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Modeling, Simulation and Optimization of Hybrid Renewable Power System for Daily Load demand of Metropolitan Cities in India

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Abstract: - Demand for energy is increasing day by day because of increasing the residents and industrialization. In this critical stage of energy crisis, renewable energy is one of the most important substitute energy sources. Electricity consumption in India has more than doubled in the last decade, outpacing economic growth. The paper presents a study and design of a complete hybrid renewable power system model for day to day load demand of Metropolitan cities in India. The optimized renewable energy power systems for four different locations are presented. The possible sources of powers are photovoltaic and wind turbine system and two possible storage systems are a battery bank and a hydrogen storage fuel cell system. The proposed power system is photovoltaic-wind system. The sizing, optimization and economic estimation of the systems were performed using HOMER software. HOMER solves the optimization problem to minimize the total cost and provides the optimum photovoltaic, wind turbine, battery and fuel cell ratings. In addition, a comparison between the three different suggested power system configurations is illustrated in details.

Keywords: **-** *Optimization, Modeling, Simulation, Net present cost, Homer, Sizing*

I. INTRODUCTION

India's significant and sustained economic growth is placing enormous demand on its energy resources. However, there is a pervasive demand-supply imbalance that necessitates serious efforts by the government of India to augment energy supplies. The country imports about 80 percent of its oil. With the threat of a further increase in oil prices, serious problems with regard to energy security is anticipated. India also runs the substantial risk of lesser thermal capacity being installed. While dependence on imported coal is increasing, supply of indigenous coal is likely to decrease in the coming years because of production and logistic constraints [1]. Economic growth, increasing prosperity and urbanization, rise in per capita consumption, and spread of energy access are the key factors that would be responsible for substantially increasing the total demand for electricity. Thus there is an emerging energy supply-demand imbalance. According to a Central Electricity Authority report, the anticipated energy and peaking shortage in the country is estimated to be 10.3 percent and 12.9 percent, respectively, in 2011 and 2012.

Renewable energy can make a substantial contribution in each of the above mentioned areas. It is in this context that the role of renewable energy needs to be seen. It is no longer "alternate energy", but is increasingly becoming a vital part of the solution to the nation's energy needs. In terms of all renewable energy categories, India is currently ranked fifth in the world with 15,691.4 MW grid connected and 367.9 MW off-grid renewable-energy based power capacity [1].

This paper proposes three different renewable energy system models for four different locations in India.

II. SYSTEM SPECIFICATIONS

2.1 Homer

HOMER (Hybrid optimization model for electric renewable) Simulation simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, HOMER compares the electric and thermal load in the hour to the energy that the system can supply in that hour. For systems that include batteries or fuel-powered generators, HOMER also decides for each hour how to operate the generators and whether to charge or discharge the batteries. If the system meets the loads for the entire year, HOMER estimates the lifecycle cost of the system, accounting for the capital, replacement, operation and maintenance, fuel and interest costs [2].

2.2 Study Locations

An Indian metropolitan cities was taken for the study.

Chennai (Latitude 13° 04' N, Longitude 80° 17' E) is the capital city of Tamil Nadu. Located on the Coromandel Coast of the Bay of Bengal. As of the 2011 census, the city had 4.68 million residents making it the sixth most populous city in India, the urban agglomeration, which comprises the city and its suburbs, was home to approximately 8.9 million, making it the fourth most populous metropolitan area in the country [4].

Kolkata (Latitude 22° 57' N, Longitude 88° 36' E) is the capital of West Bengal. Located on the east bank of the Hooghly river. As of 2011, the city had 4.5 million residents; the urban agglomeration, which comprises the city and its suburbs, was home to approximately 14.1 million, making it the third-most populous metropolitan area in India. Kolkata confronts substantial urban pollution, traffic congestion, poverty, overpopulation, and other logistic and socioeconomic problems [4].

Mumbai (Latitude 19° 07' N, Longitude 72° 87' E) is the capital of Maharashtra. It is the most populous city in India, and the fourth most populous city in the world, with a total metropolitan area population of approximately 20.5 million. Mumbai lies on the west coast of India and has a deep natural harbor [4].

Delhi (Latitude 28° 63' N, Longitude 77° 22' E), officially the National Capital Territory of Delhi (NCT) that includes the Indian capital is the largest metropolis of India. With the population of 16.7 million in 2011. There are nearly 22.2 million residents in the greater NCR urban area, which includes the neighboring cities of Baghpat, Gurgaon, Sonepat, Faridabad, Ghaziabad, Noida and Greater Noida along with other smaller nearby towns [4].

2.3 Load Profile

A typical electrical load system shown in Table I for single residence has been considered for load analysis. For a particular residence we consider a fluorescent light, fan, television, compact disc player, computer, water heater and other small loads. In HOMER made a 24 hours load profile for a single home [2]. If we consider an average load demand of all locations are same. The total electrical load demand for the residence is 2kWh / day, 350W peak. Fig. 1 Shows the daily load profile a small base load of 100W occurs throughout the day and night. Small peaks of 300W occur at morning and at night, while the majority of the load occurs in the evening.

TABLE 1 LOAD DETAILS OF SINGLE HOME USER

Appliances	**Number**	**Wattage**
Florescence light	2	20
Fan	1	80
TV	1	100
CD Players	1	80
Computer	1	150
Water Heater	1	150
Others	2	50
Total capacity		630

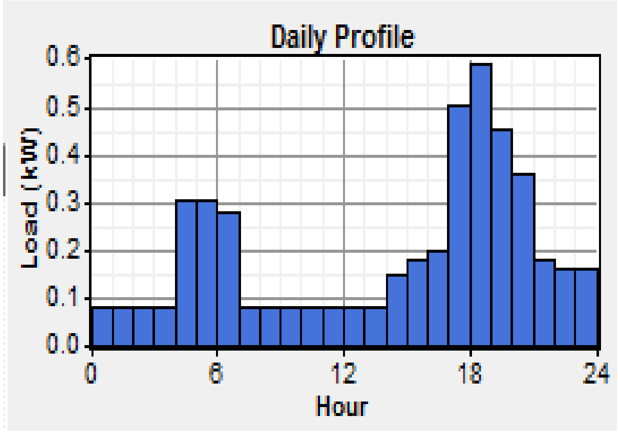


FIG. 1.DAILY LOAD PROFILE

The evening load, with a peak load of 600 W, would likely include fluorescent lighting, television load, fan, computer and audio system.

2.4 System Components

2.4.1 Photovoltaic (PV)

Solar energy is the most promising of the renewable energy sources in view of its apparent unlimited potential. The sun radiates its energy at the rate of about 3.8 x 1023 kW per second. Most of this energy is transmitted radially as electromagnetic radiation which comes to about 1.5kW/m2 at the boundary of the atmosphere. After traversing the atmosphere, a square meter of the earth's surface can receive as much as 1kW of solar power, averaging to about 0.5 over all hours of daylight. Solar radiation data for the study regions was obtained from Synergy Environmental Engineers (India) Private Limited web site. The Synergy Environmental Engineers (India) Private Limited has been monitoring solar radiation data in India at for the last many years. Monthly clearness index and radiation data is shown in table II [5].

TABLE 2 MONTHLY CLEARNESS INDEX AND RADIATION DATA

City / Month	**Chennai**		**Kolcutta**		**Mumbai**		**Delhi**	
	A*	**B****	**A***	**B****	**A***	**B****	**A***	**B****
Jan	0.581	4.93	0.663	4.67	0.698	5.32	0.602	3.66
Feb	0.636	5.89	0.604	4.9	0.728	6.25	0.638	4.65
Mar	0.659	6.64	0.589	5.54	0.726	7.05	0.66	5.85
Apr	0.637	6.72	0.527	5.51	0.701	7.38	0.659	6.76
May	0.577	6.12	0.5	5.5	0.674	7.33	0.638	7.08
Jun	0.498	5.24	0.315	3.51	0.516	5.64	0.58	6.6
Jul	0.45	4.73	0.323	3.56	0.46	5	0.512	5.74
Aug	0.457	4.8	0.351	3.73	0.483	5.12	0.513	5.4
Sep	0.492	5.01	0.352	3.43	0.568	5.65	0.564	5.25
Oct	0.467	4.42	0.477	4.04	0.644	5.72	0.685	5.3
Nov	0.471	4.06	0.62	4.5	0.689	5.38	0.68	4.31
Dec	0.539	4.42	0.663	4.43	0.686	5	0.623	3.55
Ave	0.539	5.248	0.499	4.443	0.631	5.903	0.613	5.346

*Clearness index **Radiation

2.4.2 Wind turbine system

The energy available in the wind depends on the density and air velocity. The density, as any other gas, changes with the temperature and pressure which varies with the high level of the sea. The energy of a mass of air which is displaced is determined by the Kinetic Energy (K.E) flux [2]. The hub height of the wind turbine system is 10m. Wind speed details of study areas are shown in table III [5].

TABLE 3 MONTHLY WIND SPEED DATA

City / Month	Chennai	Kolcutta	Mumbai	Delhi
Jan	4.87	1.63	3.84	2.77
Feb	4.46	2.00	4.66	3.13
Mar	4.45	2.27	5.10	3.46
Apr	4.49	3.10	5.62	3.87
May	4.86	3.15	5.67	4.02
Jun	5.52	2.87	5.64	4.11
Jul	5.30	2.56	6.46	3.39
Aug	5.24	2.19	5.84	2.91
Sep	3.83	2.01	4.05	2.85
Oct	3.56	1.43	3.48	2.16
Nov	4.56	1.57	3.41	1.83
Dec	5.28	1.54	3.45	2.40
Ave	4.702	2.193	4.768	3.075

2.4.3 Fuel cell

Hydrogen storage Fuel Cell (FC) is available in different configurations, power ranges, type of electrodes and operating characteristics. Proton Exchange Membrane (PEM) FC has a good start up and shut down characteristics. The basic structure of PEM fuel cell has two electrodes (anode and cathode) separated by a solid membrane. In the hydrogen storage system, surplus renewable power goes to an electrolyzer which produces hydrogen. Hydrogen goes into a storage tank to be consumed by the fuel cell when required. Hydrogen fuel is fed continuously to the anode and air is fed to the cathode [3].

2.4.4 Electrolyzer and Hydrogen Tank

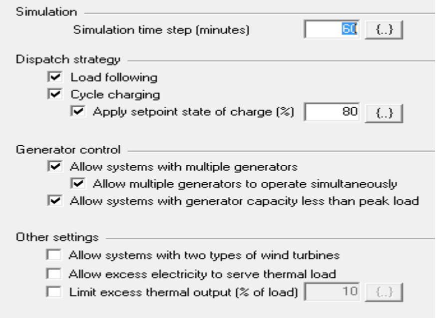
Hydrogen can be produced by the decomposition of water into its elementary components by passing the electric current. An electrolyzer consists of several cells connected in series. Two electrodes of the electrolyzer are separated by an aqueous electrolyte or solid polymer electrolyte. Electrical current through the electrolyzer enables the decomposition of water into hydrogen and oxygen. The hydrogen tank stores hydrogen produced by the electrolyzer for later use in a hydrogen-fueled generator. Homer assumes that the process of adding hydrogen to the tank requires no electricity, and that the tank experiences no leakage [3].

2.4.5 Battery

Battery bank is a conventional approach to store electrical energy with high efficiency. Its discharging level cannot exceed a minimum limit defined as depth of discharge. The capacity of the battery is so designed so as to supply the ultimate load during the non-wind hours.

2.5 System Control

Homer model, the system control inputs define the operation of the battery bank and generators and dispatch strategy determines how the system charges the battery bank Fig. 2). The control strategies have been selected to see which is more suitable in the given constraints of the system. The simulation time step is 60 minutes and set point charge for the batteries is at 80% [2].



Simulation
Simulation time step (minutes) 60

Dispatch strategy
☑ Load following
☑ Cycle charging
  ☑ Apply setpoint state of charge (%) 80

Generator control
☑ Allow systems with multiple generators
  ☑ Allow multiple generators to operate simultaneously
☑ Allow systems with generator capacity less than peak load

Other settings
☐ Allow systems with two types of wind turbines
☐ Allow excess electricity to serve thermal load
☐ Limit excess thermal output (% of load) 10

Fig. 2 System control inputs

2.6 Economics

Our plan is to minimize the total net present cost (NPC) and the optimal system configuration. Homer applies the economic inputs (Figure 3) to each system it simulates to calculate system's net present cost.

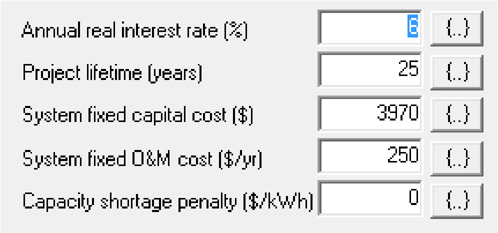

Annual real interest rate (%) 6
Project lifetime (years) 25
System fixed capital cost ($) 3970
System fixed O&M cost ($/yr) 250
Capacity shortage penalty ($/kWh) 0

Fig. 3 System economic inputs

2.7 System constrains

The constraints (Figure. 4) are conditions that system meet to be feasible. Infeasibility systems do not include operating in the sensitivity and optimization analysis [2].

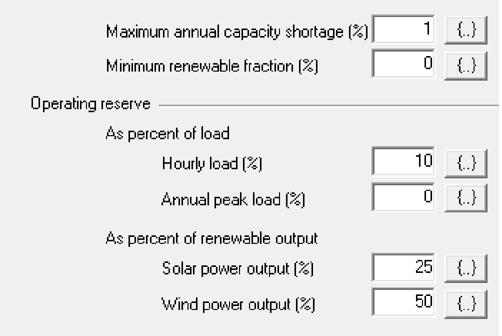
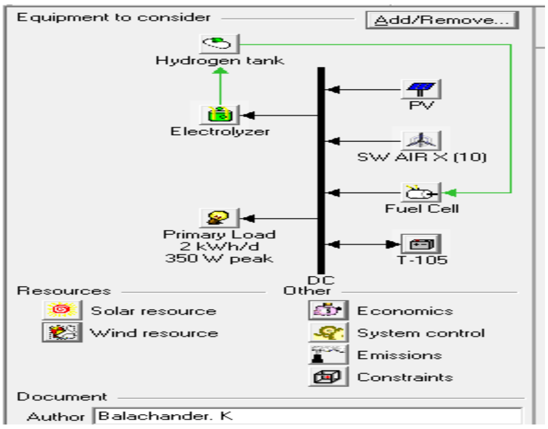

Maximum annual capacity shortage (%) 1
Minimum renewable fraction (%) 0
Operating reserve
As percent of load
Hourly load (%) 10
Annual peak load (%) 0
As percent of renewable output
Solar power output (%) 25
Wind power output (%) 50

Fig. 4 System constraints

III. METHODOLOGY

The proposed hybrid renewable system (Fig. 5) consists of a photovoltaic and wind turbine system. Hydrogen storage fuel cell, electrolzer and battery are back-up and storage system. The project lifetime is estimated at 25 years. The annual interest rate is fixed at 6%.



Author Balachander. K

Fig. 5 Hybrid RES

IV. SIMULATION

In this paper we consider four metropolitan cities in India i.e. Chennai, Kolkata, Mumbai, New Delhi and load condition is 2KWh/day 350W peak for simulation. Components to be considered for stand-alone Photovoltaic Wind Hybrid Power System and storage medias are a Battery bank and a Hydrogen storage Fuel Cell system is shown in table IV.

TABLE 4 COMPONENTS ASSESSMENT

Component	Parameter	
PV Array	Rated power	1KW DC
	Derating factor	90%
	Slope	23°
	Life time	20Years
Wind turbine	***SW AIR X***	
	Rated power	0.55kW DC
	Hub height	15m
	Life time	15Years
Electrolyzer	Rated power	1KW DC
	Life time	15Years
	Efficiency	76%
Hydrogen tank	Size	1Kg
	Life time	25Years
Fuel cell	Rated power	1KW DC
	Life time	40000 operating hrs
	Fuel	Stored Hydrogen
Battery	***Trojan T-105***	
	Nominal capacity	225Ah
	Nominal voltage	6V
	Batteries per string	1 (6V Bus)
	Float life	10Years
Load	***Primary Load***	
	Type of Load	2kWh/Day 350W peak DC

HOMER performs the simulation for a number of prospective designed configurations. After examining every design, it selects the one that meets the load with the system constraints at the least life cycle cost. HOMER performs its optimization and sensitivity analysis across all mentioned components and their resources, technical, cost parameters, system constraints and sensitivity data over a range of exogenous variables [2]. Table V and VI shows the cost summary of the overall system and cost analysis of the three different Renewable Energy System (RES) options are compared regarding the least-cost scenario.

TABLE 5 COST SUMMARY

Component	Rating	Cost (INR)
PV Panel	1kW	306000
Wind Turbine	0.55kW	76500
Electrolyzer	1kW	102000
Hydrogen Tank	1Kg	66300
Fuel Cell	2kW	153000
Battery	6V, 225Ah	6120

Table 6 Cost Analysis of 3 RES and 3 different locations

Cost / Location	**Chennai**		
	RES 1	**RES 2**	**RES 3**
System Combination	Pv, Bat	Pv, wind, Bat	Pv, Fc, Bat, Ele
Initial Capital (Rs.)	435,030	425,850	537,030
Operating Cost (Rs./yr)	17,901	18,972	17,544
Total Net Present Cost (Rs.)	663,714	668,610	761,022

Cost of energy (Rs./kWh)	71.15	71.96	81.60
Cost / Location	**Calcutta**		
	RES 1	***RES 2***	***RES 3***
System Combination	Pv, Bat	Pv, wind, Bat	Pv, Fc, Bat, Ele
Initial Capital (Rs.)	496,230	511,530	598,230
Operating Cost (Rs./yr)	18,411	20,910	18,054
Total Net Present Cost (Rs.)	731,901	779,025	829,209
Cost of energy (Rs./kWh)	78.44	83.49	88.84
Cost / Location	**Mumbai**		
	RES 1	***RES 2***	***RES 3***
System Combination	Pv, Bat	Pv, wind, Bat	Pv, Fc, Bat
Initial Capital (Rs.)	410,550	450,330	512,550
Operating Cost (Rs./yr)	17,799	20,400	17,442
Total Net Present Cost (Rs.)	638,265	710,838	735,573
Cost of energy (Rs./kWh)	68.90	76.30	79.41
Cost / Location	**New Delhi**		
	RES 1	***RES 2***	***RES 3***
System Combination	Pv, Bat	Pv, wind, Bat	Pv, Fc
Initial Capital (Rs.)	435,030	450,330	537,030
Operating Cost (Rs./yr)	17,901	20,400	17,544
Total Net Present Cost (Rs.)	663,714	710,838	761,022
Cost of energy (Rs./kWh)	71.25	76.25	81.70

Pv – Photovoltaic array Wind - Wind turbine System
Bat – Battery Fc – Fuel Cell

Table 7 Electrical Production

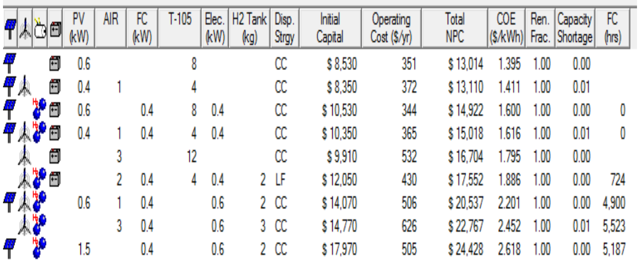
Components	**Chennai**		
	RES 1 **(Pv,Bat)**	***RES 2*** (Pv, wind, Bat)	***RES 3*** **(Pv, Fc)**
PV(kWh/Yr)	1,055	703	1,055
Wind(kWh/Yr)	-	538	-
Total	1,055	1,241	1,055
Components	**Calcutta**		

	RES 1 **(Pv,Bat)**	***RES 2*** (Pv, wind, Bat)	***RES 3*** **(Pv, Fc)**
PV(kWh/Yr)	1,511	1,133	1,511
Wind(kWh/Yr)	-	149	-
Total	1,511	1,282	1,511
Components	**New Delhi**		
	RES 1 (Pv,Bat)	***RES 2*** (Pv, wind, Bat)	***RES 3*** **(Pv, Fc)**
PV(kWh/Yr)	1,175	783	1,175
Wind(kWh/Yr)	-	147	-
Total	1,175	930	1,175
Components	**Mumbai**		
	RES 1 (Pv,Bat)	***RES 2*** (Pv, wind, Bat)	***RES 3*** **(Pv, Fc)**
PV(kWh/Yr)	1,114	743	1,114
Wind(kWh/Yr)	-	152	-
Total	1,114	895	1,114

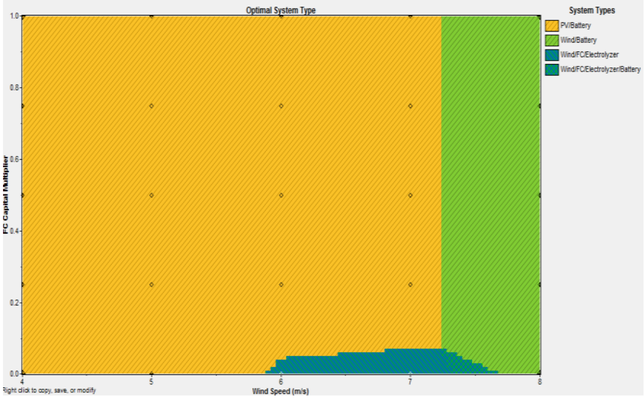
V. OPTIMIZATION

For the single residential load demand of metropolitan cities in India, various combinations have been obtained of hybrid systems with photovoltaic, wind turbines, fuel cell, batteries and converters from the HOMER Optimization. Sensitivity analysis eliminates all infeasible combinations and ranks the feasible combinations taking into account uncertainty parameters [2].

HOMER allows taking into account future developments, such as increasing or decreasing load demand as well as changes regarding the resources, for example fluctuations in the river's water flow rate, wind speed variations or the biodiesel prices. In this model the various sensitive variables are considered to select the best suited combination for the hybrid system to serve the load demand [2].

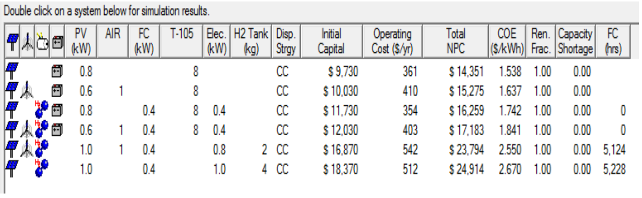


PV (kW)	AIR	FC (kW)	T-105	Elec. (kW)	H2 Tank (kg)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	FC (hrs)
0.6			8			CC	$ 8,530	351	$ 13,014	1.395	1.00	0.00	
0.4	1		4			CC	$ 8,350	372	$ 13,110	1.411	1.00	0.01	
0.6		0.4	8	0.4		CC	$ 10,530	344	$ 14,922	1.600	1.00	0.00	0
0.4	1	0.4	4	0.4		CC	$ 10,350	365	$ 15,018	1.616	1.00	0.01	0
	3		12			CC	$ 9,910	532	$ 16,704	1.795	1.00	0.00	
	2	0.4	4	0.4	2	LF	$ 12,050	430	$ 17,552	1.886	1.00	0.00	724
0.6	1	0.4		0.6	2	CC	$ 14,070	506	$ 20,537	2.201	1.00	0.00	4,900
	3	0.4		0.6	3	CC	$ 14,770	626	$ 22,767	2.452	1.00	0.01	5,523
1.5		0.4		0.6	2	CC	$ 17,970	505	$ 24,428	2.618	1.00	0.00	5,187

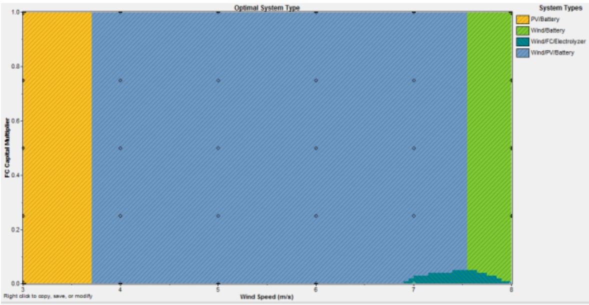


i. Chennai

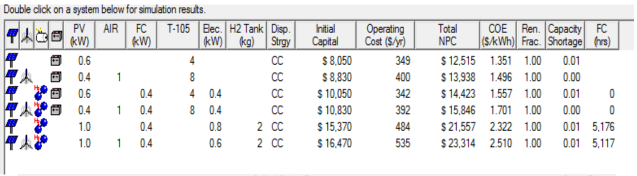
Figure 6 shows the sensitivity analysis and optimal system type for four metropolitan cities in India. It can be observed that with change in the sensitive variables, the configuration of the system changes. Even in this analysis, HOMER ranks the configurations in descending order of


Double click on a system below for simulation results.

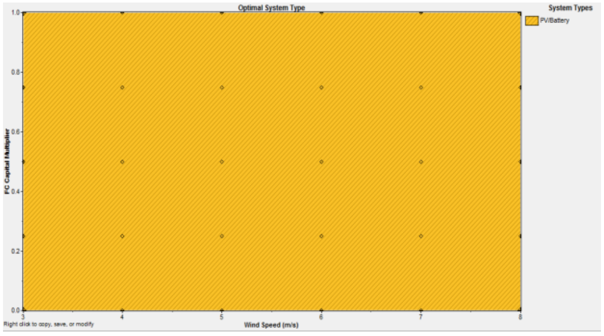
PV (kW)	AIR	FC (kW)	T-105	Elec. (kW)	H2 Tank (kg)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	FC (hrs)
0.8			8			CC	$ 9,730	361	$ 14,351	1.538	1.00	0.00	
0.6	1		8			CC	$ 10,030	410	$ 15,275	1.637	1.00	0.00	
0.8		0.4	8	0.4		CC	$ 11,730	354	$ 16,259	1.742	1.00	0.00	0
0.6	1	0.4	8	0.4		CC	$ 12,030	403	$ 17,183	1.841	1.00	0.00	0
1.0	1	0.4		0.8	2	CC	$ 16,870	542	$ 23,794	2.550	1.00	0.00	5,124
1.0		0.4		1.0	4	CC	$ 18,370	512	$ 24,914	2.670	1.00	0.00	5,228



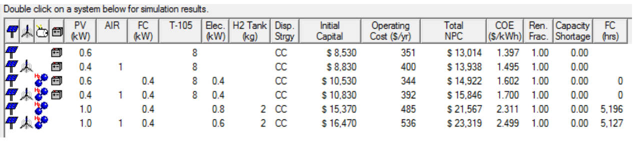
ii. Calcutta


Double click on a system below for simulation results.

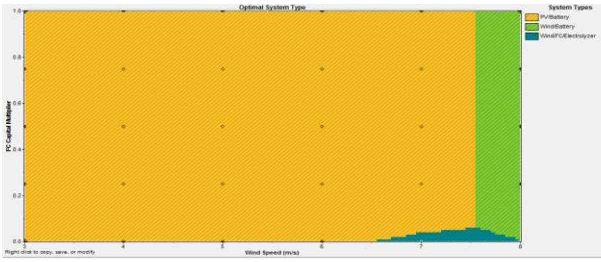
PV (kW)	AIR	FC (kW)	T-105	Elec. (kW)	H2 Tank (kg)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	FC (hrs)
0.6			4			CC	$ 8,050	349	$ 12,515	1.351	1.00	0.01	
0.4	1		8			CC	$ 8,830	400	$ 13,938	1.496	1.00	0.00	
0.6		0.4	4	0.4		CC	$ 10,050	342	$ 14,423	1.557	1.00	0.01	0
0.4	1	0.4	8	0.4		CC	$ 10,830	392	$ 15,846	1.701	1.00	0.00	0
1.0		0.4		0.8	2	CC	$ 15,370	484	$ 21,557	2.322	1.00	0.01	5,176
1.0	1	0.4		0.6	2	CC	$ 16,470	535	$ 23,314	2.510	1.00	0.01	5,117



iii. New Delhi


Double click on a system below for simulation results.

PV (kW)	AIR	FC (kW)	T-105	Elec. (kW)	H2 Tank (kg)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	FC (hrs)
0.6			8			CC	$ 8,530	351	$ 13,014	1.397	1.00	0.00	
0.4	1		8			CC	$ 8,830	400	$ 13,938	1.495	1.00	0.00	
0.6		0.4	8	0.4		CC	$ 10,530	344	$ 14,922	1.602	1.00	0.00	0
0.4	1	0.4	8	0.4		CC	$ 10,830	392	$ 15,846	1.700	1.00	0.00	0
1.0		0.4		0.8	2	CC	$ 15,370	485	$ 21,567	2.311	1.00	0.00	5,196
1.0	1	0.4		0.6	2	CC	$ 16,470	536	$ 23,319	2.499	1.00	0.00	5,127



iv. Mumbai

Fig. 6 I, ii, iii and iv Sensitivity analysis and Optimal system solution of Metropolitan Cites in India their total net present cost. The feasible system and economical details of all the configurations of the hybrid systems from the optimization process are shown (Fig. 6). The above optimum results confirmed that the proposed stand alone hybrid system will be able to provide for the power to the DC load of 2KWh/day 350W Peak, constantly right through the year.

VI. RESULTS AND CONCLUSION

After analyzing the simulation, one can suggest that for higher loading stand-alone PV-Battery System is most suitable, for supplying the power to the DC load. The simulation result suggests that this Hybrid system is most suitable for all locations and result suggests that from the different possible configuration, one can choose the better optimal solution and the cost of energy production is calculated for Chennai, Mumbai, Kolcutta and New Delhi (Table. 8). It can be concluded that for loading condition of 2KWh/day, 350W Peak.

Table 8 Cost of Energy

Locations	**Cost of Energy (INR)**
Chennai	71.15
Mumbai	68.90
Kolcutta	78.44
New Delhi	71.25

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