International Journal of Scientific Research in Science, Engineering and Technology
© 2019 IJSRSET | Volume 6 | Issue 2 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
doi : https://doi.org/10.32628/IJSRSET2182136

Feasibility Assessment of a Standalone Hybrid Rural Microgrid Using a Load Following Dispatched Strategy

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ABSTRACT

This research delves into the techno-economic-environmental feasibility and optimal unit sizing of various hybrid power sources for a standalone microgrid serving a remote educational institution in Gujarat, India. Central to the investigation is the adoption of a load-following dispatch strategy to effectively balance energy supply and demand. The study explores different combinations of standalone hybrid sources, including Solar PV, Diesel Generators (DG), and Li-Ion Battery microgrid systems, strategically optimized to meet the institution's energy requirements. Furthermore, the research meticulously examines the overall costs and viability of the hybrid system. Among the studied configurations, the Hybrid PV-DG-Battery standalone microgrid emerges as the most feasible system. It is found to have a Net Present Cost (NPC) of $714,556 and a Cost of Energy (COE) of $0.0899 per kWh. Additionally, the Hybrid PV-DG-Battery standalone microgrid exhibits the highest environmental responsiveness compared to other configurations, with the lowest CO2 emissions estimated at 3,356 kg per year.

Keywords: Cost of Energy, Solar PV, Load following (LF) Strategy, Micro grid, Optimization, Sensitivity Analysis

I. INTRODUCTION

Amidst the global energy shortfall and escalating environmental degradation, renewable energy sources have garnered increasing attention in power generation, primarily owing to their emission-free and eco-friendly characteristics. Furthermore, distributed generation (DG) technologies, rooted in renewable energy, emerge as highly viable solutions, particularly for developing nations like India, where industrial power demands have witnessed a significant surge over the past decade. [1,2] According to the Global Trends in Renewable Energy Investment in the last decade, solar PV costs were reduced by 81%, onshore wind by 46% and offshore wind by 44%. When compared with traditional energy sources, the low ongoing running costs of renewable energy sources become apparent, making them attractive choices to countries aiming to lower their emissions long-term. [3][4] The hybrid power systems exhibit higher reliability and lower cost of generation than those that use only one source of energy. A power generating system which combines two or more different sources of energy is called a hybrid system.[5] The hybrid energy generating systems (such as wind -diesel, pv-diesel, wind-pv-diesel etc. with and without battery storage options) for standalone and grid connected are not new technologies or systems rather existed in practice for the last two decades. Solar and wind resources are abundantly available in Gujarat, India. In India, Till May, 23, 2020 the total installed electric power capacity in respect of Renewable Energy Sources is 87,269 MW. Solar and wind power plants contributed 34,627 MW and 37,693 MW respectively [3].

This paper focuses on conducting a comprehensive assessment of the techno-economic-environmental aspects associated with a standalone microgrid employing hybrid power sources. The study proposes various combinations of hybrid systems, taking into account the feasibility of different energy sources and optimizing component sizing to achieve a load-following control strategy with minimal costs and environmental impact. Additionally, the research investigates all feasible combinations of standalone hybrid systems, considering input parameters such as inflation rate, discount rate, and the impact of rising diesel fuel prices through sensitivity analysis. The results of the study provide valuable insights into component sizing, particularly emphasizing the maximum utilization of renewable sources. Through optimized simulation studies based on load-following techniques, the paper evaluates the economic and environmental performance of the hybrid power system in the absence of grid connection. These findings offer significant implications for the site in question, ensuring trustworthy, efficient, and economically viable operation while reducing reliance on conventional sources and promoting the utilization of non-conventional energy, thereby contributing to a less polluted environment, particularly in the tribal area of Gujarat, India.

The primary motivation driving this study stems from the imperative to maximize the utilization of renewable energy sources available at the study site, situated in a tribal area where family incomes are low. The institution, serving as the study site, envisions achieving self-sustainability in electricity generation within its campus, emphasizing the optimal utilization of renewable energy resources to mitigate pollution and safeguard the environment. Additionally, the decision to pursue a hybrid standalone system arises from the necessity to circumvent the frequent power outages from the grid, which pose challenges to uninterrupted power supply. Aligned with this vision, the research endeavours to identify the most feasible solution for the site, considering technical, economic, and environmental parameters. By leveraging hybrid standalone systems utilizing renewable power sources, the study aims to not only enhance the site's energy autonomy but also contribute to reducing its ecological footprint and fostering resilience against grid disruptions.

II. MATHEMATICAL MODELLING OF COMPONENTS OF STANDALONE HYBRID MICROGRID:

a. Solar PV Module:

Using the amount of solar radiation and the temperature available, the Solar PV output power can be calculated according to the following equation1, [6]

$$P_{spv} = S_{spv} * f_{spv} \left(\frac{R_t}{R_{t,std}} \left[1 + \alpha_p \left(T_c - T_{c,std}\right)\right] \right. \text{----- (1)}$$

Where,

Sspv = The PV rated capacity under standard test conditions (kW)

fspv = The derating factor of Solar PV.

Rt = The solar radiation incident on the PV array in the current time step (kW/m2)

Rt,std = The incident irradiance at standard test conditions (1 kW/m2)

αp = The temperature coefficient of power(%/oC).

Tc = The temperature of the PV cell (oC) in the current time step.

Tc,std = The temperature of the PV cell under standard test conditions (25oC).

b. Diesel generator:

The diesel generator is used to provide the peak load demand of the system. Hourly Diesel consumption of diesel generator is expanded as below equation 2:[6]

$$\boldsymbol{DG_{fuel}\ (t)\ =\ \alpha * P_R + \beta * P(t)} \text{ ------ (2)}$$

Where,

DG fuel (t) =The fuel consumption of diesel generator

P (t) I = the diesel generator power at a certain time

PR = the rated power of diesel generator

α, β = constants and range start from 0.08 & 0.24

c. Battery Storage Device:

The additional electricity generated from Solar PV is used to charge the batteries to supply the load in case of a shortage of electricity. Maximum charge or discharge power at any time is the main factor to optimize a renewable system and can be calculated by the following equation (3). the state of charge (SOC) of the battery either on discharge and charge mode can be calculated using Eqns. (4, 5) respectively [20]

$$P_{batt,Max} = \frac{N_{batt} * V_{batt} * I_{max}}{1000} \text{ ----- (3)}$$

$$E_b\ (t+1) = E_b\ (t) * (1-\sigma) - \frac{\left(\frac{E_l\,(t)}{\eta_{cnv}} - E_g(t)\right)}{\eta_{bd}} \text{ --- (4)}$$

$$E_b\ (t+1) = E_b\ (t) * (1-\sigma) + \left(E_g\ (t) - \frac{E_l\,(t)}{\eta_{cnv}}\right) * \eta_{bc}\text{'\_\_\_(5)}$$

At every hour (t) , the state of Charge of Battery (Eb) is controlled by the minimum and maximum capacity of battery bank the detail given below in equations (6)

$$E_{bmin} \leq E_b\,(t) \leq E_{bmax} \text{ Or } E_{bmin} = (1-DOD) * E_{bmax} \text{---(6)}$$

Where,

Vbatt = the voltage of a single battery.

I max = battery's maximum charging current

N batt = the number of batteries

ηbc , ηbd = the charge and discharge efficiencies of the battery

σ= Self discharge constant, it can be neglected

Eg = Electrical Energy generated by renewable sources i.e. Solar PV

El(t) = Load demand at each hour (t).

DOD = Depth of discharge for battery.

d. Net Present Cost (NPC):

The total net present cost (NPC) of a system is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid.[7]

$$C_{NPC} = \frac{C_{ann,tot}}{CRF\ (i, R_{Proj})} \text{ ---------- (7)}$$

Where C ann,tot is the total annualized cost, i the annual real interest rate (the discount rate), Rproj the project lifetime, and CRF is the capital recovery factor.

e. Cost of Electricity (COE):

COE is the ratio of total system discounted annualized cost to total energy served by the system (Eserve), which includes energy served to the load and energy supplied to the grid. COE is calculated by using Equation 8

$$\mathbf{COE} = \frac{\mathbf{CRF(i,N)} \times \boldsymbol{C_{NPC}}}{\boldsymbol{E_{serve}}} \text{ ------- (8)}$$

Where N is the project lifetime. C_{NPC}, is the net present cost of the hybrid power system.

III. METHODOLOGY

A. Proposed Load Following Dispatched Energy Strategy:

In the Load following (LF) dispatch strategy, if the Solar PV source does not have enough capacity to meet the load demand, the available DG set start immediately and supply electricity to load without recharging battery bank during operation. If, $P_{PV} > 0$, $P_{pv} = P_{Load}$ + Excess power charge battery bank B_{soc} and DG set must OFF.

- If, $P_{pv} < 0$, then $B_{soc} \geq B_{socmin}$ then battery bank provide electricity to the load
- If, $P_{pv} < 0$, then $B_{soc} < B_{socmin}$, here DG set provide electricity to load demand and DG set does not charge battery bank. At the end, the DG set turns ON when $P_{load} = P_{pv}$ and battery bank will be charged only when Solar PV generated excess electricity more than load demand. Time steps are dependent on the controller.

B. Proposed Algorithm For Micro grid:

The detailed algorithm steps to build the schematic and carry out Optimum unit sizing and techno-economic feasibility analysis.

1. Select different types of generators depending upon the availability of resources. Prior survey of site for available resources, load and existing generation is required for this purpose.
2. Decide maximum generation capacity for each type of generation. The attributes to be taken into account for this purpose can be reliability of Microgrid and operating reserve. Power exchange with grid can be additional attribute for energy deficit country.
3. Select incremental step size for each generator which is available commercially and generally installed..
4. Give priority to the DG source, i.e., from where the power should come first. For example, natural resources will be on higher priority as compared to fossil fuel based DGs.
5. Generate all possible combinations for selected generators, ranging from zero to maximum possible installation of each DG.
6. Check the generated combinations for validity. Each valid combination has to satisfy systems electrical requirement.
7. Calculate NPC and COE for each valid combination.
8. Find minimum of all NPC values and index corresponding to the minimum NPC.
9. The combination corresponding to minimum NPC is the optimal mix of the DGs.

When understand the system components and the equations, Modelling and simulations of the micro power system is carried out. Large number of options are available for different sizes of the components used, components to be added to the system which make sense, cost functions of components used in the system. Optimization and sensitivity analysis algorithms evaluated the possibility of system configuration. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel and interest. Figure 1 indicates the schematic modeling for PV - Diesel hybrid system consisting of converter and load with and without grid connection

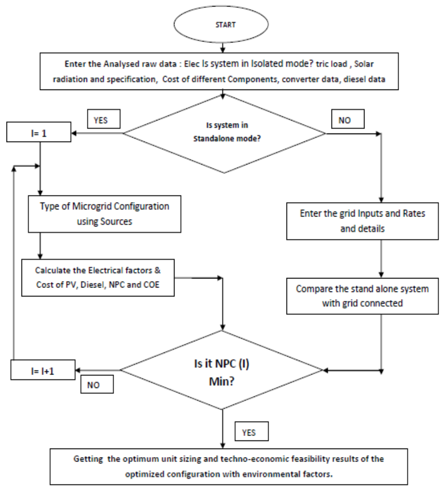

Figure 1: Proposed Flowchart of Standalone Microgrid

C. Site Description, Resources details and components specification:

An Academic Institute located in Vataria, a small village in tribal area of Gujarat, India, having the geographical coordinates of 21.565875N and 73.118107E. Campus have one academic block and one hostel with a total connected load 130 kW. The scaled annual average load profile of Campus around 715.19 kWh/day, 96.6 kW peak demand, 29.8 kW Avg. demands for 24 hrs and a load factor of 31 %. In this study, the day-to-day (10%) and time step to time step (10%) random variability of load is taken as zero. The energy requirements vary daily and monthly depending on many factors like institute & hostel operating time, vacations, events, working recess and seasonal changes etc. the figure 2 showing the yearly load profile of the site. The life of whole project considered 25 years with expected inflation rate 3.34 % and nominal discount rate 5.40 % considered for the various feasible combination of hybrid system.

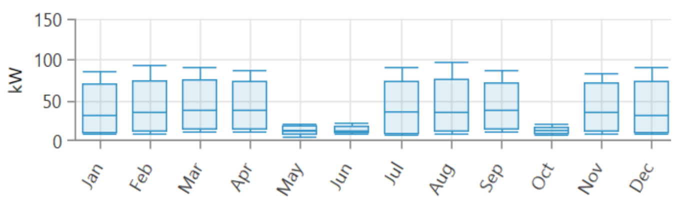

Figure 2: Yearly Load Profile of the Site.

The solar radiation data for SRICT Campus site was obtained from the NASA surface meteorology and solar energy database. [4]. Figure 3 shows the Yearly Solar Radiation Data with clearness index. It can be seen that the solar daily radiation ranges from 3.55 kWh/m2 /day (August) to 6.65 kWh/ m2 /day (April), and the annual average of the solar daily radiation is estimated to be 5.18 kWh/m2 /day.

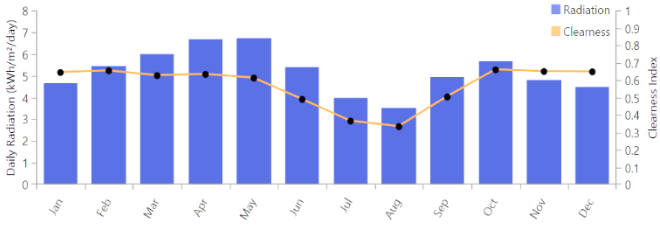

Figure 3: Yearly Solar Radiation Data with clearness Index.

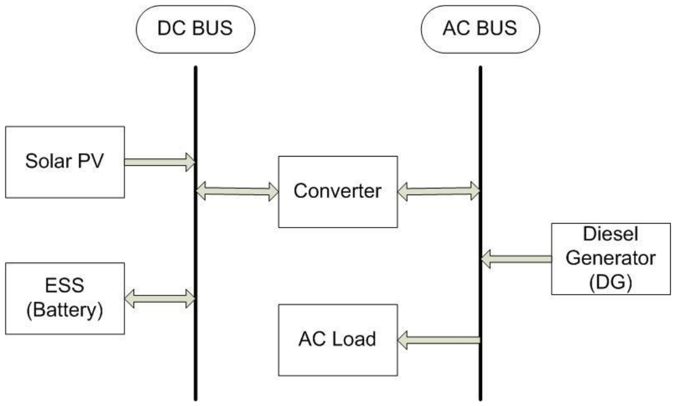

Figure 4: Standalone Solar PV/DG/Battery Hybrid Microgrid

Proposed strategy implemented in the standalone Solar PV/DG/ Battery hybrid microgrid as shown in figure 4

Table 1: Given the details of system components

Technical & Economic parameters of the PV module:	
Parameters	**Data description**
Solar PV module Model	Generic flat plate PV
Name of Modele	Tata Power Solar Systems300TP300LBZ
Material	Polycrystalline
Rating (kW)	0.3
Derating factor (%)	85
Operating Temp in degree cel	48.8
Tracking system	No tracking - Fixed
Ground reflectance (%)	20

Slope (°C)	21.57
Efficiency at standard test condition (%)	15.4
Life of Module (Year)	25
Capital Cost ($/kW)	514
Replacement Cost ($/kW)	500
O& M Cost ($/kW/Year)	1
Lifetime (Hr)	20000
Technical & Economic parameters of the Diesel Generator (DG) Set:	
Parameters	**Data description**
DG Model	Generic
Fixed Capacity Rating (kW)	100
Min. Load Ratio (%)	25
Fuel Lower heating value (MJ/kG)	43.2
Fuel Density(kG/M3)	820
Price of fuel per Litre in $	1
Lifetime Operating Hours	15000
Capital Cost ($/kW)	400
Replacement Cost ($/kW)	400
O& M Cost ($/Operating hours)	0.1
Technical & Economic parameters of the Storage System:	
Parameters	**Data description**
Type of Battery	Li-Ion
Rating in kWh	1
Nominal voltage of each battery (V)	6
Nominal capacity of each batter (Ah)	167
Min. state of charge	20
Throughput (kWh)	3000
Round trip efficiency (%)	90

Battery string	1
Max. Charging Current (A)	167
Min. discharge Current(A)	500
Capital Cost ($/kW)	183.0985915
Replacement Cost ($/kW)	125
O& M Cost ($/kW/Year)	0
Lifetime (Year)	10
Technical & Economic parameters of the Converter:	
Parameters	**Data description**
Rating in kW	1
Inverter Efficiency (%)	90
Rectifier Efficiency (%)	95
Lifetime in year	10
Capital Cost ($/kW)	300
Replacement Cost ($/kW)	300
O& M Cost ($/kW/Year)	0.5
Project Life(year)	25
Random Variability of Load:	
day to day %	10
Time step %	10
Average Load kWh/Day	715.19
Average Load KW	29.8
Peal KW	109.95
Min Load in KW	4.12
Load Factor	0.27

IV. RESULTS AND DISCUSSION

The performance evaluation of optimal standalone hybrid micro grid has been conducted using HOMER Pro software. Various combinations including Hybrid PV-DG-Battery and DG-only systems have been assessed to determine their effectiveness. HOMER Pro was utilized to optimize the sizing of energy sources, ensuring continuous power generation at the lowest cost by implementing load following control strategies under diverse technical and economic parameters. Simulation results are presented in Table 2, offering an overview of all proposed feasible combination for standalone hybrid energy systems. The table encompasses an analysis of all feasible hybrid system combinations, providing valuable insights into their performance characteristics.

Configuration	**Units**	**CASE 1 Standalone PV/DG/BS hybrid Microgrid**	**CASE 2 Standalone Only DG based Microgrid**
Solar PV	kW	704	0
Wind turbine Generator (WT)	kW	0	0
Biomass Generator (BM)	kW	0	0
Diesel generator(DG)	kW	50	130
Battery	Nos	464	0
Converter	kW	104	0
PV production	kWh/Year	1093899	0
WT Production	kWh/Year	0	0
BM Production	kWh/Year	0	0
Diesel generator production	kWh/Year	3318	354841
Diesel Fuel consumption	L/year	1282	120582
Renewable fraction	%	98.7	0
Batteries throughput	kWh/year/battery	82,799	0
Batteries nominal capacity	kWh	464	0
Batteries autonomy	hour	12.5	0
NPC	$	714556	56008800
COE	$/kWh	0.0899	7.04944

Table 2: Technical Parameter Results of Optimisation

In table 2 shown the comparisons of various technical parameters optimised output result of both cases. The COE of Standalone PV/DG/BS hybrid Microgrid and Standalone DG Microgrid are $/kWh 0.0899 and 7.04 respectively. The NPC for the first case for this proposed hybrid microgrid is $ 714556 and for the second cases is taken is $ 56008800. The total yearly Solar PV production and consumption by load of the proposed Standalone PV/DG/BS hybrid Microgrid 1093899 kWh/yr.

Table 3 facilitates the analysis of pollution emissions, particularly carbon dioxide emissions, allowing for a comparison between Case 1 and Case 2. The data indicates a significant reduction in carbon dioxide emissions in Case 1 compared to Case 2. This reduction in emissions holds substantial importance in terms of environmental impact, highlighting the efficacy of the measures implemented in Case1

Configuration	**Units**	**CASE 1 Standalone PV/DG/BS hybrid Microgrid**	**CASE 2 Standalone Only DG based Microgrid**
Carbon Dioxide	kg/year	3,356	3,15,637
Carbon Monoxide	kg/year	21	1,990
Unburned Hydrocarbons	kg/year	0.923	86.8
Particulate Matter	kg/year	0.126	12.1
Sulfur Dioxide	kg/year	8.22	773
Nitrogen Oxides	kg/year	19.7	1,869

Table 3: Environment Parameters Result of Optimisation

V. CONCLUSION

This paper investigates the technical, economic, and environmental aspects of a standalone hybrid microgrid across two feasible combinations. The study focuses on load following control strategies to optimize system performance and assess its sustainability in terms of technical, economic, and environmental parameters. The Hybrid PV-DG-Battery Standalone microgrid is more cost effective compared to other hybrid system for the Educational institute located in tribal area of Gujarat, India. The suggested standalone optimal PV-DG-Battery hybrid system was found with an NPC of $ 714556 and a COE of $/kWh 0.0899 respectively. also found that Hybrid PV-DG- Battery standalone microgrid was the most environment responsive rather than other cases by having lowest amount of CO_2 is 3,356 (kg/year) respectively.

VI. REFERENCES

[1]. He L, Chen YZ, Zhao HH, et al. Game-based analysis of energy-water nexus for identifying environmental impacts during Shale gas operations under stochastic input. Sci. Total Environ. 2018; 627:1585–601.

[2]. Chen Y, Lu H, Li J, et al. Regional planning of new-energy systems within multiperiodand multi-option contexts: a case study of Fengtai, Beijing, China[J]. Renew Sustain Energy Rev 2016; 65:356–72

[3]. Das B.K., Hoquea N., Mandala S., Pal T.K., Raihana Md A: A techno-economic feasibility of a stand-alone hybrid power generation for remote area application in Bangladesh. Energy 134, 775–788 (2017). https://doi.org/10.1016/j.energy.2017.06.024

[4]. Arevalo P, Benavides D, Lata-García J, Jurado F. : Energy control and size optimization of a hybrid system (photovoltaic hydrokinetic) using various storage technologies. Sustain Cities Soc 2019.

[5]. Fazelpour F.; Soltani N.; Rosen M.A.: Economic analysis of standalone hybrid energy systems for application in Tehran, Iran. Int. J. Hydrogen Energy 2016, 41, 7732–7743.

[6]. Homer renewable energy software documentation. http://www.homerenergy.com/documents/MicropowerSystemMode lingWithHOMER.pdf

[7]. Barzola, J., Espinoza, M., Cabrera, F.: Analysis of hybrid solar/wind/diesel renewable energy system for off-grid rural electrification. Int. J. Renew. Energy Res. 6(3) (2016)

Cite this Article

Praful P. Chudasama, Dr. Chetan D Kotwal, "Feasibility Assessment of a Standalone Hybrid Rural Microgrid Using a Load Following Dispatched Strategy", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 6 Issue 2, pp. 825-832, March-April 2019. Available at doi : https://doi.org/10.32628/IJSRSET2182136

Journal URL : https://ijsrset.com/IJSRSET2182136