Comparative Analysis of Solar-Wind Hybrid System with Diesel Generator System in Powering Remote Telecom Towers of Nepal using HOMER

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Abstract: Nepal has approximately 5,222 telecom towers which form the backbone of its telecom market. These towers require millions of kWh of electrical energy and contribute up to 60% of the total network operating cost in rural areas. This expenditure on energy as a result of the lack of grid availability highlights a potential barrier to telecom industry growth. Uncertainty in power availability has compelled infrastructure providers to use diesel generators to ensure a continuous supply of power for network availability. Annually, 7,120 liters of diesel are consumed to operate a telecom tower optimally producing 19.52 million tons of CO_{2eq} per telecom tower. Hybrid energy systems such as solar and wind energy sometimes in combination with diesel generator can be applied successfully in those areas where grid connection is not available or considered uneconomical. To address this problem, this study report presents a techno-economic evaluation of solar-wind hybrid systems to power a remote telecom tower and compares some economic consideration with diesel generator system for the same. As a case study of Nepal Telecom CDMA-BTS (Code Division Multiple Access-Base Transceiver Station) located at Dadakharka (Latitude 27^{o}23’50’’ N and Longitude 86^{o}44’23’’ E) of Solukhumbu district Nepal, the model has been optimized using HOMER (Hybrid Optimization Model for Electric Renewable). From the load demand, the net present cost, operating cost per year and the energy cost/kWh for different models at the available resources are determined.

Keywords: Green Communication; Renewable Energy Technologies; Carbon Footprint; Hybrid Energy Systems; Green Solutions for Telecom Towers; HOMER

1. Introduction

Every year, 120,000 new base stations are deployed servicing 400 million new mobile subscribers around the world [3] [17]. Remote regions of Nepal often rely on inefficient diesel generators for power, which will significantly grow the carbon footprint of tele-communications. Operational costs in remote reasons are aggravated more due to transportation difficulties and the fact that diesel costs have risen 100% since 2002 [14]. It is expected that deregulation of diesel prices, if continued with current regulatory fees, tax structure and marketing margin, would result in an increase in diesel price further in upcoming days. In other words, energy costs could constitute more than 90% of the cost of operating telecom towers, everything else being constant [16]. So, to curb the power issues and to reduce carbon emissions, it has become imperative for the telecom industries to evaluate all alternative options. The growing cost of energy due to diesel prices and concerns over rising greenhouse emissions have caused tower infrastructure companies to focus on better power management methods [4][6]. Various methods in the categories of demand management, supply management and renewable energy technologies (RETs) are being adopted [21]. The current trial deployment of RET solutions like solar photovoltaic, wind power, biomass and fuel cells across the world are proving that each RET has its own challenges but no single RET provides a silver bullet solution while the majority of these trials have been with solar photovoltaic technology [16] [27] [33] [34][36].

Nepal has about 5,222 telecom towers [32] and poised to increase to 6,000 shortly. Since, electricity supply is erratic and is not available throughout the day in many parts, diesel generators have been the choice of telecom operators in spite of their higher operating expenditure (OPEX) and carbon imprint. In Nepal, 1,135 telecom towers operate on diesel generators [32] of 15KVA capacity in general. They consume about 3 liters of diesel/hour and produce 2.63 kg of CO_2/liter [16]. The telecom operators annually spends $66,679 per telecom towers towards running diesel generators in remote locations where grid base power is limited which translates to an operational energy expense of around 80 to 90% of total operating costs. DGs are operational for 10-12 hours in average in rural areas and 4-8 hours in urban areas putting a stress on the environment through carbon emission and noise pollution [2][16].

In general, a telecom tower running on diesel generator with an average running of 12 hours a day, produce 18.75 metric tonnes of CO_2 per year. Thus extensive use of diesel generators has very adverse impacts on environment causing global warming. The imperative solution towards this problem is to switch over to the renewable energy options for environmental benefits [29] [30] [31].

Nepal Telecom (NT) has a 12.87 % growth in outgoing calls to foreign destination in January 2014 compared to the same month last year [24] [25]. According to the Management Information System (MIS) report of the company, a total of 15.25 million calls (42.03 million minutes) were made during January 2014 compared to 13.51 million calls (35.81 million minutes) in January 2013. With pulse duration of 60 seconds charging NRs 1 per pulse rate, NT alone generates revenue of 42.03 million NRs per month. But this revenue could be generated if and only the company made a better network availability. Considering the existing power outage from 4 hours to 12 hours, if no backup power is regulated, NT alone get loss of its revenue from 84 to 252 million NRs per year. This translates the total traffic loss of 2.54 to 7.625 million calls per month (if a calling subscriber has average hold time of 3 minutes per call) that means 2 to 7 million subscribers are directly affected per month due to such power outage problem. This necessitates a sustainable way of solution with RET options for better network availability.

Amanna Ashwin in 2010 made a study report based on several cellular operators experimenting with 6kW wind turbine and 28kW solar panels combined with battery capable of providing 60 hours of operations. The study found the use of solar and wind as a cost effective energy solution for cellular base stations and calculated a return on investment of 3 years with a saving of 4,850 kg of CO_2 annually compared to a typical grid installation [3].

Majid Alabdul Salam. (2013) made a study to determine the optimum size of systems to fulfil the electrical energy requirements of remote sites of Oman using HOMER. A list of feasible power supply system according to their net present cost was suggested [20].

Sonali Goel. (2014) studied the feasibility of using different hybrid systems for the same load demand in two remote locations in southern India. An optimization model of a hybrid renewable system was prepared which simplified the task of evaluating the design of an off-grid/standalone system. After simulating all possible system equipment with their sizes, a list of many possible configurations was suggested on the basis of net present cost [35].

Intelligent Energy Limited on its whitepaper titled "Green Solution for Telecom Towers" shows a potential diesel saving and corresponding reduction in CO_2 emission at a telecom tower site using several attempts for green communications initiatives [16] [30].

Paudel S. in his thesis work analyzed the feasibility study of RET for remote telecom towers using HOMER. The methodology was applied to telecom load consisting VSAT and CDMA 2C10 BTS of NT located at Dadakharka Solukhumbu. The study shows that the existing system have had 36.6% of unmet load during a year. This shortcoming was optimized using HOMER and other design tools and produce a system reliability of 99.99% with a significant cost reduction as well as reliable energy production [28].

Dahal M. in his MSC thesis work provide a techno economic consideration of solar PV system for telecom service with an intensive evaluation of PV system to power CDMA BTS of Nepal Telecom as a case study. Despite, the larger per unit energy cost of PV system than that of energy provided by NEA, this study report recommend a PV system design to power remote telecom as a good alternative [8].

2. Method

With subsequent review of various literatures based on hybrid energy optimization models, HOMER is found to be most appropriate research tool for this study. The methodological approach for this study is presented below (Figure 1). HOMER can perform energy balance calculations for each system configuration we've considered. It then determines whether a configuration is feasible, i.e., whether it can meet the electric demand under specified conditions, and estimates the cost of installing and operating the system over the lifetime of the project as an optimized solution [11].

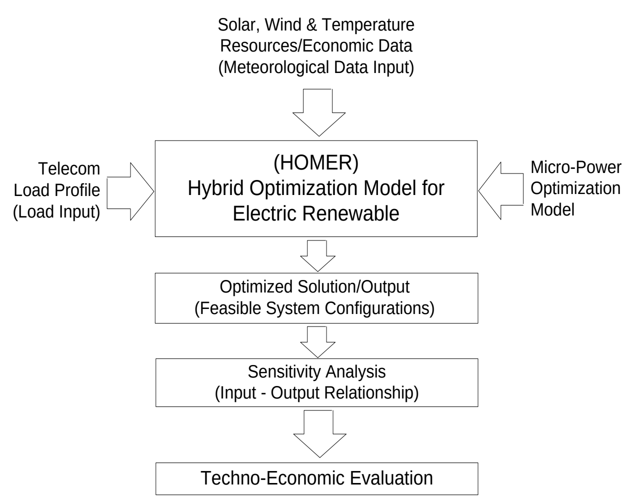


Figure 1: Strategic Framework Design

HOMER analysis starts up with some basic input parameters with sufficient data viability and ends with optimized output with different system configuration throughout several iterations of simulation.

The best possible system then can be implemented as per the nature of site with economic and financial analysis. Here are some basic protocols used in HOMER to acquire most feasible solution (Table 1).

Table 1: Input/Outpur Protocols in HOMER [11][18]

HOMER Inputs	
Load	Telecom loads (BTS, VSAT & RS)
Resources	Solar, wind and temperature profile
Components	Solar PV, wind turbine, diesel generator, converter and battery
Decision Variables	Telecom loads, solar insolation, wind speed, temperature and diesel price
Economics Parameters	Costs (capital, replacement, O&M), interest rate, project life time.
Other Parameters	Emission, System Control and Constraints
HOMER Outputs	
Simulation	Energy balance calculation, life cycle cost of the system, annual electrical energy production, state of charge of battery bank
Optimization	Feasible configuration with least lifecycle cost (size of PV array, wind turbine, batteries and generator) with dispatch strategy.
Sensitivity Analysis	Impact in cost of energy for the system with changes in input variables.

2.1 RETs Assessment with HOMER

Nepal has an abundant potential of renewable energy, if 40% share of energy consumption of such telecom towers can be fulfilled with RETs, huge operating expenditure (OPEX) could be minimized along with short payback period of capital expenditure (CAPEX) [22][24]. This way, to deal with such economic and financial analysis of RETs adoption in telecom towers, HOMER proved its best. In this part, HOMER is used to assist in the design of powering telecom towers and to facilitate the comparison of power generation technologies based upon their technical and economic merits [7]. The effects of uncertainty or changes in the inputs are analyzed and quantified through sensitivity analysis and optimized outputs.

3. Case Study

To realize a telecom tower site with renewable energy technologies, the methodology is applied as a case study of Nepal Telecom (NT) for this particular project. NT is the largest telecom operator in Nepal which provides telecommunication network at remote location through VSAT (Very Small Aperture Terminal), BTS and RS (Repeater Stations). NT has also installed solar-wind hybrid system at few remote location [24].

Since, HOMER requires relevant data as an important parts to analyze, select and to design the system, all necessary data (meteorological, technical, economic) are taken from secondary source of information (previous reports and databases) that actually represents the real essence of this project. Furthermore, solar and wind resource data validation is assessed with SWERA (Solar and Wind Energy Resource Assessment) database [1] and ASDC (NASA Atmospheric Science Data Center) [15].

3.1 Site Location and Existing Architecture

Nepal Telecom has installed a hybrid solar and wind energy system in Dadakharka, Solukhumbu District of Sagarmatha Zone (Latitude: 27^{o}23’50’’N, Longitude: 86^{o}44’23’’E) [24] [28]. The architecture of existing system is given below (Figure 2).

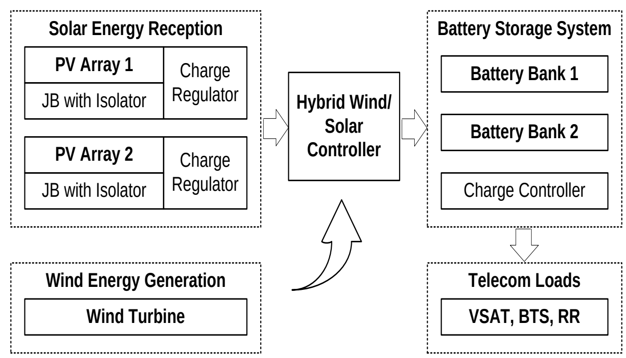


Figure 2: Site Archiecture of Existing System

The existing system consist a parallel connection of two 3.06 kW Kyocera KC85T PV array, 1kW Hummer H3.1 DC turbine and two battery bank (24 each) of Narada GFM-800. The renewable energy from solar and wind is directly fed to the battery bank through solar-wind hybrid controller, while the telecom load is powered by battery backup system.

Two charge regulators (TRISTAR TS-60) are connected with PV array regulating the charge to battery bank, while a charge controller (PROSTAR PS 15M-48V PG) is connected with battery banks to provide adequate supply to telecom loads. Telecom load consist of 530W CDMA2C10 BTS, 75W VSAT and 50W Repeater Station) operated under negative 48 DC voltage.

Apart from the real environmental constraints and historical costs associated with the existing site, This report tries to replicate the existing system components with their corresponding technical characteristics at current price and provides a good techno-economic analysis for the existing system in present context using HOMER.

3.2 Model I: Solar Wind Hybrid System

This includes PV array, wind turbine and battery bank with their technical specifications as described in section 3.1.

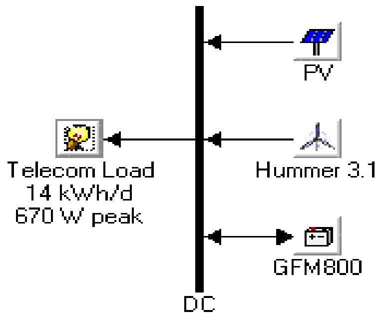


Figure 3: Solar Wind Hybrid System Design in HOMER

The average scaled telecom load is found to be 670W peak corresponding an average energy consumption of 14 kWh per day with load factor 0.871 (Figure 3).

3.3 Energy Resource Profile and Telecom Load

For this system, the meteorological monthly solar insolation and wind speed data (Table 2) for the location are taken and assessed with NASA ASDC and SWERA Database [1][[9].

HOMER synthesize these monthly average profile into hourly data [7]. Scaled annual average daily solar radiation and wind speed is found to be 5.75 kWh/m^2/d and 3.41 m/s. Since, HOMER uses ambient temperature data to calculate the power produced by solar PV in each time step [7] [37], monthly average temperature profile is taken as scaled average annual average of 11.4^{o}C.

According to NT, telecommunication traffic in Nepal is very low at 1:00 am to 6:00 am and 11:00 pm to 12:00 pm. Therefore, BTS is operated at full load and half load condition under maximum and minimum traffic, hence the power consumption of BTS is categorized according to the time interval carried by the traffic. As per the manual provided by ZTE for ZTE 1xEVDO BTS, CDMA 2C10 BTS has output power of 20W with full load and half load power of 530W and 480W respectively. Hence, the peak load on demand of the site is found to be 654W between 6:00 am to 10:00 pm and low demand of 400W at 0:00am to 6:00am and 10:00 pm to 12:00 pm.

HOMER determines the average daily consumption of the system based on the outlined power profiles. The random variable parameter is set to 0% for accurate power load measurement (Figure 4).

Table 2: Monthly Averaged Solar Insolation, Wind Speed and Temperature Profile of the Site [1][9][15][28]

Weather/ Month	Solar Insol^n. (kW/m^2/d)	Wind Vel^y. (m/s)	Site Temp^r. (^{o}C)
Jan	5.75	5.4	3.85
Feb	6.21	5.87	5.53
Mar	6.47	6.1	9.65
Apr	6.32	5.93	12.59
May	5.92	5.23	14.22
Jun	5.29	4.31	16.27
Jul	4.85	3.58	16.81
Aug	4.89	3.48	16.68
Sep	4.9	3.52	15.16
Oct	5.98	4.6	11.7
Nov	6.1	5.35	8.22
Dec	5.83	5.23	5.52

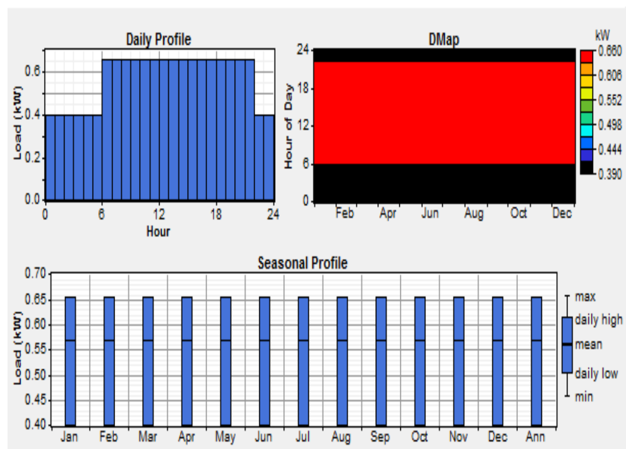


Figure 4: Telecom Load, Data Map and Seasonal Profile

3.4 Equipment and their Cost Details

The cost details of major system components are presented below (Table 3). But, the cost details of other equipment (Charge Regulator, Charge Controller and Solar-Windybrid Controller) are not included. They are supposed to be embedded with associated system itself. HOMER deals with these costs details as initial capital investment and compares with other life cycle costs.

Table 3: System Equipments and Cost [12][13][26]

System	Size (kW)	Initial Cost ($/kW)	Rep. Cost ($/kW)	O&M Cost ($/kW)	Life (Yrs)
Solar	6.12	1030	927	0	20
Wind	1	1555	1400	80	20
Battery	48 Units	$150 /Unit	$145 /Unit	$10 /Year	15

HOMER models 24 hours variation of load based upon the system components and resources. It generates synthetic hourly global solar radiation and wind speed profile from monthly averaged data (Figure 4 and 5).

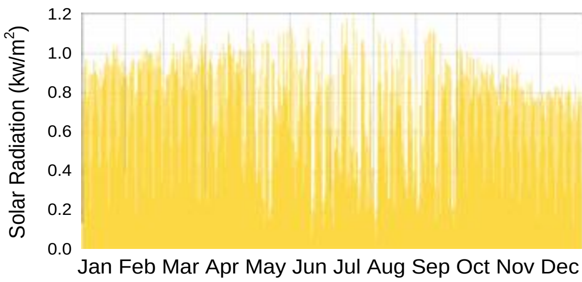


Figure 4: Synthesized Hourly Solar Insolation Profile

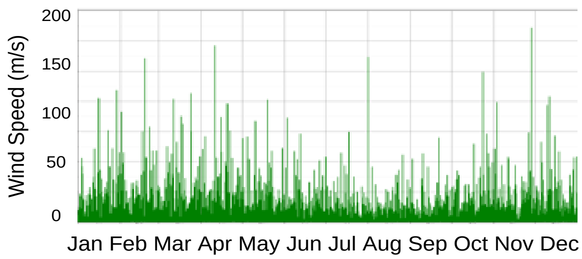


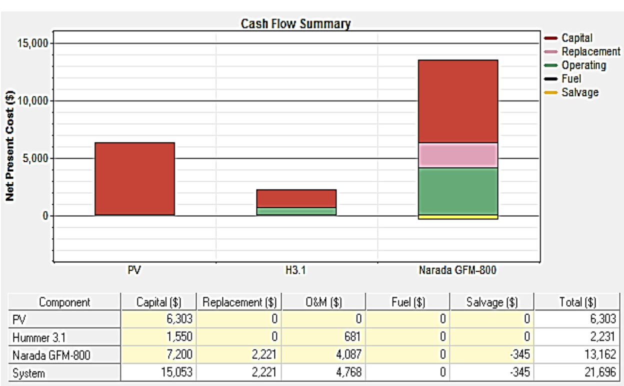
Figure 5 Synthesized Hourly Wind Speed Profile

3.5 HOMER Output Analysis for Model I

The existing system architecture is characterized by net present cost (NPC) with levelized cost of energy (LCOE). The result is based upon the system with 14kWh telecom load at 5.75kWh/m^2 of solar radiation, 4.88m/s of wind speed (Table 4).

Table 4: Optimization Results for Existing Systems

System	Solar-Wind
Solar Array Size	6.12kW
Wind Turbine Size	1kW
No. of Batteries	48
Initial Capital Cost	$15,053
Operating Cost	$780
Total NPC	$21,696
LCOE	$0.499/kWh



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	6,303	0	0	0	0	6,303
Hummer 3.1	1,550	0	681	0	0	2,231
Narada GFM-800	7,200	2,221	4,087	0	-345	13,162
System	15,053	2,221	4,768	0	-345	21,696

Figure 6: Component wise Cost Summary of the System

The life cycle cost details of each components is presented below (Figure 6), of which battery system cost constitute about 60% of total cost because it needs to be maintained periodically over its lifetime.

The total average electric production of existing solar-wind hybrid system is found to be 14,093kWh per year, of which PV array contribute 93%. But the consumption as per the dc telecom load is found to be 5,110kWh per year resulting excess electricity of 8,487kWh per year with no unmet electric load and capacity shortage (Figure 7).

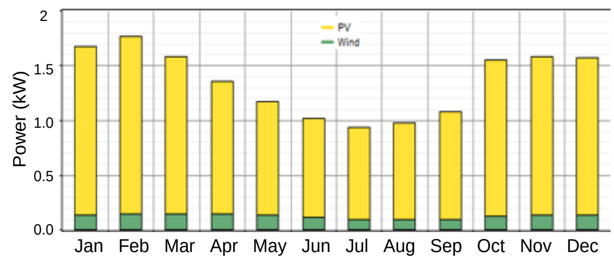


Figure 7: Monthly Average Electric Production

The total energy in to the battery system is found to be 2,503 kWh/year while the total energy out from the battery is 2,007 kWh/year with losses of 494 kWh/year. The battery system has annual throughput of 2,244 kWh. The monthly statistics and frequency of state of charge of battery bank is shown in Figure 8.

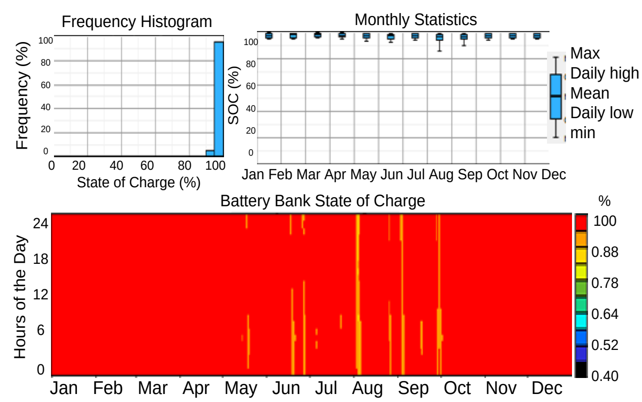


Figure 8: Battery Bank State of Charge & Statistics

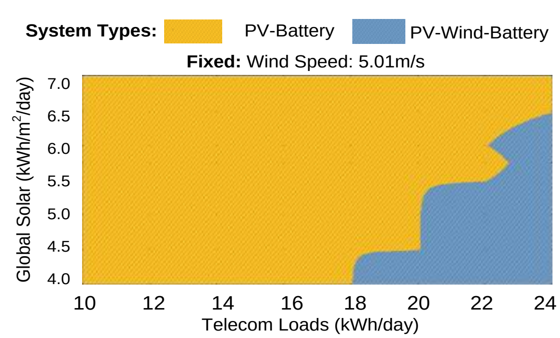


Figure 9: Sensitivity Analysis

HOMER calculates an optimal solution ranked by NPC rather than COE. Hence, the tota NPC is analyzed as an output parameter with varying global solar insolation profile keeping the wind velocity, fixed at 5.01m/sec

The sensitivity analysis (Figure 9) shows that the telecom load greater than 18 kwh/day (L_{TH}) with solar insolation up to 6 kW/m^2/day is best supported by Solar Wind Hybrid System, while the remaining is best supported by Solar PV System. Higher telecom loads demand higher energy, so PV system alone can not fulfill the demand.

On the other hand solar PV along with wind turbine can add up the additional power but with large operating cost than solar PV system. From the analysis it is found that NPC could go up from $15,435 to $20,760 for telecom load higher than L_{TH} with solar-wind hybrid system, while it is $15,435 to $9,255 for telecom loads lower than L_{TH} with solar PV system.

3.6 *Model II: Diesel Generator (DG) System*

The current status shows that most of the rural-off grid telecom towers are mostly using diesel generator of size 15 kVA to 25 kVA as per the nature of site and traffic demand.

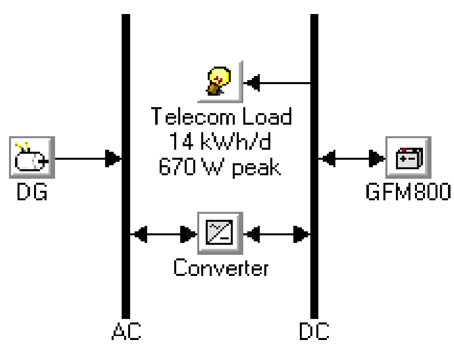


Figure 10: DG-Battery System Design in HOMER

DG-Battery System (Figure 10) is designed to have a comparative study with previous system in terms of cost effectiveness and resource consumption. The primary cost associated with DG with its fuel (Diesel: $1.1/liter) and converter is presented below (Table 5).

Table 5: Cost Details of DG and Converter [15] [26]

System	Size (kW)	Initial Cost, $/kW	Rep. Cost, $/kW	O&M Cost, ($/hr)	Life Time
DG	15	600	500	0.075	15000 Hours
Converter	1	700	700	70/Year	10 Years

Since, telecommunication traffic in Nepal is very low at 1:00 am to 6:00 am and 11:00 pm to 12:00 pm [24] (as described in section 3.3), diesel generator is scheduled accordingly for different time of day throughout the year. Apart from the time of high traffic demand, DG is scheduled to run in optimal conditions for the rest of hours (Figure 11).

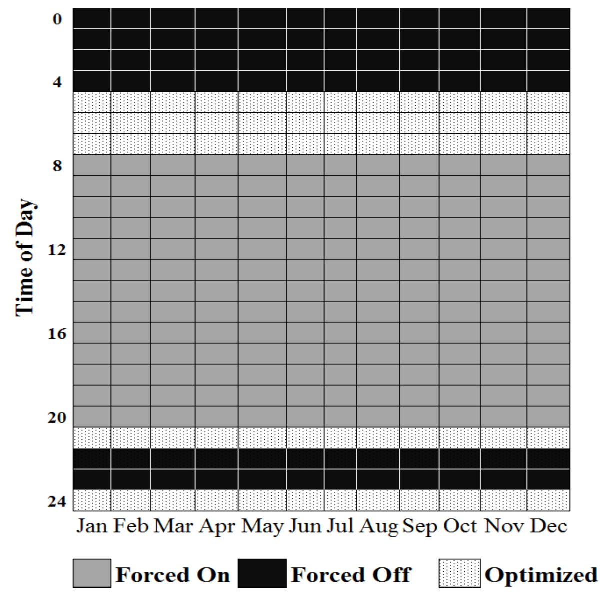


Figure 11: Diesel Generator Scheduling

3.7 *HOMER Output Analysis for Model II*

The system conveys large NPC because of huge operating cost. It reveals that a telecom tower powered by DG running 4,380 hours/year consume 7,120 liters of diesel with operating cost $15,128 per year and this seems to be too large when compared with solar-wind hybrid system for the same (Table 6). This cost grew up again with higher traffic demand and with rise in diesel price also.

Table 6: Optimization Result for Diesel-Battery System

System	Diesel-Battery
DG Size	15kW
Converter Size	2kW
Initial Capital	$14,000
Operating Cost	$15,128/Year
Total NPC	$142,795
LCOE	$3.282/kWh
Diesel Consumption	7,120 Liter/Year
DG Operation Hours	4,380

The total electrical energy production from the DG system is found to be 7,646 kWh/year with DC primary load consumption of 5,475kWh resulting an excess of electricity 534 kWh/year with no capacity shortage. Whereas total energy in to the battery system is 2,909 kWh/year and total energy out from the battery is 2,331 kWh/year with losses of 576 kWh/year and storage depletion of 2 kWh/year. As of impact evaluation due to the autonomy operation of diesel generator, CO_2 emission is found to be 18,874 kg per year followed by 46.6 kg/year of CO emission per telecom tower.

3.8 Economic Analysis of Different Systems

Different solution configurations are demonstrated and analyzed separately. To meet the objective of this study, these systems are put into common platform for a comparative study, which will give the best solution in powering remote telecom towers with the system merit order ranked by total net present cost. For this purpose, telecom loads of 12, 14 and 15 kWh/day are considered for fixed solar insolation (5.75 kWh/m^2/day), wind speed (5.01 m/s) and temperature (11.4^{O}C) profile with diesel price $1.1/liter.

This study reveals that DG-Battery System is very costly with cost of energy (COE) $3.282/kWh due to the huge operation cost even the surplus electricity is about 809kWh/year. Whereas COE of solar-battery system ($0.27/kWh) is found to be minimum at telecom load 14kWh/day with total net present cost (NPC) of $10,285. Where, solar wind hybrid system has minimum COE ($0.285/kWh) for telecom load 16kWh/day with total NPC $12,433.

Table 7: Comparative Analysis of Different System

Model	Parameters	Load (kWh/day)		
		12	14	16
Solar-Wind-Battery System	COE ($/kWh)	0.349	0.326	0.285
	Total NPC ($)	11,403	12,433	12,433
	Op.Cost ($/Yr)	423	423	423
	Excess Electr^y (kWh/Yr)	2,556	3,902	3,086
Solar-Battery System	COE ($/kWh)	0.314	0.27	0.259
	Total NPC ($)	10,285	10,285	11,315
	Op.Cost ($/Yr)	343	343	343
	Excess Electr^y (kWh/Yr)	3,689	2,865	4,199
DG-Battery System	COE ($/kWh)	3.812	3.282	2.893
	Total NPC ($)	142,142	142,795	143,815
	Op.Cost ($/Yr)	15,052	15,128	15,248
	Excess Electr^y (kWh/Yr)	1480	809	295

Here, the simulation result recommends that even a Solar-Battery System with 4kW of solar PV array with 24 numbers of single string battery bank is enough to fulfill the demand for basic telecom load profile with excess of electricity 2,865kWh/year. Since, HOMER models the battery system to be charged with cycle charge dispatch strategy [7] i.e. the battery system is charged to its set point with highest priority. Whereas, the excess electricity is supposed to be utilized for dummy loads.

4. Conclusion

The methodology has been developed for carrying out the techno-economic assessment for an optimal sizing of standalone PV/Wind hybrid system with battery storage using HOMER. The optimal configuration of the system is achieved by defining the cost function in terms of total NPC and COE. The assessment result is analyzed by varying the wind speed and solar insolation as a function of remote telecom load. At the same time a comparative study has been done between RET system and DG system in powering remote telecom towers. It is found that DG system requires huge operating cost ($15,128/year) with COE $3.282/kWh while solar-wind hybrid system has an operating cost of $423/year with COE $0.326/kWh for basic telecom load. With regard to the cost associated with each system, DG powered telecom towers has huge NPC ($142,795) when compared with PV ($10,285) and/or PV-Wind Hybrid System ($12,433).

About 22% (1,135) of telecom towers of Nepal do operate on diesel generators [32]. For an optimal run of typical tower with 670W peak load powered by DG system, 7,120 liters of diesel is consumed per year. This reveals the fact that annually 8.0812 million liters of diesel is being consumed to run the telecom towers of Nepal, while each tower is producing 19.52 million tons of CO_{2eq} per year. On the other hand, RETs as an alternative measure is proven the best against DG system in powering such remote telecom towers. They require a minimum operating cost with long life span and are environmentally clean. Therefore, RETs are the sustainable way of powering remote telecom towers and it could be a good deal for telecom operators also.

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