Modeling A Simple Dc Micro Grid Using Solar Panel, Battery Storage And Backup Generator Arrangement And Do Cost Benefit Analysis For Supplying Isolated Dc Electric Power To Rural Village In Navamalai, Aliyar Region, Tamilnadu, India

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Abstract: This paper is written with respect to the modeling of DC Micro grid using solar panel and backup generator by applying Hybrid Optimization Model for Electric Renewable (HOMER) pro software tool to supply cost effective and reliable independent power to a limited number of rural communities that used specific type of DC loads. The model area was selected ahead of the modeling and analysis process and indicated on Map using the HOMER pro area search facility. A generator that used Methanol was added to the system to enable the designed model more reliable. The contribution of each source type was analyzed in detail in the analysis section of the paper. It showed that the contribution of the generator is insignificant as compared to the contribution of the solar panel in supplying the loads. This paper mainly focused in analyzing the primary and secondary simulation data outputs by considering the base and current model systems. The base model system contained the solar panel and battery storage only. Whereas the current model system contained the solar panel, battery storage and generator. The optimal operation shows a unit cost of Rs. 0.125/kWh with the selected energy system with 100% renewable energy contribution eliminating the need for conventional generator. The developed model helped in sizing the components of the energy system and decides the optimal combination for electrification of the rural village in Navamalai, Aliyar region, Coimbatore District, India by DC power. Final conclusion reached based on the identified optimal model and analysis.

Index Terms: DC Micro Grid, Independent Power Source, Power Generation Economics, Rural Electrification, HOMER pro, Solar PV .

◆

1. INTRODUCTION

Over 1.3 billion people worldwide primarily in Africa and South-East Asia have no access to electricity. Electrification of these remote rural regions through national power grids is largely unviable low due to i) a high infrastructure cost and ii) limited power generation capacity in many countries. Therefore, low-power, low-voltage, solar photovoltaic (PV) based DC micro grids are becoming very popular in these regions. That is, Delivering grid electric power to rural communities is not practically simple and cost effective option. The reason for this is that rural communities usually live in a distributed and scattered manner and usually cover a wide geographical area. It is a known fact that rural communities mostly use generators and/ or batteries for fulfilling their energy demand requirements [1, 2].

Life in remote Indian villages grinds to a standstill as darkness descends. Workers down tools, kids strain to see their schoolbooks under the faint glow of aged kerosene lamps and adults struggle to carry out the most basic of household chores. The arrival of solar power has changed all of that. On a humid evening, children sit cross-legged to study, fans whirr and adults are delighted to see what they are eating and drinking [3]. DC power systems has been gaining attention by researchers and investigated for several issues that need to be considered during this transition interval from current conventional power systems into modern smart grids involving DC micro grids. Photovoltaic (PV) hybrid systems can make a positive contribution to the sustainability of rural communities in many parts of the world that do not have access to electricity grid. Integration of solar photovoltaic system with diesel generator for remote and rural areas would assist in expanding the electricity access [4, 5, and 6]. Hybrid energy systems generally integrate renewable energy sources with fossil fuel powered diesel/petrol generator to provide electric power where the electricity is either fed directly into the grid or to batteries for energy storage. The role of integrating renewable energy in a hybrid energy system is to save diesel fuel. Some of the renewable energy sources are small wind turbines, photovoltaic systems, micro-hydro, biomass, fuel cells and so on. A hybrid energy system may or may not be connected to the grid. They are generally independent of large centralized electric grids and are used in rural remote areas. In hybrid systems it is possible for the individual power sources to provide different percentages of the total load [7, 8]. Hybrid energy system is an excellent solution for electrification of remote rural areas where the grid extension is difficult and not economical. Such system incorporates a combination of

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one or several renewable energy sources such as solar photovoltaic, wind energy, micro-hydro and may be conventional generators for backup [9, 10].

2. RESEARCH METHODS

The methodologies that followed for the modeling and analysis of the isolated DC Micro grid for supplying electric power to the rural village in Navamalai District area is as depicted in figure 1 below. The first step in the modeling and analysis process is the sizing of the loads of the system and entering it into the HOMER pro software. The load data is manually entered to the software for the peak month of January and the daily, seasonal and yearly load profiles are generated and analyzed. In the modeling process, the specific area Solar global horizontal irradiance, GHI and temperature data are downloaded either from the NASA surface meteorology and solar energy database or National Renewable energy Laboratory, NREL, database using of internet.

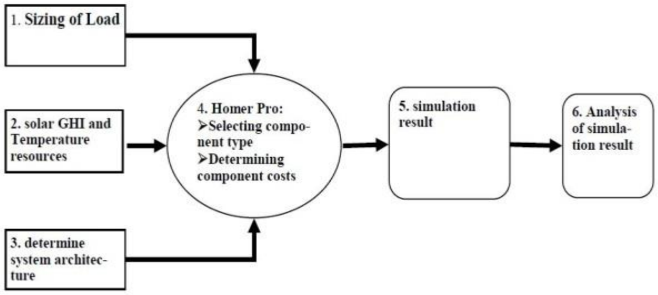
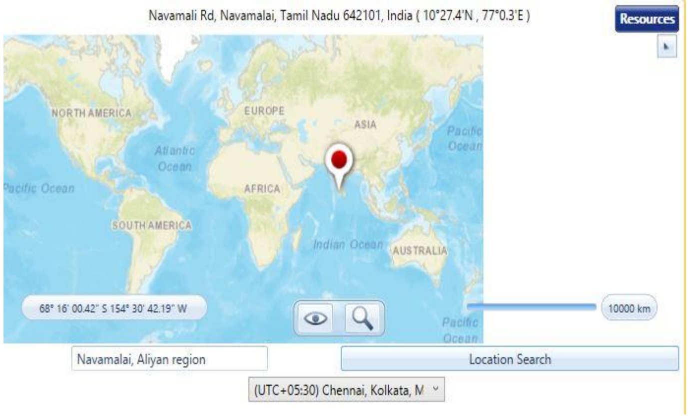


***Fig. 1**. Research methodology map*

These data resources are used as inputs for selecting the right type of components and also to choose the right system architecture. Before modeling of the system Architecture in HOMER pro software, each components actual market price has been identified from Indian market price perspective. Indian rupees are used for setting the price of all types of components used in the modeling. Finally, based on the simulation results of the designed system model architectures in HOMER pro software, detailed analysis of results has been done, conclusions reached and recommendations given.

3. LOCATING THE DESIGN AREA ON MAP


Navamali Rd, Navamalai, Tamil Nadu 642101, India (10°27.4'N , 77°0.3'E)

Navamalai, Aliyan region

(UTC+05:30) Chennai, Kolkata, M


Discount rate (%): 6.00

Inflation rate (%): 2.00

Annual capacity shortage (%): 4.00

Project lifetime (years): 25.00

***Fig. 2**. Design area location on Map Using HOMER pro area search*

4. SIZING OF LOAD: HOUSEHOLD LEVEL LOAD ESTIMATION

1. DC Light ………..20W×7hrs/day×2= 40W×7hrs/day
2. DC Fan…………… 40W×14hrs/day= 40W×14hrs/day
3. TV Load…………..20W×5hrs/day = 20W×5hrs/day

Total……… 100W per day per household

4. Additional 5% of the total household power assumed as extra power for loss to each household. Hence, 5 %(100W) =5Watts additional power added as loss power to each household daily power requirement.
5. Therefore, Total power required by individual household per day will be equal to
   100W+5W=105Watts/day
6. Total number of households included in the design model =20
7. Total power requirement for the whole village per day equals
   105Watts/day×20=2100Watts/day

The following operational time profiling of the loads is estimated based on the above operational hours duration for each load type.

***Table 1.** Rural village load operational time profiling*

Hr. of Day	FAN, W	LAMP, W	TV, W	LOSS, W	Load Watt/day	Total village load Watt/day	Total village load KW/day
0	40	40		5	85	1700	1.7
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11	40			5	45	900	0.9
12	40			5	45	900	0.9
13	40			5	45	900	0.9
14	40			5	45	900	0.9
15	40			5	45	900	0.9
16	40			5	45	900	0.9
17	40			5	45	900	0.9
18	40	40	20	5	105	2100	2.1
19	40	40	20	5	105	2100	2.1
20	40	40	20	5	105	2100	2.1
21	40	40	20	5	105	2100	2.1
22	40	40	20	5	105	2100	2.1
23	40	40		5	85	1700	1.7

5. SYSTEM MODELLING

5.1. Component Specifications

The following Component specifications are used in the Model system Architecture.

a. Solar panel
- ✓ Name: Froniussymo 4.5 -3-S with generic PV(Fron4.5)
- ✓ Type: Flat plate
- ✓ Capacity: 4.4KW
- ✓ Temperature coefficient: -0.4100
- ✓ Operating temperature: 45^0C
- ✓ Efficiency: 17.30%
- ✓ Life time: 15 years

b. Battery Storage
- ✓ Name: Powersafe SBS 1800
- ✓ Nominal Capacity: 24.8Kwh
- ✓ Maximum Capacity: 2.06E+03Ah
- ✓ Capacity Ratio: 0.298
- ✓ Round Trip efficiency: 97%
- ✓ Maximum Charge Current: 1.8E+03A
- ✓ Maximum Discharge Current: 2.3E+03A
- ✓ Maximum Charge Rate:1A/Ah
- ✓ Life Time: 15 years

c. Generator
- ✓ Name: Oorja 1.5KW Model T-1
- ✓ Capacity: 1.5KW
- ✓ Fuel Type: Methanol
- ✓ Fuel Curve Intercept: 0L/hr
- ✓ Fuel Curve Slope:0.800L/hr/KW
- ✓ Emissions:
  - CO: 0 g/L fuel
  - Unburned HC: 0 g/L fuel
  - Particulates: 0 g/L fuel
  - Fuel sulphur to PM: 0%
- ✓ Site Specific Specs:
  - Minimum Load Ratio: 100%
  - Life Time: 10,000.00 hours

d. Component costs

***Table 2**. Component Cost Estimation*

No	Component type	Capital	Replacement	O&M
1	Solar Panel:Froniussymo 4.5 -3-S with generic PV(Fron4.5)	110,000.00 Rs.	70,000.00 Rs.	1000.00 Rs./Year
2	Battery Storage:Powersafe SBS 1800	26,250.00 Rs.	8,750.00 Rs.	3,500.00 Rs./Year
3	Generator: Oorja 1.5KW Model T-1	150,000.00 Rs.	30,000.00 Rs.	10.00 Rs. Per Operating Hour

5.2. Hybrid Model System Architecture with Solar Panel, generator and battery Storage

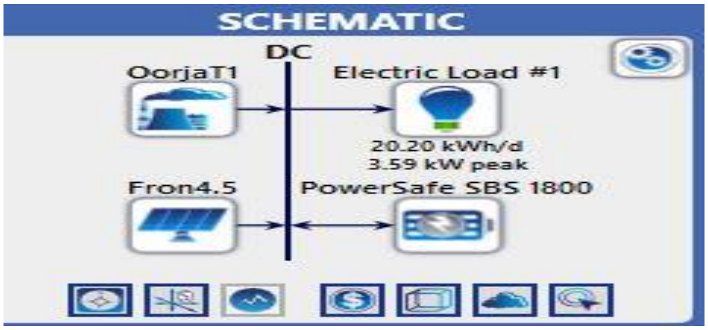


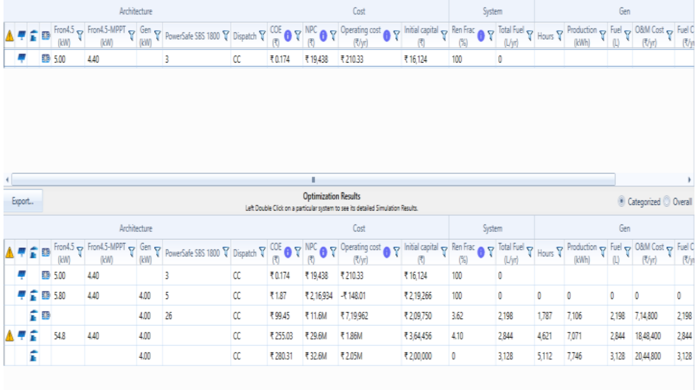
***Fig.3**. HOMERpro Hybrid Model System Architecture with solar panel, Generator and battery storage.*

- ➢ The model before the inclusion of the generator, Oorja T1, is used as a base model for doing all the analysis in comparison with the current model after the inclusion of the generator as depicted in the system architecture of figure 3.

6. HOMERpro SIMULATION RESULT TABLES AND FIGURES FOR THE BASE AND CURRENT MODEL ARCHITECTURES

6.1. Primary simulation results of the base and current model architectures

The primary simulation results of the base and current model architectures are as depicted in figure 4 below.



				Architecture					Cost				System		Gen				
⚠				Fron4.5 (kW)	Fron4.5-MPPT (kW)	Gen (kW)	PowerSafe SBS 1800	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹/yr)	Initial capital (₹)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)	O&M Cost (₹/yr)	Fuel C (₹/y
	●		●	5.00	4.40		3	CC	₹ 0.174	₹ 19,438	₹ 210.33	₹ 16,124	100	0					

Export...

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

● Categorized ○ Overall

				Architecture					Cost				System		Gen				
⚠				Fron4.5 (kW)	Fron4.5-MPPT (kW)	Gen (kW)	PowerSafe SBS 1800	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹/yr)	Initial capital (₹)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)	O&M Cost (₹/yr)	Fuel C (₹/y
	●		●	5.00	4.40		3	CC	₹ 0.174	₹ 19,438	₹ 210.33	₹ 16,124	100	0					
	●	●	●	5.80	4.40	4.00	5	CC	₹ 1.87	₹ 2,16,934	-₹ 148.01	₹ 2,19,266	100	0	0	0	0	0	0
		●	●			4.00	26	CC	₹ 99.45	₹ 11.6M	₹ 7,19,962	₹ 2,09,750	3.62	2,198	1,787	7,106	2,198	7,14,800	2,198
⚠	●	●		54.8	4.40	4.00		CC	₹ 255.03	₹ 29.6M	₹ 1.86M	₹ 3,64,456	4.10	2,844	4,621	7,071	2,844	18,48,400	2,844
		●				4.00		CC	₹ 280.31	₹ 32.6M	₹ 2.05M	₹ 2,00,000	0	3,128	5,112	7,746	3,128	20,44,800	3,128

***Fig. 4**.HOMERpro Primary Simulation Result for base and current.*

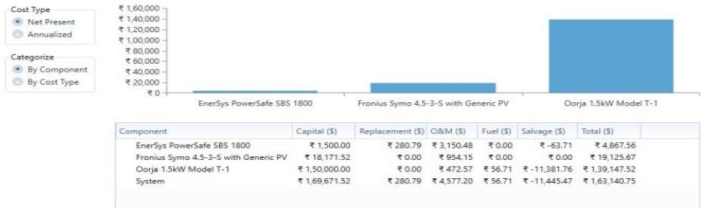
6.2. Secondary simulation results

The secondary simulation results are those obtained from the primary simulation results of figure 5 of the base and current models. They are cost summary, cash flow, economic comparison, electrical output, renewable penetration, state of battery, state of solar panel, generator set and emissions level. The simulation results for all are depicted here for latter comparison and analysis of the base and the current model system architectures.

a. Cost summary

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
EnerSys PowerSafe SBS 1800	₹ 1,125.00	₹ 210.59	₹ 2,362.86	₹ 0.00	₹ -47.78	₹ 3,650.67
Fronius Symo 4.5-3-S with Generic PV	₹ 14,999.47	₹ 0.00	₹ 787.59	₹ 0.00	₹ 0.00	₹ 15,787.06
System	₹ 16,124.47	₹ 210.59	₹ 3,150.45	₹ 0.00	₹ -47.78	₹ 19,437.73

***Fig. 5**. Cost graph and summary table for the base Model*



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
EnerSys PowerSafe SBS 1800	₹ 1,500.00	₹ 280.79	₹ 3,150.48	₹ 0.00	₹ -63.71	₹ 4,867.56
Fronius Symo 4.5-3-S with Generic PV	₹ 18,171.52	₹ 0.00	₹ 954.15	₹ 0.00	₹ 0.00	₹ 19,125.67
Oorja 1.5kW Model T-1	₹ 1,50,000.00	₹ 0.00	₹ 472.57	₹ 56.71	₹ -11,381.76	₹ 1,39,147.52
System	₹ 1,69,671.52	₹ 280.79	₹ 4,577.20	₹ 56.71	₹ -11,445.47	₹ 1,63,140.75

***Fig. 6**. Cost graph and summary table for the current Model*

b. b. Cash flow

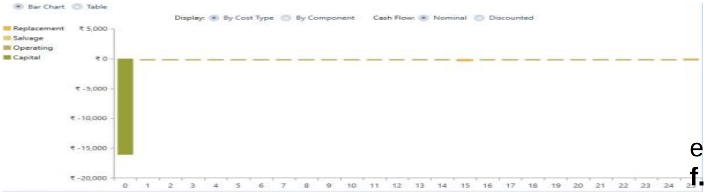
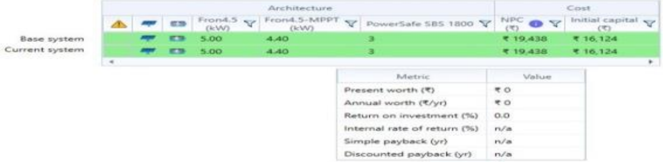


***Fig. 7**. Cash flow graph for the base Model*

***Fig. 8**. Cash flow graph for the current Model*

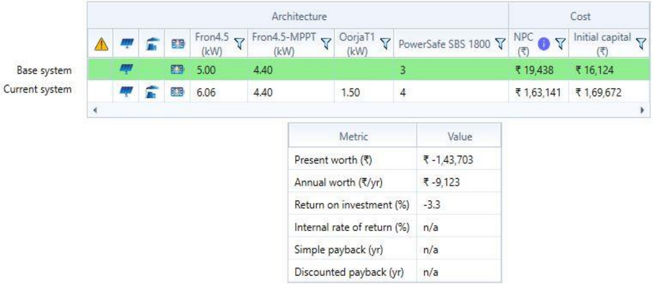
c. c. Economic comparison



	Architecture						Cost	
	⚠			Fron4.5 (kW)	Fron4.5-MPPT (kW)	PowerSafe SBS 1800	NPC (₹)	Initial capital (₹)
Base system				5.00	4.40	3	₹ 19,438	₹ 16,124
Current system				5.00	4.40	3	₹ 19,438	₹ 16,124

Metric	Value
Present worth (₹)	₹ 0
Annual worth (₹/yr)	₹ 0
Return on investment (%)	0.0
Internal rate of return (%)	n/a
Simple payback (yr)	n/a
Discounted payback (yr)	n/a

***Fig. 9.** Economic comparison summary for the base Model*



	Architecture							Cost	
	⚠			Fron4.5 (kW)	Fron4.5-MPPT (kW)	OorjaT1 (kW)	PowerSafe SBS 1800	NPC (₹)	Initial capital (₹)
Base system				5.00	4.40		3	₹ 19,438	₹ 16,124
Current system				6.06	4.40	1.50	4	₹ 1,63,141	₹ 1,69,672

Metric	Value
Present worth (₹)	₹ -1,43,703
Annual worth (₹/yr)	₹ -9,123
Return on investment (%)	-3.3
Internal rate of return (%)	n/a
Simple payback (yr)	n/a
Discounted payback (yr)	n/a

***Fig. 10.** Economic comparison summary for the current Model*

d. Electrical output

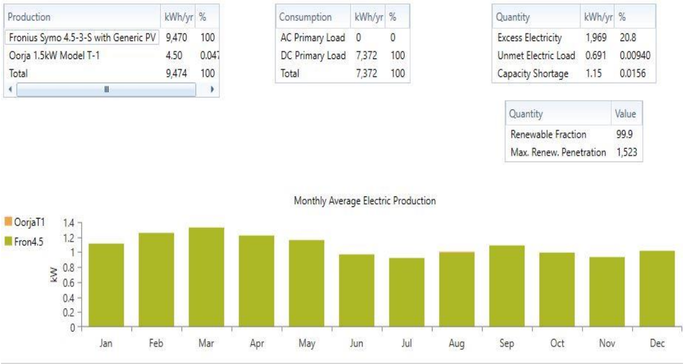
Production	kWh/yr	%
Fronius Symo 4.5-3-S with Generic PV	8,035	100
Total	8,035	100

Consumption	kWh/yr	%
AC Primary Load	0	0
DC Primary Load	7,109	100
Total	7,109	100

Quantity	kWh/yr	%
Excess Electricity	809	10.1
Unmet Electric Load	264	3.58
Capacity Shortage	301	4.08

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	1,443

***Fig.11.** Electrical output summary tables and graph for the base Model*



Production	kWh/yr	%
Fronius Symo 4.5-3-S with Generic PV	9,470	100
Oorja 1.5kW Model T-1	4.50	0.047
Total	9,474	100

Consumption	kWh/yr	%
AC Primary Load	0	0
DC Primary Load	7,372	100
Total	7,372	100

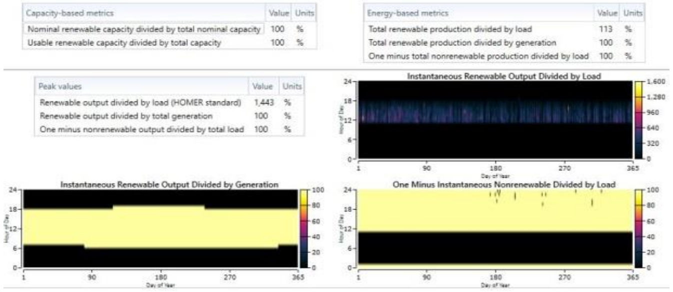
Quantity	kWh/yr	%
Excess Electricity	1,969	20.8
Unmet Electric Load	0.691	0.00940
Capacity Shortage	1.15	0.0156

Quantity	Value
Renewable Fraction	99.9
Max. Renew. Penetration	1,523

***Fig. 12.** Electrical output summary tables and graph for the current Model*

e.

f. Renewable penetration

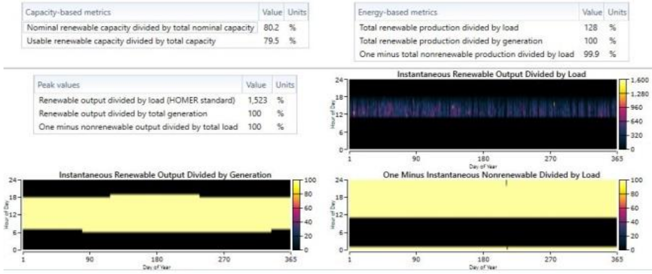


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	113	%
Total renewable production divided by generation	100	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	1,443	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

***Fig.13**. Renewable penetration Summary*



Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	80.2	%
Usable renewable capacity divided by total capacity	79.5	%

Energy-based metrics	Value	Units
Total renewable production divided by load	128	%
Total renewable production divided by generation	100	%
One minus total nonrenewable production divided by load	99.9	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	1,523	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

***Fig.14**. Renewable penetration Summary tables and graphs for the current Model*

g. f. Battery, Enersys powersafe SBS1800 summary tables and Graphs

Quantity	Value	Units
Batteries	3.00	qty.
String Size	1.00	batteries
Strings in Parallel	3.00	strings
Bus Voltage	12.0	V

Quantity	Value	Units
Autonomy	61.8	hr
Storage Wear Cost	0.00480	₹/kWh
Nominal Capacity	74.3	kWh
Usable Nominal Capacity	52.0	kWh
Lifetime Throughput	77,217	kWh
Expected Life	15.0	yr

Quantity	Value	Units
Average Energy Cost	0	₹/kWh
Energy In	5,187	kWh/yr
Energy Out	5,070	kWh/yr
Storage Depletion	39.6	kWh/yr
Losses	156	kWh/yr
Annual Throughput	5,148	kWh/yr

***Fig.15.** Battery summary tables and graphs for the base model*

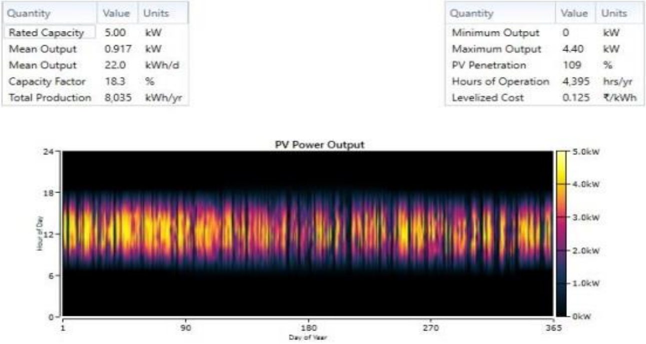
Quantity	Value	Units
Batteries	4.00	qty.
String Size	1.00	batteries
Strings in Parallel	4.00	strings
Bus Voltage	12.0	V

Quantity	Value	Units
Autonomy	82.4	hr
Storage Wear Cost	0.00480	₹/kWh
Nominal Capacity	99.1	kWh
Usable Nominal Capacity	69.3	kWh
Lifetime Throughput	80,205	kWh
Expected Life	15.0	yr

Quantity	Value	Units
Average Energy Cost	0	₹/kWh
Energy In	5,399	kWh/yr
Energy Out	5,266	kWh/yr
Storage Depletion	29.1	kWh/yr
Losses	162	kWh/yr
Annual Throughput	5,347	kWh/yr

***Fig.16**. Battery summary tables and graphs for the current Model*

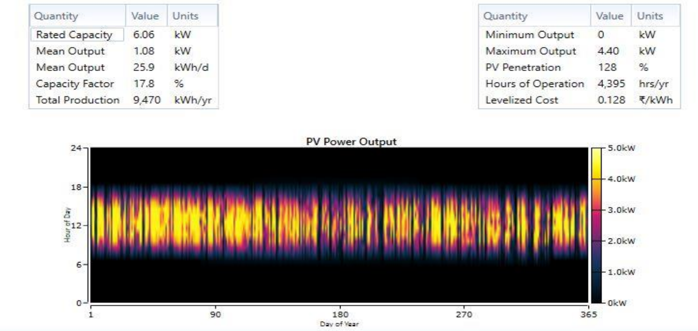
h. g. Solar Panel summary tables and graph



Quantity	Value	Units
Rated Capacity	5.00	kW
Mean Output	0.917	kW
Mean Output	22.0	kWh/d
Capacity Factor	18.3	%
Total Production	8,035	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	4.40	kW
PV Penetration	109	%
Hours of Operation	4,395	hrs/yr
Levelized Cost	0.125	₹/kWh

***Fig.17.** Solar Panel summary tables and graph for the base Model*

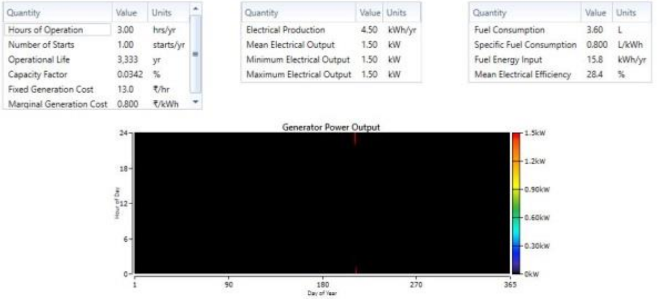


Quantity	Value	Units
Rated Capacity	6.06	kW
Mean Output	1.08	kW
Mean Output	25.9	kWh/d
Capacity Factor	17.8	%
Total Production	9,470	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	4.40	kW
PV Penetration	128	%
Hours of Operation	4,395	hrs/yr
Levelized Cost	0.128	₹/kWh

***Fig.18.** Solar Panel summary tables and graph for the current Model*

i. Generator set summary tables and Graph



Quantity	Value	Units
Hours of Operation	3.00	hrs/yr
Number of Starts	1.00	starts/yr
Operational Life	3,333	yr
Capacity Factor	0.0342	%
Fixed Generation Cost	13.0	₹/hr
Marginal Generation Cost	0.800	₹/kWh

Quantity	Value	Units
Electrical Production	4.50	kWh/yr
Mean Electrical Output	1.50	kW
Minimum Electrical Output	1.50	kW
Maximum Electrical Output	1.50	kW

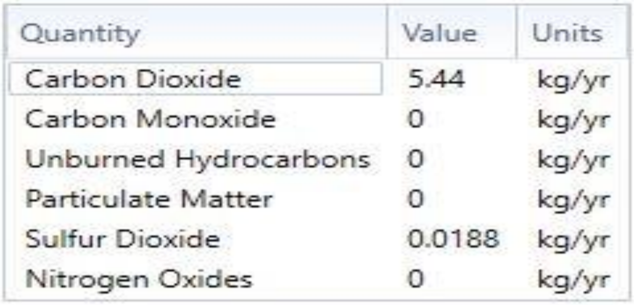
Quantity	Value	Units
Fuel Consumption	3.60	L
Specific Fuel Consumption	0.800	L/kWh
Fuel Energy Input	15.8	kWh/yr
Mean Electrical Efficiency	28.4	%

***Fig.19.** Generator set simulation result summary and graph for the current Model*

j. Emissions Level

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

***Fig.20.** Emissions Level for the base model*



Quantity	Value	Units
Carbon Dioxide	5.44	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0.0188	kg/yr
Nitrogen Oxides	0	kg/yr

***Fig.21.** Emissions Level for the current model*

7. ANALYSIS OF SIMULATION RESULTS

7.1. Analyses of the primary simulation result

The base model which used the selected components type of solar panel and battery is the optimum model to efficiently supply DC electric power to the 20 rural residential houses in comparison with the current model with the inclusion of generator. The base model is the one which used one solar panel of type FroniusSymo 4.5-3-S generic PV with capacity 4.4KW and an energy storage battery of type Enersys Power Safe SBS 1800 having 1 string. The base mode has total net present cost, NPC, of 19,438INR, levelized cost of energy, COE, of 0.174INR, operating cost 210.33INR, Initial capital 16,124.00INR, production 8,035KWh/yr and renewable fraction of 100%. The current model is the one which used one solar panel of type FroniusSymo 4.5-3-S generic PV with capacity 4.4KW, an energy storage battery of type Enersys Power Safe SBS 1800 having 1 string and a generator set of type Oorja 1.5KW Model T-1 with capacity 1.5 KW. The total net present cost for the current model is equivalent to 163,141.00INR, with levelized cost of energy equals 1.40INR, operating cost of -414.59 INR, initial capital of 169,672.00INR, production 9,470KWh/yr and renewable fraction equivalent to 99.9%. By closely observing the renewable fraction in both the base model and current model, it is clear that the solar panel only can efficiently and reliably supply the required DC power to all the rural DC loads. That is, the 20 rural houses daily energy demand is 20.20KWh/day as seen in the model architecture. This is equivalent to 7,373KWh/yr. This total annual energy demand of the loads can be met with the base model since it is below 8,035KWh/yr. Therefore, the system model can be developed only with the selected Solar panel and battery storage types with the exclusion of the generator.

7.2. Analyses of the secondary simulation result graphs and data in section 6.2 above:

Section 6.2 displays the pairs of the secondary simulation result graphs and data for the base model and the current model for further analysis. The secondary simulation result graphs and data are derived from the primary simulation result data of the respective model in section 6.1.The secondary simulation results are cost summary, cash flow, economic comparison, electrical output, renewable penetration, state of battery, state of solar panel, state of generator and Emissions level. Some of the analysis for each parameter will be done as follows:

1. Cost summary Analysis: The capital, replacement, O&M, Fuel, Salvage, and total cost for the base model are 16,124.47, 210.59, 3150.45, 0, -47.78 and 19,437.73 respectively. All are in terms of Indian rupees (INR). And that of the current model are 189,671.52I, 280.79, 4577.2, 56.71, -11445.47and 163,140.75. All are in terms of INR.
2. Cash Flow Analysis: Using the bar chart and cost type option for cash flow as given in section b of 6.2, it is evident that the cash flow for the base model goes far below -15,000INR and that of the current model goes far below -150,000INR.
3. Economic comparison Analysis: The net present cost for the base model is 19,438INR and that of the current model is 163,141INR. Initial capital for the base model is 16,124INR and that of the current model is 169,672INR. Present worth, annual worth and return on Investment for the base model are 0 INR, 0 INR/yr and 0% respectively and that of the current model are -143,703INR, - 9,123INR/yr and -3.3%.
4. Electrical output Analysis: total electrical output production from the base model is 8035KWh/yr with 100% production where as that of the current model is 9470KWh/yr from the solar panel and 4.50KWh/yr from the generator totaling 9474KWh/yr. Excess electricity in the case of base model is 809KWh/yr or 10.1% and that of the current model is 1969KWh/yr or 20.8%.
5. Renewable Penetration Analysis:

Table 3.*Renewable Penetration Analysis*

System Model Architecture type	Capacity Based Metrics		Energy Based Metrics			Peak Values		
	Nominal renewable capacity divided by total nominal capacity %	Usable renewable capacity divided by total capacity %	Total renewable production divided by load %	Total renewable production divided by generation %	One Minus total renewable production divided by load %	Renewable output divided by load %	Renewable output divided by total generation %	One minus renewable output divided by total load %
Base	100	100	113	100	100	1443	100	100
Current	80.2	79.5	128	100	99.9	1523	100	100

6. Generator set Analysis:

The generator has 3hr/yr operational time with electrical production level of 4.5KWh/yr, mean electrical output of 1.50KW, minimum electrical output of 1.50KW and maximum electrical output of 1.5KW. It will have a fuel consumption of 3.60Litter, specific fuel consumption of 0.800Litter/KWh, fuel energy input of 15.8KWh/yr and mean electrical efficiency of 28.4%.

7. Emissions Level Analysis:

Carbon dioxide emission for the base model is 0kg/yr where as it is equal to 5.44kg/yr for the current Model. Similarly, sulphur dioxide emission is 0kg/yr and 0. 0188kg/yr for the base and current models respectively. All other types of emissions like carbon monoxide, unburned hydrocarbons, particulate matter, and nitrogen oxide are 0kg/yr for both the base and current models as seen from the secondary simulation result.

8. CONCLUSION

From the preceding analyses in section VI and VII, the following conclusions can be made:

1. The power and energy demand of the twenty rural residential houses included in this model study is equal to 20.20KWh of energy per day equivalent to 7,373KWh of energy per year. This can be met with the base model which comprised of solar panel of type Fronius Symo 4.5-3-S generic PV with capacity 4.4KW and an energy storage battery of type Enersys Power Safe SBS 1800.
2. The base model option of design is free from any type of emissions besides its capability to sufficiently and reliably supply the required power and/or energy to the village loads.
3. The prototype of this model can easily be implemented and practical parameters easily analyzed if funding for the project obtained from concerned stakeholders of governmental or private sources.

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