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Solar/Wind/Diesel Hybrid Energy System with Battery Storage for Rural Electrification

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Abstract: This paper presents solar/wind/diesel hybrid energy system with battery storage. More than 70% of rural population in Myanmar still has difficulty been accessing electricity? Therefore, solar and wind potential energy are considered as the main power sources for the system. Solar and wind energies are intermittent and fluctuate resources. To get continuous power supply, diesel generator and battery storage are considered in this study. The study area is situated at latitude 20◦ 53’ N, longitude 95◦ 53' E. The HOMER software is used to evaluate the optimum size and cost hybrid system for this study area. The result of this analysis shows that the most feasible system comprises 15kW PV, 10kW one wind turbine, 15kW generator, 16 batteries and 8kW converter with 63% renewable energy fraction. The cost of energy is $0.453/kWh.

Keywords: Hybrid Energy System, Solar, Wind, Diesel Generator.

I. INTRODUCTION

Remote rural areas, especially in developing countries, are in great need of affordable and reliable electricity to achieve development. Likewise, an overview through the most important literature on rural electrification proves that RESs are one of the most suitable and environmentally friendly solutions to provide electricity within rural areas. Autonomous decentralized (off-grid) rural electrification based on the generation of renewable power on the site through the installation of stand-alone power systems in rural households, and the set-up of electricity distribution mini-grids, fed by RES or mixed ones, have been proven for being capable of delivering high quality and reliable electricity for lighting, communication, water supply and motive power, among others. Off-grid renewable energy technologies satisfy energy demand directly and avoid the need for long distribution infrastructures. Hybrid systems can provide a steady community-level electricity service, such as village electrification, offering also the possibility to be upgraded through grid connection in the future. Hybrid systems with a backup Genset run with minimal fuel consumption because the Genset is brought on line only to in periods of high loads or low renewable power availability.

This line only to assist in periods of high loads or low renewable power availability. This in turn results in a large reduction in fuel consumption as compared to a Genset only powered system. Furthermore, due to their high levels of efficiency, reliability and long term performance, these systems can also be used as an effective backup solution to the public grid in case of blackouts or weak grids, and for professional energy solutions, such as telecommunication stations or emergency rooms at hospitals. The advantages of using renewable energy sources for generating power in remote islands are obvious such as the cost of the transported fuel are often prohibitive fossil fuel and that there is increasing concern on the issues of climate change global warming[1].

II. HYBRID ENERGY SYSTEM

Hybrid energy system is an excellent solution for electrification of remote rural areas where the grid extension is difficult and not economical. Such system incorporates a combination of one or several renewable energy sources such as solar photovoltaic, battery and wind energy. A hybrid system uses a combination of energy producing components that provide a constant flow of uninterrupted power. Hybrid, wind turbine and photovoltaic modules, offer greater reliability than any one of them alone because the energy supply does not depend entirely on any one source. For example, on a cloudy stormy day when PV generation is low there's likely enough wind energy available to make up for the loss in solar electricity. Wind and solar hybrids also permit use of smaller, less costly components than would otherwise be needed if the system depended on only one power source. This can substantially lower the cost of a remote power system. The use of renewable energy sources presents a tremendous potential for many applications and especially off-grid standalone systems. In this context, one of the most promising applications of renewable energy technology is the installation of hybrid energy systems (HES) in rural areas, where the grid extension is costly and the cost of fuel increases drastically with the remoteness of the location [2].

III. THE STUDY AREA

In this study (see fig 1), the proposed system is considered for Nyaung Myint village in Meikhtila township, Mandalay division situated in central part of Myanmar. According to the geographical location, the site is located at latitude 20˚ 53' N, longitude 95˚ 53' E and 225m altitude above sea level. It has 150 houses and its population is 850.

Fig1. The study area.

A. Solar Resources for Study Area

Solar resources is an important factor for know how many power can be generated by a photovoltaic system. Solar radiation data was obtained from the NASA SMSE satellite measurements. The NASA SMSE database was derived from the meteorology and solar energy parameter that have been recorded by 20 years over 200 satellites. Solar data from meteorology department is used in this study. Among the twelve parameters available data base, for this thesis, only

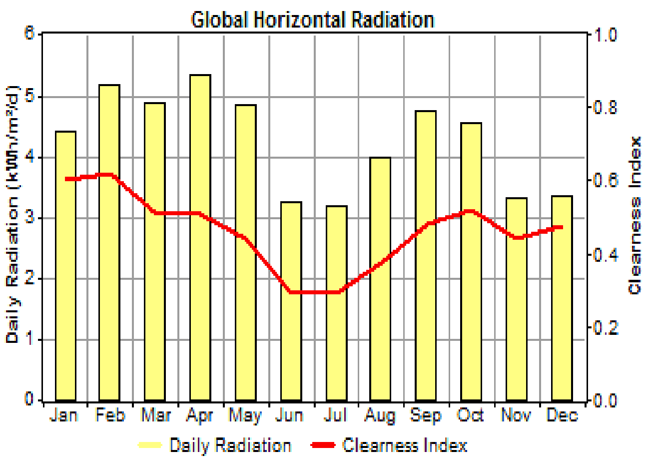

Fig2. Global Horizontal Solar Radiation and Clearness Index for Study Area.

solar insolation on horizontal surface and clear index were used. Detailed solar resources for the selected area are shown in Fig. 2.The annual average solar radiation for study area is 4.243 kWh/m2/day ranges from 3.196 kWh/m2/day to 5.328 kWh/m2/day. The annual average clearness index is 0.453 and varies from 0.292 to 0.618.

B. Wind Energy Potential for Study Area

Myanmar has potentially available wind energy of 360.1 TWh/year. Promising areas to harness wind energy are in three regions, namely Hilly Regions and Shan States, Coastal Regions in the South and Western part of the Country and central part of Myanmar [3]. The proposed system is situated in the central part of the Myanmar. Therefore, wind potential energy is also considered as the main power source for the system. Wind speed data obtained meteorology department is considered as shown in Fig.3.

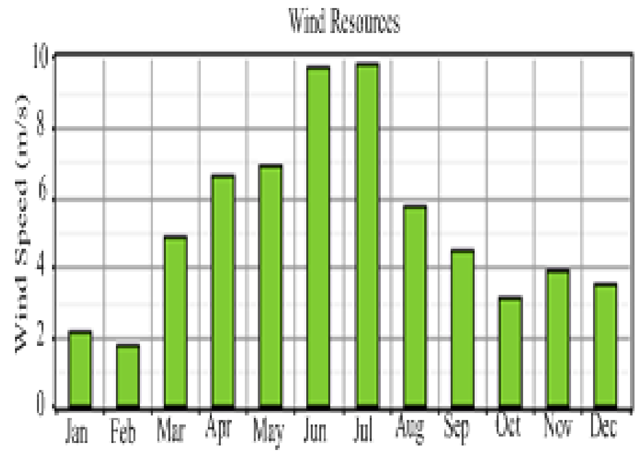

Fig3. Monthly average wind speed for study area.

A. Load Profile Data

The main electricity usage of the village is lighting and also use for other domestic facilities such as watching TV, fan, radio, CD/DVD player, refrigerator, mobile phone and water pump. The ratings of the appliances that are used for load profile calculation is as shown in Table 1 and the daily load profile is shown in Fig. 4.

TABLE I: APPLIANCES AND RATINGS USED FOR LOAD PROFILE

Appliance	Amount	Rating (W)	Power (kW)
4′ Fluorescent Light	247	40	9.88
2′ Fluorescent Light	185	20	3.7
21″ color TV	70	60	4.2
Fan	71	70	4.97
Mobile Phone	90	15	1.35
CD/DVD player	70	20	1.4
Refrigerator	20	60	1.2
Radio	80	8	0.64
Water pump	1	1	0.746

According the load data, peak load and average daily load demand are 22kW and 4.78kW, respectively with 5% of day-to-day randomness and time-step- to-time-step randomness in the study. The maximum load demand occurs between 19:00 and 21:00 0'clock because the main load of rural area is to supply the lighting. Load profile of the selected site by month is as shown in Fig.5.

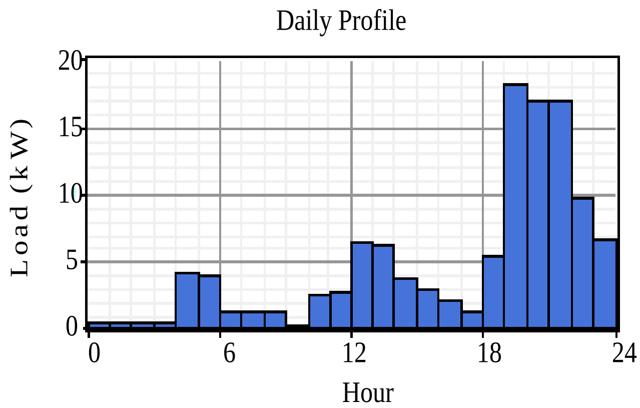

Fig4. Daily load profile.

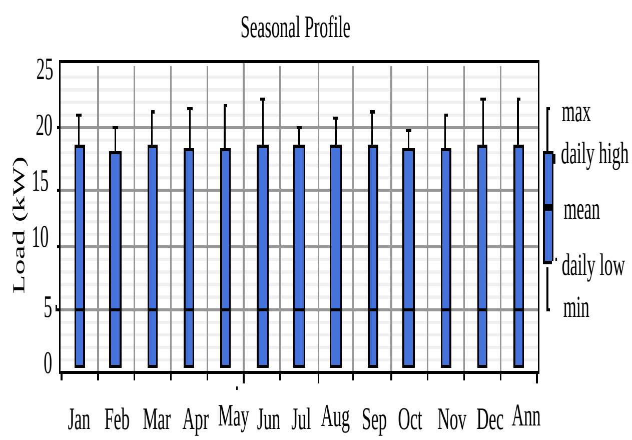

Fig5. Monthly load profile.

IV. THE COMPONENTS SIZING FOR STUDY AREA

The components of the proposed system are done by Hybrid Optimization Model for Electrical Renewable

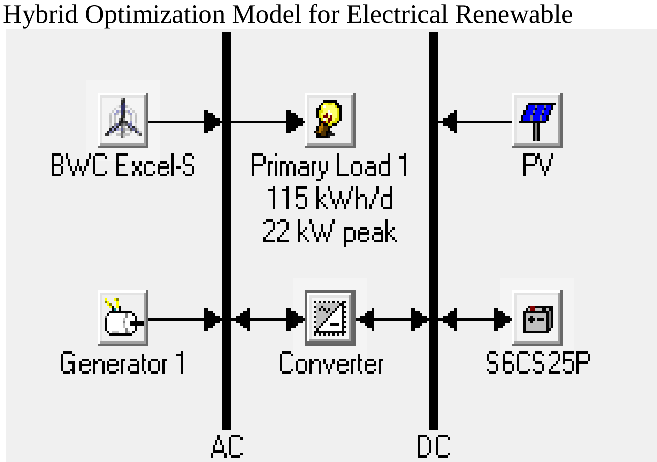

Fig6. PV-wind-diesel hybrid model used in the study.

(HOMER) software. The proposed system is comprised renewable energies (solar and wind) as primary sources and non- renewable energies (diesel and battery) as standby sources. Converter is also used as a device which provides the conversion of AC and DC link. HOMER determines the best optimal size and the cost of the components.

A. Photovoltaic Array

PV array is the device that produces DC electricity in direct proportion to the global solar radiation incident upon it, independent of its temperature and the voltage to which it is exposed. In this study, 300W PV module polycrystalline silicon solar cells which have 17.5V and 17.14A at STC are connected in series parallel. The capital cost and replacement cost for a 300W PV is taken as $218 and $218 respectively. As there is very little maintenance required for PV, only $10/year is taken for O&M costs. The lifetime of the PV arrays is taken as 10 years. The derating factor is considered 80% for each panel to approximate the varying effects of temperature and dust on the panels. The panels have no tracking system and are modeled as fixed tilted south at 20°53' N latitude of the location with the slope of 29°. This angle rating is considered to obtain the optimum performance of PV power for the whole year

B. Wind Turbine

In this hybrid system, one AC Wind turbine is used. Its model is BWC-Excel-S. Its rated capacity is 10kW and produced AC power. According to the Bergrey wind turbine source, the capital cost of this wind turbine is $28895 and replacement cost is estimated at 20000. It's operating and maintenance cost is $100 for one year and its life time is taken to be 15 year.

C. Batteries

Batteries are used as a backup in the system and to maintain a constant voltage during peak loads or a shortfall in generation capacity. HOMER models a number of individual batteries to create a battery bank connected in series-parallel and decide whether to charge or discharge the batteries for each hour. The battery chosen for this study is sureette 6CS25P. It is a 6V battery voltage with a nominal capacity of 1,156 Ah (6.94 kWh). It has a lifetime throughput of 9,645kWh. The capital cost, replacement cost and O&M costs for one unit of this battery is considered as $2293, $1000, and $10/year respectively. These costs are taken from the AEE-Solar-catalog.

D. Diesel Generator

The AC generator has a capacity of 15 kW. Its initial capital cost is $1000 and its replacement costs are $800. The operation and maintenance cost is $0.15 per hour. The lifetime of the generator is estimated at 15000 operating hours. Diesel is priced at $1.01 per liter. Homer decides for each hour how to operate the generators. These costs are collected from Changchai, cheap diesel generator product on Alibaba.

E. Converter

A converter is an electronic power device that is required in a hybrid system to maintain the energy flow between AC and DC electrical components. It has an inverter and a rectifier to do the conversions from DC to AC and inverter for AC to DC. The converter size that is used in this system is 8kW. The initial capital cost is considered as $700/kW and its replacement cost is $550. The operation and maintenance cost is estimated as $100 per one year.

V. RESULT AND DISCUSSION

HOMER simulates many different system configurations in the optimization process by discarding the infeasible ones, ranking the feasible ones according to total net present cost, and presents the feasible one with the lowest total net present cost as the optimal system configuration. Fig.7 shows the overall optimization results table showing system configuration sort by total net present cost. The first row in Fig.7 is the optimal system configuration, meaning the one with the lowest net present cost. In this case, the optimal configuration contains one wind turbine, the 15kW generator, 16 batteries and 8kW converter. The third rank is the same the first rank except that it contains 8-kW converter instead of 8-kW converter. The 19th ranked system contains no wind

PV (kW)	XLS	Label (kW)	S6CS25P	Conv. (kW)	Efficiency Measures	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Batt. Lf. (yr)
15	1	15	16	8	No	$ 82,083	12,610	$ 243,280	0.453	0.63	8,156	1,969	12.0
15	1	15	16	8	Yes	$ 82,083	12,610	$ 243,280	0.453	0.63	8,156	1,969	12.0
15	1	15	16	10	No	$ 83,483	12,595	$ 244,490	0.456	0.64	7,922	1,902	12.0
15	1	15	16	10	Yes	$ 83,483	12,595	$ 244,490	0.456	0.64	7,922	1,902	12.0
10	1	20	16	8	No	$ 78,450	13,137	$ 246,381	0.459	0.57	9,016	1,755	12.0
10	1	20	16	8	Yes	$ 78,450	13,137	$ 246,381	0.459	0.57	9,016	1,755	12.0
15	1	20	16	8	No	$ 82,083	12,859	$ 246,462	0.459	0.63	8,390	1,590	12.0
15	1	20	16	8	Yes	$ 82,083	12,859	$ 246,462	0.459	0.63	8,390	1,590	12.0
15	1	20	16	10	No	$ 83,483	12,778	$ 246,825	0.460	0.63	8,098	1,499	12.0
15	1	20	16	10	Yes	$ 83,483	12,778	$ 246,825	0.460	0.63	8,098	1,499	12.0
20	1	15	16	8	No	$ 85,716	12,617	$ 247,005	0.460	0.67	7,802	1,840	12.0
20	1	15	16	8	Yes	$ 85,716	12,617	$ 247,005	0.460	0.67	7,802	1,840	12.0
10	1	20	16	10	No	$ 79,850	13,113	$ 247,474	0.461	0.57	8,777	1,680	12.0
10	1	20	16	10	Yes	$ 79,850	13,113	$ 247,474	0.461	0.57	8,777	1,680	12.0
20	1	15	16	10	No	$ 87,116	12,598	$ 248,162	0.463	0.68	7,564	1,778	12.0
20	1	15	16	10	Yes	$ 87,116	12,598	$ 248,162	0.463	0.68	7,564	1,778	12.0
15	1	15	16	12	No	$ 84,883	12,785	$ 248,314	0.463	0.64	7,878	1,929	12.0
15	1	15	16	12	Yes	$ 84,883	12,785	$ 248,314	0.463	0.64	7,878	1,929	12.0
20		20	16	8	No	$ 56,821	15,020	$ 248,823	0.464	0.47	10,723	1,977	12.0
20		20	16	8	Yes	$ 56,821	15,020	$ 248,823	0.464	0.47	10,723	1,977	12.0
15	1	15	16	6	No	$ 80,683	13,206	$ 249,506	0.465	0.61	8,938	2,252	12.0
15	1	15	16	6	Yes	$ 80,683	13,206	$ 249,506	0.465	0.61	8,938	2,252	12.0
15	1	20	16	12	No	$ 84,883	12,899	$ 249,781	0.466	0.64	7,992	1,491	12.0
15	1	20	16	12	Yes	$ 84,883	12,899	$ 249,781	0.466	0.64	7,992	1,491	12.0
25		20	16	8	No	$ 60,455	14,874	$ 250,595	0.467	0.53	10,224	1,843	12.0
25		20	16	8	Yes	$ 60,455	14,874	$ 250,595	0.467	0.53	10,224	1,843	12.0

Fig.7 Overall optimization results table showing system configuration sort by total net present cost.

PV (kW)	XLS	Label (kW)	S6CS25P	Conv. (kW)	Efficiency Measures	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Batt. Lf. (yr)
15	1	15	16	8	No	$ 82,083	12,610	$ 243,280	0.453	0.63	8,156	1,969	12.0
20		20	16	8	No	$ 56,821	15,020	$ 248,823	0.464	0.47	10,723	1,977	12.0
25	1	25		8	No	$ 52,662	25,391	$ 377,245	0.703	0.54	20,761	4,783	
35		25		8	No	$ 31,033	28,985	$ 401,553	0.748	0.47	24,050	5,459	

Fig.8 Categorized optimization results.

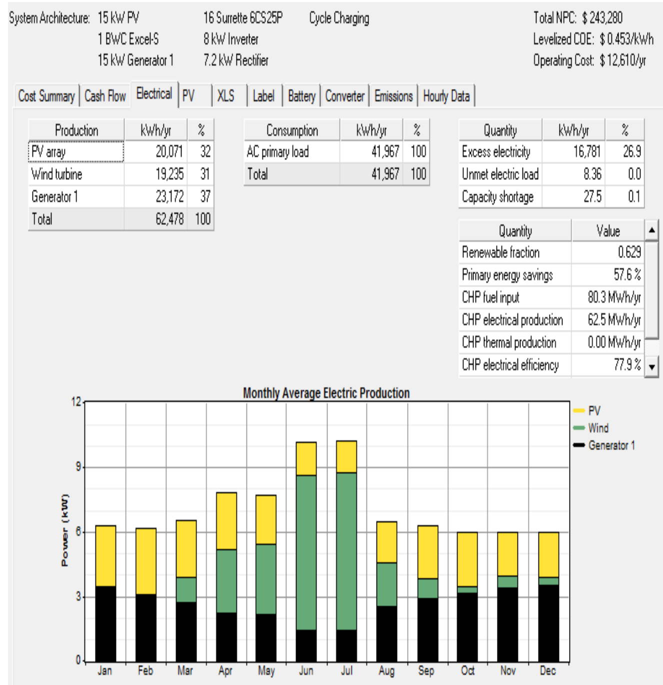

Fig.9 Energy production for the feasible PV-wind-generator-battery hybrid system.

turbines. In the overall list shown in Fig.7, the top ranked system is the least cost configuration within PV-wind –diesel –battery category. Similarly, the 19th ranked system is the least cost configuration within PV-diesel-battery category.

In optimization results of categorized shown in Fig.8, the optimization results provide the four feasible hybrid systems. According to that figure, the most feasible hybrid system for the lowest cost of energy is the first row (PV-diesel–battery hybrid system). The initial capital cost of this system is higher than the other three systems. However, the total net present cost is the least one between the four feasible systems. The renewable energy fraction is also the highest among them. Therefore, the system which comprises 15kW PV, 10kW one wind turbine, 15kW generator, 16 batteries and 8kW converter is the most feasible system for study area. This system reduce the fuel consumption which impact on the global warming. Fig. 8 shows the energy production for the feasible PV-wind-generator-battery hybrid system. It depicts the details related energy production by wind turbine, PV array and generator, excess electricity, unmet electric load and capacity shortage for the most economically feasible for study area. According to Fig.9, It can be seen that unmet load is 0% and excess electricity generated is 26.9%.

VI. CONCLUSION

A hybrid power generation which comprises of PV arrays, wind turbine, diesel generator with battery bank and power condition units has been discussed in this study to achieve a cost effective system configuration which is supposed to supply electricity to a village of 150 households to uplift the life standard of people in rural areas where electricity from national grid has not reached yet. The HOMER simulation program developed by the NREL has been used as optimization and simulation tool. The result was analyzed and the PV/wind/diesel hybrid system with battery storage was selected among the many feasible systems based on some important parameters such as high renewable penetration, less annual diesel consumption, and small levelized cost of energy. The COE of the selected feasible system is high as compared to the current electricity tariff of the country. However, considering the absence of electricity usage in rural areas, this cost should be taken as a decisive factor. Moreover, the high renewable energy penetration and less diesel fuel consumption effects on the development of clean energy, reduce the pollutant emission into the environment and improve the life standard of people in rural. Considering these issues, the solar and wind energy potential should be utilized to supply the electricity for the inhabitants living in rural areas.

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