Viability Analysis of Photovoltaic/Wind Hybrid Distributed Generation in an Isolated Community of Northeastern India

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ABSTRACT

This article examines the viability of standalone PV/Wind Hybrid system for remote household in north eastern region (NER) of India. Sizing, optimization, and the economical analysis of the Hybrid system is done through HOMER software. Sensitivity analysis is carried out with solar radiation data, wind speed data, cost of PV and Wind system for a 1kW PV/Wind Hybrid system. Annual peak, scaled annual average, and the average load of 697 W, 3.85 kWh/day, and 0.175 kW respectively are assumed for a remote household for analysis purpose. This article presents the optimal sizing, cost of electricity (COE), battery profile, and converter profile of PV/Wind hybrid system for different NER states. The outcome of this study shows that COE for the NER states lies in the range of 0.279-0.518 $/kWh, making hybrid PV/Wind system the most successful option for mitigation of power demand in the rural areas of the region concerned.

Keywords: Hybrid Distributed Generation, Renewable Energy, Optimization, Homer, Economic Assessment

INTRODUCTION

The utilization of renewable energy resources has shown promising results in recent years due to the large power demand throughout the globe due to exhausting fossil fuel, ever rising fuel price, economic development and increasing global warming [1]. With an expected average growth rate of 2.8% globally, the anticipated electricity demand will get doubled by 2020. Owing to economic advances in Developing countries, like India, a rapid increase in energy demand has been seen over recent years. But in many regions, the extension of present power grids could not keep pace with the rise in the power demand. In many regions, diesel generators (DGs) are installed in order to increase the reliability of power supply. But, DGs require a high maintenance work and consume relatively huge amounts of diesel for low-level power outputs [2]. Thus, renewable energy sources (RESs), such as photovoltaic (PV) and wind, are particularly attractive for remote communities as they offer a clean power in remote locations which cannot be served by means of grid extension economically. The economic viability of such hybrid system is always location specific [3]. In case of developing countries like India, people residing in the remote community, farms and rural destinations do not always benefit from the grid connected electricity for power supply due to difficult terrain, remoteness and high connection cost of connected transmission and distribution systems. The electricity consumption per capita in India is just 566 kW, which is far below when compared to the rest of the world. Although 85% of the rural locations in the country are believed to have been electrified, 57% of the rural households and 12% of the urban households, i.e. 84 million households in the country are still devoid of electricity [4]. But, an individual renewable energy source alone cannot provide continuous supply of energy due to seasonal and periodic intermittency; the attempt of doing so may result in an expensive system [5].The combinations of the different power generating sources for supplying a particular load is determined on the basis of the economic and technical feasibility of the hybrid project [6]. Thus, a sustainable combination and implementation of PV-Wind energy hybrid systems can act as a viable solution in overcoming this shortage of electricity in remote location and rural houses in India. The hybrid system is a feasible option for sustainable energy production because it allows the utility to utilize the strength of both these renewable energy sources [7]. Combining Wind and Solar PV in a hybrid renewable energy system, reduces fluctuation of energy production, therefore greatly reducing energy requirements of the connected area [8].

In recent times the Government of India has taken special initiatives to disseminate renewable energy systems in North Eastern states of India [9], because the supply of grid electricity in many parts of the region is either extremely challenging or technically unviable. The potential of wind generation in India is around 48,500 MW, with a capacity addition of 12,800 MW, which contributes to roughly 75% of the grid-connected renewable power installed capacity. In this country the major wind power capacity is in the province of Tamil Nadu, Gujarat, Maharashtra, Karnataka and Rajasthan. India enjoys sufficient solar radiation with an average of 4-7 kWh/day annually and about 300 clear sunny days, as it is lying near the equatorial Sunbelt regions. In this regard the Prime Minister of India in January 2010 launched the Jawaharlal Nehru National Solar Mission (JNNSM) which targets 20,000 MW power generation from grid connected solar power by 2022 [9,10].

The combinations of solar and wind energy technologies, also known as PV-Wind hybrid power system is progressively growing amongst the different types of Renewable Energy sources. Moreover, these sources are eco-friendly, sustainable and require less maintenance. These energy sources either acting alone or in combination with others have been seen to improve load factors and help saving on maintenance and replacement costs as they complement each other [11]. That is why hybrid power systems having more than one source are given preference as they provide a better, stable, reliable and continuous supply of power [12]. On the other hand, long life, reliability of operation and cost-effectiveness of such systems are a must to overcome the high initial capital cost [13]. The high preference for adoption of PV/Wind hybrid system is due to the fact that standalone solar photovoltaic system is intermittent, depending upon insolation and weather condition due to which it is unable to provide dependable power, while the standalone wind system is incapable to meet the constant load demand under fluctuating wind speed profile. Small scale PV-Wind hybrid power system while generating low power can monumentally improve the quality of life in remote areas [14]. The impact of 1kWh of electricity use in India is ten times more than in Indiana, likewise the use of two small wind generators for water heating in two homes in the United States is corresponding to the use of the same energy for water pumping in Morocco for 4000 people[15].

This article investigates and explores the techno-economic analysis, optimal sizing and possible potential use of stand-alone 1kW PV/Wind hybrid power systems as a viable alternative for rural electrification in the eight North Eastern states (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura) India. The study is first of its kind for the region and attempt has been made to address a prominent predicament of acute shortage in electricity availability in the far flung areas housing small populations, which account for a significant portion of the population in the region. Hybrid Optimization Model for Electric Renewable (HOMER), an optimization tool developed by the United

States National Renewable Energy Laboratory (NREL) has been used for analysis. HOMER simulation tool which has been applied in this article currently attracts a great deal of popularity and preference in the subject of techno-economic analysis for new energy power generation system due to its relative simplicity and powerful computational proficiency [16-24].

A hybrid electric power system based on a combination of wind/solar energies has been observed to be more reliable rather than a single energy source system acting in a standalone mode due to the complementary nature of solar and wind source (high insolation at low wind speed and low levels of insolation in windy situations due to seasonal variation in available resource profile) [25-27]. Moharil and Kulkarni et al. [28] suggest that a hybrid energy source (either one or more renewable source) when combined with a storage element, i.e. battery bank is seen to have overcome the limitation of intermittence and the randomness of availability of the solar and wind energy generation capability. Shrestha, G.B. et al.[29], Anindita, R et al.[30], Al-Badi, A.H. 2011a [31] through their works haves shown that an established technology in use that supplies electricity to distant spots that are far from the grid is a hybrid combination of wind and/or solar (with or without battery banks). Kaldellis (2004) [32] too investigate the impact of the important factors of the proposed isolated system and carried out an integrated parametric analysis focusing on the contributing parameters of wind energy source such as wind power quality, the power curve type of wind turbine used, the remote consumer's size and the minimum size of the acceptable system. El-Shafy and Nafeh (2011) [33] made use of genetic algorithm optimization technique while building up a new formulation for optimizing the design of a PV-Wind hybrid energy home system with storage battery. Kaiser and Aditya [34] experimentally showed using a HOMER simulation tool that the best technically viable renewable energy system for consumers in Saint Martin Island, Bangladesh is achieved by creating PV-Wind microgrid combination system for fifty homes is more rewarding than a single home system. Taking outages due to primary energy fluctuations and hardware failure into consideration, Karaki, Chedid and Ramadan (1999)[33] developed a general probabilistic model of an autonomous solar-wind energy conversion system, which were composed of several wind turbines, PV modules and storage battery feeding the load. Considering minimizing the kilowatt-hour (kWh) cost, optimal configuration of hybrid systems was determined by Muselli, et al. (2000) [36]. DIAF S., et al. (2008) [37] considered a techno-economic optimization study for Hybrid PV-Wind systems operating in standalone mode, indicating that the hybrid configuration worked with higher levels of performance than the individual sources acting on their own. To find the optimal sizing and minimizing the cost of hybrid power systems with specific demands, Homer software was used by Kamel and Dahl (2005) [38] and Khan and Iqbal (2005) [39]. Elhadidy, M.A. et al. (1999)[40], investigated the feasibility of use of Hybrid energy systems in Saudi Arabia which fall in the arid regions. Kellogg et al. (1996) [41] studied the possibility of an optimal combination of wind and PV system with battery storage for a hypothetical site in Montana. Considering the weather profile of Malaysia, HOMER software tool was used for feasibility analysis, techno-economic viability and optimal configuration assessment of Hybrid power systems [42-44].

DESCRIPTION OF INTEGRATED RENEWABLE ENERGY SOURCES

Any favorable site for setting up the PV/Wind hybrid system has to be characterized by good average renewable sources potential. Therefore, in this present work, monthly average solar and wind resource has been estimated by the use of NASA surface meteorology and solar energy (SSE) [45], based on satellite observation. The latitude, longitude and elevation of the area of investigation are shown in Table 1. The elevation of the respective states is obtained from the NASA GEOS-4 model elevation. The time zone for India is GMT +5:30 hours. The map of states in India under investigation is shown in Figure 1.

Table 1. Geographic location of the eight North Eastern states

States	Latitude	Longitude	Elevation (m)
Arunachal Pradesh	27.12	93.67	2317
Assam	26.13	91.80	950
Manipur	24.82	93.99	675
Meghalaya	25.56	91.89	194
Mizoram	23.69	92.77	554
Nagaland	25.58	94.17	769
Sikkim	27.34	88.61	2817
Tripura	23.84	91.39	378

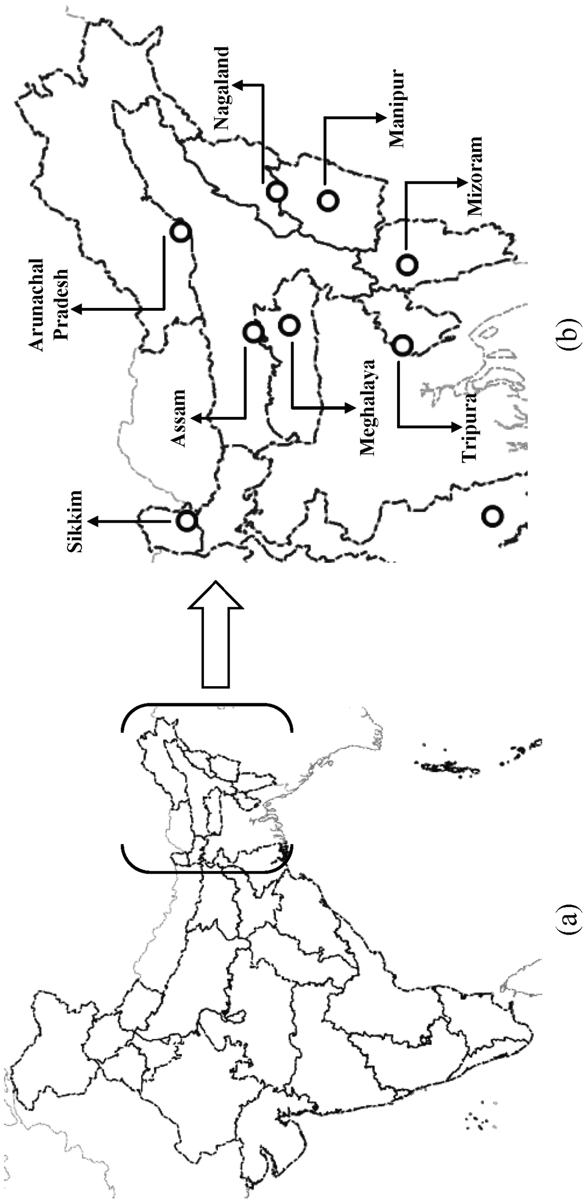

Figure 1. (a) Map of India and (b) location of NE region with states boundaries

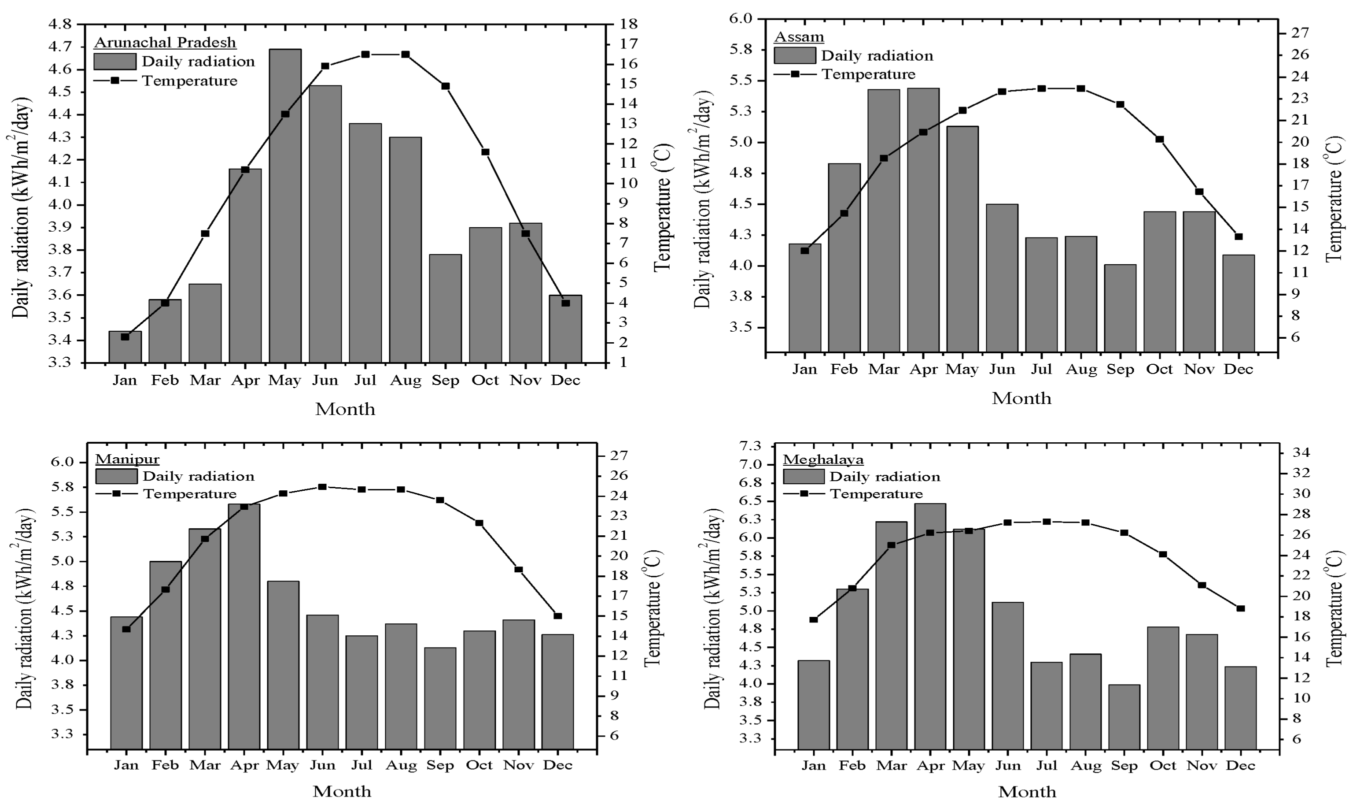

Figure 2. Solar radiation and temperature profile of different NE states

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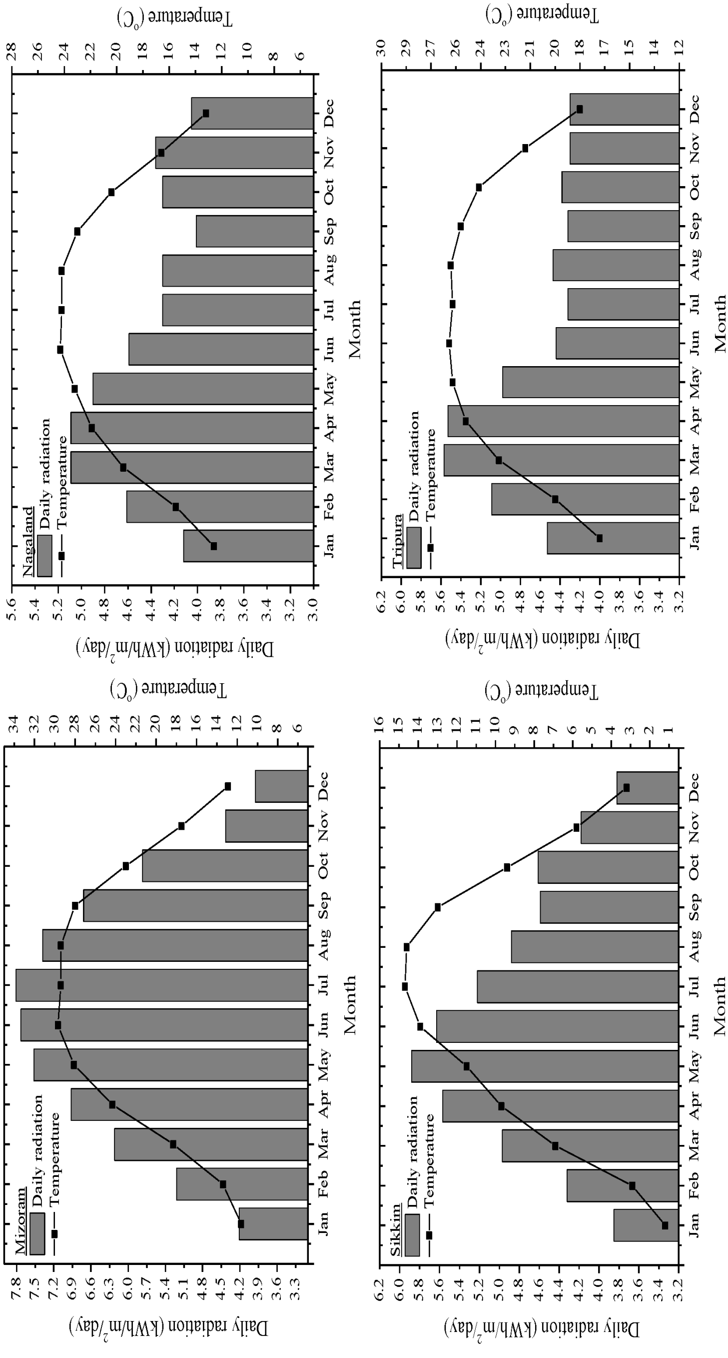

Figure 2. Solar radiation and temperature profile of different NE states

Profile of Solar Radiation

The monthly mean solar radiation and temperature for the eight NE states are shown in Figure 2. The values taken have been averaged monthly for a period of 22 years (July 1983 to June 2005). For the state of Arunachal Pradesh it is seen that the highest and lowest monthly average solar radiation is 4.69 kWh/m^2/day in the month of May and 3.44 kWh/m^2/day for the month of January, while the annual average value is seen to be 3.89 kWh/m^2/day. Assam notes the similar situation of highest and lowest monthly average solar radiation to be 5.74 kWh/m^2/day in the month of April and 4.11 kWh/m^2/day in the month of September with the average annual value of 4.87 kWh/m^2/day. In the case of Manipur, highest and lowest values are seen to be 5.78 kWh/m^2/day (April) and 4.13 kWh/m^2/day (September) having the annual average value equal to 4.70 kWh/m^2/day. Meghalaya is subjected to having the profile of highest and lowest values of solar radiation to be 6.47 kWh/m^2/day (April) and 3.99 kWh/m^2/day (September), the annual average value being 4.99 kWh/m^2/day. In the state of Mizoram it is seen that 7.81 kWh/m^2/day in July and 3.98 kWh/m^2/day in December are the highest and lowest values of solar radiation with an annual mean value of 6.17 kWh/m^2/day. In Nagaland 5.09 kWh/m^2/day (March-April) and 4.03 kWh/m^2/day (December) reflect the highest and lowest values of radiation while the average value is 4.97 kWh/m^2/day. In Sikkim similar variation is seen in the months of May and December for the highest and lowest values of radiation being 5.78 kWh/m^2/day and 3.87 kWh/m^2/day respectively with the annual average value seen to be 4.79 kWh/m^2/day. The highest and lowest values of radiation are seen to be 5.57 kWh/m^2/day (March) and 4.37 kWh/m^2/day (November and December) for Tripura where the average value of solar radiation is 4.88 kWh/m^2/day.

Wind Speed Parameter

The region registers a wide seasonal variation in the distribution of wind speed profile. The monthly average variations in the wind speed in the different North Eastern States (for a 10 year average value between 1991-2001) are shown in Figure 3.

It is seen that Arunachal Pradesh has a highest and minimum wind speed to be 4.78 m/s and 3.17 m/s in the month of March and August respectively where the annual average is 3.88 m/s. In Assam the same phenomenon of highest and minimum wind speed are noted

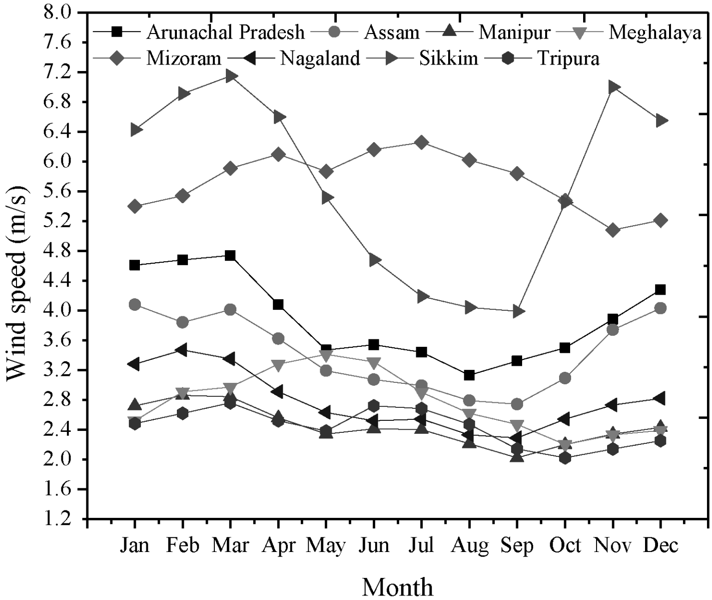

Figure 3. Monthly averaged wind speed profile for NE states

to be 4.78 m/s (January) and 2.74 m/s (September) with an annual average of 3.48 m/s In Manipur wind speeds of 2.84 m/s (March) and 2.04 m/s (September) are the highest and lowest values respectively while the annual average value is seen to be 2.44 m/s. Meghalaya experiences the highest wind speed of 3.41 m/s (May) and the lowest wind speed of 2.20 m/s (September) with an average of 2.78 m/s annually. Mizoram has a highest wind speed of 6.26 m/s (July) and lowest wind speed of 5.08 m/s (November), the annual average value being 5.74 m/s. In the state of Nagaland the highest and minimum values speed values are 3.47 m/s (February) and 2.29 m/s (September), having an annual average value of 2.78 m/s. Sikkim, has the best wind speed profile amongst all other states experiencing the highest wind speed of 7.12 m/s (March) and a lowest of 3.98 m/s (September) with the annual average value being 5.75 m/s. While in the state of Tripura, it is seen that the highest wind speed of 2.72 m/s and lowest speed of 2.02 m/s occurs in the month of March/June and October respectively, with the annual average value being 2.43 m/s.

HYBRID SYSTEM LAYOUT

A PV/Wind hybrid system comprises of sets of PV panels, wind turbine, a suitable interconnection of batteries in series or parallel to form the battery bank, DC-AC converter and the electrical load. Figure 4 shows the arrangement of such a system. The variation in the wind velocity results in large changes in the frequency and the output power of the generator. That is why it is viable to convert the AC output to the DC and consequently convert it back to AC by the use of an inverter interface. The PV output and the rectified output of the wind generator are connected in parallel to form the DC bus. The converter is connected to the electrical load through AC bus. However to avoid the inconsistency of the PV and Wind power generation, a minimum number of batteries in the battery bank are required to meet the load demand. The battery operates in the charging or discharging mode depending on the availability of the power output of the solar and/or wind source's ability to meet the load demand.

Details of Load profile under Consideration

A typical load profile reflecting the energy consumption in a single household in a rural area has been considered herein. For simplicity of assessment, the load profile is assumed to be same for all the eight North Eastern states. The energy used in a single household by the people

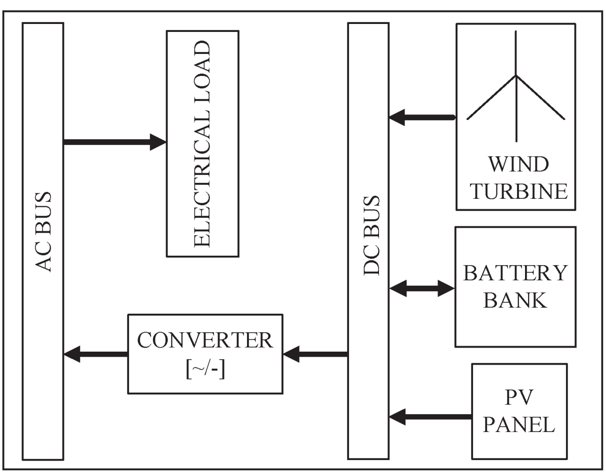

Figure 4. PV/Wind Hybrid system layout

residing is generally limited by the number of appliances that are used. The electrical load has a seasonal variation due to changes in energy consumption amount during winter season comprising of December, January and February and the rest of the year (considered as summer period), and in is shown in Table 2 (for summer and winter month).

Table 2. Load profile under study

Summer load profile			
Electrical Load	Watts(W)	Quantity	Total Watts
CFL	18	3 × 18	54
Incandescent lamp	40	2× 40	80
Fan	75	2 × 75	150
Television	120	1 × 120	120
Total			404
Winter load file			
Electrical Load	Watts(W)	Quantity	Total Watts
CFL	18	3 × 18	54
Incandescent lamp	40	2 × 40	80
Television	120	1 × 120	120
Total			254

The daily hourly energy consumption of appliances for winter and summer months are shown in Figure 5 while the seasonal load profile variation on a monthly basis is shown in Figure 6.The annual peak, scaled annual average, and the average load is 694 W, 3.95 kWh/day, 0.165 kW respectively.

Parameter Considered in Simulation

In this study we have considered the life time of the PV array system is 20 years with a de-rating factor of 90% and ground reflectance to be 20%. The PV plant with a tracking system is not considered, however the effect of temperature in solar and wind power generation is taken into consideration (Figure 2). The SW Whisper 200 wind turbine manufactured by Southwest Wind power having a rotor diameter of 2.7 m, and

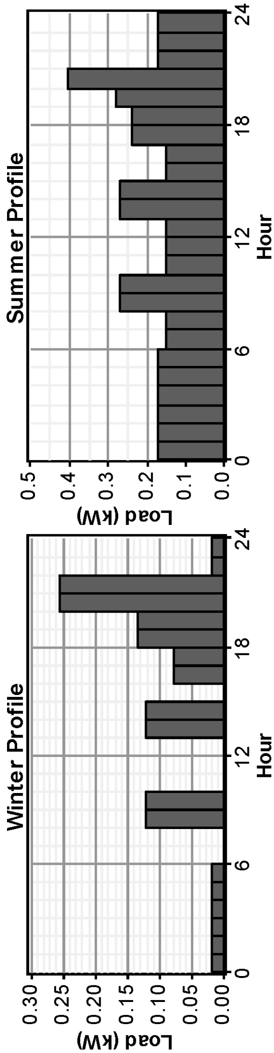

Figure 5. Daily hourly load profile for winter and summer season

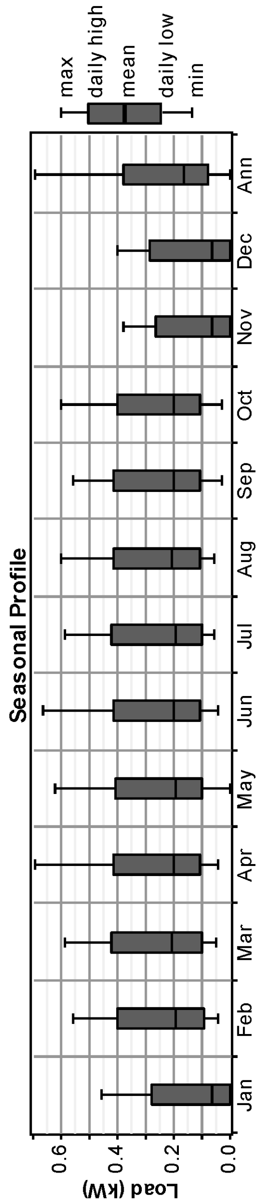

Figure 6. Monthly average load profile considered in the study

rated output power of 1kW is considered. The tower height of this wind turbine may be of 7.3m, 9.1m, 15.2m, 19.8m, or 24.4m. The power curve of wind turbine is shown in Figure 7. As the typical turbine price range lies between $900-$1270/kW (depending on the technology), the cost of wind turbine in this study is considered to be $1270 with a replacement cost of $1270. The type of battery used in this simulation is Vision6 FM 200D manufactured by Vision Battery. The nominal voltage, nominal capacity, and lifetime throughput is 12 V, 200 Ah (2.4 kWh), 917 kWh respectively. The battery per string considered is 4 volts per string with DC bus voltage of 48 V. The cost of single battery assumed to be $175 with a replacement cost of $170. The round trip efficiency, minimum state of charge, float life, highest charge rate, highest charge current of this type of battery is 80%, 40%, 10 years, 1 A/Ah, 60A respectively. The capacity curve of battery is shown in Figure 8.

The size of the converter (in this case inverter) is considered to be 0, 0.5, 1 kW with an efficiency of 90%. The expected lifetime for the inverter in years considered as 15 years. The cost of the converter is considered to be $200/kW. For a 1kW PV module, the cost is assumed to be US$3000, having a replacement cost of $ 3000.

ANALYSIS OF SYSTEM ECONOMICS

HOMER simulation requires the economic input parameters which include annual real interest rate and project lifetime. After the completion of the simulation process, HOMER performs ranking of all systems based on the total net present cost. In addition to that, the Levelized cost of energy might also be taken into consideration to obtain the optimal results of different configurations of the system, because it serves as another vital parameter for comparison. The following section discusses these economic parameters.

Annual Real Interest Rate

The annual real interest rate is the discount rate which is used to convert between one-time costs and annualized costs. It is represented mathematically by Eq. (1)

$$i = \frac{i' - r}{1 + r} \qquad (1)$$

States	Wind penetration (%)	Mean output (kW)	Capacity factor (%)	Highest output (kW)	Total production (kWh/yr)	Hour of operation (hr/yr)
Arunachal Pradesh	104	0.17	17.2	1.00	1,506	6,095
Assam	73.5	0.12	12.1	1.00	1,060	5,476
Manipur	22.9	0.04	3.77	0.91	331	3,441
Meghalaya	36.3	0.06	5.97	0.99	523	4,231
Mizoram	23.9	0.39	39.3	1.00	3439	7,400
Nagaland	36.5	0.06	6.00	1.00	526	4,259
Sikkim	232	0.38	38.2	1.00	3,348	7,458
Tripura	22.5	0.04	3.70	0.93	324	3,414

Figure 7. The power curve of wind turbine under consideration (SW Whisper 200)

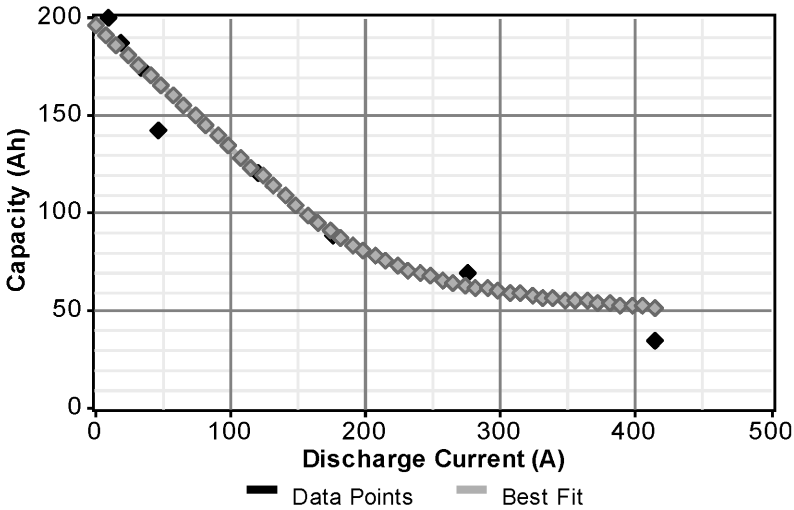

Figure 8. Capacity curve of battery under consideration (Vision6 FM 200D)

Where, i is the real interest rate, i′ is the nominal interest rate and *r* is the annual inflation rate. Therefore, the annual real interest rate of 6.5% was used in this simulation [33].

Net Present Cost (NPC)

The net present cost, which indicates the present value of installing and operating the system over its lifetime of the project, also referred to as life cycle cost. HOMER gives optimization results of simulation, ranked and based on the total NPC which is calculated according to Eqs. (2) and (3).

$$C_{NPC} = \frac{C_{an,t}}{CRF(i,N)} \tag{2}$$

$$CRF(i,N)\quad \frac{i(1+i)^{N}}{(1+i)^{N}-1} \tag{3}$$

Where, $C_{an,t}$ is the total annualized cost ($/year) which includes the capital, replacement, annual operating and maintenance, and fuel costs. CRF is the capital recovery factor, used to calculate the present value of a series of equal annual cash flows, i is the real interest rate (%) and N is the project lifetime (in number of years).

Levelized Cost of Energy (COE)

The levelized cost of energy is the average cost per kilowatt hour ($/kWh) of useful electrical energy produced by the system. It is calculated as follows:

$$COE = \frac{C_{an,t}}{E_{pr,AC} + E_{pr,DC}} \quad (4)$$

where
$C_{an,t}$ is the total annualized cost ($/year)
$E_{pr,AC}$ is the AC primary load served (kWh/year) and
$E_{pr,DC}$ is the DC primary load served (kWh/year).

Development of the Optimization Model

The aim of the proposed optimization model is to optimize the availability of energy to the loads in a sustainable manner according to the distributed generation capacity. We have also projected to maintain a good level of battery energy storage to meet peak load demand (together with the wind, and PV array), during decreasing wind speed and low or no solar radiation periods. The loads are categorized as primary and deferrable loads.

In order to maximize the availability of the distributed generation (DG) to the load at optimum cost and sizing of DG systems, the objective function must aim at minimizing the difference between the total connected load and the energy available for supplying the load as per the following equations.

Minimize

$$\sum_{n=1}^{24} \left\{ \sum_{k} G_k \cdot T_m(n) - P_{Solar,k}(n) - P_{wind,k}(n) - P_{Batt,k}(n) \right\} \quad (5)$$

With $T_m(n) \geq 0$

Where
n is the hour of the day n = 1, 2, 3, 4, ……, 24
k is the type of the load primary or deferrable
$P_{Solar,k}(n)$ is the photovoltaic energy supplied to the k^{th} load in n^{th} hour of the day

$P_{wind,k}(n)$ is the wind energy supplied to the k^{th} load in the n^{th} hour of the day

$P_{Batt,k}(n)$ is the energy supplied by the battery to the k^{th} load in the n^{th} hour of the day.

Constraints for Photovoltaic array

The total energy produced by the photovoltaic array is the summation of energy supplied by PV array to the batter and Energy supplied by the PV array to the load.

$$\Sigma_k P_{Solar,k}(n) + P_{Solar,Batt.}(n) = P_{Solar,Total}(n) \tag{6}$$

Where

$P_{Solar,k}(n)$ is the photovoltaic energy supplied to the k^{th} load in n^{th} hour of the day

$P_{Solar,Batt.}(n)$ is the energy supplied to the battery by photovoltaic array in n^{th} hour of the day

$P_{Solar,Total}(n)$ is the total energy produced by the photo voltaic array.

Since energy generated by the photovoltaic system varies with insolation. Thus the energy produced by photovoltaic array at any hour of the day is given as

$$P_{Solar,Total}(n) = i_{solar} \times PV_{area} \times \eta_{PV} \tag{7}$$

Where

i_{solar} is the solar insolation received for that particular hour.

PV_{area} is the total area of the photovoltaic array known to us by the manufacturer.

η_{PV} is the efficiency of the photovoltaic panel specified by the manufacturer.

Constraints for Wind Energy System

The total energy produced by the wind energy system is the summation of energy supplied by PV array to the batter and energy supplied by the PV array to the load.

$$\Sigma_k P_{Wind,k}(n) + P_{Wind,Batt.}(n) = P_{Wind,Total}(n) \tag{8}$$

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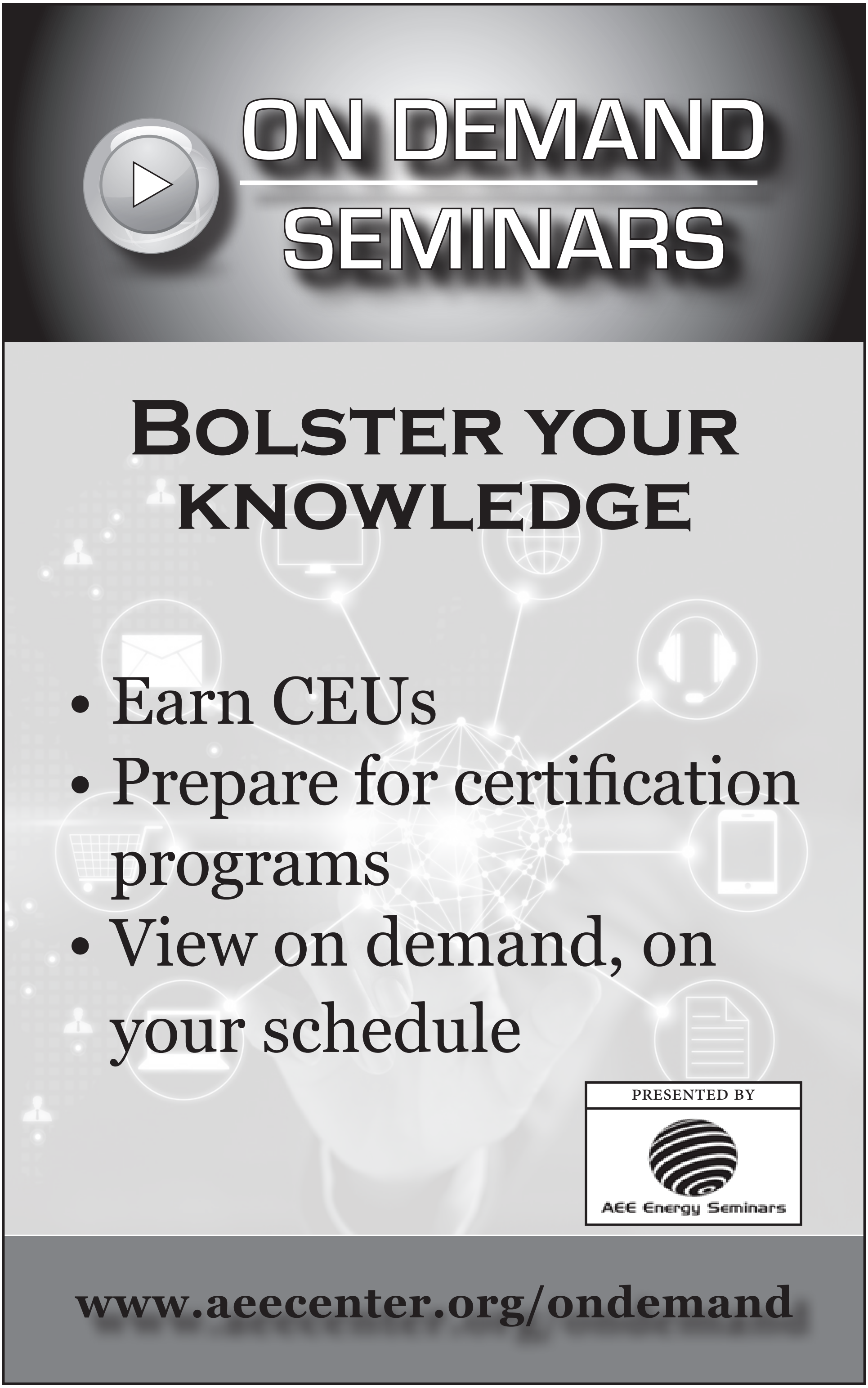
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The total power generated by wind turbine is expressed as

$$P_{Wind,Total}(n) = 0.5\rho AV^3C_p(\tau_i,\theta) \quad (9)$$

where P_w is the power generated by the wind turbine W, ρ is the density of air in atmosphere (kg/m³)v specified for a given area, A is cross-sectional area of a wind turbine blade (m²) specified by the manufacturer, V is wind velocity (m/sec), and C_p is the wind turbine energy conversion coefficient specified by the manufacturer.

Constraints for Battery Bank

The battery acts as backup power source in the discharging mode and it acts like a load when operating in a charging mode. The net energy input at the battery terminals decides its state of charge (SOC) which is expressed as follows:

$$P_{Batt}SOC(n) = P_{Batt}SC(n-1) + [P_{Solar}(n) + P_{wind}(n)] - \Sigma_k P_{Batt,k}(n) \quad (10)$$

Where P_{Batt} is the battery bank capacity.

The SOC of the battery has to be kept between a specific range to protect it from overcharging or discharging and in line with the literature this range is kept between 20% (SOC min.) and 80% (SOC max.)

$$SOC_{min} \leq SOC(n) \leq SOC_{max}$$

ANALYSIS OF RESULTS OF OPTIMIZATION

The simulation was carried out assuming that the hybrid system comprises of 0, 0.5, and 1kW PV panel, 0 and 1kW Wind turbine, a variable number (0-16) of strings in the battery bank and a 0.5 and 1kW converter (in our case an inverter). The project lifetime considered in the study was for a period of 25 years.

Cost Analysis

As shown in the Table 3, the COE obtained for the state of Arunachal Pradesh (0.517 $/kWh) and Manipur (0.579 $/kWh) are on the higher side while Assam, Meghalaya, Nagaland and Tripura have

0.478, 0.485, 0.487 and 0.497 $/kWh as their COE respectively. The states of Mizoram and Sikkim are seen to have the lowest COE values of 0.279 and 0.287 $/kWh respectively. The highest PV Levelized cost obtained is 0.214 $/kWh for the state of Arunachal Pradesh. Assam, Manipur, and Nagaland lies in the range of 0.190 $/kWh. Mizoram has a lowest PV Levelized cost of 0.152 $/kWh as compared to the other states. Meghalaya and Sikkim are observed to have 0.180 and 0.177 $/kWh as their respective PV Levelized cost. The wind Levelized cost is higher in Tripura having 0.424 $/kWh. While, Mizoram and Sikkim have the lowest values of the Wind Levelized cost having values of 0.040 and 0.041 $/kWh respectively. Arunachal Pradesh is seen to have this value as 0.0913 $/kWh. Assam, Manipur, Meghalaya and Nagaland are seen to have Wind Levelized Cost of 0.130, 0.416, 0.263 and 0.261 $/kWh respectively. Mizoram is seen to have the lowest operating cost of 96 $/yr. The states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Nagaland, Sikkim and Tripura are seen to have the operating cost as 190, 154, 150, 167, 152, 100, 157 $/yr respectively.

Table 3. Cost Analysis

States	Initial cost ($)	Operating cost ($/yr)	Total NPC ($)	PV Levelized cost ($/kWh)	Wind Levelized cost ($/kWh)	COE ($/kWh)
Arunachal Pradesh	6,470	190	8,791	0.214	0.0913	0.517
Assam	5,070	154	6,953	0.191	0.130	0.478
Manipur	5,070	150	6,904	0.191	0.416	0.579
Meghalaya	5,070	167	7,131	0.180	0.263	0.485
Mizoram	3,570	96	4,745	0.152	0.040	0.279
Nagaland	5,070	152	6,921	0.197	0.261	0.487
Sikkim	3,570	100	4,788	0.177	0.041	0.287
Tripura	5,070	157	6,979	0.190	0.424	0.497

Optimization of System Parameters

The optimized system according to required capacity is shown in the Table 4. It is observed that the capacity required for Arunachal Pradesh, Assam, Manipur, Meghalaya, Nagaland and Tripura is 1kW for PV and 1kW for Wind turbine. Mizoram and Sikkim both require 0.5 kW PV capacity and 1kW Wind turbine. The no of battery for Arunachal Pradesh is 12, while the rest of the NE states all require 4 numbers of batteries each. The converter size obtained is 0.5kW for all the states.

Table 4. Optimized sizing of Hybrid system components

States	PV (kW)	Wind (kW)	No. of batteries	Converter (kW)
Arunachal Pradesh	1	1	12	0.5
Assam	1	1	4	0.5
Manipur	1	1	4	0.5
Meghalaya	1	1	4	0.5
Mizoram	0.5	1	4	0.5
Nagaland	1	1	4	0.5
Sikkim	0.5	1	4	0.5
Tripura	1	1	4	0.5

Optimized Results for the Hybrid Electrical System

The optimized results for the Hybrid Electrical System of all the NE states are represented in the Table 5. The highest PV array production is obtained in the state of Meghalaya and the lowest is obtained in Sikkim. The wind turbine production is seen to be highest in Sikkim and the lowest is seen in case of Nagaland. The AC primary load consumption is more in case of Mizoram closely followed by Arunachal Pradesh and Sikkim, while Assam, Meghalaya, Manipur, Nagaland and Tripura are next in the order of consumption. Mizoram and Sikkim note the highest excess electricity, while in case of Tripura it is the least. The highest unmet capacity is seen in case of Manipur, closely followed by Tripura and Nagaland, while in Mizoram it is the lowest. The capacity shortage is highest in Manipur and minimum for Arunachal Pradesh.

The combined monthly average PV and Wind electric production for all the states is shown in Fig. 9.

Optimized Results for Photovoltaic modules

Table 6 shows the Optimized results for Photovoltaic modules for all the 8 states of North East India. The PV penetration is more than 100% in the states of Assam, Manipur, Meghalaya and Tripura. The mean output for the entire year ranges from 0.09 kW in Sikkim to 0.18kW for Meghalaya, while the mean output per day ranges in between 2.14 kW/day for Sikkim to 4.22 kW/day for Meghalaya. The capacity factor is 14.8% for Arunachal Pradesh. The states of Nagaland, Assam, Manipur, Tripura, Meghalaya, Sikkim and Mizoram are seen to have a capacity

Table 5. Optimized results for the Hybrid Electrical System

States	Electrical (kWh/year)					
	PV array production	Wind turbine production	Consumption (AC primary load)	Excess electricity	Unmet electric load	Capacity shortage
Arunachal Pradesh	1,294 (46%)	1,506 (54%)	1,414	1,079 (38.5%)	27.8 (3%)	39 (2.7%)
Assam	1,454 (58%)	1,060 (42%)	1,290	946 (37.6%)	152 (10.6%)	191 (13%)
Manipur	1,456 (81%)	331 (19%)	1,121	411(23%)	321(22.3%)	392 (27.2%)
Meghalaya	1,539(75%)	523(25%)	1,271	499(24.2)	171(11.9%)	211(14.6%)
Mizoram	915 (21%)	3,439 (79%)	1,433	2,676(61.5%)	8.85 (0.6%)	14.3 (1%)
Nagaland	1,412(73%)	526(27%)	1,172	503(26%)	269(18.7%)	333(23.1%)
Sikkim	782(19%)	3,348(81%)	1,400	2,484(60.1%)	42.0(2.9%)	57.8(4%)
Tripura	1,461(82%)	324 (18%)	1,154	366(20.5%)	288(19.9%)	353(24.5%)

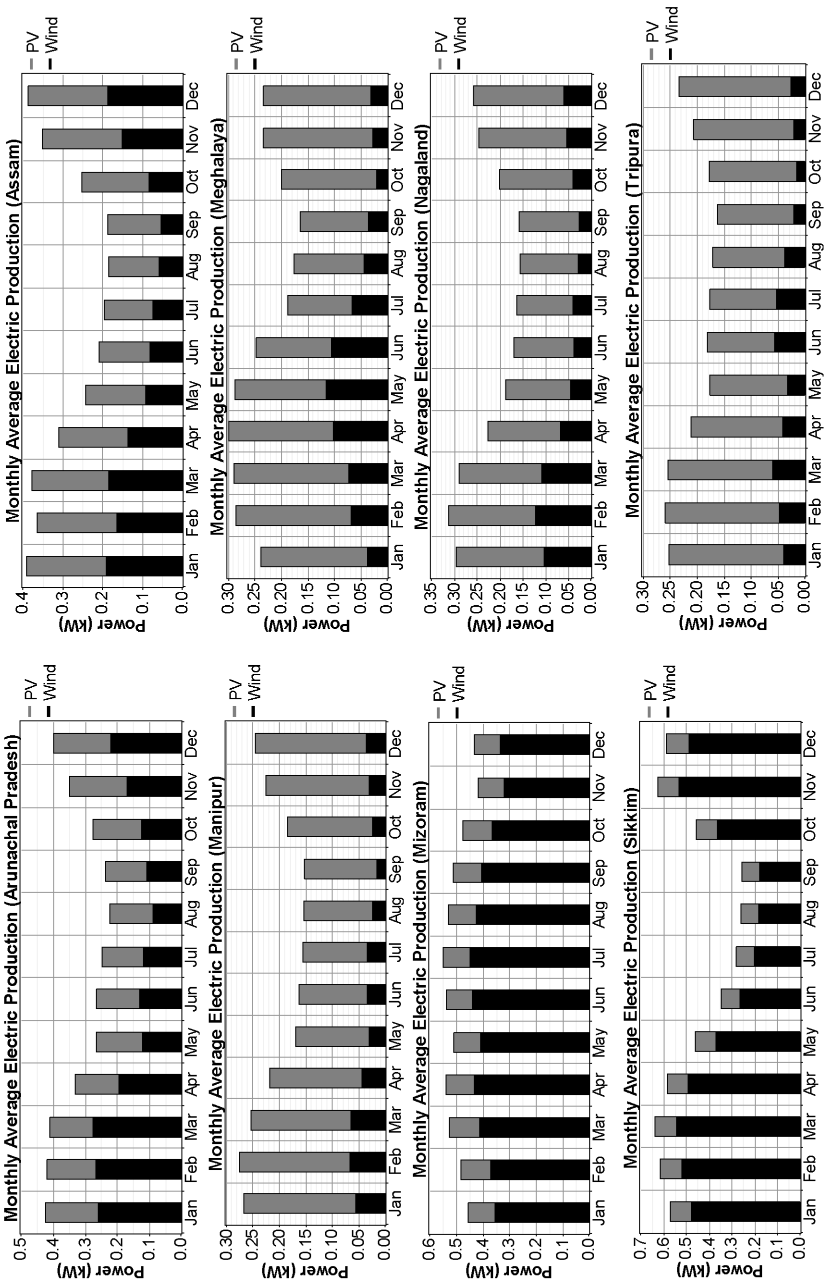

Figure 9. PV/Wind monthly electrical production

factor of 16.1%, 16.6%, 16.6%, 16.7%, 17.6%, 17.8% and 20.9% respectively. The highest output in kW is seen to vary from 0.45 in Mizoram to 0.94 in Arunachal Pradesh. The total production in kWh/year varies between a minimum of 782 kWh/year in Sikkim to a highest of 1,539 kWh/year in the state of Meghalaya.

Optimized Results for Wind Energy System

Wind penetration is more than 100% in case of Arunachal Pradesh. However for the rest of the states this value is less than 74% with a minimum value of 22.5% in Tripura. The mean output (in kW) varies from 0.04 kW in Tripura and Manipur to 0.39 kW in Mizoram. The Highest output is 0.91 kW in Manipur, 0.93 kW in Tripura, 0.99 kW in Meghalaya, and 1.00 kW in Arunachal Pradesh, Assam, Mizoram, Nagaland, and Sikkim. The capacity factor is seen to vary between 3.70% in case of Tripura to 39.3% in Mizoram. The total production (in kWh/yr) is minimum in Tripura and highest in case of Mizoram, indicating that there is a variation in the wind energy potential of the different states. Hours of operation are highest in Sikkim while in the state of Tripura it is the minimum. This indicates that the region has a wide variation in the energy potential available for generation from wind. The data is shown in Table 7.

Optimized Converter Parameters

The mean output in kW of the converter is seen to be 0.13 kW for Manipur, Nagaland and Tripura. This value is 0.15 kW in Assam and Meghalaya, and 0.16 kW in Arunachal Pradesh, Mizoram and Sikkim. Manipur is seen to have a capacity factor of 25.6% and Mizoram has a capacity factor of 32.7% which are respectively the minimum and highest values of capacity factor in the region. The highest loss in kWh/year is 159 kWh/year for Mizoram, and the minimum loss is 125 kWh/year for Manipur. The region sees highest hours of operation 8,191 hr/year in Mizoram and a minimum of 7,229 hr/year for Manipur. Thus it can be said that the converter operates to meet the energy requirement essential for the region to see to the critical meeting of the electrical load. Table 8 summarizes the results for the optimized converter parameters.

Optimized Battery Parameters

The number of parallel strings of battery is 3 in Arunachal Pradesh while all other states are seen to be sufficient with one parallel string, hours of autonomy is 105 hours for Arunachal Pradesh and 35 hours for the rest of the states. A similar phenomenon is seen in the case of Usable

Table 6. Optimized Results for Photovoltaic Modules

States	PV penetration (%)	Mean output (kW)	Mean output (kWh/day)	Capacity factor (%)	Highest output (kW)	Total production (kWh/yr)
Arunachal Pradesh	89.8	0.15	3.55	14.8	0.94	1,294
Assam	101	0.17	3.98	16.6	0.89	1,454
Manipur	101	0.17	3.99	16.6	0.88	1,456
Meghalaya	107	0.18	4.22	17.6	0.86	1,539
Mizoram	63.5	0.10	2.51	20.9	0.45	915
Nagaland	97.9	0.16	3.87	16.1	0.89	1,412
Sikkim	54.2	0.09	2.14	17.8	0.48	782
Tripura	101	0.17	4.00	16.7	0.86	1,461

Table 7. Optimized results for Wind energy system

States	Wind penetration (%)	Mean output (kW)	Capacity factor (%)	Highest output (kW)	Total production (kWh/yr)	Hour of operation (hr/yr)
Arunachal Pradesh	104	0.17	17.2	1.00	1,506	6,095
Assam	73.5	0.12	12.1	1.00	1,060	5,476
Manipur	22.9	0.04	3.77	0.91	331	3,441
Meghalaya	36.3	0.06	5.97	0.99	523	4,231
Mizoram	23.9	0.39	39.3	1.00	3439	7,400
Nagaland	36.5	0.06	6.00	1.00	526	4,259
Sikkim	232	0.38	38.2	1.00	3,348	7,458
Tripura	22.5	0.04	3.70	0.93	324	3,414

nominal capacity (kWh), where in Arunachal Pradesh this value is 17.3 kWh while in all the other states it is seen to be 5.76 kWh. Life throughput (kWh) is 11,004 kWh in Arunachal Pradesh while in the rest of the states it is seen to be 3,668 kWh. The wear cost of the battery is 0.213 $/kWh for all the states. The storage depletion (kWh/year) is seen to be 0 kWh/year for Assam, Mizoram and Sikkim while this value is seen to be 1 kWh/year in the states of Arunachal Pradesh, Manipur, Meghalaya, Nagaland and Tripura. Losses in the system are seen to be in the range from a minimum of 86 kWh/year in Mizoram to a highest of 150kWh/year for Meghalaya. The annual throughput is minimum for Mizoram is found to be 387 kWh/year and is a highest of 682 kWh/year in Meghalaya. The expected life of the battery is a highest of 10 years for Arunachal Pradesh and 5.38 years for Meghalaya, which is the minimum value obtained after the optimization performed by HOMER. The results for the optimized battery parameters are summarized in Table 9.

CONCLUSION

In the past decade many solar photovoltaic and wind energy based systems were adopted by many utilities globally. These resources can generate clean and sustainable energy with the help of PV and wind generators. The combination of small PV/wind hybrid system can provide sustainable electric energy supply to an isolated area where grid connectivity is not a viable option. The objective of this study was to investigate the performance of hybrid systems consisting of PV panels, Wind turbine and storage batteries for rural communities of eight different states of North East India. In this context, techno-economical analysis via simulation was carried out for a 1 kW PV/WIND hybrid stand alone system considering a typical summer and winter load profile of an isolated single household. Optimized results reflect that the COE for all eight states of the region are 0.517, 0.478, 0.579, 0.485, 0.279, 0.487, 0.287, and 0.497 $/kWh respectively. This research work clearly shows that the setting up of a stand-alone PV/wind hybrid power system for meeting rural community load demand is a viable, cost effective, reliable and sustainable option. After optimizing the economics of the hybrid renewable energy system its implementation can lead to a significant decrease in polluting emissions. In this regard, both wind and solar PV technologies are expected to deliver sustainable clean energy at lower cost in years to come.

Table 8. Optimized Converter parameters

States	Mean output(kW)	Capacity factor (%)	Energy in(kWh/yr)	Energy out(kWh/yr)	Losses (kWh/yr)	Hour of operation (hr/yr)
Arunachal Pradesh	0.16	32.3	1,571	1,414	157	8,154
Assam	0.15	29.4	1,433	1,290	143	7,824
Manipur	0.13	25.6	1,245	1,121	125	7,229
Meghalaya	0.15	29.0	1,412	1,271	141	7,726
Mizoram	0.16	32.7	1,592	1,433	159	8,191
Nagaland	0.13	26.8	1,303	1,172	130	7,468
Sikkim	0.16	32.0	1,555	1,400	156	8,102
Tripura	0.13	26.4	1,282	1,154	128	7,309

Table 9. Optimized Battery Parameters

States	String in parallel	Usable nominal capacity(kWh)	Autonomy (hr)	Life throughput (kWh)	Battery wear cost ($/kWh)	Energy in (kWh/yr)	Energy out (kWh/yr)	Storage depletion (kWh/yr)	Losses (kWh/yr)	Annual throughput (kWh/yr)	Expected life (yr)
Arunachal Pradesh	3	17.3	105	11,004	0.213	750	600	1	149	671	10.0
Assam	1	5.76	35.0	3,668	0.213	680	544	0	135	608	6.03
Manipur	1	5.76	35.0	3,668	0.213	657	526	1	129	589	6.23
Meghalaya	1	5.76	35.0	3,668	0.213	761	610	1	150	682	5.38
Mizoram	1	5.76	35.0	3,668	0.213	432	346	0	86	387	9.49
Nagaland	1	5.76	35.0	3,668	0.213	665	533	1	131	596	6.16
Sikkim	1	5.76	35.0	3,668	0.213	453	363	0	91	406	9.03
Tripura	1	5.76	35.0	3,668	0.213	690	553	1	136	619	5.93

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