SIMULATION OF A HYBRID SOLAR PV/ DIESEL PLANT WITH BATTERY STORAGE

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ABSTRACT

Solar PV has witnessed to sharp fall in capital cost in the last few years because of economies of scale and industrialization of solar power. The capital cost of solar PV has come down to the extent that Levelized Cost of Electricity (LCOE) is already in the shooting range of grid electricity rates for the commercial and industrial consumers. India suffers from a perennial power shortage and there is a sizable energy security market in India. Solar can meet this unmet demand. However, the output of solar PV plant is dependent on the sun light and not very predictable. In order to make the solar energy firm and more reliable, a commercially viable storage solution is the need of the hour. It is recognized that large scale storage at the MW scale is still not economically viable. In view of this a study is undertaken to design, simulate and optimize the size of Solar PV, Battery Storage and diesel generator with respect to delivered energy cost.

Keywords: Levelized Cost, Sizable Energy, Perennial Power and Solar PV.

I. INTRODUCTION

India has high solar insolation with regions having 5-6 hours of peak irradiance. In the solar energy sector, some large projects have been proposed, and a 35,000 km^2 area of the Thar Desert has been set aside for solar power projects, sufficient to generate 700 GW to 2,100 GW. Government of India (GoI) has launched National Solar Mission, which is one of the eight initiatives under the National Action Plan on Climate Change (NAPCC). Ministry of New and Renewable Energy (MNRE) is responsible for operationalizing the Solar Mission, christened as **Jawaharlal Nehru National Solar Mission** (JNNSM)[1].The objective of the JNNSM is to establish India as a global leader in solar energy , by creating the policy conditions for its diffusion across the country as quickly as possible. The immediate aim of the Mission is to focus on setting up an enabling environment for solar technology penetration in the country both at a centralized and decentralized level. The first phase (up to 2013) will focus on capturing of the low hanging options in solar thermal l; on promoting off –grid systems to serve populations without access to commercial energy and modest capacity addition in grid-based systems. In the second phase, after taking into account the experience of the initial years, capacity will be aggressively ramped up to create conditions for up scaled and competitive solar energy penetration in the country. The goal is to have 20 GWP of installed solar capacity by 2022.

Solar energy is available only during the sunshine hours also it is subject to both predictable and unpredictable intermittencies. Unexpected or expected weather variations can reduce electricity production rapidly. Thus, by very nature the solar energy is infirm in nature. As the penetration of solar power plants in the overall electricity generation increases, the infirmness of power is likely to pose bigger challenge and more severe consequences. It is, therefore, imperative to increase the predictability of energy generation, which can be brought about by integrating storage systems with the existing solar power plants. Off-grid solar power plants having capacities in the range of 1-100 KWP already have storage facility. However, the challenge is to scale up to MW level in a cost-effective manner. There have been some sporadic attempts in the developed world but they are few and far in between.

1.1 Need For Energy Storage

Peak Shaving: The reduction of the amount of electricity drawn from a power utility during utility designated peak time periods. Peak shaving using PV-Storage systems require that the PV provides all required power above a specified threshold and if PV is not available, there is adequate energy storage to fill the gap.

Load Shifting: Technically, load shifting is similar to peak shaving, but its application is useful to customers purchasing utility power on the time-of-use (TOU) basis. Many peak loads occur late in the day, after the peak for PV generation has passed. Storage can be combined with PV to reduce the demand for utility power during late-day, higher-rate times by charging a storage system with PV generated energy early in the day to support a load later in the day.

Demand Response: This allows the utility to control selected high-load devices, such as heating, ventilation, and air conditioning (HVAC) and water heating, in a rolling type of operation during high-demand periods. For both residential and small commercial customers, using an appropriately sized PV-Storage system should allow the implementation of demand response strategies with little or no effect on local operations. Control systems for demand response systems will require at least one-way communications between the PV-storage site and the utility.

Outage Protection: An important benefit of a PV Storage system is the ability to provide power to the residential or small commercial customers when utility power is unavailable (i.e., during outages). To provide this type of protection it is necessary to intentionally island the residence or commercial establishment to comply with utility safety regulations designed to prevent the back feeding of power onto transmission and distribution (T&D) lines during a blackout. Islanding can be beneficial to both the utility and the customer, because it allows the utility to shed loads during high demand periods while protecting the customer's loads if the utility fails.

Grid Power Quality Control: In addition to outage protection, power quality ensures constant voltage, phase angle adjustment, and the removal of extraneous harmonic content from the electric grid. On the customer side, this function is currently supplied by UPS devices. A UPS must sense, within milliseconds, deviations in the AC power being supplied and then take action to correct those deviations. UPS functions can be added to PV-Storage systems in the power conditioning system by designing it to handle high power applications and including the necessary control functions. UPS functionality can be combined with peak shaving capability in the same system.

II. DESIGNING A HYBRID PHOTOVOLTAIC PLANT FOR A SPECIFIC LOAD IN INDIA

2.1 DESIGNING TOOL

We have considered a stand-alone PV/diesel/battery hybrid plant to serve the load. There are many soft wares available in the market for design and simulation of such plants, such as PVSyst, HOMER, RET Screen, sunny design etc. The accuracy of each of these soft wares are follows:

	PVsyst	HOMER	RETscreen	Sunny design
total average percentage difference from actual yield	-4.33%	-1.44%	-2.31%	-4.93%
Standard deviation monthly percentage deffrences from actual yield	5.48%	4.75%	5.11%	6.04% (annual std deviation)

Table 1. Software Comparision [6]

HOMER and RETScreen in particular provide the most accurate results, while PVSyst generally provides conservative result. Sunny Portal is the simplest of the models and has the least accuracy. HOMER software has the highest accuracy -1.44% followed by RET Screen which has the accuracy of -2.31%. Here we have used HOMER for design and simulation.[7]

2.2 Load To Be Served

Suppose we have to serve a load which is constant throughout the day i.e. 1MW. This load is same for the night as well. This corresponds to a total of 24000 KWh units per day. The load is same for whole year, which means it will consume 87, 60,000 KWh units per year. Now our plant should be designed in such a way that it is able to serve such load. The load profile for this case is as follows. [11]

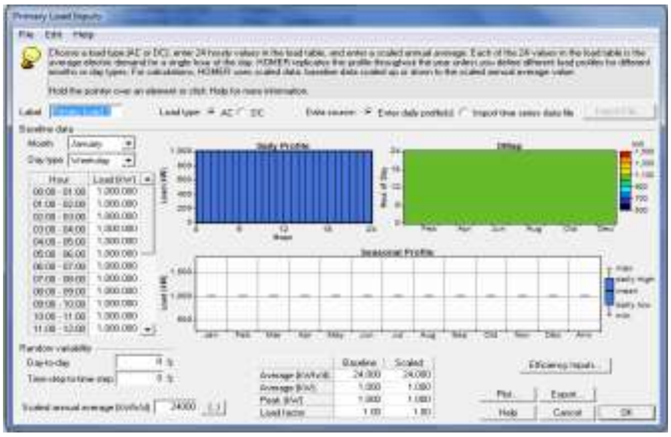
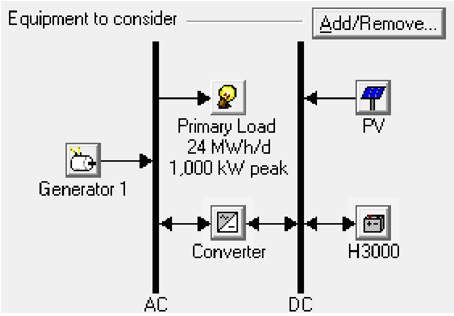


Table 2. Primary Load Inputs

INPUT TABLE	
Control parameters	
Annual real interest rate (%)	11
Plant working life span	20
Diesel price considered (US$/l)	1
Dispatch strategy	load following
Apply setpoint state of charge (%)	50
Photovoltaics modules	
Photovoltaic sizes considered (kW)	0,4000,4100,4200,4400,4600,4800,5000,5200,5400,5600,5800,6000,6200,6400,6600,6800,7000,7100,7200,7400,10000,11000,12000
Cost of photovoltaic array (US$/kW)	950
Replacement cost of photovoltaic array (US$/kW)	950
Operation and maintenance cost of PV array (US$/kW/year)	20
Type of Photovoltaic modules tracking	fixed
Working life of photovoltaic panels (years)	20
Power converter	
Power converter sizes considered (kW)	1200
Cost of power converter (US$/kW)	90
Replacement cost of power converter (US$/kW)	90
Operation and maintenance cost of power converter (US$/kW/year)	0
Working life span of power converter (years)	15
Batteries	
Nominal capacity of each battery (Ah)	3000
Nominal voltage of each battery (V)	2
Round trip efficiency (%)	86
Minimum state of charge (%)	30
Number of batteries per string	220
Number strings considered	016,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,79,80,81
Minimum battery life (years)	5
Expected lifetime throughput (MWh)	10,196
Cost of battery (US$/battery)	300
Replacement cost of battery (US$/battery)	300
Operation and maintenance cost of batteries (US$/battery/year)	10
Diesel generators	
Generator sizes considered (kW)	0,1100
Lifetime operating hours (hours)	20,000
Minimum load ratio (%)	30
Capital cost (US$/kW)	60
Replacement cost (US$/kW)	40
Operation and maintenance cost (US$/hour)	0

Table 3. Input Table

III. RESULTS OF HYBRID PV/ DIESEL PLANT DESIGN



3. AC DC LINE

PV (kW)	DG (kW)	H3000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)	Batt. Lf. (yr)
6400	1100	4400	1200	$ 7,574,000	598,460	$ 12,339,733	0.177	0.87	368,760	1,672	10.4
4000	1100		1200	$ 3,974,000	1,663,013	$ 17,217,118	0.247	0.50	1,568,702	6,708	
11000		17600	1200	$ 15,838,000	397,713	$ 19,005,120	0.273	1.00			20.0
	1100		1200	$ 174,000	2,430,447	$ 19,528,444	0.280	0.00	2,411,414	8,760	
	1100	3520	1200	$ 1,230,000	2,461,345	$ 20,830,500	0.299	0.00	2,407,147	8,745	20.0

Table 4. OPTIMIZED RESULT

Here we have five results in the solution. We will describe each of the result and finally select the best suited for our condition.

CASE 1 PV/ DIESEL/ BATTERY

CASE 2 PV/ DIESEL

CASE 3 PV/ BATTERY

CASE 4 DIESEL

CASE 5 DIESEL/ BATTERY

CASE	PV	DG	Hoppecke 24 OPzS 3000	Converter
	kW	kW	nos	kW
CASE 1 PV/ DIESEL/ BATTERY	6,400	1,100	4,400	1,200
CASE 2 PV/ DIESEL	4,000	1,100	0	1,200
CASE 3 PV/ BATTERY	11,000	0	17,600	1,200
CASE 4 DIESEL	0	1,100	0	1,200
CASE 5 DIESEL/ BATTERY	0	1,100	3,520	1,200

Table 5. Cases

In above cases PV is used only in first three cases, in case (1) 6,400 KW of PV is used with 1100 KW of diesel generator and 4400 nos batteries. In case (3) 11,000 KW of PV with 17600 nos batteries are used. In case (2)

4000KW of PV with 1100 KW of diesel generator is used. Last two cases are without PV source. Case (4) has diesel generator of 1100 KW and case (5) has 1100 KW diesel generator with 3520 nos batteries.1200 KW of converter is used in all the cases.

CASE	Total Capital Cost	Total NPC	Tot. Ann. Cap. Cost	Tot. Ann. Repl. Cost	Total O&M Cost	Total Fuel Cost	Total Ann. Cost	Operating Cost	COE
	$	$	$/yr	$/yr	$/yr	$/yr	$/yr	$/yr	$/kWh
CASE 1 PV/ DIESEL/ BATTERY	7,574,000	12,339,733	951,110	57,700	172,000	368,760	1,549,570	598,460	0.177
CASE 2 PV/ DIESEL	3,974,000	17,217,118	499,038	14,311	80,000	1,568,702	2,162,051	1,663,013	0.247
CASE 3 PV/ BATTERY	15,838,000	19,005,120	1,988,867	1,713	396,000	0	2,386,580	397,713	0.273
CASE 4 DIESEL	174,000	19,528,444	21,850	19,032	0	2,411,414	2,452,297	2,430,447	0.28
CASE 5 DIESEL/ BATTERY	1,230,000	20,830,500	154,458	18,999	35,200	2,407,147	2,615,803	2,461,345	0.299

Table 6. Cost

In the above cases it is seen that the total capital cost for case (3) is highest. But if we look at total net present cost case (1) has the least following case (2). The levelized cost of energy (COE) is also least for case1 followed by case2, case 3, case 4and case 5. For case 1 levelized COE is $0.177/kWh.

3.1 Optimum Case

CASE	Total NPC	COE	Emission	Ren. Fraction	Fuel consumption	Unmet Load
	$	$/kWh	kg/yr		L/yr	kWh/yr
CASE 1 PV/ DIESEL/ BATTERY	12,339,733	0.177	997,249	0.87	368,760	0
CASE 2 PV/ DIESEL	17,217,118	0.247	4,242,285	0.5	1,568,702	0
CASE 3 PV/ BATTERY	19,005,120	0.273	0	1	0	7,192
CASE 4 DIESEL	19,528,444	0.28	6,521,253	0	2,411,414	0
CASE 5 DIESEL/ BATTERY	20,830,500	0.299	6509712	0	2,407,147	0

Table 7. Optimum Case

To get the final conclusion we have selected few parameters like COE, total NPC, pollution emission, renewable fraction, fuel consumption, unmet load and compared them. In the above comparison we can see that case (3) has highest percentage of renewable fraction. Also there is no pollution emission and no fuel consumption in this case. But the cost of energy and net present value in case (1) is least. In case (3) there is some unmet load i.e. there are times when plant will not be able to serve the load. Hence we can conclude that case (1) is the best case suited to our load.[21]

In all the possible cases of PV/ Diesel/ battery to get the final conclusion we select the case with minimum cost of electricity and net present cost. The chart below shows all the cases with PV on one side, battery size on other side and cost of energy plotted between them. The size of the diesel generator is constant i.e. 1100 KW.

	BATTERY																			
PV	3520	3740	3960	4180	4400	4620	4840	5060	5280	5500	5720	5940	6160	6380	6600	6820	7040	7260	7480	7700
5000	0.188	0.189	0.19	0.19																
5200	0.185	0.185	0.186	0.187	0.188	0.189	0.189	0.19												
5400	0.182	0.183	0.183	0.184	0.184	0.185	0.186	0.187	0.188	0.188	0.189	0.19								
5600		0.18	0.181	0.181	0.182	0.182	0.183	0.184	0.184	0.185	0.186	0.187	0.187	0.188	0.189	0.19	0.191			
5800			0.179	0.179	0.179	0.18	0.18	0.181	0.182	0.182	0.183	0.184	0.185	0.185	0.186	0.187	0.187	0.188	0.189	0.19
6000				0.178	0.178	0.179	0.179	0.179	0.18	0.181	0.181	0.182	0.182	0.183	0.184	0.184	0.185	0.186	0.187	0.187
6200				0.177	0.177	0.178	0.178	0.179	0.179	0.18	0.18	0.181	0.181	0.182	0.182	0.183	0.184	0.184	0.185	0.185
6400					0.177	0.177	0.178	0.178	0.178	0.179	0.179	0.18	0.18	0.181	0.181	0.182	0.183	0.183	0.184	0.184
6600					0.177	0.177	0.178	0.178	0.178	0.179	0.179	0.18	0.18	0.181	0.181	0.182	0.182	0.183	0.184	0.184
6800					0.178	0.178	0.178	0.178	0.179	0.179	0.18	0.18	0.181	0.181	0.182	0.182	0.183	0.183	0.184	0.184
7000						0.179	0.179	0.179	0.18	0.18	0.18	0.181	0.181	0.182	0.182	0.183	0.184	0.184	0.185	0.185
7100						0.179	0.18	0.18	0.18	0.181	0.181	0.181	0.182	0.182	0.183	0.183	0.184	0.185	0.185	0.186
7200						0.18	0.18	0.18	0.181	0.181	0.182	0.182	0.183	0.183	0.183	0.184	0.185	0.185	0.186	0.186
7400						0.182	0.182	0.182	0.182	0.182	0.183	0.183	0.184	0.184	0.185	0.185	0.186	0.186	0.187	0.187

Table 8. Battery V/S PV

In the above table it can be seen that $0.177 /KWh is the least levelized cost of energy among all the cases. Among them the case with PV size 6,400 KW and battery size 4400 nos has the least net present cost i.e. $12,339,733. Hence this is the optimum solution for case PV/ Diesel/ Battery. The graph is plotted between PV, battery and LCOE is shown below.

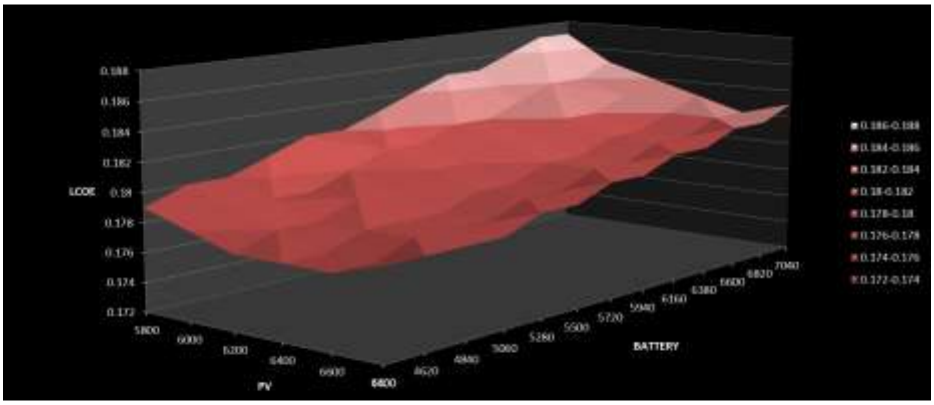


Table 9. Graph Plot

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