOMER, Cost of Energy, Excess Capacity

I. INTRODUCTION

The application of renewable energy system has become an important alternative as power provider in rural electrification program when the price of oil is reaching its highest level. However the evaluation of the correct type of renewable energy system needs to be done so that the system can be optimized.

Several studies have been done to evaluate the competitiveness of renewable energy systems as alternatives to the diesel generator such as by Schmid and Hoffman [1] and feasibility of the stand-alone hybrid systems by Elhadidy and Shaahid [2][3][4]. While it is found that the renewable energy system is competitive and feasible for off-grid application, single source renewable usually leads to component oversizing, which increases the operating and life cycle costs [5]. A combination of one or more resources of renewable energy, called hybrid, will improve load factors and help saving on maintenance and replacement costs as the renewables can complement each other [6]. High initial capital of the hybrid is a barrier to adopt the system thus the needs for long lasting, reliable and cost-effective system [7]. Designing a hybrid system would require correct components selection and sizing with appropriate operation strategy [8][9]. Initial optimization and component sizing methods are based on worst month scenario leads to non-optimal design with excess capacity [10]. Muselli *et al.* [11] proposed the optimal configuration for hybrid systems should be determined by minimizing the kilowatt-hour (kWh) cost. Kamel and Dahl [12] and Khan and Iqbal [13] used a software, Hybrid Optimization Model for Electric Renewables (HOMER) [14] to find optimum sizing and minimizing cost for hybrid power system with specific load demand. Studies on genetic algorithm are done to find the optimum sizing as well as the suitable operation strategies to meet different load demand by, among others, Seeling-Hochmuth [15], Dufo-Lopez and Bernal-Augustine [16] and Ashok [17].

However while the results of these optimization processes show the optimum sizing and appropriate combination of components for the system, the problem of maximum usage of component capacity is neglected. Some of the results show as much as 50% excess energy is produced while providing to meet the load demand.

This paper explores the importance of reducing excess energy in minimizing the cost of energy (COE) for the renewable energy hybrid system. Since the excess energy is still counted as part of the cost of producing the total energy against specific load demand reducing it means reducing the cost. This paper discusses two suggestions to meet this objective by minimizing the COE.

II. METHODOLOGY

The proposed hybrid renewable consists of a pico hydro turbine, wind turbine and solar photovoltaic (PV) panels. Diesel generator, battery and inverter are included as part of

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Authors are with the Solar Energy Research Institute, Universiti Kebangsaan Malaysia 43600 Bangi, Selangor Darul Ehsan, MALAYSIA, juhari@utem.edu.my http://pkukmweb.ukm.my/~SERI/index

back-up and storage system. The proposed system is shown in Figure 1. The project lifetime is estimated at 25 years. The annual interest rate is fixed at 4%.

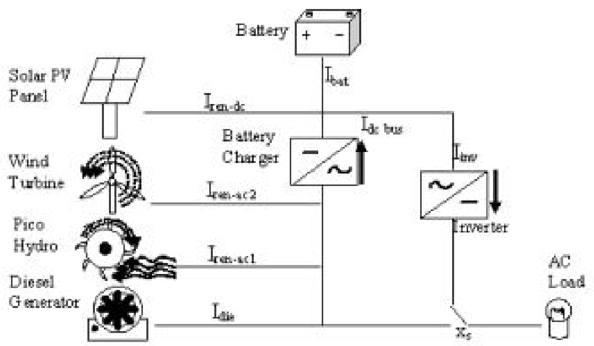

Fig. 1 Renewable Energy Hybrid System

2.4

2.1 Pico Hydro Turbine

The initial capital cost for pico hydro turbine is RM10500 which include some civil works. Its replacement is priced at RM10000. The turbine is estimated to last the project lifetime at 25 years. The water flow rate is assumed to be constant all year at 24 L/s. The turbine has a nominal power of 1 kW and average output of 0.959 kW.

2.2 Wind Turbine

The wind turbine has a capacity of 0.6kW. Its initial cost is RM20500 and its replacement at RM20000. Annual operation and maintenance cost is RM500. Its hub and anemometer is located at 15 meter height. The turbine is estimated to last the project. The monthly wind speed is as shown in Table 1.

2.3 Solar PV Panels

There are six PV panels with each has a capacity of 75 Watt. The intial cost of the panels is RM11750 and the replacement for each panel is RM1875. The lifetime of the panels will last the project. Monthly clearness index and daily radiation is as shown in Table 2.

Table 1 Monthly Wind Speed

January	2.948 m/s
February	2.082 m/s
March	2.287 m/s
April	1.857 m/s
May	1.571 m/s
June	1.687 m/s
July	1.487 m/s
August	2.035 m/s
September	1.533 m/s
October	1.829 m/s
November	1.800 m/s
December	1.938 m/s

Table 2 Monthly Solar Radiation

Month	Clearness Index	Daily Radiation
January	0.376	3.654
February	0.437	4.439
March	0.395	4.129
April	0.432	4.465
May	0.443	4.397
June	0.446	4.298
July	0.478	4.653
August	0.398	4.021
September	0.386	3.993
October	0.387	3.943
November	0.349	3.413
December	0.369	3.517

2.4 Diesel Generator

The AC generator has a capacity of 1 kW. Its initial capital cost is RM8500 and its replacement costs RM8000. The operation and maintenance is RM0.10 per hour. The lifetime of the generator is estimated at 15000 operating hours. Diesel is priced at RM1.98 per liter.

2.5 Battery and Inverter

The valve regulated lead acid battery is rate at 2 V and has a capacity 500 Ah. Twelve batteries initially cost RM20500. The replacement batteries will cost another RM20000. The operation and maintenance cost add further RM25 to the total cost annually.

2.6 Demand Load

In order to show the dependency of the excess electricity to the demand load, three types of loading are used in the simulation. They are shown in Figures 2, 3 and 4. Figure 2 represents the load of pond lighting at night. Domestic electric demand and pond lighting is shown in Figure 3. Figure 4 shows constant loadings during the day and night.

Another set of loadings used the same figures except the pond lighting power is reduced to match the pico hydro turbine capacity.

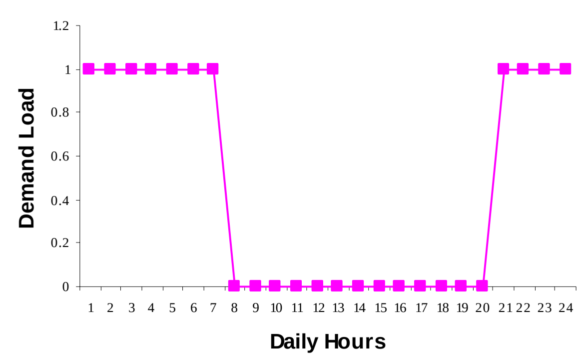

Fig. 2 Load 1

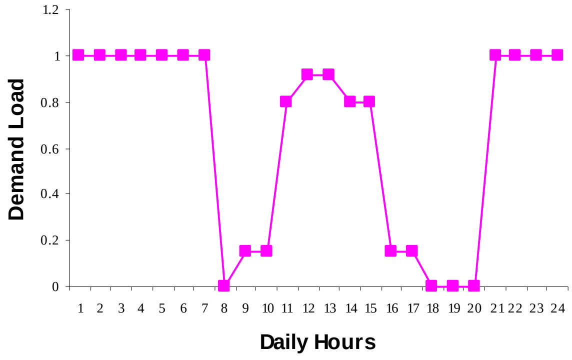

Fig. 3 Load 2

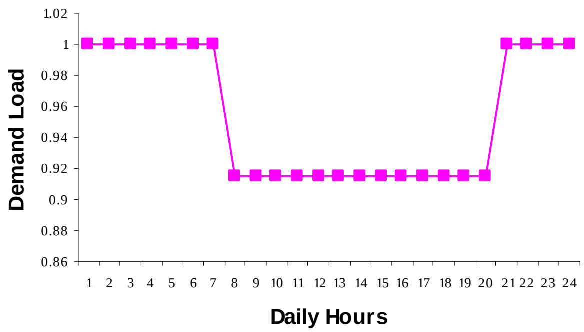

Fig. 4 Load 3

III. RESULTS AND DISCUSSIONS

The optimization results of the renewable hybrid are shown in Tables 3, 4 and 5 for loads 1, 2 and 3 respectively. In case 1 when the pond lighting total is 1 kW simulation by HOMER produced a combination of pico hydro, battery and inverter as the optimum hybrid for loads 1 and 2. Load 3 would have one PV panel added to that combination.

Table 3 Case 1 Load 1

Comp	IC	TNPC	COE
BHI	51000	63887	1.019
BHIS	52938	66152	1.055
BGHI	59500	69461	1.107
BGHIS	61438	71726	1.144
GH	19000	73247	1.168
G	8500	84479	1.347

Table 4 Case 1 Load 2

Comp	IC	TNPC	COE
BHI	51000	63887	0.708
BHIS	52938	66152	0.733
BGHI	59500	69461	0.770
BGHIS	61438	71726	0.795
GH	19000	73247	0.811
GHW	39500	88519	0.981

Table 5 Case 1 Load 3

Comp	IC	TNPC	COE
BHIS	52938	66152	0.507
BGHI	59500	69788	0.535
BGHIS	61438	71726	0.549
GH	19000	73247	0.561
BHIW	71500	92198	0.706
GHW	39500	93059	0.713

B = Battery
G = Generator
H = Pico Hydro Turbine
I = Inverter
S = Solar PV
W = Wind Turbine
IC = Initial Capital
TNPC = Total Net Present Cost
COE = Cost of Energy

In each table the result shows steady decrease of COE for a specific combination such as BHIS, from RM1.055 to RM0.507. While the total net present cost (TNPC) remains the same the total load served has increased. Based on the results the use of generator as stand-alone to provide electricity becomes less important when demand load is increased. Generator is placed as thirteenth and twelfth in simulation of loads 2 and 3 respectively.

The next set of table further shows the relationship between demand load, excess energy and COE. In Tables 6 and 7 the total annualized cost for loads 1 and 2 is RM4090 and TNPC is RM63887. However the levelized COE for load 1 is RM1.1019/kWh and RM0.708/kWh for load 2. These are due to the excess electricity of 4305 kWh (51%) and 2542 kWh (30%) for loads 1 and 2 respectively. By having more demand load excess energy is reduced by 20% and COE is reduced by about 30%.

Table 6 Output for Load 1

	Hydro	Batt	Inv	Total
IC	10500	20500	20000	51000
AC	672	1312	1280	3265
AR	0	224	551	775
AOM	0	25	25	50
TA	672	1561	1856	4090
Total NPC = RM63887				
Levelized COE = RM1.019 kW/h				
Total Production = 8405 kWh				
Total Load Served = 4015 kWh				

Table 7 Output for Load 2

	Hydro	Batt	Inv	Total
IC	10500	20500	20000	51000
AC	672	1312	1280	3265
AR	0	224	551	775
AOM	0	25	25	50
TA	672	1561	1856	4090
Total NPC = RM63887				
Levelized COE = RM0.708 kW/h				
Total Production = 8405 kWh				
Total Load Served = 2542 kWh				

Table 8 Output for Load 3

	Hydro	Batt	Inv	PV	Total
IC	10500	20500	20000	1938	52938
AC	672	1312	1280	124	3389
AR	0	224	551	21	796
AOM	0	25	25	0	50
TA	672	1561	1856	145	4235
Total NPC = RM66152					
Levelized COE = RM0.507 kW/h					
Total Production = 8503 kWh					
Total Load Served = 8358 kWh					

IC = Initial Capital
AN = Annualized Capital
AR = Annualized Replacement
AOM = Annualized Ops. & Maintenance
TA = Total Annualized

One PV panel (75 W) is needed to meet the electricity demand of 8358 kWh in load 3 (Table 8). This panel only provide one percent of the total production of 8305 kWh. Since the demand is increased the excess electricity is reduced to 74.9 kWh (1%). The levelized COE is reduced to RM0.507/kWh down about 50% from load 1.

In case 2 the maximum loading is tailored to meet the capacity output of the dominant component, which in this combination is the pico hydro turbine. The maximum load (pond lighting) is reduced to 0.950 kW to make sure it is below the average output of pico hydro of 0.959 kW. As a result all three loadings will have pico hydro as the optimum renewable energy system. The comparison for the three loadings is as shown in Table 6.

Table 9 Case 2 Comparison

	Load 1	Load 2	Load 3
TNPC	10500	10500	10500
TProd	8405	8405	8405
TLS	3814	5577	8140
EE	4590	2827	265
LCOE	0.176	0.121	0.803

TNPC = Total Net Present Cost
TProd = Total Production
TLS = Total Load Served
EE = Excess Electricity
LCOE = Levelized Cost of Energy

Load 1 with the least load served has an excess electricity of 55%, load 2 with 34% and load 3 has 3%. Reducing the excess electricity from 55% to 3% again reduce the LCOE by about 50%.

IV. CONCLUSION

The results from the simulation of renewable hybrid system shows that in order to reduce the COE it is important to look into the amount of excess energy the system produced. A reduction of 50% excess energy would have similar effect on the COE. Since COE is defined as the ratio of total annualized cost and annual load served, reducing the annualized or/and increasing the annual load served should be one of the objective of optimization. Another alternative is to limit the load towards the dominant power supplier the renewable energy hybrid system. This is to ensure that the initial capital and annualized cost to be at its minimum

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