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Micro-Grid: Techno-Economic-Greener Solution for Power Distribution System

Radhika Savalia[1], Sounik Roy[2]

[1, 2]Gujarat Energy Research and Management Institute, Gandhinagar, Gujarat, India

Abstract: ***Centralized power systems are providing way to massive number of distributed generation and energy storage system in micro-grid. Technical, environmental and economic obligation are alternating the trends of electricity generation and transmissions. Renewable energy sources are considered as important preference in micro-grid. Simulation results by HOMER shows a case study of an optimal contour of micro grid with solar energy, diesel generators and energy storage system at a site, Ranchi. For different cases including a base case (main grid and diesel generators) and micro-grid case (main grid, solar energy, diesel generators and energy storage system) are simulated and compared. The main focus of the system is on the optimal design and scheduled operation of micro-grid to maximize usage of green energy, reduction of environmental emissions and decrement of levelized cost of electricity.***

Keywords: Diesel Generator, Economic Analysis, Energy Storage, Environmental Emission, Micro-Grid, Renewable Energy, Solar Energy

Nomenclature

^{0}C	Degree Celsius
DG	Diesel Generator
hrs	Hours
kWh	Kilo Watt Hour
kW	Kilo Watt
m/s	Meter Per Second
m^2	Square Meter (Sq. Mt.)
PV	Photovoltaic
Rs.	Rupees (In Indian Currency)
RTPV	Rooftop Photovoltaic Solar System
W	Watt
yr	Year

1. Introduction

The cost of energy is depended on fuel prices. The main motivation for environmental awareness leads to reduce green-houses emissions. In addition, the utilization of renewable energy sources, non-renewable energy sources drive the most effective energy usage technique. Energy policies and regulations are endorsing energy security renewable energy sources, distributed energy resources, renewable energy production from solar, wind, hydro and biomass, etc [1].

The energy generation for solar and wind systems are depended on weather conditions. In this case, there is no correlation between the load demand and energy production. To overcome this issue, power source and demand response management came into the picture.

This provides the facility to customers to modify their load profile with respective energy charges in different duration of time[2]. This may increase the enhancement of the power distribution system. In the grid control system, load shaving, power quality, load priority, energy efficiency improvement techniques are being considered. Traditional power generation is depended on conventional power sources – diesel or coal-based generators [3]. The problems associated with these are the distance from adjacent utility connecting node, unmet load, unreliable utility power supply, the excess energy, diesel prices and amount of pollution emissions, etc. Many renewable and distributed generation technologies have now progressed to the stage.

A micro-grid is a localized grouping of electricity generations, energy storage, and loads [4]. Micro-grid connects different customers with different distribution energy sources and storage, this approach combines small energy generation systems to low and medium voltage level in spite of conventional large power systems. This also provides reliable power distribution option with renewable energy systems and energy storage system. The main purpose of the micro grid is to develop a local grid and provide clean, safe, reliable, secure, resilient, efficient and sustainable energy [5]. It provides better efficiency, local reliability, uninterrupted power supply and maximum penetration of renewable energy sources on the traditional mains grid. Although micro-grid also works with main utility framework. Basically, it is worked on three modes: In grid-connected mode, it is connected to the traditional grid via a switch at the point of common coupling. The traditional grid regulates the frequency and voltage of the system in this mode. In transition mode, a micro-grid can disconnect from the traditional grid at a point of common coupling due to sense grid outage. In islanded mode, the micro-grid behaves an autonomous power system, it supplies power from a distributed generation system to load demands and distributed generations regulate the frequency and voltage of the system in this mode[6].

Thus, the micro-grid can make an effective solution to the centralized problem (grid outages, poor power quality, high electricity transmission loss, interrupted power supply to the end-users, etc.) of the conventional grid system.

2. Problem Statement

The site has a large energy shortage from the mains grid. There is a huge imbalance between the energy provided by utility and the load demand of the site. There were three diesel generators to fulfill the energy shortage. These engender high consumption of diesel, energy bills, carbon footprints, and poor service quality and high.

The micro-grid has been introduced to overcome the aforementioned issues. Micro-grid uses renewable energy sources technology. The main objectives to implement micro-grid is to reduce diesel consumption, carbon emission and better utilization of renewable energy sources. The efficiency of the renewable energy source is expected to be more without the energy storage system and generated energy is directly fed to the load of the site.

The main objectives of this paper are to compare/correlate the two approaches: "base case" and "micro-grid case"; compare/correlate the comprehensive advantages of the optimally designed micro-grid case with existing conventional called base case grid configuration.

3. System under Consideration

The site is located at a latitude of 23.35° N, longitude 85.3° E and at an altitude of 651 meters. Geographical conditions are good for renewable sources throughout the year. Both cases are designed and simulated on HOMER software. HOMER is software that stands for the Hybrid Optimization of Multiple Electric Renewables. It is developed by the U.S. National Renewable Energy Laboratory (NREL). It is used for hybrid systems. It is a modeling software to design and analyze various energy sources, energy storage and electrical-thermal loads. It abridges the work of off-grid and in-grid power systems which includes renewable energy sources like solar photovoltaics, wind turbine, hydro turbine, flywheel, etc. and non-renewable energy sources like coal-based power plants and diesel generators. HOMER is used to simulate the systems to overcome denounce of analysis and design, emergent of uncertain parameters such as energy projection, fuel cost, and load growth. In HOMER, mainly three tasks have been performed: simulation, sensitivity analysis, and optimization. In the simulation, HOMER defines various technical configuration along with the lifecycle expenses of a microgrid for every hour of the year. In optimization, HOMER determines technical feasibility with life span and cost under the constraints defined by the user. In a sensitivity analysis, the user can evaluate the effects of tools with time. For this paper, input data has been taken from the site and database of the software [7][8].

3.1 Load Profile

The average energy consumption per day is 3189.2 kWh/day. The average power is 133.26 kW. Peak demand is 706.07 kW. The load factor is 0.19. The peak month for power consumption is July month. The demand is high in the summer season and low during the winter season. The monthly load profile is shown in Figure 1. The yearly load profile is shown in Figure 2.

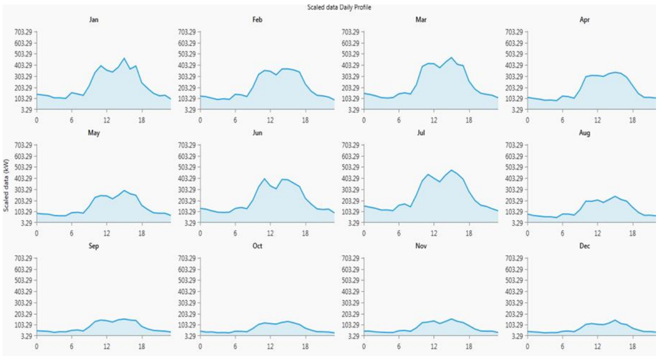

Figure 1: Monthly load profile

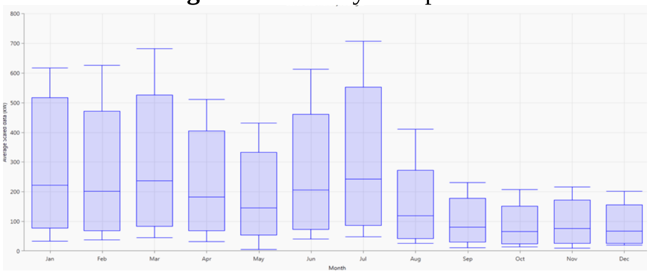

Figure 2: Yearly load profile

3.2 Energy Resources Availability

3.2.1 Solar Radiation

Table 1: Solar Radiation

No	Month	Clearness Index	Daily Radiation (kWh/m^2/day)
1	January	0.439	4.418
2	February	0.507	5.263
3	March	0.441	4.635
4	April	0.536	5.462
5	May	0.521	5.021
6	June	0.434	4.036
7	July	0.387	3.658
8	August	0.459	4.556
9	September	0.508	5.255
10	October	0.513	5.313
11	November	0.475	4.793
12	December	0.401	3.973

Table 1 shows the average daily solar radiation data in kWh per sq. mt per month along with a clearness index. Figure 3 indicates the solar irradiation of the year. As mentioned in Figure 3, the daily solar radiation of April and May are very high while comparing to the rest of the month. The lowest daily radiation is in December which is 3.973 kWh/m2/day. Another column indicates the clearness index from the sun every month. The clearness index is a proportion of the clearness of the air. It is the portion of the solar radiation that is transmitted through the climate to strike the outside of the Earth. It is a dimensionless number somewhere in the range of 0 and 1, characterized as the surface radiation partitioned by the extraterrestrial radiation. The annual average of solar radiation is 4.7 kWh/m2/day.

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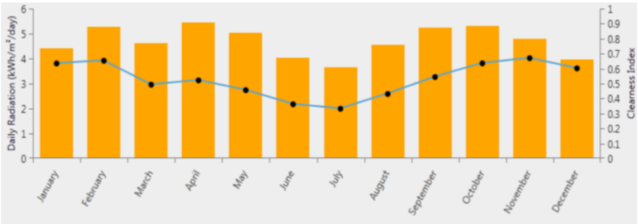

Figure 3: Solar Irradiance

3.2.2 Temperature

Table 2: Temperature

No	Month	Air temperature (^{0}C)
1	January	16.7
2	February	19.9
3	March	25.87
4	April	27.71
5	May	31.21
6	June	27.66
7	July	26.56
8	August	27.04
9	September	27.87
10	October	26.60
11	November	23.45
12	December	18.18

Table 4 illustrates air temperature in degrees Celsius. Figure 4 shows the monthly air temperature in degrees Celsius. The highest temperature is 31.21 ^{0}C in May. The lowest temperature is 16.7 ^{0}C in January. The annual average temperature is 24.90 ^{0}C.

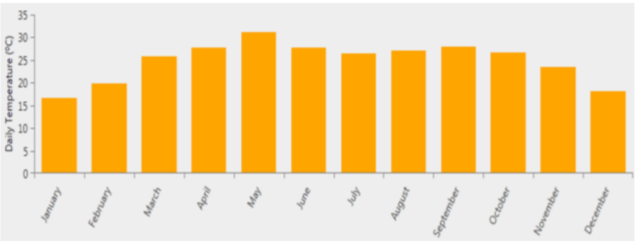

Figure 4: Temperature

3.2.3 Wind Speed

Table 3: Wind Speed

No	Month	Average wind speed (m/s)
1	January	1.390
2	February	1.590
3	March	1.190
4	April	1.150
5	May	1.140
6	June	1.280
7	July	1.460
8	August	1.400
9	September	1.180
10	October	0.640
11	November	0.530
12	December	0.830

The aforementioned Table 3 indicates average wind speed in meter per second for every month. Figure 5 reveals wind speed in each month. The annual average wind speed is 10 m/s. The apical wind speed is 1.590 m/s in February. The undermost wind speed which is 0.530 m/s in November.

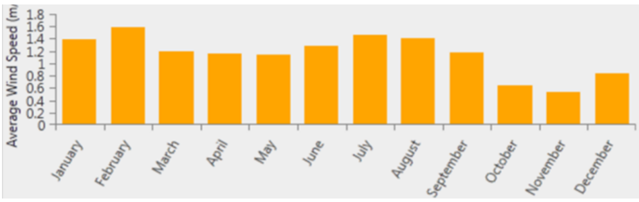

Figure 5: Wind Speed

3.3 Component Details

3.3.1 Base Case

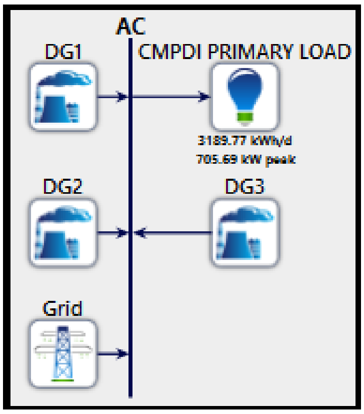

Figure 6: Base case

Figure 6 represents the base case. In the base case, the conventional system has been simulated. The AC primary load of a site is an electrical load which is indicated as CMPDI primary load in Figure 6. Utility grid and three diesel generators provide electricity to the primary load of the site. The consumption of the AC primary load is 1,164,198 kWh per year. Three diesel generators and main grid (utility grid) provide 22% and 78% energy to AC primary load respectively.

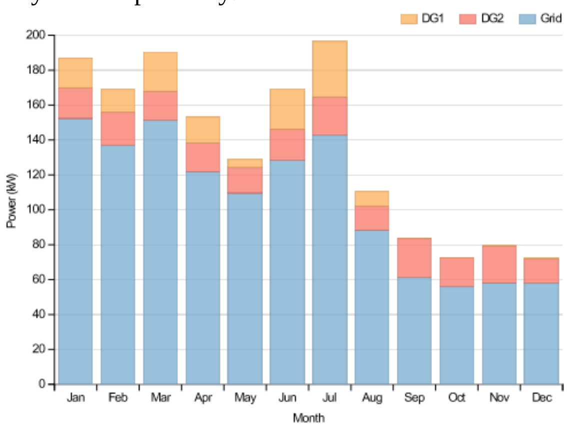

Figure 7: Energy shares in % by energy sources to meet energy demand (Base case)

The unmet load is 69 kWh per year. For Diesel Generator 1, operation hours are 341 hrs/yr, several starts are 140 starts/yr, operational life is 44 yr, mean electrical efficiency is 30%, fuel energy input is 335,544 kWh/yr. For Diesel Generator 2, operation hours are 1615 hrs/yr, a number of starts are 474 starts/yr, operational life is 9 yr, mean electrical efficiency is 18%, fuel energy input is 836,840 kWh/yr. Diesel generator 3 is on standby mode.

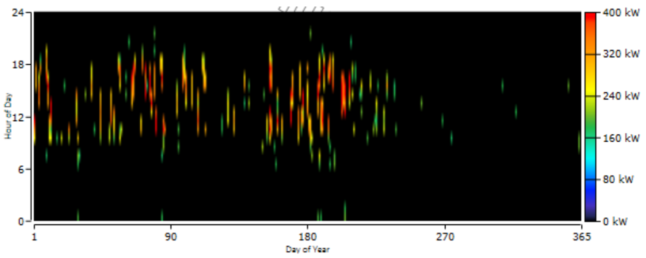

Figure 8: Diesel generator 1 (Base case)

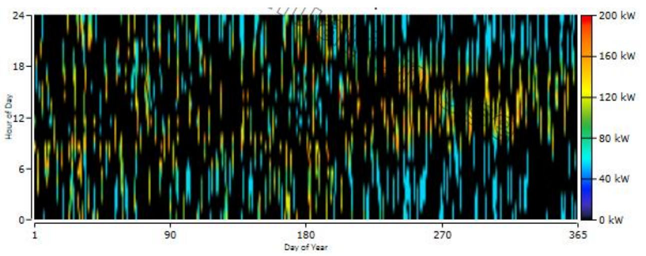

Figure 9: Diesel generator 2 (Base case)

The grid power price is Rs.6.5 per unit. The grid sale capacity is 800 kW. The mean failure frequency is calculated 450 per year. Mean repair time is considered 4.2 hours. Repair time variability is 5%.

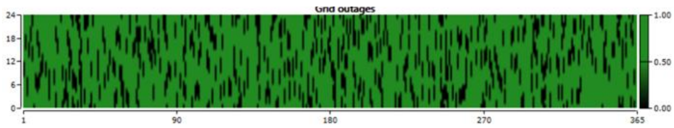

Figure 10: Mean failure frequency

The annual average peak demand is 704 kW. In March, the peak demand is 678 kW. In December, the peak demand is 215 kW which is lowest. Energy purchased from the grid and net purchases from the main grid are 921,984 kWh. The highest energy purchased from the grid is 113,410 kWh in the month of January. The lowest energy purchased from the grid is 41,612 kWh in the month of October.

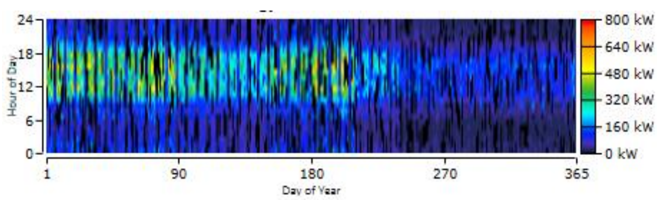

Figure 11: Energy purchased from grid

The total net present cost is Rs. 180,219,040. Levelized cost of energy is 11.408 Rs. /kWh.

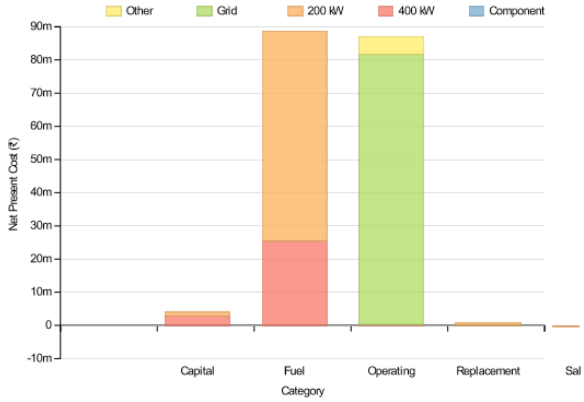

Figure 12: Cost summary (Base case)

3.3.2 Micro grid Case

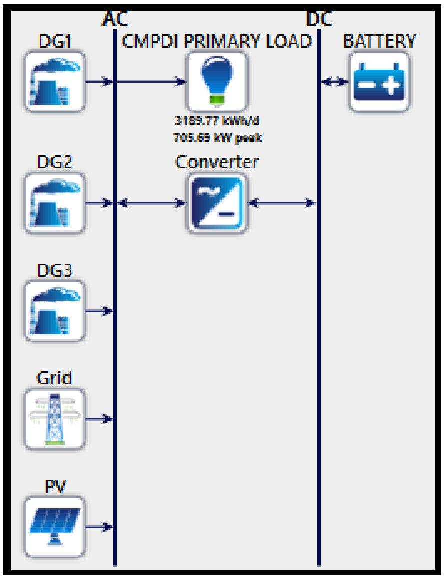

Figure 13: Micro-grid case

In the micro-grid case, the renewable-storage system has been simulated. The AC primary load (CMPDI primary load) is the electrical load. Utility grid, three diesel generators, renewable energy sources along with energy storage system provide electricity to a primary load of the site. In the renewable energy system, a rooftop solar PV (RTPV) system has been introduced. The capacity of the RTPV plant is freeze based on the shadow-free area available on the roof of the site. Converter and energy storage system sizing is determined from the load demand and priority of the load. The consumption of the AC primary load is 1,164,198 kWh per year. To meet this demand, diesel generators, mains grid, and solar system contributed 0%, 76%, and 24% respectively.

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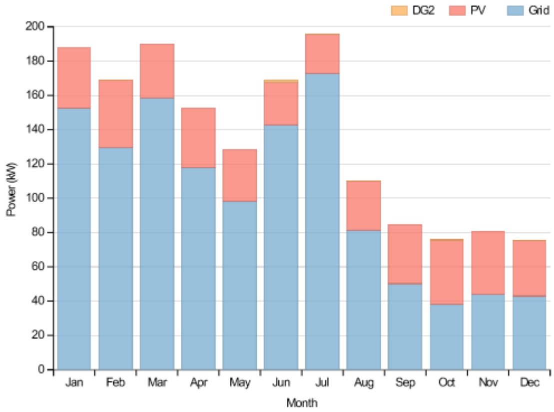

Figure 14: Energy shares in % by energy sources to meet energy demand (Micro-grid case)

The unmet load is 151 kWh per year. For Diesel Generator 1, operation hours are 23 hrs/yr, several starts are 10 starts/yr, operational life is 652 yr, mean electrical efficiency is 31 %, fuel energy input is 6122 kWh/yr. Diesel generator 2 and Diesel generator 3 is on standby mode. For the micro-grid case, fuel governing system has been determined in diesel generators. It will maintain fuel according to load demand. For 320 kW and 240 kW output rating, the fuel consumption is 100 liter per hour and 77.40 liters per hour respectively. For 160 kW and 120 kW output rating the fuel consumption is 52.66 liter per hour and 39.49 liters per hour respectively.

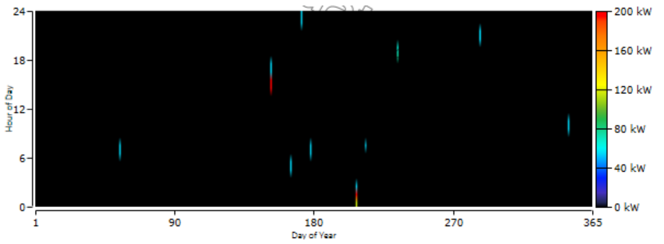

Figure 15: Diesel generator (Micro-grid case)

For the rooftop solar PV plant (RTPV), the total rated capacity is 190 kW. The mean output is 32 kW. The mean output per day is 772.51 kWh per day. Hours per operation is 4377 hrs/yr. Levellised cost is 5.298 Rs. /kWh.

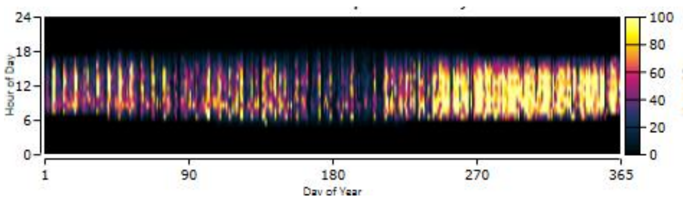

Figure 16: Solar Rooftop PV plant (Micro-grid case)

For the energy storage system (batteries), the nominal capacity is 50 kWh. The usable nominal capacity is 40 kWh. The average energy cost is 8.329 Rs. per kWh. The energy is 1581 kWh per yr. Energy out is 1265 kWh per year. Annual throughput is 1414 kWh per year. The expected life is 10 years.

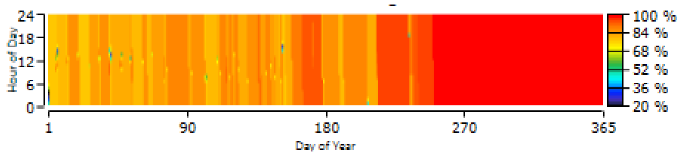

Figure 17: State of charge of battery (Micro-grid case)

For converter, capacity is 200 kW. The maximum output is 21 kW. The hours of operation are 85 hrs/yr. The energy is 1265 kWh per yr. Energy out is 1189 kWh per yr. Losses are 76 kWh per yr. For rectifier, capacity is 188 kW. The maximum output is 25 kW. The hours of operation are 324 hrs/yr. The energy is 1756 kWh per yr. Energy out is 1581 kWh per yr. Losses are 176 kWh per yr.

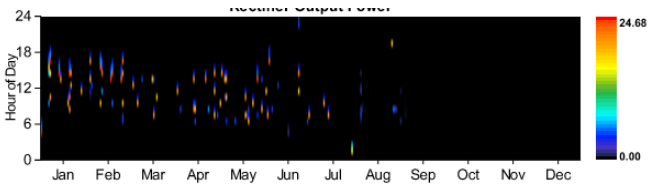

Figure 18: Rectifier output power (Micro-grid case)

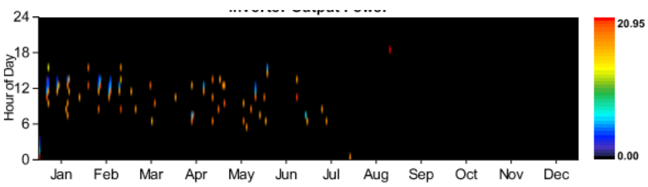

Figure 19: Inverter output power (Micro-grid case)

Grid power price is Rs.6.5 per unit and the grid sell back price is Rs.7.48 per unit. The grid sale capacity is 800 kW. The mean failure frequency is 10 per year. Mean repair time is calculated for 2.2 hours. Capital cost is Rs. 8000 per km.

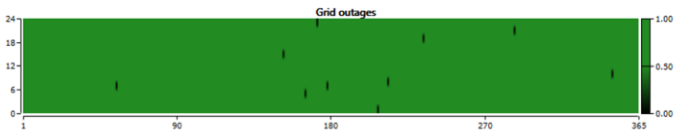

Figure 20: Mean failure frequency (Micro-grid case)

Total energy purchased from grid is 896,873 kWh and total energy sold to grid is 15,641 kWh.

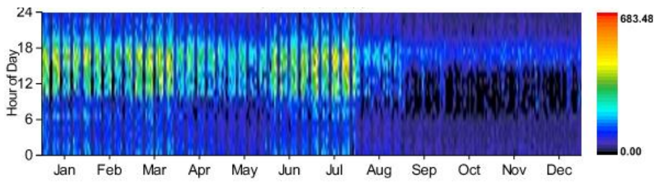

Figure 21: Energy purchased from grid (Micro-grid case)

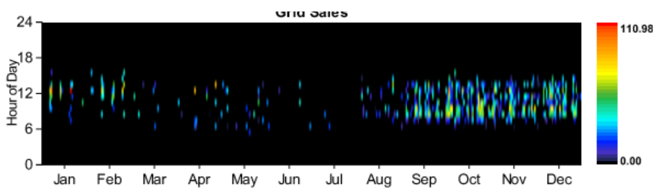

Figure 22: Energy sales to grid (Micro-grid case)

The total net present cost is Rs. 123,917,928. Levelized cost of energy is 7.741 Rs. /kWh.

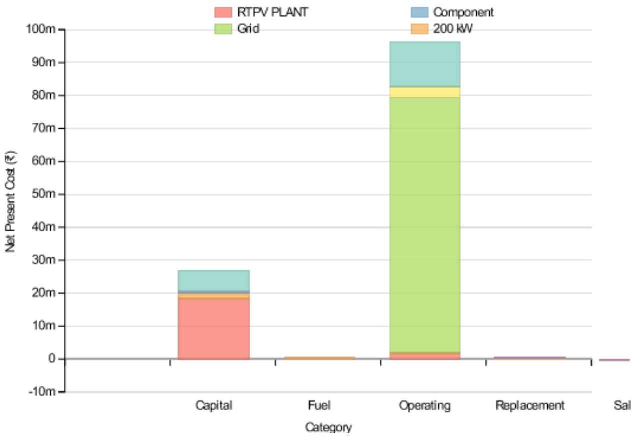

Figure 23: Cost summary (Micro-grid case)

4. Comparison between both configuration

4.1 Comparison of technical parameters

The contribution of diesel generators and main grid are decreased by 22% and 2% respectively in micro-grid. Renewable energy systems are sharing 24% energy in micro-grid. Mean failure frequency proportion is scaled down by 97.77% in micro-grid case.

4.2 Comparison of economic parameters

Net present cost and levellised cost of energy of micro-grid are decreased by 31.24% and 32.21% respectively.

Table 4: Economic comparison

	Economic Components	
	Net Present Cost (Rs.)	Levellised Cost of energy (Rs. /kWh)
Base Case	180,219,040	11.408
Micro grid Case	123,917,928	7.741

4.3 Comparison of environmental emission

Taking carbon emission as an example, the system connected with solar-energy storage is as high as 896,441 kg per year. The pollution emission of the micro-grid case is completely reduced.

Table 5: Environmental comparison

Pollution Content	Emission (kg/year)	
	Base Case	Micro grid Case
Carbon dioxide	896,441	558,578
Carbon monoxide	774	4
Unburned Hydrocarbon	86	0
Particular matter	58	0
Sulphur dioxide	3,156	2,418
Nitrogen oxide	8,146	1,217

However, base case system connected with DG has certain amount of carbon dioxide, carbon monoxide, unburned hydrocarbon, particular matter, Sulphur dioxide and nitrogen However, the base case system connected with DG has a certain amount of carbon dioxide, carbon monoxide, unburned hydrocarbon, particular matter, Sulphur dioxide, and nitrogen oxide. In the micro-grid case, carbon dioxide is reduced by 62%. Carbon monoxide, unburned hydrocarbon, and particular matter are scaled-down totally. Sulfur dioxide and Nitrogen oxide are decreased by 76% and 14% respectively due to reliable renewable energy systems.

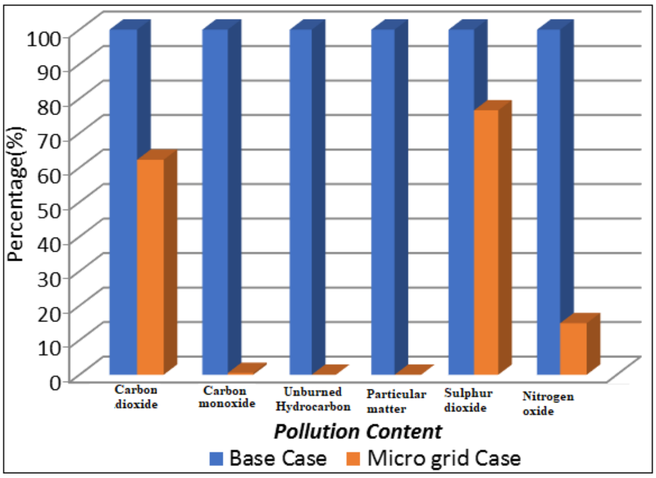

Figure 24: Comparison of both cases

5. Conclusion

This paper analyzed the optimization of available local energy resources and maximizing the use of renewable energy resources. The simulation result also shows that solar-storage-diesel generators-grid configuration reduced mean frequency failure, levellised cost of electricity., net present cost and carbon footprint. It is the best complimentary solution throughout the year.

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Author Profile

Radhika Savalia received the B.E. and M. Tech degrees in Electrical Engineering from Gujarat Technological University in 2014 and Nirma University in 2016, respectively. She is working as Project Officer in Gujarat Energy Research and Management Institute (GERMI). She is a Certified Master Trainer by Skill Council for Green Jobs (SCGJ), National Skill Development Corporation (NSDC), Ministry of Power and Ministry of New and Renewable Energy (MNRE), Govt. of India and Renac Renewable Academy, Germany.

Sounik Roy received the B. Tech degree in Chemical Engineering from Nirma University in 2009. He received M. Engg. (Sustainable Energy) and Graduate Diploma (Engineering Management) in 2011 and 2012 respectively from RMIT University. He has been served as Project Officer at Gujarat Energy Research and Management Institute from 2014 to 2018. He was an active team member of GERMI's Project management consultancy (PMC) team in examining policies, writing proposals, project coordination, site deputation activities, and commissioning.