ENGINEER - Vol. [volume no.], No. [issue no.], pp. [page range], [year]

Optimum Home Power Systems for Off-grid Rural Electrification In Sri Lanka

Mahinsasa Narayana

Abstract: Though expansion of the main grid is the principal vehicle for electrification, wind and solar home systems and community-level independent grids - are frequently better suited to serve remote, rural communities in an economic and efficient manner. According to present statistics solar and wind home power systems are commonly used for off-grid electrification and solar home systems are much popular in the country. Focal point of this study is optimising the solar and wind home power systems with considering available wind and solar resources and electric energy demand. Wind and solar energy is identified as most promising energy resources for rural home power systems. In this paper, optimisation of system capacities and system combinations of solar and wind system options is discussed. Electric energy output of each system is determined by considering the system performance and available resources. According to the results of this study, Solar Home Systems are more appropriate when electricity demand is less than 250Wh/day and it shows that, at the higher electricity demand wind power is more economical, when average wind speed of the site is more than 5m/s. Outcomes of this study give better guidance to select the optimum solar/wind home power system combination for a selected site. In this study, simulations for system combinations are done by the "HOMER" computer model.

Keywords: wind turbine, Solar, hybrid, optimum, home system, photo-voltaic (PV) array

1. Introduction

Rural electrification is identified as a catalyst for enhancing rural economic and social development. While conventional grid extension has made good progress connecting nearly 63 percent of Sri Lankans on average to grid electricity, accessibility differs widely among regions. The more developed Western Province has over 80 percent coverage, but other Provinces like Uva has less than 30 percent coverage. According to the available data in year 2003, status of electrification is shown in table.1 [2].

Table 1- Status of electrification in Sri Lanka[3]

Total number of households:	4,576,554
Urban households	23 %
Rural households	77 %
Number of electrified households	3,000,721
Number of non-electrified households	1,575,833

Electric energy requirement of the 23% of rural households in Sri Lanka is not catered by the main grid electricity supply due to high costs and lack of energy generation capacity. Harnessing of renewable energy is a possible option to accomplish the rural electric energy demand.

Present status of off-grid rural energy supply as follows [3].

- More than 44,911 houses connected to solar home systems
- 257 village hydro schemes
  - 122 pre ESD projects (1,003 houses 175kW)
  - 35 RERED projects (2,293 houses/350kW)
  - 49 RERED projects under construction (2,229 houses/541kW)
- Two village dendro schemes
- Wind energy systems
  - Two community wind projects
  - More than 20 wind home systems

According to present status of off-grid rural electricity supply only solar and wind small systems are been used as home power systems. Home power system is the small power system that can be used for fulfilling the single house electricity requirement. Micro hydros are commonly used as community base power systems and few community base dendro power schemes are operated to fulfil the electric energy requirement in off-grid rural community.

MAHINSASA NARAYANA, B.Sc. Eng. (Moratuwa), MPhil (Eng) (Moratuwa). Mechanical Engineer, NERD Centre of Sri Lanka.

2. Rural electric energy demand in Sri Lanka

Presently under the World Bank/GEF project titled "Renewable energy for rural economic development (RERED)" an exercise has been undertaken to develop renewable energy resources based electricity generation in Sri Lanka. Therefore most of the renewable energy based rural electric energy supply schemes were developed under these projects, especially solar home systems and small hydropower generations.

Table 2- The daily energy demand for a typical rural house in Sri Lanka [1]

	Appliance	W	Daily use	Total (Wh/ day)
1	Compact fluorescent lamp (CFL) for kitchen	11	3hr	33
2	Compact fluorescent lamp (CFL) for the living room	11	4hr	44
3	Compact fluorescent lamp (CFL) for out side the house or one bedroom.	11	2hr	22
4	Black & white Television (12" screen)	20	3hr	60
5	AM/FM radio	15	7hr	105
	Total Load			**264**

Biomass (fire wood) is the main source of domestic energy supply in a rural house in Sri Lanka. Normally, in off-grid areas kerosene oil lamps are been commonly used for lighting purposes and dry cells are been used for radio and hand lantern or torch. Solar or wind power home systems have been identified as a possible options to fulfil the electricity requirement for illumination purposes, television and radio. Quality illumination of houses is the befit of using solar/wind power systems when compare the using of kerosene oil lamps. Added advantage is that, other appliances like televisions and radios can be powered by the solar/wind power systems. Then basic electricity requirement of typical a rural house is only for lighting, television and radio. The daily energy demand for a typical rural house in Sri Lanka is shown in table 2 [4]. Total electric net power requirement is around 264Wh/day.

Efficiency of electrical equipment used in home power generation is shown in table 3. If average efficiency of electrical equipment is 69%, the daily gross electric energy requirement is 382Wh and monthly gross electric energy requirement is approximately 10 kWh for a rural house in Sri Lanka.

Table 3-Efficiency of electrical equipment [1]

Equipment	Efficiency
DC to AC Inverter	85 to 95 %
Battery charge regulator (includes losses due to cables)	90 to 95 %
Battery	75 to 90 %
Overall efficiency of the electrical system	**57 to 81 %**

3. Solar home system

Presently, solar home systems (SHS) are using in 3% of non-electrified houses in Sri Lanka and it is the major component of home power systems in Sri Lanka. Installed solar home systems at March 31, 2005 are shown in table 4 [3].

Table 4- Installed solar home systems in Sri Lanka at March 31, 2005 [4]

SHS Capacity Peak watt (Wp)	Number of Households (HH)
10 to <20 Wp	35
20 to <40 Wp	6,367
40 to <60 Wp	38,404
>60 Wp	105
Total	44,911

Under the UNEP/GEF project titled "Solar and Wind Resources Assessment (SWERA)" 10-km solar map and 1-km wind map was developed for Sri Lanka [1]. According to the 10-km solar map, solar potential tilted at latitude of most part of the Island is existed within 4kWh/m²/day to 5kWh/m²/day. Therefore daily energy output of SHSs can be determined, if conversion efficiency and capacity are known.

$$E = \eta A I_s \qquad \text{-(1)}$$

$$Electricity\ Demand = \frac{E}{(1+k)}$$

Where;

E - Daily electric energy output

η - Conversion efficiency (6% –No tracking and slope is 8^0)

A - Area of the solar panel (PV array) – Area of the 10Wp PV array is $0.15m^2$.

I_s - Daily solar insolation tilted at latitude ($kWh/m^2/day$)

k- daily electric energy demand variation is taken (5%)

Required capacities of SHSs to fulfil the various electricity demands at the site of solar potential of $5kWh/m^2/day$ are shown in table 5. For this calculation, allowable daily electric energy demand variation is taken as 5%.

Table 5- Daily energy generation of various capacities of SHSs

Demand (Wh/d)	SHS capacity (Wp)
382	*90*
350	90
300	70
250	60
200	50
150	40
100	30
50	10

Available data shows that, capacity range of 40W-60W SHSs have been installed in the most of households in Sri Lanka (table 4). Capacity of 50pW SHS generates around 200Wh/day at the site of solar potential of $5kWh/m^2/day$ (table 5).

4. Economic Viability of the Home power systems

Cost of energy and initial cost of the system are the most important parameters to evaluate and compare the each home power system.

$$COE = \frac{C_{ann,tot}}{E_{prim} + E_{def}} \quad \text{------------(2)}$$

Where;

COE = Cost of energy (Rs./kWh)

$C_{ann,tot}$ = Total annualised cost of the system(Rs./Year)

E_{prim} = Primary load (kWh/day)

E_{def} = Deferrable load (kWh/day)

Total annualised cost of the system ($C_{ann,tot}$) is sum of the annualised capital cost ($C_{ann,cap}$), annualised replacement cost and annual operation and maintenance cost.

$$C_{ann,cap} = C_{cap}.CRF(i, R_{proj}) \text{ -----(3)}$$

Where;

C_{cap} = Initial capital cost (Rs.)

$CRF()$ = Capital recovery factor

i = Interest rate

R_{proj} = Project lifetime

Annualised replacement cost of a system is the annualised value of the all the replacement cost occurring throughout the lifetime of the project minus the salvage value at the end of the project.

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad \text{------(4)}$$

Where;

i = Interest rate

N = Number of years

Project lifetime of the SHSs is taken as 15 years. Initial cost of a 10W Solar panel with controls is Rs.12,000.00 and cost of 70Ah battery bank is Rs.4,000.00. Then energy cost of each capacity of SHSs can be determined by using the equation (2) and results are shown in the table 6. Every possible combination of PV capacity and battery capacity is simulated to find out the suitable combination to fulfil the required demand. Cost of energy generation and energy generation per day for each SHS system is shown in table 6.

Table 6- Energy cost of SHSs

PV (Wp)	No. of 70Ah-Batteries	Initial capital (Rs.)	Demand (kWh/day)	COE (Rs./KWh)
90	*3*	*120000*	*0.382*	*133.60*
90	2	116000	0.350	138.60
70	3	96000	0.300	137.90
60	2	80000	0.250	136.10
50	2	68000	0.200	146.00
40	1	52000	0.150	145.60
30	1	40000	0.100	170.10
10	2	20000	0.050	197.70

5. Wind power home systems

There are only few types of wind home systems (WHS) are used in Sri Lanka. Wind turbine generator capacity range of 100W to 200W is commonly used for off-grid wind power home systems. Wind potential in Sri Lanka is seasonal hence continuous and reliable firm power supply could not obtain by wind power home systems. This may be the one reason of SHSs is much popular than using of wind home power system.

The two-parameter Weibull distribution is often used standard method to characterize wind regimes because it has been found to provide a good fit with measured wind data. The probability density function is given by the following equation:

$$f(v)=\frac{k}{c}\left(\frac{v}{c}\right)^{k-1}.\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (5)$$

Where v is the wind speed, k is a unit less shape factor, and c is a scale parameter with the same units as v. Average wind speed of the wind potential is described by the c value of the Weibull distribution. As an example, best fit of the Weibull distribution with the wind measurements of Hambantota Met station is shown in the figure 1.

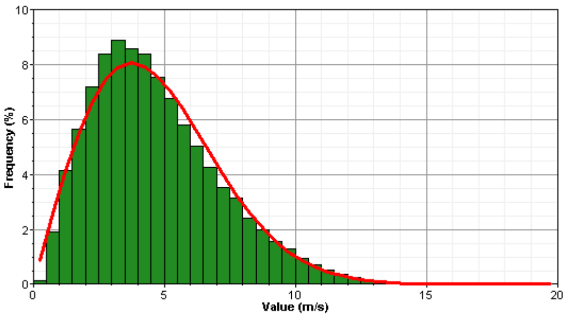

Figure 1- Weibull distribution of Hambantota Met station wind data

In this study, assume the wind pattern of the considered sites is identical and average wind speed is varied with the site. Therefore, k value for the Weibull distribution is taken as 2 and c value will be changed according to the average wind speed of the site. Then energy generation of a certain wind turbine at a specific location can be determined, when average wind speed of the site (k value) and characteristic performance of the wind turbine are known. Typical characteristic performance of a 100W small wind turbine is shown in figure 2. Generated energy from the WHS at the certain location is calculated by using the weibull curve, which is fitted the local wind potential (k & c value) and wind turbine power performance curve (figure 2)

Project lifetime of the WHSs is taken as 15 years. Initial cost of a 100W wind turbine with all controls is taken as Rs.70,000.00 and cost of 70Ah battery bank is Rs.4,000.00. Then energy generation cost of 100W WHSs can be calculated by using the equation 2. Energy generation cost of the 100W wind turbine in the several sites with different wind potentials are shown in the table 7. Selected power systems in the table 7 (wind turbine & battery bank) can be fulfilled the electric energy demand of 382Wh/day.

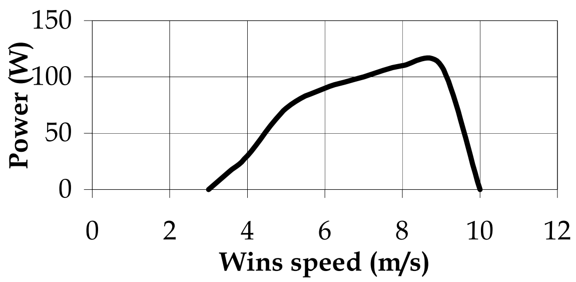

Figure 2- Typical characteristic performance of the 100W small wind turbine

Table 7- Energy generation cost of 100W WHSs

Average wind speed (m/s)	Capacity of Wind (× 100W)	No. of 70Ah-Batteries	Capital cost (Rs.)	COE (Rs./ kWh)
4.5	1	5	90000	114.00
5.0	1	3	82000	100.70
5.5	1	2	78000	94.10

When the average wind speed is higher than 4.5m/s, WHS to be fulfilled the energy demand of 382Wh/day is more economical (Table 6 & 7).

6. Wind-solar hybrid home systems

Wind and solar energise are the most promising available options for home power systems (HPS) in Sri Lanka. To design the optimised home electric power system, mix of wind and solar energies should be considered. Energy generation cost of wind, solar and wind-solar hybrid home power systems at the site of average wind speed 4.5m/s and solar installation 5.5kWh/day is shown in table 8. The results in the table 8 were obtained by using the simulation calculations of every possible combination of solar/battery, wind/battery and solar/wind/battery systems.

These all selected system combinations can be fulfilled the energy demand of 382Wh/day.

Table 8- Energy cost of wind, solar and wind-solar hybrid home power systems

HPS	PV (Wp)	Capacity of Wind (× 100W)	No. of 70Ah-Batteries	Initial capital	COE (Rs./ kWh)
Hybrid	10	1	3	94000	113.40
Wind		1	5	90000	114.00
Solar	90		3	120000	133.60

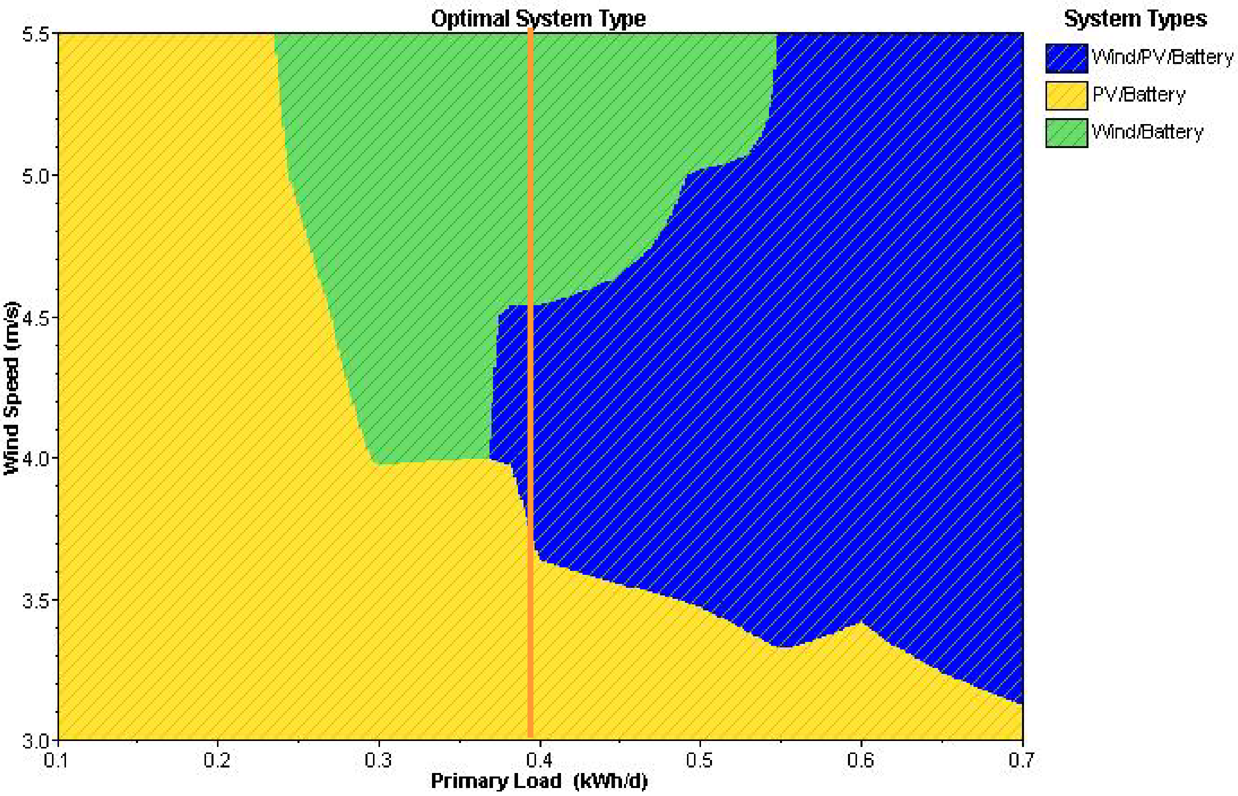

Figure 3 – Sensitivity analysis of wind and solar home systems generated by "HOMER" computer model

7. Sensitivity analysis

To find out energy cost of each home power system for a selected site, available solar & wind resources and energy demand should be considered. Then optimum system can be selected, by using sensitivity analysis of all possible system combinations. Sensitivity analysis of wind/battery, solar/battery and wind/solar/battery for a site with solar installation 5kWh/day is done by the HOMER computer model. HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation applications. National Renewable Energy Laboratory, USA, developed the micro power optimisation model "HOMER".

The Optimum system combinations for different energy demands with the average wind speeds are shown in figure 3. The optimum system combinations, which can be fulfilled the energy demand of 382Wh/day is indicated in figure 3 and then results are categorised in table 9.

Table 9 – Optimum system combinations to fulfil the 382Wh/day energy demand

Average wind speed	Optimum system
<3.7m/s	Solar
3.7m/s – 4.5m/s	Wind (100W)/Solar hybrid
>4.5m/s	Wind

8. Conclusions

This study was done to find out the optimum mix of solar and wind home systems for different sites in Sri Lanka. Cost of energy generation and initial cost of the system are taken as major economic parameters to compare the different system combination. Optimum solar/wind home power system is selected based on the minimum levelised cost of energy. According to the sensitivity analysis, SHSs are more appropriate when energy demand is less than 250Wh/day and it shows that, at the higher energy demand wind power is more economical. Other important thing is sensitivity analysis gives better guidance to select the optimum home power system combination for a selected site.

References

[1] Christoph Schillings, Richard Meyer, Franz Trieb, Solar and Wind Energy Resource Assessment (SWERA), High Resolution Solar Radiation Assessment for Sri Lanka, Deutsches Zentrum für Luft- und Raumfahrt, DLR-Stuttgart, Institut für Technische Thermodynamik, Pfaffenwaldring 38-40, D-70569 Stuttgart, Germany

[2] http://www.ceb.lk, Visited, 29th July 2005.

[3] http://www.energyservices.lk, Visited, 29th July 2005.

[4] Narayana M and Sugathapala A G T, "Performance of the High Solidity Wind Turbines in Low Wind Potential Sites of Sri Lanka", Engineer, Vol: XXXVIII. No.01, pp7-15, 2005, Institution of Engineers, Sri Lanka