Demand and Supply Analysis of Community Type Wind power System at Gurugoda Village in Sri Lanka

Mahinsasa Narayana
Renewable Energy Department, National Engineering Research & Development Centre of Sri Lanka
2P/17B, IDB Industrial Estate, Ekala, Ja-ela,
narayana@nerdc.lk

***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. More recently a small wind power system was installed at Gurugoda Village in Northwest region of Sri Lanka. This system was installed to supply electricity for 13 houses. Focal point of this study is analyzing the wind power system with considering available wind resources and electric energy demand. This wind/battery system was analyzed by making energy balance calculations for each of the 8,760 hours in a year simulating the operation of the system. For each hour, the electric demand is compared with the energy that the system can supply, and the flows of energy from each components of the system are calculated. For systems that include batteries, for each hour the simulation process can decide how to charge or discharge the batteries. Time series wind resource data, power curve of wind turbine, battery efficiency, demand pattern and demand variation were considered for this simulation. According to the results of this study, from May to October there is a good wind potential and electric production of wind turbine is sufficient to fulfill the demand. However, there may be an electric supply shortage in February, April and November.**

I INTRODUCTION

At the present time 65% of Sri Lanka's electricity is generated by fossil fuels. In this situation, utilization of renewable energy for electricity generation is very important to mitigate economic and environmental impacts. Wind energy has been identified as one of the more promising renewable energy sources that could generate electricity in Sri Lanka. 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 community based wind/battery system was installed to fulfill the electricity requirement of Gurugoda village. This wind system consists of 2.5kW small 2500LMW wind turbine, 900Ah/24V (21.6kWh) battery bank, 2kW inverter, a dump load and battery-charging regulator. If wind systems supply more current to the battery, the charge regulator reduces the charging current. The excess current is transferred to a dump load. The full charging current is automatically switched on again when the battery voltage drops. When over-discharged limit is reached, an automatic load rejection mechanism has been installed in the consumer side inverter. As soon as the battery resumes the reset threshold, the load is switched on again. A yaw control mechanical safety system is used for small wind turbines to limit the rotational speed of the rotor and to limit the axial forces acting upon the rotor.

II ENERGY DEMAND

This off grid system should be supplied electricity for 13 houses in Gurugoda village. Electricity requirement of a typical 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 1. Total electric net energy requirement for a house is around 295Wh/day. Efficiency of electrical equipment used in this type of system is shown in Table 2. If overall efficiency of the electrical distribution and controls is 70%, the daily gross electric energy requirement for the village is 5.56kWh. Daily electric demand pattern in the village can be determined and shown in the Fig 1. According to the load profile, peak power requirement is 1.31kW. In this study, for secure situation daily load variation is taken as 10% and hourly load variation is taken as 5%. Therefore, average annual electrical energy requirement of the 13 houses is 2027 kWh.

TABLE 1
The daily energy demand for a typical rural house in Sri Lanka

	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	5hr	55
3	Compact fluorescent lamp (CFL) for out side the house or one bedroom.	11	2hr	22
4	Black & white Television (12" screen)	20	4hr	80
5	AM/FM radio	15	7hr	105
	Total Load			**295**

TABLE 2

Efficiency of electrical equipment

Equipment	Efficiency
DC to AC Inverter	90%
Battery charge regulator & transmission (includes losses due to rectifiers and transmission cables)	70 %
Battery	80%

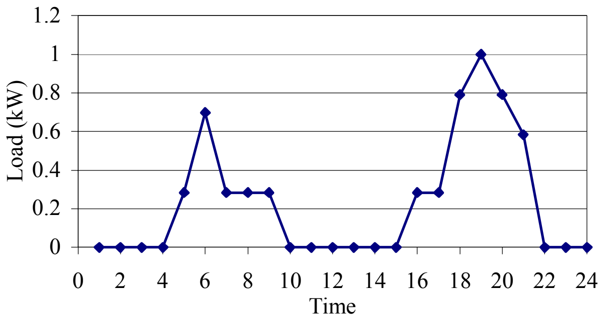


Fig. 1 Daily electric demand pattern in the village

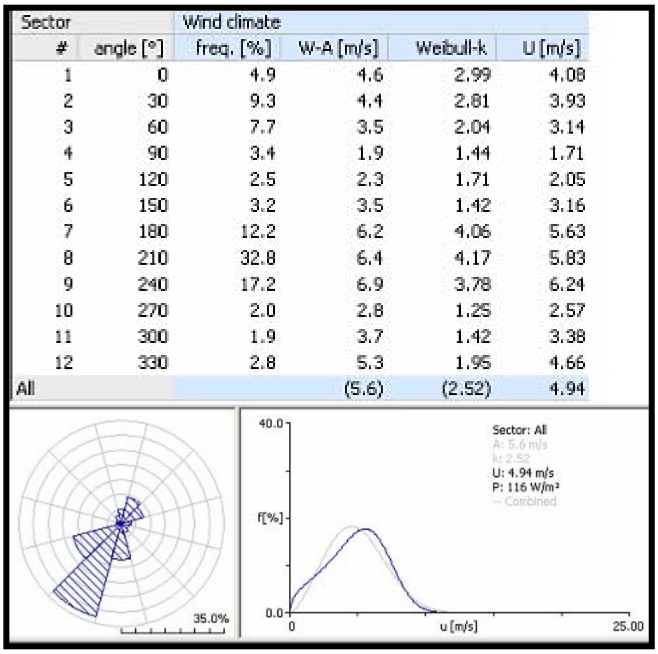
III ENERGY GENERATION BY THE WIND TURBINE

Power generation of the wind turbine can be determined by using the power curve of the LMW2500 small wind turbine and the wind potential distribution. As measured wind data is not available in the Gurugoda site, predicted wind potential distribution was used for this study. Characteristics performance of wind turbine was taken from the manufacture's technical data sheet. The hourly basis variation of power production should be taken in to consideration in order to properly analyze the supply and demand

A Wind resources

Location of Gurugoda wind system is N: 07^0, 47.227' E: 80^0,01.986'. To find out the wind resource at this location, micrositing was done by using the measured wind data at Narakkaliya (N:08^0,00.707', E:79^0,43.338') measuring station, which is located 37.718km away from the site. WAsP produces the wind resources at the wind turbine site [7]. Wind Atlas software Programme (WAsP) was developed to make wind resources predictions at required locations by using the collected time based wind data. Ceylon Electricity Board was installed a 40m height wind mast at Narakkaliya to collect energy based wind data. Nearest available wind data to the Gurugoda site is Narakkaliya measured wind data and these are more suitable and reliable for prediction.

To get a better idea for predicted wind resources, WAsP prediction was compared with the Wind resource assessment model (WRAM) [1][3] wind map and collected wind data in the small wind power home systems site in Nikaweratiya (N:07^0, 45.448', E: 80^0, 03.034'), which is located 5km away from the Gurugoda site. Predicted wind climate in the wind turbine site at the 20m heights is shown in Fig 2 and monthly average wind speed in the site is shown in Fig 3. Predicted annual average wind speed at 20m heights in the Gurugoda site is around 4.9m/s. Weibull parameters of predicted wind data; k= 2.52 and A=5.66



#	angle [°]	freq. [%]	W-A [m/s]	Weibull-k	U [m/s]
1	0	4.9	4.6	2.99	4.08
2	30	9.3	4.4	2.81	3.93
3	60	7.7	3.5	2.04	3.14
4	90	3.4	1.9	1.44	1.71
5	120	2.5	2.3	1.71	2.05
6	150	3.2	3.5	1.42	3.16
7	180	12.2	6.2	4.06	5.63
8	210	32.8	6.4	4.17	5.83
9	240	17.2	6.9	3.78	6.24
10	270	2.0	2.8	1.25	2.57
11	300	1.9	3.7	1.42	3.38
12	330	2.8	5.3	1.95	4.66
All			(5.6)	(2.52)	4.94

Fig. 2 Wind climate at the wind turbine location

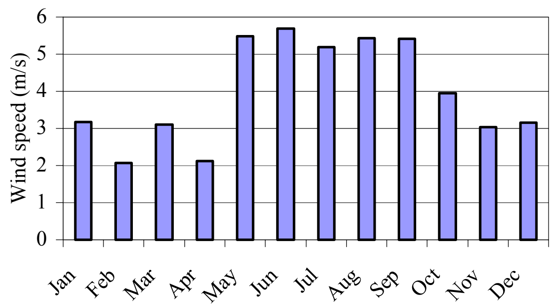


Fig. 3 Monthly average wind speed in selected location (20m height)

In this study, hourly basis wind speed values are needed to properly analyze the supply and demand. However, wind resources are predicted by monthly basis and then hourly wind speed values are not available. Therefore, hourly data should be generated synthetically from monthly averages. To generate synthetic wind data, mean, standard deviation, median, percentiles, Weibull distribution parameters, autocorrelations and spectral density of wind speed values are required [4]. Parameters related to the wind potential were computed by the predicted wind speeds. Parameters related to the wind pattern, which is represented hourly variations, were computed by considering the Narakkaliya measured wind data. As Narakkaliya is located only 37.718km away from the Gurugoda site, assume that wind pattern in Narakkaliya is more similar to the Gurugoda site.

B Power curve of the wind turbine

TABLE 3

Technical specification of LMW2500 wind turbine

Parameter	LMW 2500
Output, W	2500
Wind speed, m/s: - Cut in - Rated - Design	 2 12 3.5
Rotor blades: - Number - Diameter, m - Swept area, m^2	 3 5 19.6
Speed at rated output, rpm	350
Maximum speed, rpm	450
Speed control	Inclined hinged vane
Hub type	Rigid
Blade material	Fibre-glass reinforced polyestr or epoxy
Airfoil	NACA 4415
Tip speed ratio	9
Generator PMG	38 pole
Maximum output, W	2700
Voltage DC, V	24
Frequency, Hz	0-70
Output control	Voltage regulator + rectifier
Yaw system	Passive, aligned by tail vane
Braking mechanism	Turning tail 90 degrees
Rotor position	Upwind
Tower	Guyed tower 20 m

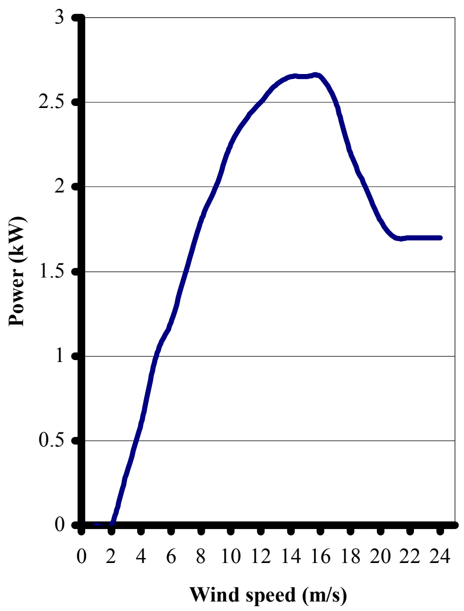


Fig. 4 Power curve of LMW2500 small wind turbine

C Electric energy production

Hourly basis energy production was determined by considering synthetically generated wind speeds to analyze the demand and supply. Annual electric energy production of the wind turbine at the Gurugoda site is 5363.03kWh. Monthly energy production was calculated for predicted wind speeds and presented in Fig 5.

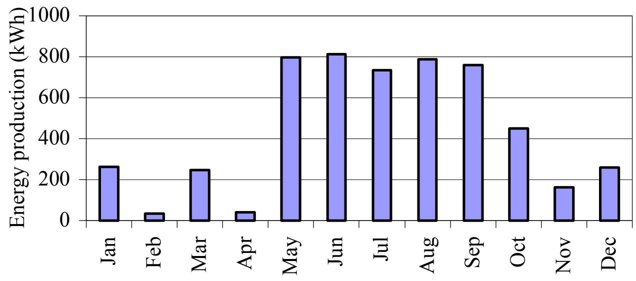


Fig. 5 Monthly energy production

IV Simulation of the Operation

In this study, the operation of the system is simulated by making energy balance calculations for each of the 8,760 hours in a year. For each hour, the electric demand in a particular hour was compared with the energy that the system can supply in that hour, and the energy flows by the wind turbine and the batteries are considered [6]. Configuration of the stand along wind system is shown in Fig 5.

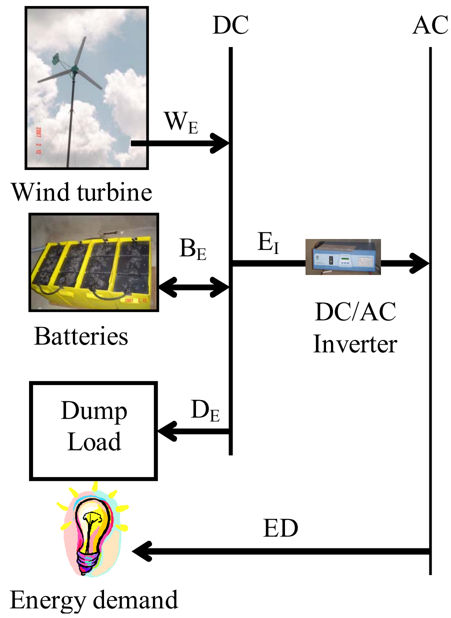


Fig. 5 Configuration of the stand along wind system

$$W_E \pm B_E - D_E = E_I$$
$$ED = 0.90\, E_I$$

Where;

W_E – Energy generated by the wind turbine
B_E – Energy flow of the battery.
E_I – Energy supply to the inverter
D_E - Dump energy
ED – Energy demand

Energy flows by the each component of the system are calculated in hourly basis. Round trip efficiency of the batteries is 80%. In this study, overall efficiency of the electrical distribution and controls is considered as 70%.

V CHARGING AND DISCHARGING STATUS OF THE BATTERY BANK

In simulation, the electric demand is compared for each hour with the energy that the system can supply, and calculate the flows of energy from the wind turbine and the battery bank. To calculate flow of energy from the battery bank, modeling should be done for charge acceptance and discharge rate of batteries. As batteries are non-linear and highly dependent on diverse parameters like temperature, state of charge (SOC) and short-term history, the implementation of battery models is very difficult and a simple modeling with high precision is consequently nearly impossible [5][2]. Limitations of state of charge depend on the characteristics of battery charging regulator. Normally, charge regulator was set for preventing the state of charge is below the 40% in order to avoid damaging the battery bank by excessive discharge. Therefore, according to the demand and supply, operation of the system was simulated by considering the limitation of battery SOC and allowable charge rate. According to the simulation, battery state of charge monthly average is presented in Table 4.

TABLE 4
Battery State of Charge Monthly Averages

Month	Minimum %	Daily low %	Average %	Daily high %	Maximum %
Jan	80.55	84.55	90.54	96.38	100.00
Feb	40.00	40.45	41.88	45.10	83.87
Mar	41.01	76.60	82.64	89.92	98.31
Apr	40.00	40.39	41.75	45.15	78.32
May	44.57	97.70	99.14	99.81	100.00
Jun	98.12	99.77	99.96	100.00	100.00
Jul	94.57	98.95	99.77	99.97	100.00
Aug	94.41	99.19	99.82	99.97	100.00
Sep	97.62	99.49	99.90	99.99	100.00
Oct	89.04	93.17	97.50	99.43	99.79
Nov	68.29	80.59	86.38	93.22	98.33
Dec	77.48	84.56	90.16	95.98	98.89

VI DEMAND AND SUPPLY

Hourly basis energy production, supply and demand were calculated by using the time series data and then monthly averages are calculated and shown in Table 5. Unmet load is electrical load that the power system is unable to serve. It occurs when the electrical demand exceeds the supply of the system (wind turbine and battery bank). According to the results of this study, from May to October there is a good wind potential and electric production of the wind turbine is sufficient to fulfil the demand. However, there may be some electric supply shortage in February, April and November. According to the simulation, large amount of excess energy is wasted through the dump load in several months of the year.

TABLE 5
Demand and supply of each months

	Energy Production (kWh)	Supply (kWh)	Demand (kWh)	Unmet load (kWh)	Excess (kWh)
Jan	263.00	172.36	172.36	0.00	90.64
Feb	36.94	36.94	155.68	118.74	0.00
Mar	249.22	172.36	172.36	0.00	76.86
Apr	42.94	42.94	166.80	123.86	0.00
May	796.51	172.36	172.36	0.00	624.15
Jun	814.20	166.80	166.80	0.00	647.40
Jul	736.40	172.36	172.36	0.00	564.04
Aug	788.41	172.36	172.36	0.00	616.05
Sep	759.56	167.28	166.80	0.48	592.27
Oct	452.11	172.36	172.36	0.00	279.75
Nov	163.33	163.33	166.80	3.47	0.00
Dec	260.40	170.62	170.62	0.00	89.79
Total	5363.03			245.58	3580.96

VII DISCUSSION

Consistent with simulated results large amount of excess energy is wasted through the dump load in the several months and excess energy is very much higher than the required demand. Therefore, battery capacity can be increased to store some amount of this energy to minimize the unmet load. However, to eliminate the unmet load, capacity of 16200Ah/24V (388.8kWh) battery bank is required. As batteries are so expensive, usage of large battery bank is not economically viable. Therefore, introduction of a hybrid energy system will be a good option. Solar PV, small dendro power system and small diesel generator set are the possible options for hybrid sources in this village. To evaluate the suitable combination of the hybrid system, multi-criteria analysis should be done by considering the socio-economic and environmental effects.

To utilize wasted energy by the dump load in the windy season, useful electricity consumable applications can be initiated. Though villages need to pump water for their agricultural purposes, this energy is not sufficient to drive water pumps for irrigation. Gurugoda village is located in an off grid rural area. Large amount of un-electrified houses are available around this wind system. Presently, portable rechargeable batteries are used in some of these houses to fulfil their basic electric requirement. There is good possibility to charge their batteries by using the excess electricity of the system in the windy seasons.

ACKNOWLEDGMENT

The Gurugoda small wind project was implemented as a collaboration work of National Engineering Research and Development Centre of Sri Lanka, University of Peradeniya, Practical action and “SANGRAMA” Nikaweratiya. The author wishes to acknowledge the partnership of Prof. Janaka Ekanayake at University of Peradeniya, Mr. Namiz Musafer at Practical action, and employees in the “SANGRAMA” Nikaweratiya.

REFERENCES

[1] Elliott D, Schwartz M, Scott G, Haymes S, Heimiller D, George R, “Wind Energy Resource Atlas of Sri Lanka and the Maldives”, National Renewable Energy Laboratory, USA

[2] Esperilla, J. Fe´lez, G. Romero, A. “A model for simulating a lead-acid battery using bond graphs”, Simulation Modelling Practice and Theory 15 (2007) 82–97

[3] Heimiller D M, Haymes S R, “Geographic Information System in Support of Wind Energy Activities At NREL”, 39th AIAA Aerospace Science Meeting. Reno, Nevada, USA, January 8-11, 2001.

[4] Shamshad, A. Bawadi, M.A. Wan Hussin, W.M.A. . Majid T.A and Sanusi, S.A.M. “First and second order Markov chain models for synthetic generation of wind speed time series”, Energy, Volume 30, Issue 5, April 2005, Pages 693-708

[5] Thele, M. Schiffer, J. Karden, E. Surewaard, E. Sauer, D.U. “Modeling of the charge acceptance of lead–acid batteries”, Journal of Power Sources xxx (2007) xxx–xxx (Article in press)

[6] T. Lambert, P. Gilman, and P. Lilienthal, “Micropower System Modeling with HOMER” Integration of Alternative Sources of Energy, by F. Farret and M. Simões. Copyright © 2006 by John Wiley & Sons, Inc

[7] Erik L Petersen, Niels G. Mortensen, Lars Landberg, Jorgen Horjstrup and Helmut P; Frank, “Wind Power Meteorology”, RisØ National Laboratory, Roskilde, Denmark, December 1997.