Optimal operational strategy for hybrid renewable energy system using genetic algorithms

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Abstract: Off-grid settlements require efficient, reliable and cost-effective renewable energy as alternative to the power supplied by diesel generator. Techno-economic analysis is required to find the optimum renewable energy system in the long run. This paper reviews the application of genetic algorithms in optimization of hybrid system consisting of pico hydro system, solar photovoltaic modules, diesel generator and battery sets. It is intended to maximize the use of renewable system while limiting the use of diesel generator. Daily load demand is assumed constant for derivation of annual load. Power derived from the hybrid should be able to meet the demand. Local weather data is used and analyzed to assess the technical and economic viability of utilizing the hybrid system. Optimization of the system will be based on the component sizing and the operational strategy. Genetic algorithms programming is used to evaluate both conditions in minimizing the total net present cost for optimum configuration. Manufacturer data for the hybrid components is used in calculation of sizing to represent actual power derivation. Several operation strategies will be considered while forming the vectors for optimum strategy. Random selection of sizing and strategy is used to initiate the solution for the problem which will have the lowest total net present cost. Sensitivity analysis is also performed to optimize the system at different conditions.

Keywords: Genetic algorithm; Operation strategy; Hybrid system; Renewable energy, Optimization

1. Introduction

Power supply to off-grid location is usually supplied by generator using diesel or petrol. It is often only available at night and for certain number of hours. Applications of renewable energy at this location are through solar energy via photovoltaic (PV) panels, wind turbines and small hydro turbines. Initially, the system is a single source system. However a single source renewable usually tends to be oversized to accommodate load demand [Bagul, 1996]. It leads to high wear and tear, thus increasing operating and life cycle costs. A combination of one or more resources of renewable energy such as solar, wind, hydropower and biomass with other technologies such as batteries and generator, defined as hybrid renewable is a better option [Kaldellis, 2006]. Hybrid system can complement each other and component capacities are better utilized, improve load factors of generators and better exploitation of renewable leads to saving on maintenance and replacement cost. However the hybrid initial capital cost is high thus the needs for long-lasting, reliable and cost-effective system [Kellog, 1996]. While designing a hybrid system it is important to look into correct combination of components selection and sizing together with the operation strategy [Borrowy, 1994].

Kellog *et al.* (1998) studied a simple numerical algorithm for unit sizing and cost analysis of a stand-alone wind, solar PV hybrid system. Borrowy and Salameh (1996) reported an algorithm based on energy concept to optimally sized solar PV array in a PV/wind hybrid system. Museli *et al.* (1999) has suggested that optimal configuration for hybrid systems should be determined by minimizing the kWh cost. Optimally sizing the components is not enough to get the maximum performance of the hybrid as the problems getting complicated when power supplied by the renewable unable to meet the load demand. The use of battery for storage and power supply and the question of when to start the back-up generator require a proper algorithm for operation strategy.

Barley *et al.* (1995) has set a guidelines about main operation strategies, namely frugal discharge, load-following, state of charge (SOC) set point and the full power strategy. However, the SOC set point procedure is user-defined and it is not optimized. Frugal discharge is based on critical load, where if the net load is higher than the critical load, it is economical to run the generator set. In load-following strategy, batteries are not charged by diesel generator. The diesel operating point is set to match the net load. SOC setpoint Strategy is used to charge batteries at user defined point for the diesel generator to be started. The generator operated at full-power with the excess power is used to charge the batteries without dumping power. Otherwise the generator is set to operate at at maximum point without dumping. Full power strategy is when generator to operate at full power for a minimum time at a low setpoint.

Seeling-Hochmuth (1997) had investigated the use of genetic algorithm [Goldberg, 1989] to solve optimization problem with various constraints. He further suggested an optimization consept combining system sizing and operation control [Seeling-Hochmuth, 1998]. Koutroulis *et al.* (2006) used genetic algorithms to minimize the total system cost based on to load energy requirements. Dufo-Lopez and Bernal-Augustine (2005) developed a program based on genetic algorithms, called HOGA, for optimizing the configuration of a PV–diesel system with AC loads and the control strategy. Ashok (2007) developed a reliable system operation model based on Hybrid Optimization Model for Electric Renewable [HOMER] to find an optimal hybrid system among different renewable energy combinations while minimizing the total life cycle cost. Dufo-Lopez and Bernal-Augustine later improved HOGA program to include fuel cell and hydrogen in the hybrid system [Dufo-Lopez, 2007]. Yet the control strategies in HOGA are the same as the ones used in HOMER.

This paper will review a methodology of finding optimum component sizing and operational strategy using genetic algorithm programming. It is focused on maximizing the renewal energy components while trying minimizing the use of generator to provide for the load demand. Several operation strategies will be used in derivation strategy vectors. The objective of the program is to meet the load demand using an optimum operation strategy while maintaining minimum component size, thus minimizing the total operation cost.

2. Methodology

The proposed hybrid renewable is consists of a pico hydro turbine, wind turbine and solar photovoltaic (PV) panels. Generator (diesel or petrol-based) with battery and inverter are added as part of back-up and storage system. This proposed system is shown in Figure 1.The study involves a theoretical load demands as shown in Figure 2. The load is assumed constant all year. The renewable energy supplied is based on hourly basis as the fluctuation of parameters involved in wind turbine and solar PV. The following equations, used in the algorithms, are based on equations used by HOMER and Ashok (2007) to derive the power supplied by renewable, battery charging and discharging and the calculation of the total net present cost (TNPC)

The hydro power:

$$P_h = \eta_h * \rho_{water} * g * H_{net} * Q$$

The wind power:

$$P_w = \eta_w * \eta_g * 0.5 * \rho_a * C_p * A * V_r^3$$

The PV power:

$$P_{pv} = \eta_{pv} * N_{pvp} * N_{pvs} * V_{pv} * I_{pv}$$

Total renewable power:

$$P(t) = \sum_{h=1}^{n_h} P_h + \sum_{w=1}^{n_w} P_w + \sum_{s=1}^{n_s} P_s$$

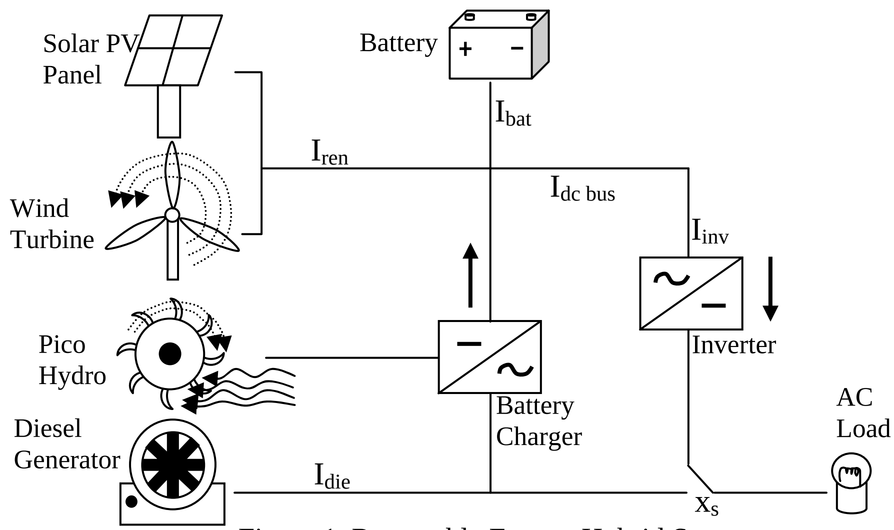

Figure 1. Renewable Energy Hybrid System

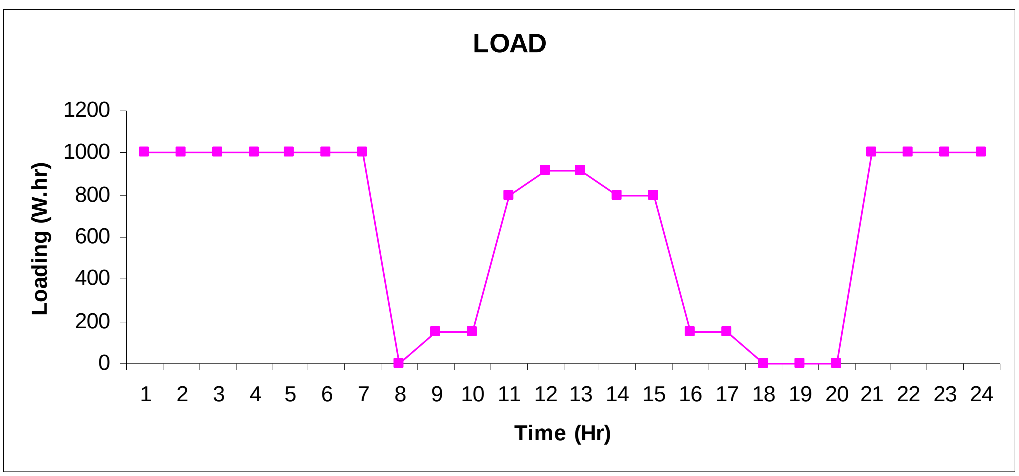

Figure 2 Daily load demands

Battery discharging:

$$P_b(t) = P_b(t-1) * (1-\sigma) - [P_{bh}(t)/\eta_{bi} - P_{bl}(t)]$$

Battery charging:

$$P_b(t) = P_b(t-1) * (1-\sigma) +$$
$$[P_{bh}(t) - P_{bl}(t)/\eta_{bi}] * \eta_{bb}$$

The annualized cost of a component includes annualized capital cost, annualized replacement cost, annual O&M cost and annual fuel cost (generator). Operation cost is calculated hourly on daily basis.

$$\sum_{h=1}^{N_h}(C_h + C_{oh} + C_{reph}) + \sum_{w=1}^{N_w}(C_w + C_{ow} + C_{repw}) +$$
$$\sum_{s=1}^{N_s}(C_s + C_{os} + C_{reps}) +$$
$$\sum_{g=1}^{N_g}(C_g + C_{og} + C_{repg} + C_{fg}) + \sum_{b=1}^{N_b}(C_b + C_{ob} + C_{repb})$$

Example for operating cost:

$$C_{op} = \sum_{1}^{365}\{\sum_{1}^{24}[C_{oh}(t)]\}$$

Net present cost (NPC) for each component is derived using

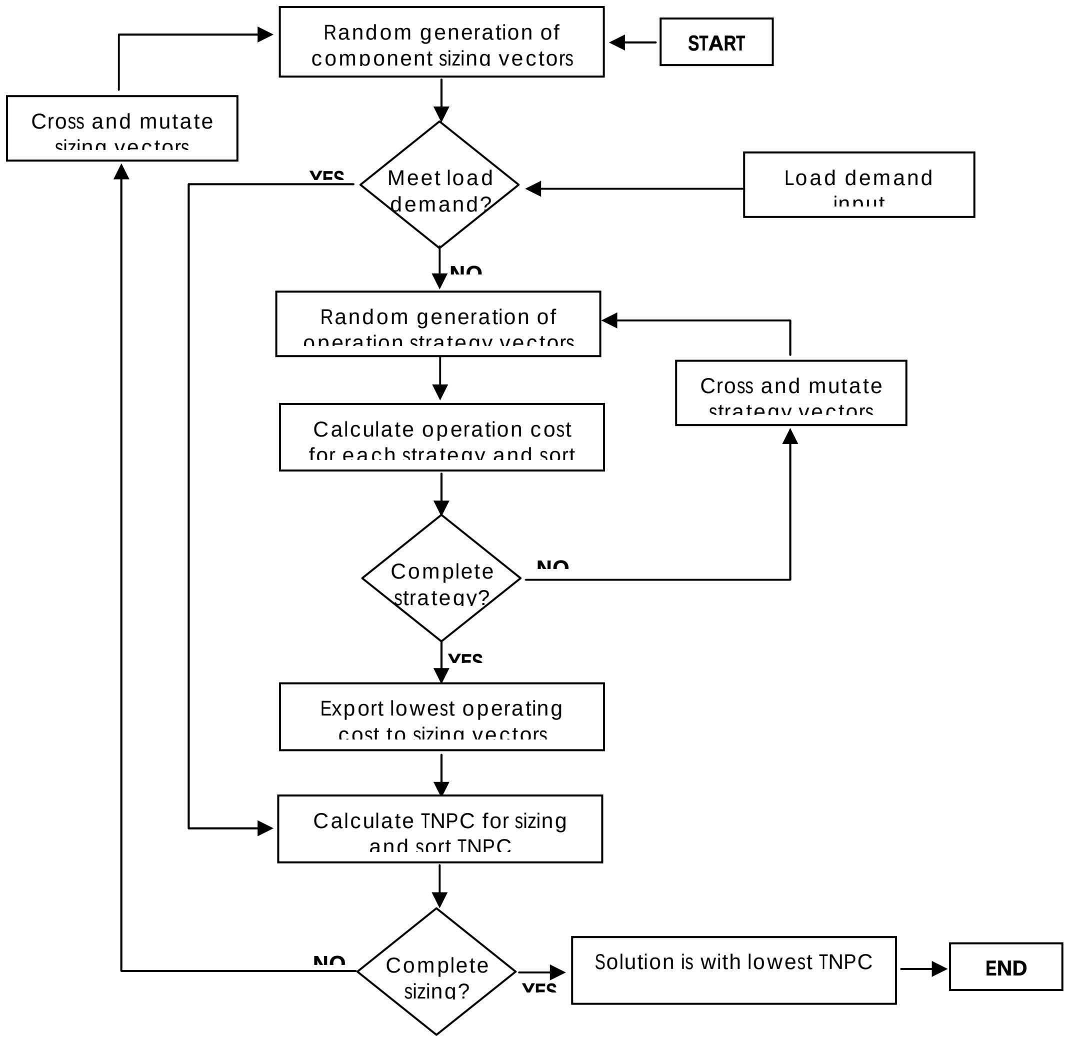

Figure 3 Flowchart of the genetic algorithms

$$C_{NPC} = \frac{C_{ann,tot}}{CRF} \text{ where } CRF = \frac{i*(1+i)^N}{(1+i)^N - 1}$$

Annualized capital cost is calculated using

$$C_{acap} = C_{cap} * CRF_{proj}$$

Replacement cost is formulated based on its salvage value at the end of the project, if any, and the cost of replacement itself

$$C_{arep} = C_{rep} * f_{rep} * SFF_{comp} - S * SFF_{proj}$$

$$f_{arep} = \begin{cases} CRF_{proj} / CRF_{rep} \\ 0 \end{cases} \quad \text{when}$$

$$R_{rep} > 0$$

$$R_{rep} = 0$$

$$R_{rep} = R_{comp} * INT\left(\frac{R_{proj}}{R_{comp}}\right) \quad \text{and}$$

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep})$$

$$S = C_{rep} * \frac{R_{rem}}{R_{comp}} \quad \text{and}$$

$$SFF = \frac{i}{(1+i)^N}$$

Figure 3 shows the flowchart of genetic algorithms programming.The algorithms first randomly select a set of vector for sizing of the hybrid system. The power derived from these components is compared to the daily load

Table 2 Optimization results for component sizing

Hydro (kW)	PV (kW)	Diesel (kW)	Wind (kW)	Battery	Inverter (kW)	In Cap (RM)	Tot NPC (RM)	COE (RM/kW
1.001				12	1	51,000	63,887	0.708
1.001		1				19,000	65,339	0.724
1.001	0.075			12	1	54,417	67,303	0.746
1.001		1		12	1	59,500	69,461	0.770
1.001	0.075	1		12	1	62,917	72,887	0.807
1.001			1	12	1	71,500	92,198	1.021
1.001	0.075		1	12	1	74,917	95,614	1.059
1.001	0.075	1	1		1	42,417	97,751	1.083
1.001		1	1	12	1	80,000	97,772	1.083

Table 1 Total Annualized Cost

Component	Initial Capital (RM)	Annualized Capital (RM/yr)	Annualized Replacement (RM/yr)	Annual O&M (RM/yr)	Annual Fuel (RM/yr)	Total Annualized (RM/yr)
Hydro	10500	673	0	0	0	673
Battery	20500	1312	224	25	0	1561
Inverter	20000	1280	551	25	0	1856
Total	51000	3265	775	50	0	4090

Table 2 Optimization results for component sizing with sensitivity variables

PV Price (RM/kW	PV (kW)	Hydro (kW)	Battery	Inverter (kW)	In Cap (RM)	Tot NPC (RM)	COE (RM/kWh)
44444	0.075	1.001	12	1	54,417	67,303	0.746
33333	0.075	1.001	12	1	53,583	66,470	0.736
22222	0.075	1.001	12	1	52,750	65,637	0.727
11111	0.075	1.001	12	1	51,917	64,803	0.718

demands. If the power generated by the system able to meet the load demands then TNPC can be calculated. If power derived unable to meet the load demands then the operation strategy takes place. The operation strategy vector is randomly selected. Cost for each strategy is calculated. The lowest operation strategy cost will be added to the sizing for the TNPC for each sizing. Another sizing of component is randomly selected for the next calculation. The solution of the problem will be the one with the lowest cost of TNPC.

3. Results & Discussions

The optimization using genetic algorithm derived the following results as shown in Table 2. Pico hydro powered system with battery and inverter have the lowest TNPC at RM63,887 and COE of RM0.708 per kWh. Diesel generator with the fuel cost at RM1.98 per liter still proves economical as a second choice. However, the COE of the optimum combination is still too much if compared with the current electricity tariff set by government at RM0.236 per kWh. Table 3 shows the annualized cost of the pico hydro powered components. Table 4 shows the optimization of the hybrid system by changing the capital and replacement cost of PV panels as its prices shows a downward trend.

5. Conclusions

The initial results shows that the algorithms manage to optimize the sizing and the operation strategy for a simple daily load with a set of manufacturer data. The solution will become more interesting when data from other manufacturers are added and daily load are varied to represent actual demands. Future works include adding constraints such as renewable fraction and maximum generator usage, sensitivity optimization calculations using petrol for generator and varied daily load demands.

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ACRONYM

Notation	Explanation
P_w	Hydro turbinepower output
η_h	Efficiency of hydro turbine
ρ_{water}	Density of water
g	Gravitational acceleration
H_{net}	Effective head
Q	Flowrate
P_w	Wind turbine power output
η_w	Efficiency of wind turbine
η_g	Efficiency of generator
ρ_a	Density of air
C_p	Power coefficient of wind turbine
A	Wind turbine swept area
V_r	Wind velocity
P_{pv}	PV power output
η_{pv}	Converesion efficiency of PV
N_{pvp}	Number of PV panels in parallel
N_{pvs}	Number of PV panels in series
V_{pv}	Operating Voltage of PV panels
I_{pv}	Operating Current of PV panels
P_b	Battery energy at time interval
P_{bh}	Total energy generated by PV array
σ	Self discharge factor
P_{bl}	Load demand at time interval
η_{bi}	Inverter efficiency
η_{bb}	Battery charging efficiency
C_{oh}	Hydro turbineoperation cost
C_{reph}	Hydro turbine replacement cost
C_{ow}	Wind turbineoperation cost
C_{repw}	Wind turbine replacement cost
C_{os}	PV operation cost
C_{reps}	PV replacement cost
C_{og}	Generator operation cost
C_{repg}	Generator replacement cost
C_{fg}	Generator fuel cost
C_{ob}	Battery operation cost
C_{repb}	Battery replacement cost
C_{acap}	Annualized capital cost
CRF	Capital recovery factor
CRF_{proj}	CRF project
CRF_{comp}	CRF component
f	Factor due to difference of component and pro lifetime
S	Salvage value
SFF	Sinking fund factor
C_{rep}	Replacement cost
R_{rep}	Replacement years
R_{comp}	Component years
R_{rem}	Remaining years
C_{npc}	Net present cost
$C_{ann,tot}$	Annualized total cost
N	Number of years
i	Interest rate