Performance optimization of a Rooftop Hybridized Solar PV-AC Grid assisted power system for peak load management

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ABSTRACT
Nowadays, the power system utility has started to consider the green power technology in order for the world to have a healthier environment. A small-scale hybridized solar PV-AC grid (HSPVACG) power system is proposed to be developed to operate with AC grid. This system consists of a photovoltaic array installed on the rooftop. Moreover the roof is flat, which implies that system can be placed in such a way so as to get maximum output from the PV modules. This system is analysed by The Hybrid Optimization Model for Electric Renewable (HOMER) software. It has been used to perform random selection of sizing and operational strategy of generating system in order to obtain the finest solution of hybrid renewable energy (solar PV –AC grid assisted power system) with lowest Total Net Present Cost (TNPC). Also it is presents a scenario for supplying electricity by using mini-grid hybrid power system consisting of renewable energy, backup battery and surplus ac grid connection.

Keywords **–**Grid assisted, Rooftop solar PV, Hybrid power system, HOMER simulation, Optimization.

I. INTRODUCTION
The conventional fossil fuel energy sources such as petroleum, natural gas, and coal which meet most of the world's energy demand today are being depleted rapidly. Also, their combustion products are causing global problems such as the greenhouse effect and pollution which are posing great danger for our environment and eventually for the entire life on our planet. The renewable energy sources (solar, wind, tidal, geothermal etc.) are attracting more attention as an alternative energy. Among the renewable energy sources, the photovoltaic (PV) energy has been widely utilized in low power applications. It is also the most promising candidate for research and development for large scale users as the fabrication of low cost PV devices becomes a reality. Photovoltaic generators which directly convert solar radiation into electricity have a lot of significant advantages such as being inexhaustible and pollution free, silent, with no rotating parts, and with size-independent electric conversion efficiency. [1-3]

The energy efficiency and renewable energy under The Indian Ministry of renewable energy is focused on targeting for renewable energy to be significant contributor and for better utilization of energy Resources. An emphasis to further reduce the dependency on petroleum has also led to extra effort in integrating alternative source of energy.

Regency Institute of Technology (RIT) -Yanam is located between latitudes 16°42′ N to 16°43′ North and longitudes 82°11′ ′to 82°19′ East. It has the highest solar energy density the solar energy density is low during July and August because of the monsoon season .due to coastal area it has relatively high wind speed also. The yearly average daily solar radiation and average wind speed 5.82 kWh/m2/day and 3.8 m/s respectively. The objective of this paper is to determine the best configuration of hybrid renewable system, which is consist of rooftop solar PV assisted by AC Grid for selected sample load to the optimal sizing and operational strategy of solar energy that can offer the lowest Amount of Total Net Present Cost (TNPC).

The Hybrid Optimization Model for Electric Renewable (HOMER) software has been used to perform random selection of sizing and operational strategy of generating system in order to obtain the finest solution of hybrid renewable energy (Rooftop installed solar PV –AC grid assisted power system) with lowest TNPC. Also it is presents a scenario for supplying electricity by using mini-grid hybrid power system consisting of renewable energy, backup battery and surplus ac grid connection.

1.1 Hybrid energy
A combination of different but complementary energy generation systems based on renewable energies or mixed with backup provision is known as a hybrid power system ("hybrid system"). Based on type of load demand Electricity generation coupled at DC/AC bus line through different converter arrangement. Figure 1.

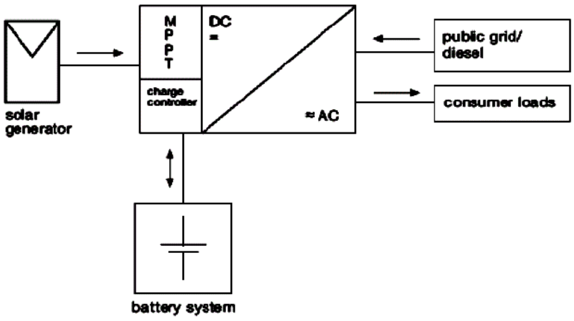


Fig 1: Sample Hybrid System

1.2 Benefits offered by rooftop-PV

The benefits offered by rooftops for the economical and sustainable deployment of renewable solar energy also include: easy Access to sunlight. Because the roof surface is generally located above the "shade line" for trees and adjacent structures, this surface offers virtually unobstructed access to available solar energy. It is placed secure location. In general, the users of the energy generated by rooftop solar are located directly beneath the rooftop, reducing transmission and operating costs. In addition, because rooftop solar is generally located directly within the current developed electric grid, no new transmission lines or controls are necessary .The roof top arrangement is the economics of rooftop solar are becoming increasingly attractive for both commercial and residential customers. For the homeowner, the cost of rooftop solar after available federal and local incentives may generate up to a 15% return on investment[6]. Currently the rooftop solar can be effectively combined into Building Integrated Photovoltaic (BIPV) systems, offering significant material, installation, and maintenance cost savings.

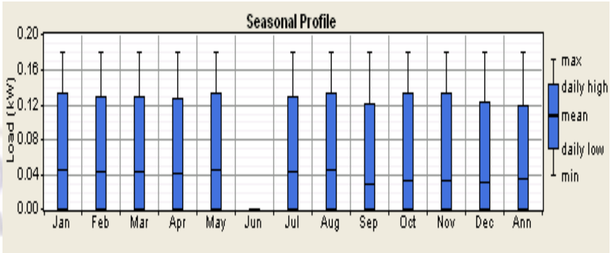
II. OPERATIONAL SCHEME

The intended hybrid energy system is incorporated of Renewable source PV and AC grid supply. Battery is acting the part of storage device charged by PV current. A Power Converter has been used for changing the source bus from DC to AC. This integrated system is totally designed for supply electrification to the selected sample load. i.e., 849 Wh/d, 180 W peak loads. For operational measurement a software HOMER (Hybrid Optimization Model for Electric Renewable) is assigned [4]. This software is used for cost optimizing with different sensitivity variables. Here, the varying subjects are load, global solar irradiation, wind speed, PV azimuth and converter design. Model organization of Homer has been addressed in Figure 2

2.1 Load profile

Cited place for this project is a river base land. It's latitudes 16°42′ N to ′16°43′ North and longitudes 82°11′to 82°19 East respectively. The load profile is acquired based on basic demands of utilities like Light, Cooling Fan, and other electrical apparatus and though most of the inhabitants of this land are doing academic activity. So, we have count weekdays and weekend separately for the load profile. Load is varied with seasonal and monthly consumption depending on climate[4]. Total consumption of selected area load is 849 Wh/d whereas the peak is 180 W. Here, the load is counted by yearly observation. The varying load profile of a year has been guided as following in Figure 3.

Fig 2: Operational Scheme



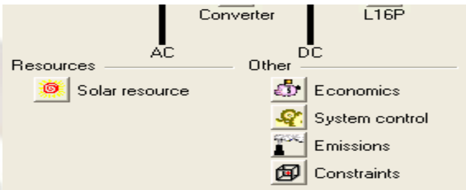


Fig 3: Yearly load profile

2.2 Solar resource and PV cost inputs

With this latitude and longitude HOMER software has automatically collected the global solar rate for the place. The average solar irradiation is 5.21 kWh / m2 /day. The site is located at GMT+05:30 Zone. The initial size of PV array used for this project is 1KW. Price for this capacity is retained at INR 40,000 /- [6] and replacement cost is INR 20,000 /-. Different sensitivity variables have been used up to 1KW, as well as different PV azimuths have been set for a lifetime of 25 years.[8]

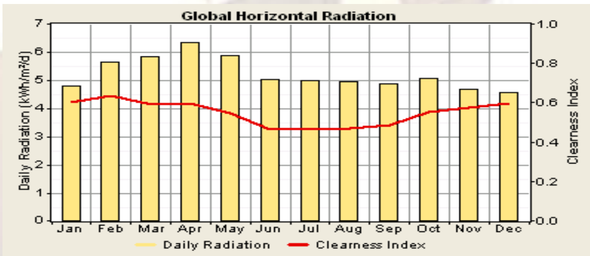


Fig 4: Month wise Clearness Index and Solar Radiation

2.3 Battery

The type of battery that used for the system is Hoppecke 8pzs 800 model with the rating of 120V, 22.8Ah, 2.742 kWh. The cost for one battery is INR 30,000/- [6] with the replacement cost of INR 10,000/-

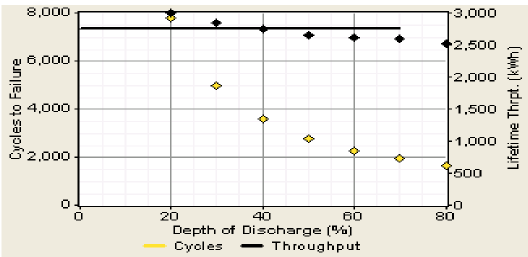


Fig 5: Battery Depth of Discharge VS Cycles to Failure

2.4. Converter

Selected converter with 90% of inverter efficiency and rectifier efficiency 85% its life time 20 years of 1KW power .its capital cost INR 5000/- and replacement cost INR 2500/-

2.5. Economics and Constraints

Annual interest rate of the project is 6% and the project life time has been set to 20 years and consider this project fixed capital cost INR 10,000/-. For constraints Minimum renewable fraction has been fixed 50 %. Maximum annual capacity storage 10 %.system operating reserve for hourly load 10% and annual peak load is 4%.

III. MODELING AND SIMULATION OF ROOFTOP PV PANEL

Fig. 6 shows the equivalent circuit of a PV panel with a load. The current output of the PV panel is modeled by the following three equations [5]- [7]. All the parameters are shown in Table I:

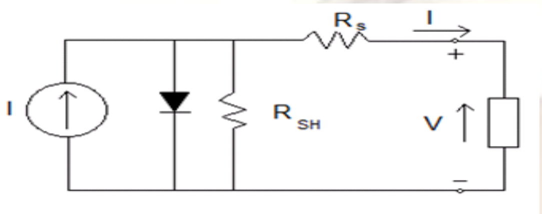


Fig 6: Single diode model of a PV cell

Table 1: Parameters for Photovoltaic Panel

Symbol	Description	Value
V_{oc}	Rated open circuit voltage	403 V
I_{ph}	Photocurrent	
I_{sat}	Module reverse saturation current	
q	Electron charge	1.602×10^{-19} C
A	Ideality factor	1.50
k	Boltzman constant	1.38×10^{-23} J/K
R_s	Series resistance of a PV cell	
R_p	parallel resistance of a PV cell	
I_{sso}	Short-circuit current	3.27 A
k_i	SC current temperature coefficient	$1.7e^{-3}$
T_r	Reference temperature	301.18 K
I_{rr}	Reverse saturation current at T_r	2.0793e^{-6} A
E_{gap}	Energy of the band gap for silicon	1.1eV
n_p	Number of cells in parallel	40
n_s	Number of cells in series	900
S	Solar radiation level	0~1000 W/m^2
T	Surface temperature of the PV	350 K

$$I\,ph = np\,Iph - np\,Isat\; X\left[\exp\left(\left(\frac{q}{AkT}\right)\left(\frac{Vph}{ns} + Ipv\,Rs\right)\right) - 1\right] \quad \text{......... (1)}$$

$$Iph = (Isso + ki(T - Tr))X\left(\frac{s}{1000}\right) \quad \text{............ (2)}$$

$$Isat = Irr\left(\frac{T}{Tr}\right)3\exp\left(\left(\frac{qEgap}{kA}\right).\left(\frac{1}{Tr} - \frac{1}{T}\right)\right) \quad \text{...... (3)}$$

3.1 PV Module characteristics Simulation

The figure 7 shows the complete Simulink diagram of the PV module characteristic. The modeling and the simulation of the whole system has been done in MATLAB – SIMULINK environment. It shows the complete PV cell Simulink model block. The various input parameters include photocurrent, cell output current and solar Insolation level. XY plot 1 will show the I V characteristic and another plotter showing PV power characteristic.

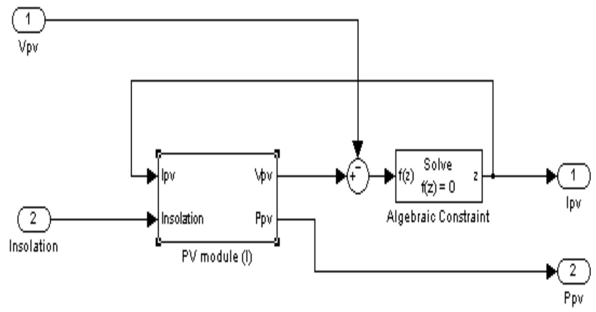


Fig 7: Simulink module of Rooftop- PV system

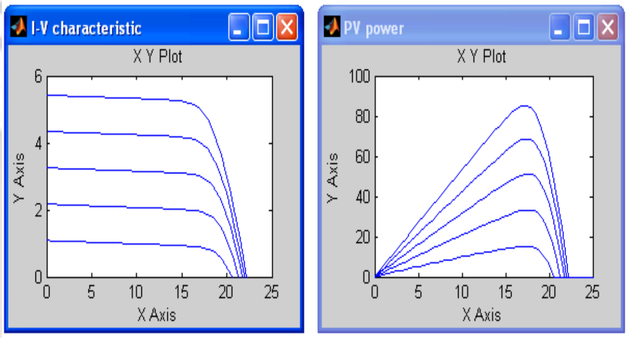


Fig 8: Current-voltage and power-voltage characteristics of rooftop solar PV module based on different solar radiation level respectively.

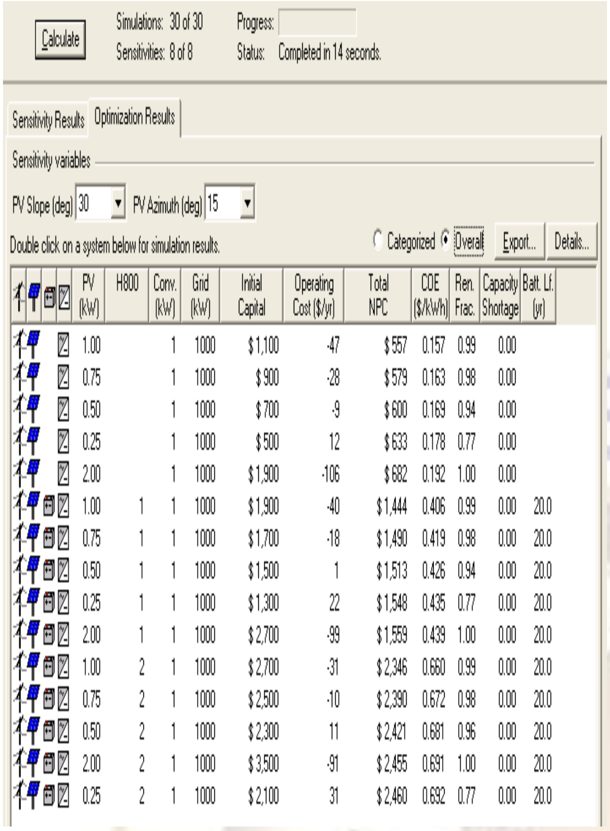
IV. OPTIMIZATION ANALYSIS OF THE HYBRID SYSTEM

HOMER performs the optimization process in order to determine the best configuration of hybrid renewable energy

System based on several combinations of equipments. Hence, multiple possible combinations of equipments could be obtained for the hybrid renewable energy system due to different size of PV array system, number of batteries and size of DC-AC converter. In the optimization process will simulate every combination system configuration in the search space. The feasible one will be displayed at optimization result sorted based on the Total Net Present Cost (TNPC) [11]-[14].The combination of system components is arranged from most effective cost to the least effective cost. The optimization results of hybrid renewable energy system are obtained for every selection of sensitivity variables.

Table 2 shows a list of optimization results for the hybrid renewable energy system with considering the sensitivity variables. The results represent different combination of components which are PV array system, AC grid supply, battery and converter. However, sensitivity variables should be taken into account in order to obtain a rational result of hybrid renewable energy system [20].

Table 2: Optimization Result for selected Hybrid Power System



PV (kW)	H800	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Batt. Lf. (yr)
1.00		1	1000	$ 1,100	-47	$ 557	0.157	0.99	0.00	
0.75		1	1000	$ 900	-28	$ 579	0.163	0.98	0.00	
0.50		1	1000	$ 700	-9	$ 600	0.169	0.94	0.00	
0.25		1	1000	$ 500	12	$ 633	0.178	0.77	0.00	
2.00		1	1000	$ 1,900	-106	$ 682	0.192	1.00	0.00	
1.00	1	1	1000	$ 1,900	-40	$ 1,444	0.406	0.99	0.00	20.0
0.75	1	1	1000	$ 1,700	-18	$ 1,490	0.419	0.98	0.00	20.0
0.50	1	1	1000	$ 1,500	1	$ 1,513	0.426	0.94	0.00	20.0
0.25	1	1	1000	$ 1,300	22	$ 1,548	0.435	0.77	0.00	20.0
2.00	1	1	1000	$ 2,700	-99	$ 1,559	0.439	1.00	0.00	20.0
1.00	2	1	1000	$ 2,700	-31	$ 2,346	0.660	0.99	0.00	20.0
0.75	2	1	1000	$ 2,500	-10	$ 2,390	0.672	0.98	0.00	20.0
0.50	2	1	1000	$ 2,300	11	$ 2,421	0.681	0.96	0.00	20.0
2.00	2	1	1000	$ 3,500	-91	$ 2,455	0.691	1.00	0.00	20.0
0.25	2	1	1000	$ 2,100	31	$ 2,460	0.692	0.77	0.00	20.0

The average annual solar radiation, Grid supply cost, component price, Technology advance and it's cost change Variables considered for the optimal design of the system.

4.1 Cost Summary of System

Based on analysis the system takes $ 1,900 for capital investment .Total system cost including replacement and operational cost it need $ 1,444.the summery based on the total cash flow, categorized either by component or by cost type.

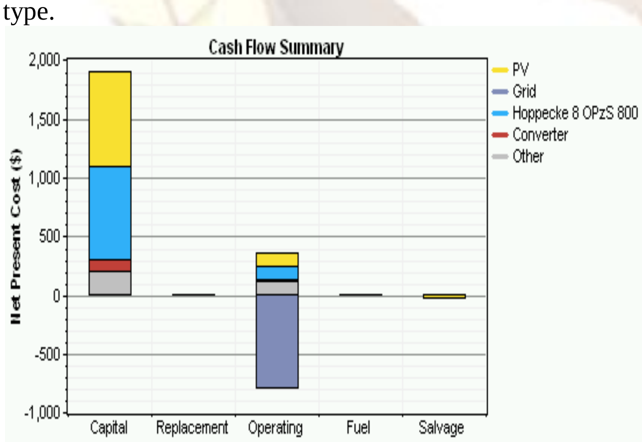


Fig 9: Cash flow Summary

4.2 Operational strategy of Power generation

In this part of simulation we can identify details about the production and consumption of electricity by the system is tabulated in table 3 and 4.

Table 3: Power Production from hybrid system

Component	Production In KWh/Yr	Percent Fraction
PV array	1,557	99%
Grid purchases	12	1%
Total	1,569	100%

Table 4: Power Consumption from system

Load	Consumption In KWh/Yr	Percent Fraction
AC primary load	310	22%
Grid sales	1,085	78%
Total	1,395	100%

Table 5: Excess Electricity production from system

Quantity	Value	Units
Excess electricity	0.0174	kWh/yr
Unmet load	0.000000328	kWh/yr
Capacity shortage	0.00	kWh/yr
Renewable fraction	0.992	

From the Table 5 the renewable fraction value can be calculated and the figure 10 clearly shown month wise Electric power production

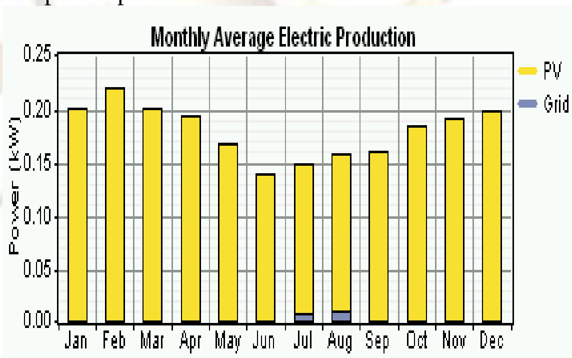


Fig 10: Month wise Electric Power Production

4.3 P V module performance

In this part of simulation used to determine roof top PV module power generation performance based on month wise .The total hours of operation is 4,314 hr/yr

Table 6: performance Data of PV module

Details of PV	Value	Units
Rated capacity	1.00	kW
Mean output	0.18	kW
Hours of operation	4,314	hr/yr
Mean output	4.27	kWh/d
Maximum output	1.04	kW

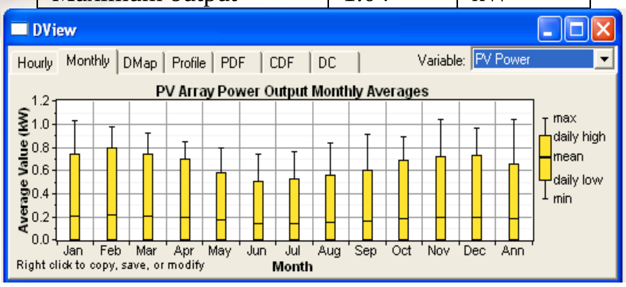


Fig 11: PV Array Power output monthly average

4.4 Grid Performance

In this part of simulation we can identify details about the purchases from grid and sales to the grid if the system is grid-connected and about the breakeven grid extension if the system is not grid-connected.

Table 7: Power Scenario of Grid

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	0	101	-101	0	-6	0
Feb	0	103	-103	0	-6	0
Mar	0	102	-102	0	-6	0
Apr	0	96	-96	0	-6	0
May	0	79	-79	0	-5	0
Jun	0	86	-86	0	-7	0
Jul	5	62	-57	0	-5	0
Aug	7	67	-60	0	-5	0
Sep	0	81	-81	0	-5	0
Oct	0	99	-99	0	-6	0
Nov	0	99	-99	0	-6	0
Dec	0	109	-109	0	-7	0
Annual	12	1,085	-1,073	0	-69	0

4.5 Battery Performance

We can simulate details about the use and expected lifetime of the battery. And it's working performance. In the month of June to August the Battery utilization was high.

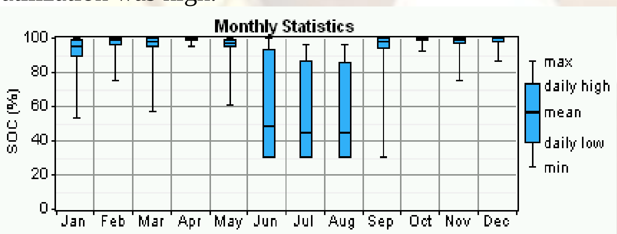


Fig 12: Monthly Statistics of State of Charge %

4.6 Converter Performance

We can find details about the operation of the inverter and rectifier, including capacity, electrical input and output, hours of operation, and losses. Total hours of operation is 4,313 hrs/yr and total loss in converter is 156 kWh/yr.

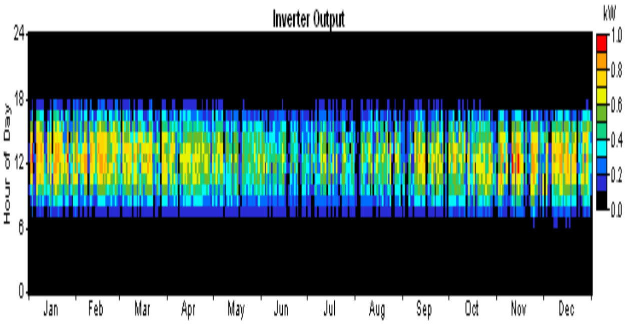


Fig 12: Inverter output performance

4.7 Emissions

We can find annual pollutants emitted by the system. It can use for find carbon credit

Table 8: Statics of Emission (kg/yr)

Pollutant	Emissions (kg/yr)
Carbon dioxide	-678
Carbon monoxide	0
Unburned hydro carbons	0
Particulate matter	0
Sulfur dioxide	-2.94
Nitrogen oxides	-1.44

V. CONCLUSION

This paper has determined the technical and economical feasibility of a roof top solar PV-AC grid assisted hybrid power system to supply electricity and energy for a selected load. i.e., 849 Wh /d and 180 W peak load .This hybrid power system has been sized, simulated and evaluated using NREL's HOMER software. The yearly average daily solar radiation intensity received at the Yanam campus has around 5.82 kWh/ m^2/ day and is a sufficient amount of energy resource for a Hybrid PV power system. From the simulation results, it is found that for a hybrid system with RF of .992, the NPC of the hybrid system is US$ 541 and the COE is $0.152 per KWh which is reasonable for energy generation based on renewable energy.

The findings of this study suggests that the roof top solar PV-AC Grid system should be implemented since it is a more economical and cleaner source of power as compared to the conventional energy power system. This hybrid system is a step towards a cleaner and greener future

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