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Case Study of Grid-Connected Photovoltaic Power System Installed at Monthly Optimum Tilt Angles for Different Climatic Zones in India

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ABSTRACT Elevated price of renewable energy (RE) systems slowed its adoption in many countries. Hence, it is important to select an optimal size of the system in order to decrease cost, excess energy produced by RE system. The RE system is used to minimize air pollution and energy security. The aim of this study is to evaluate and compare the techno-economic performance of grid-connected photovoltaic (PV) power systems for a rooftop solar PV building containing 14 families in six regions with different climate zones in India. For this purpose, grid connected PV (Grid-PV) is installed at optimum tilt angles (OTA). Then, techno-economic performance of these systems is performed in the six climatic zones in India, which is the novelty of this study. RE resources and ambient temperature for different seasons are considered during analysis. The load is fixed for all the sites for a better comparison in the study. The results show that using OTA in Grid-PV system reduces greenhouse gas emissions, e.g. COx, SOx and NOx, decreases payback time while increasing overall PV production and other project productivity parameters. These include specific yield, PV penetration, return on investment, Internal Rate of Interest, Net Present Value, Annualized Saving, Energy sold to the grid for all climatic zones in India proving useful for industry. Using these metrics and results in this paper, researchers and project developers, policy makers can promote better use of renewable energy. Therefore, it is necessary to use Grid-PV with OTA for different climatic zones.

INDEX TERMS OTA Grid-PV system, emission, PV production, energy sold to the grid, annualized saving, simple payback year.

I. INTRODUCTION

Electric power generation is required for consumer and important for economic development of the country. India has installed national grid capacity of 370.106 GW up to 31 March 2020 [1] and third largest electricity consumer. The electricity generation is 79.8% by fossil fuel and 17.3% by renewable energy. The electricity sector in India represents 72% of the coal consumption which corresponds to 622.22 million tons of coal during 2019-20. Due to high ash content in India's coal, Centre for Science and Environment assessed coal-based power sector as resource wasteful and polluting [2]. The coal fired power plant emission affects human health. in 2010-2011, 111 plants with 121 GW installed capacity consumed 503 million tons of coal and generated 580 ktons of PM2.5, 2100 ktons of SO_x 2000 ktons of NO2, 1100 ktons of CO, 100 ktons of volatile organic compounds, and 665 million tons of CO2. These emissions are the root cause of 80,000 to 115,000 premature deaths, 20.0 million asthma due to PM2.5 pollutant exposure. This results in government and public expenses of estimated INR 16,000 to 23,000 crores (USD 3.2 to 4.6 billion) [3].

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TABLE 1. Coordinate information of taken region for respective climate zone.

Region	*Latitude(ºN)*	*Longitude(ºE)*	*Altitude(m)*	*Grid*	*Climatic regions*
New Delhi	28.70	77.10	216	Northern Grid	Semi-Arid
Patna	25.6	85.10	53	Eastern Grid	Humid Subtropical
Srinagar	34.08	74.79	1585	Northern Grid	Montane
Jaipur	26.91	75.78	431	Western Grid	Arid
Hyderabad	17.38	78.48	505	Southern Grid	Tropical wet and dry
Panaji	15.49	73.82	7	Southern Grid	Tropical Wet

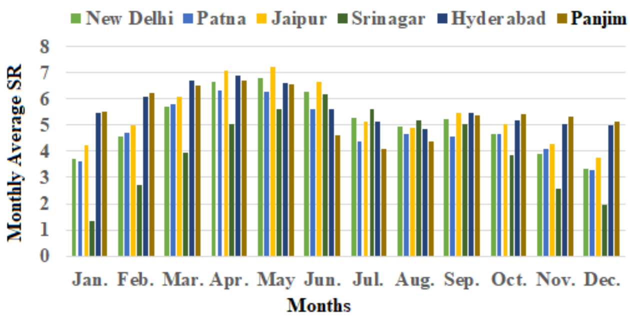

FIGURE 1. Monthly average value of solar radiation for proposed sites.

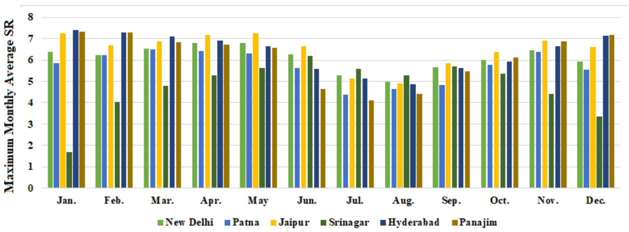

FIGURE 2. Maximum SR at monthly optimum tilt angle.

To reduce dependence on fossil fuel for power generation, Indian government launched National Solar Mission (NSM) on 11th January 2010. The target of NSM is to install 100 GW grid connected PV system by 2022 and for achievement of target Government launched different scheme to encourage solar power generation [4].

PV power generation is an important route to reduce energy based environmental problems, particularly CO2 emissions [5]. PV generation enhances the use of solar energy on power grid to reduce emission of air pollutant, global warming and greenhouse gas emission. Several researchers studied feasibility analysis of grid connected PV systems at different sites [28], [29]. Tomar and Tiwari [6] studied net metering along with feed in tariff for feasibility of Grid-PV for New Delhi India. It is found that battery storage is not economically and technically viable option for Grid-PV system. The cost of energy (COE) increases with battery size.

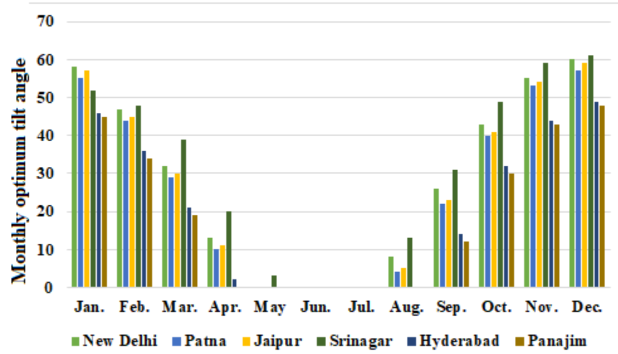

FIGURE 3. Monthly OTA for selected sites.

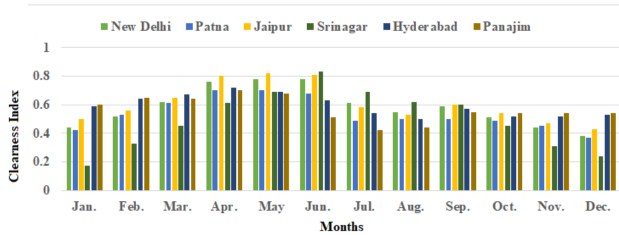

FIGURE 4. Monthly average value of clearness index for proposed sites.

TABLE 2. Electrical load profile.

Devices	Rating (Watt)	No. of devices	Run time (hour/day)	Per household daily consumption (kWh/day)	Building consumption (kWh/day)
Water heater	1500	1	1	1.5	21
Lighting	15/25/60	2/2/1	5	0.7	9.8
Electric cooker	500	1	1.5	0.75	10.5
Television	150	1	3	0.45	6.3
Washing machine	300	1	1	0.3	4.2
Air conditioning	1,100	1	5	5.5	77
Refrigerator	150	1	24	3.6	50.4
Less power rating appliances	100	1	24	2.4	33.6
Total				15.2	212.8

TABLE 3. Load baseline for six climatic zones.

	Baseline	Scaled
Average (kWh/day)	212.8	11.26
Average (kW)	8.87	0.47
Peak (kW)	26.37	1.4
Load Factor	0.34	0.34

The carbon emission is reduced by 2.5 t per year with addition of per kW capacity. Javed *et al.* [30] proposed hybrid of

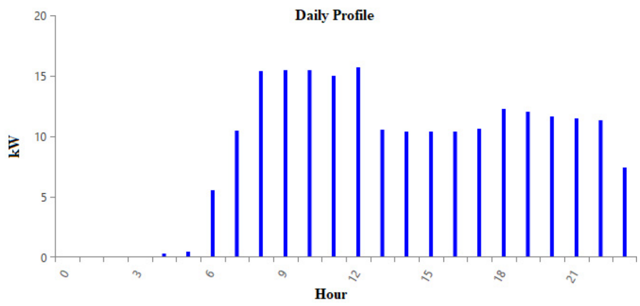

FIGURE 5. Daily load profile.

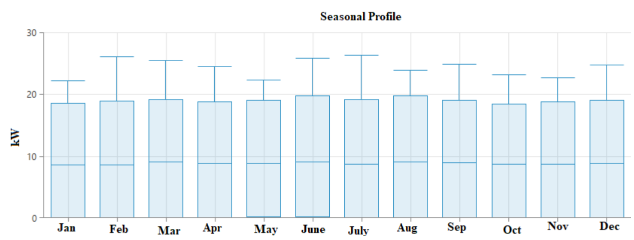

FIGURE 6. Monthly load profile.

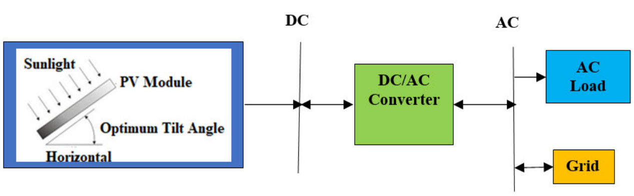

FIGURE 7. Studied Grid-PV system with OTA.

TABLE 4. PV Specification and cost.

Parameters	Specification
Type of PV Panel	Poly Crystalline Solar Panel
Rating	100Wp, 12V
Open circuit voltage (Voc)	22V
Short Circuit Current (Isc)	6.06A
Dimensions	1035x670x34
Cost of 1000 Wp	$ 596.44 (Rs 43637.04)
Property	Anti-reflective coating; Excellent Low light performance ; PID resistance Technology for safety against substantial power loss

PV-battery-capacitor for Sultanpur, India. New Fuzzy Logic Control Strategy is implemented to control power flow of battery and capacitor. This implementation reduces maintenance cost and battery life span.

Ramli *et al.* [7] investigated optimum configuration of PV/inverter, PV and inverter for grid-PV system in Makkah, Saudi Arabia. It is obtained for unmet load of 2200 MW and zero percent excess energy, PV and inverter size are 2200 MW. Numbi and Malinga [8] presented 3 kW grid-PV by proposing feed-in tariff for urban and residential household. The energy cost saving is 69.41% by energy cost management. Majidi *et al.* [9] minimized cost of PV-Fuel cell-battery-Grid hybrid system and carbon emission. Fuzzy

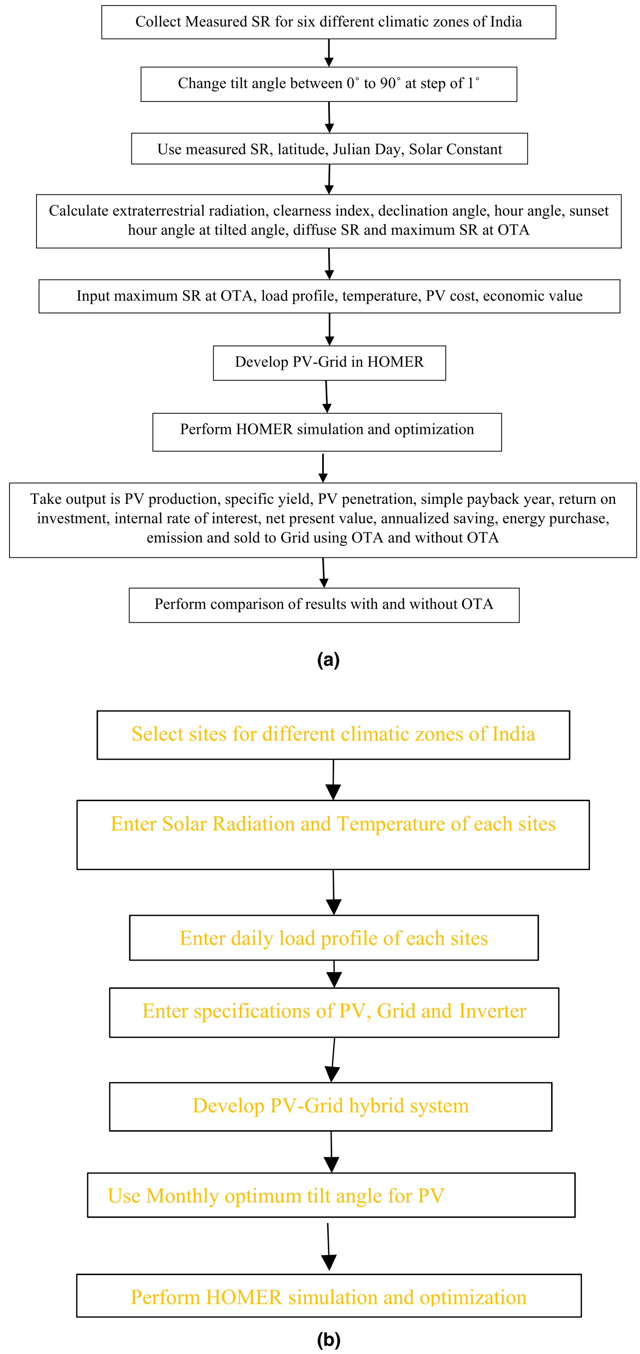

FIGURE 8. (a). Proposed algorithm (b). HOMER work flow.

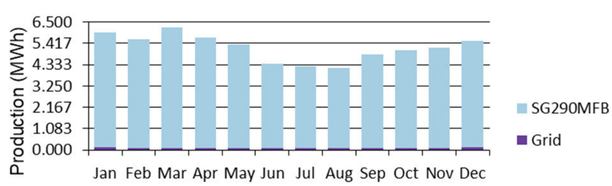

FIGURE 9. PV production without OTA in Hyderabad.

and weighted sum technique are used to solve cost optimization of hybrid system considering demand response program (DRP). Lau *et al.* [10] analyzed feasibility of Grid-PV system

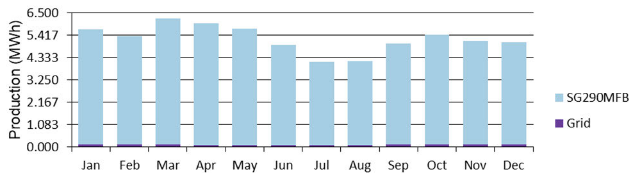

FIGURE 10. PV production without OTA in Jaipur.

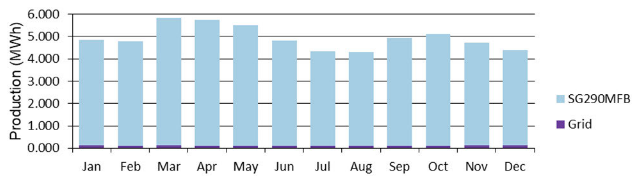

FIGURE 11. PV production without OTA in New Delhi.

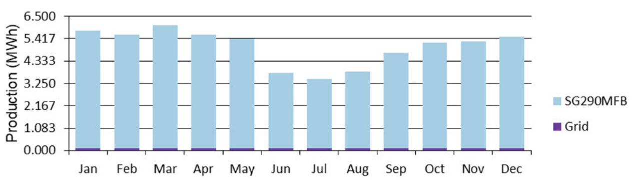

FIGURE 12. PV production without OTA in Panaji

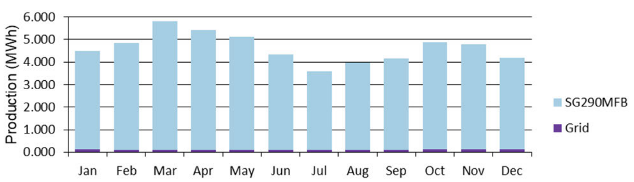

FIGURE 13. PV production without OTA in Patna.

in Malaysia and found that PV array costs less than \$1120/kW are sufficient.

The battery storage is not recommended for Grid-PV system as it increases the cost of hybrid system [31]. By introducing feed in tariff concept Net Present Cost of Grid-PV system is reduced. Kebede [11] explored potential of 5 MW grid-PV system for 35 locations in Ethiopia. It is economical viable as per analysis but there should be incentives for commercial investors. It is found that power generation is 7658MW and greenhouse gas emission is reduced by 1089 tons annually. Emmanuel *et al.* [12] presented economic viability and performance analysis of 10 kWp grid-PV system installed at Maungaraki school in Wellington, New Zealand. The Levelized cost of energy (LCOE) at discount rate of 4%, 6% and 8% are 12.1, 14.1 and 16.2 c/kWh respectively.

Choi *et al.* [13] simulated PV-battery, grid-PV and grid-only for cost optimization. The grid only system has least cost of energy and net present cost. The pollutant is decreased by 10% with addition of PV to grid. Campana *et al.* [14] considered hybrid of floating-PV and grid for utilization of solar energy in Thailand. Adaramola [15] have also focused on economic feasibility of

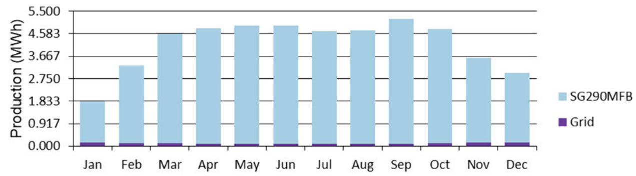

FIGURE 14. PV production without OTA in Srinagar.

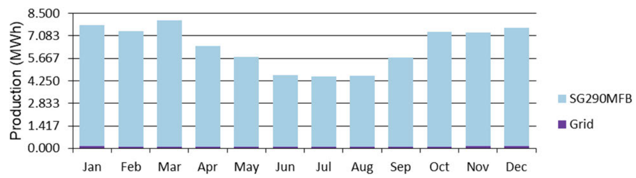

FIGURE 15. PV Production at monthly OTA in Hyderabad.

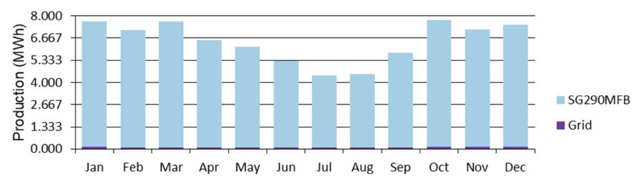

FIGURE 16. PV Production at monthly OTA in Jaipur.

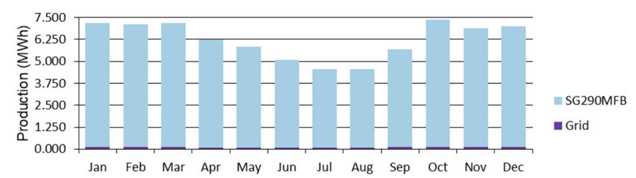

FIGURE 17. PV Production at monthly OTA in New Delhi.

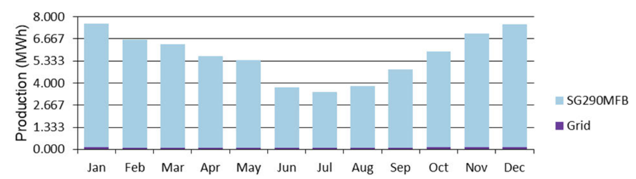

FIGURE 18. PV Production at monthly OTA in Panajim.

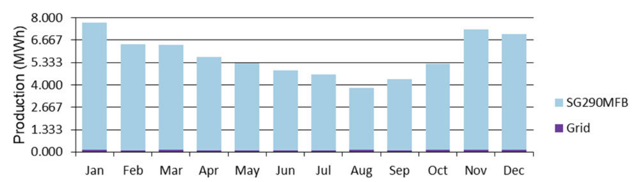

FIGURE 19. PV Production at monthly OTA in Patna.

Grid-PV system at different locations of Nigeria. It is found that Grid-PV is viable for north-eastern part of Nigeria.

The OTA influences maximum power generation and optimum sizing of PV system so analyzing grid-PV at OTA for different climatic zones of India is important as it was not done before. India, which covers 3,287,263 km^2, is a vast country with diverse climatic conditions. According to

TABLE 5. Energy purchased and sold to Grid in Hyderabad without OTA.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	120	2,498	-2,378	1.05	-$112.93	$0.00	-$112.93
February	106	2,324	-2,218	0.966	-$105.59	$0.00	-$105.59
March	117	2,569	-2,453	0.999	-$116.80	$0.00	-$116.80
April	107	2,537	-2,430	1.06	-$116.13	$0.00	-$116.13
May	97.3	2,552	-2,455	1.02	-$117.87	$0.00	-$117.87
June	94.6	2,300	-2,206	1.03	-$105.56	$0.00	-$105.56
July	92.8	2,302	-2,209	0.978	-$105.82	$0.00	-$105.82
August	103	2,153	-2,051	0.941	-$97.40	$0.00	-$97.40
September	108	2,240	-2,132	0.982	-$101.19	$0.00	-$101.19
October	107	2,413	-2,306	0.938	-$109.91	$0.00	-$109.91
November	111	2,357	-2,246	1.10	-$106.74	$0.00	-$106.74
December	120	2,390	-2,270	1.00	-$107.50	$0.00	-$107.50
Annual	1,284	28,637	-27,353	1.10	-$1,303	$0.00	-$1,303

TABLE 6. Energy purchased and sold to Grid without OTA in Jaipur.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	120	2,354	-2,235	1.05	-$105.74	$0.00	-$105.74
February	106	2,233	-2,127	0.966	-$101.05	$0.00	-$101.05
March	110	2,531	-2,421	0.999	-$115.55	$0.00	-$115.55
April	92.9	2,556	-2,463	1.06	-$118.49	$0.00	-$118.49
May	92.0	2,634	-2,542	1.02	-$122.49	$0.00	-$122.49
June	90.7	2,467	-2,376	1.03	-$114.25	$0.00	-$114.25
July	90.3	2,285	-2,194	0.978	-$105.21	$0.00	-$105.21
August	94.6	2,151	-2,056	0.941	-$98.08	$0.00	-$98.08
September	103	2,272	-2,168	0.982	-$103.25	$0.00	-$103.25
October	112	2,457	-2,345	0.938	-$111.63	$0.00	-$111.63
November	123	2,221	-2,098	1.10	-$98.74	$0.00	-$98.74
December	127	2,200	-2,074	1.00	-$97.34	$0.00	-$97.34
Annual	1,262	28,360	-27,098	1.10	-$1,292	$0.00	-$1,292

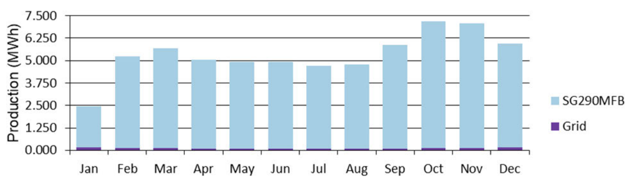

FIGURE 20. PV Production at monthly OTA in Srinagar.

Koppen classification system, the climate of India is divided into six major climate zones: Montane, Humid Subtropical, Tropical Wet and Dry, Tropical Wet, Semi-arid and Arid [32]. To study the most important impact parameters in these climate zones, six representative cities were chosen. These cities and their geographical information are given in Table 1.

This paper presents a new method for determining techno-economic comparative study of grid connected solar PV power systems under different climate conditions in India which can be very economical beneficial for other sites throughout the world. To do this, sites are selected [Table 1] from different climatic zones of India and from recent publication by Yadav and Chandel [18] calculated maximum solar radiation at monthly optimum tilt angle (OTA) is taken and is utilized for techno-economic analysis of PV-Grid system for different climatic conditions in India using the HOMER simulation tool.

II. RESEARCH METHODOLOGY

A. METEOROLOGICAL DATA

The measured solar radiation (SR) data are taken from reference [16] and temperature (T) is taken from NASA database [17]. Figure 1 shows monthly average global SR. The average value of SR values in New Delhi, Patna, Jaipur, Srinagar, Hyderabad and Panjim are 5.09, 4.83. 5.4, 4.09, 5.67 and 5.5 kWh/m2/day and it varies from 3.31 (Dec)-6.78 (May), 3.29 (Dec)-6.35 (April), 3.74 (Dec)-7.25 (May), 1.32 (Jan)-6.18 (June), 4.87 (Aug)-6.9 (April), 4.1 (July)-6.72 (April) kWh/m2/day. Figure 2 shows the maximum SR at monthly optimum tilt angle (OTA). OTA for different cities is given in Fig. 3. E.g. OTA is 0° for June and July. As shown in Fig. 4, the average value of CI values in New Delhi, Patna, Jaipur, Srinagar, Hyderabad and Panjim are 0.58, 0.54, 0.61, 0.5, 0.59 and 0.57 respectively and it varies from 0.38-0.78.

B. ELECTRICAL LOAD

Electrical load is important for PV hybrid system design. Daily electrical load profile for a building with seven floors is considered. Two families are housed per floor which means 14 houses in the six climatic zones in India was used as load in HOMER. List of available loads per house si given in Table 2. The peak load demand and load factor are shown in Table 3.

TABLE 7. Energy purchased and sold to Grid without OTA in New Delhi.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	121	2,145	-2,024	1.05	-$95.18	$0.00	-$95.18
February	106	2,124	-2,018	0.966	-$95.59	$0.00	-$95.59
March	117	2,463	-2,346	0.999	-$111.48	$0.00	-$111.48
April	95.2	2,531	-2,436	1.06	-$117.05	$0.00	-$117.05
May	92.2	2,588	-2,496	1.02	-$120.17	$0.00	-$120.17
June	90.3	2,440	-2,349	1.03	-$112.95	$0.00	-$112.95
July	90.4	2,344	-2,253	0.978	-$108.14	$0.00	-$108.14
August	96.1	2,187	-2,090	0.941	-$99.71	$0.00	-$99.71
September	105	2,243	-2,138	0.982	-$101.63	$0.00	-$101.63
October	110	2,390	-2,280	0.938	-$108.49	$0.00	-$108.49
November	132	2,109	-1,977	1.10	-$92.24	$0.00	-$92.24
December	137	2,034	-1,896	1.00	-$87.96	$0.00	-$87.96
Annual	1,293	27,598	-26,305	1.10	-$1,251	$0.00	-$1,251

TABLE 8. Energy purchased and sold to Grid without OTA in Panajim.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	120	2,478	-2,359	1.05	-$111.94	$0.00	-$111.94
February	92.6	2,335	-2,242	0.966	-$107.49	$0.00	-$107.49
March	101	2,529	-2,428	0.999	-$116.36	$0.00	-$116.36
April	92.6	2,487	-2,394	1.06	-$115.07	$0.00	-$115.07
May	91.9	2,520	-2,428	1.02	-$116.81	$0.00	-$116.81
June	91.7	2,079	-1,987	1.03	-$94.78	$0.00	-$94.78
July	91.2	1,992	-1,900	0.978	-$90.46	$0.00	-$90.46
August	93.8	2,027	-1,933	0.941	-$91.95	$0.00	-$91.95
September	99.5	2,195	-2,096	0.982	-$99.83	$0.00	-$99.83
October	113	2,437	-2,324	0.938	-$110.53	$0.00	-$110.53
November	117	2,332	-2,215	1.10	-$104.91	$0.00	-$104.91
December	120	2,408	-2,288	1.00	-$108.39	$0.00	-$108.39
Annual	1,224	27,818	-26,594	1.10	-$1,269	$0.00	-$1,269

TABLE 9. Energy purchased and sold to Grid without OTA in Panajim.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	139	1,991	-1,851	1.05	-$85.59	$0.00	-$85.59
February	105	2,162	-2,057	0.966	-$97.58	$0.00	-$97.58
March	113	2,481	-2,369	0.999	-$112.80	$0.00	-$112.80
April	109	2,502	-2,394	1.06	-$114.26	$0.00	-$114.26
May	109	2,525	-2,416	1.02	-$115.36	$0.00	-$115.36
June	99.2	2,328	-2,229	1.03	-$106.48	$0.00	-$106.48
July	101	2,061	-1,961	0.978	-$92.99	$0.00	-$92.99
August	112	2,110	-1,997	0.976	-$94.25	$0.00	-$94.25
September	110	2,013	-1,902	0.982	-$89.60	$0.00	-$89.60
October	122	2,331	-2,208	0.938	-$104.31	$0.00	-$104.31
November	125	2,170	-2,045	1.10	-$96.03	$0.00	-$96.03
December	134	1,976	-1,842	1.00	-$85.38	$0.00	-$85.38
Annual	1,378	26,649	-25,271	1.10	-$1,195	$0.00	-$1,195

The daily and monthly load profiles are shown in Fig.5 and Fig.6, respectively.

C. ANALYZED GRID-PV SYSTEM WITH OPTIMUM TILT ANGLE

In this work, Grid-PV system installed at OTA is designed for 14 houses in the six climatic zones of India considering measured SR and temperature for these zones. The proposed system is shown in Fig.7. The specification and cost of PV is shown in Table 4 [25]. The cost of 1000 W converter is $ 52.896 [26] and Inflation rate is 3.34 % [27].

D. TECHNO-ECONOMIC CALCULATION OF GRID-PV SYSTEM AT MONTHLY OTA

For analysis, there are many simulation tools available [20], [21]. In this study, HOMER is used and detailed process to use this software for PV hybrid systems is shown in references [22]–[24]. The proposed algorithm for this work is shown in Fig.8.

TABLE 10. Energy purchased and sold to Grid without OTA in Srinagar.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	149	1,010	-862	1.05	-$35.65	$0.00	-$35.65
February	112	1,591	-1,478	0.966	-$68.29	$0.00	-$68.29
March	109	2,076	-1,967	0.999	-$92.93	$0.00	-$92.93
April	91.2	2,304	-2,213	1.06	-$106.08	$0.00	-$106.08
May	90.8	2,427	-2,336	1.02	-$112.27	$0.00	-$112.27
June	80.1	2,453	-2,373	0.961	-$114.63	$0.00	-$114.63
July	77.7	2,449	-2,371	0.978	-$114.68	$0.00	-$114.68
August	92.5	2,300	-2,208	0.941	-$105.76	$0.00	-$105.76
September	101	2,260	-2,159	0.982	-$102.92	$0.00	-$102.92
October	116	2,233	-2,116	0.938	-$100.00	$0.00	-$100.00
November	136	1,630	-1,494	1.10	-$67.90	$0.00	-$67.90
December	155	1,439	-1,284	1.00	-$56.42	$0.00	-$56.42
Annual	1,311	24,172	-22,861	1.10	-$1,078	$0.00	-$1,078

TABLE 11. Energy purchased and sold to Grid with OTA in Hyderabad.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	120	2,645	-2,526	1.05	-$120.29	$0.00	-$120.29
February	106	2,464	-2,358	0.966	-$112.58	$0.00	-$112.58
March	110	2,744	-2,634	0.999	-$126.24	$0.00	-$126.24
April	95.0	2,576	-2,481	1.06	-$119.31	$0.00	-$119.31
May	93.1	2,577	-2,483	1.02	-$119.51	$0.00	-$119.51
June	92.2	2,332	-2,240	1.03	-$107.38	$0.00	-$107.38
July	90.2	2,345	-2,254	0.978	-$108.21	$0.00	-$108.21
August	96.1	2,216	-2,120	0.941	-$101.18	$0.00	-$101.18
September	104	2,380	-2,277	0.982	-$108.66	$0.00	-$108.66
October	112	2,695	-2,583	0.938	-$123.53	$0.00	-$123.53
November	122	2,517	-2,394	1.10	-$113.60	$0.00	-$113.60
December	125	2,577	-2,452	1.00	-$116.34	$0.00	-$116.34
Annual	1,266	30,068	-28,803	1.10	-$1,377	$0.00	-$1,377

TABLE 12. Energy purchased and sold to Grid with OTA in Jaipur.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	120	2,632	-2,512	1.05	-$119.60	$0.00	-$119.60
February	106	2,482	-2,376	0.966	-$113.50	$0.00	-$113.50
March	110	2,704	-2,594	0.999	-$124.24	$0.00	-$124.24
April	94.6	2,594	-2,500	1.06	-$120.26	$0.00	-$120.26
May	93.4	2,660	-2,567	1.02	-$123.65	$0.00	-$123.65
June	91.4	2,491	-2,400	1.03	-$115.43	$0.00	-$115.43
July	90.2	2,331	-2,241	0.978	-$107.54	$0.00	-$107.54
August	95.6	2,208	-2,112	0.941	-$100.84	$0.00	-$100.84
September	103	2,419	-2,316	0.982	-$110.62	$0.00	-$110.62
October	112	2,739	-2,627	0.938	-$125.72	$0.00	-$125.72
November	122	2,510	-2,388	1.10	-$113.28	$0.00	-$113.28
December	125	2,568	-2,443	1.00	-$115.88	$0.00	-$115.88
Annual	1,264	30,339	-29,075	1.10	-$1,391	$0.00	-$1,391

1) SENSITIVITY ANALYSIS (SA)

It means effect of input on output and SA is used in HOMER simulation. In this work monthly, yearly OPTA and latitude of different sites are used SA and its effects also observed on economic analysis of SAPV system.

2) PV ARRAY

The output power of PV array (P) is modeled in HOMER in directly proportional to incident SR and is given by following equation.

$$P = F_{PV} N_{PV} \frac{H_{TR}}{H_{RSR}} \tag{1}$$

TABLE 13. Energy purchased and sold to Grid with OTA in New Delhi.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	120	2,597	-2,476	1.05	-$117.81	$0.00	-$117.81
February	106	2,451	-2,345	0.966	-$111.92	$0.00	-$111.92
March	117	2,659	-2,542	0.999	-$121.27	$0.00	-$121.27
April	96.2	2,574	-2,477	1.06	-$119.06	$0.00	-$119.06
May	93.0	2,612	-2,519	1.02	-$121.28	$0.00	-$121.28
June	90.7	2,464	-2,373	1.03	-$114.10	$0.00	-$114.10
July	90.6	2,379	-2,288	0.978	-$109.87	$0.00	-$109.87
August	97.4	2,234	-2,137	0.941	-$101.97	$0.00	-$101.97
September	105	2,398	-2,293	0.982	-$109.43	$0.00	-$109.43
October	110	2,720	-2,610	0.938	-$125.00	$0.00	-$125.00
November	131	2,479	-2,348	1.10	-$110.81	$0.00	-$110.81
December	136	2,527	-2,392	1.00	-$112.79	$0.00	-$112.79
Annual	1,293	30,093	-28,800	1.10	-$1,375	$0.00	-$1,375

TABLE 14. Energy purchased and sold to Grid with OTA in Panajim.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	120	2,733	-2,613	1.05	-$124.67	$0.00	-$124.67
February	92.5	2,458	-2,366	0.966	-$113.66	$0.00	-$113.66
March	101	2,581	-2,480	0.999	-$118.94	$0.00	-$118.94
April	92.6	2,487	-2,394	1.06	-$115.07	$0.00	-$115.07
May	91.9	2,520	-2,428	1.02	-$116.81	$0.00	-$116.81
June	91.7	2,079	-1,987	1.03	-$94.79	$0.00	-$94.79
July	91.2	1,992	-1,900	0.978	-$90.46	$0.00	-$90.46
August	93.8	2,027	-1,933	0.941	-$91.95	$0.00	-$91.95
September	99.4	2,221	-2,122	0.982	-$101.12	$0.00	-$101.12
October	113	2,566	-2,453	0.938	-$117.00	$0.00	-$117.00
November	116	2,606	-2,490	1.10	-$118.66	$0.00	-$118.66
December	119	2,719	-2,600	1.00	-$124.01	$0.00	-$124.01
Annual	1,222	28,988	-27,765	1.10	-$1,327	$0.00	-$1,327

TABLE 15. Energy purchased and sold to Grid with OTA in Patna.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	138	2,580	-2,441	1.05	-$115.15	$0.00	-$115.15
February	105	2,433	-2,329	0.966	-$111.21	$0.00	-$111.21
March	112	2,581	-2,469	0.999	-$117.83	$0.00	-$117.83
April	108	2,535	-2,426	1.06	-$115.90	$0.00	-$115.90
May	109	2,555	-2,446	1.02	-$116.88	$0.00	-$116.88
June	98.8	2,453	-2,355	1.03	-$112.79	$0.00	-$112.79
July	98.8	2,445	-2,346	0.978	-$112.35	$0.00	-$112.35
August	113	2,043	-1,931	0.976	-$90.92	$0.00	-$90.92
September	110	2,054	-1,944	0.982	-$91.70	$0.00	-$91.70
October	122	2,400	-2,278	0.938	-$107.78	$0.00	-$107.78
November	124	2,545	-2,421	1.10	-$114.86	$0.00	-$114.86
December	132	2,550	-2,418	1.00	-$114.27	$0.00	-$114.27
Annual	1,371	29,175	-27,804	1.10	-$1,322	$0.00	-$1,322

where F_{PV} is derating factor of PV array which show decrease in PV power due to elevated temperature, dust and wire loss. N_{PV} is PV array capacity, H_R is reference SR (1kW/m^2). The incident SR is converted into power with efficiency (η) as shown in following.

$$\eta = \frac{P_N}{H_{TR} \times A_R} \tag{2}$$

where P_N is output power of solar cell at its maximum power point and A_R is solar cell surface area.

3) ECONOMIC ANALYSIS

The main aim is to minimize NPC by exploring optimum combination of PV, battery, converter at give value of SR resources. NPC incorporate all costs. The important

TABLE 16. Energy purchased and sold to Grid with OTA in Srinagar.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	146	1,239	-1,093	1.05	-$47.34	$0.00	-$47.34
February	110	2,113	-2,003	0.966	-$94.69	$0.00	-$94.69
March	108	2,353	-2,245	0.999	-$106.88	$0.00	-$106.88
April	90.4	2,350	-2,260	1.06	-$108.47	$0.00	-$108.47
May	90.8	2,427	-2,337	1.02	-$112.29	$0.00	-$112.29
June	80.1	2,453	-2,373	0.961	-$114.65	$0.00	-$114.65
July	77.7	2,450	-2,372	0.978	-$114.72	$0.00	-$114.72
August	92.4	2,325	-2,233	0.941	-$107.03	$0.00	-$107.03
September	100	2,436	-2,335	0.982	-$111.75	$0.00	-$111.75
October	116	2,623	-2,507	0.938	-$119.56	$0.00	-$119.56
November	131	2,443	-2,312	1.10	-$109.06	$0.00	-$109.06
December	148	2,192	-2,044	1.00	-$94.76	$0.00	-$94.76
Annual	1,290	27,405	-26,114	1.10	-$1,241	$0.00	-$1,241

TABLE 17. Annual Energy sold and purchased to Grid with and without OTA for peak annual load of 1.10 kW.

Region	Climatic regions	With OTA		Without OTA		Highlights	
		Energy Sold	Energy Purchased	Energy Sold	Energy Purchased	% increase in Energy sold with PV at OTA	% decrease in Energy purchase from Grid with PV at OTA
New Delhi	Semi-Arid	30,093	1,293	27,598	1,293	9.04	0
Patna	Humid Subtropical	29,175	1,371	26,649	1,378	9.47	0.51
Srinagar	Montane	27,405	1,290	24,172	1,311	13.37	1.62
Jaipur	Arid	30,339	1,264	28,360	1,262	6.97	-0.15
Hyderabad	Tropical wet and dry	30,068	1,266	28,637	1,284	4.99	1.42
Panajim	Tropical Wet	28,988	1,222	27,818	1,224	4.20	0.16

economics parameter are levelized cost of energy (COE), Capital recovery factor (CRF) and total net present cost (C_{NPC}) are as follows.

$$COE = \frac{C_{TAC}}{L_p + L_d + E_{gs}} \quad (3)$$

$$C_{RF(i,n)} = \frac{(i+1)^n i}{(i+1)^n - 1} \quad (4)$$

$$C_{NPC} = \frac{C_{TAC}}{CRF(i, P_L)} \quad (5)$$

where E_{gs} per year energy sold to grid, P_L is project lifetime, L_d defferable load, C_{TAC} is total annualized cost, L_p primary load, n number of year, i annual real interest.

III. RESULTS AND DISCUSSION

In this study hybrid systems such as Grid-PV system with optimum tilt angle (OTA) and without OTA for different climatic zones such as semi-arid, humid-subtropical, montane, arid, tropical wet and dry, tropical wet in India are investigated. For this New Delhi, Patna, Srinagar, Jaipur, Hyderabad, Panajim are selected based on different climatic zones and using proposed algorithm shown in Fig.8 the analysis are performed. Without OTA PV production, energy purchase and sold to Grid are shown in Fig.9 to Fig. 14 and Table 5 to Table 10. Energy charge is amount charged for energy consumed. Negative sign indicate that energy sold to grid is more than energy purchased. The demand charge means the price (in dollars per kilowatt per month) the utility charges for the peak grid demand. Here it is zero because peak demand is zero and power sell to grid is more in comparison to purchase. The Net Energy purchased is the difference between Energy purchase and Energy sold from Grid.

With OTA these are shown in Fig.15 to Fig.20 and Table 11 to Table 16. For peak load of 9 kW without OTA micro grid requires 90, 89, 87, 88, 84, 77 kWh/day for Hyderabad, Jaipur, New Delhi, Panajim, Patna, Srinagar respectively and with OTA it requires 94, 94, 94, 91, 91, 86 kWh/day respectively. It is maximum for Hyderabad, Jaipur, New Delhi and minimum for Srinagar. For peal 1.10kW annual load energy sold and purchase using OTA is shown in Table 17.

Table 18 presents different parameters related to PV with rated capacity of 36 kW and capital cost of $2143 for different climatic zones of India. It is found that at OTA, LCOE get decreases and total PV production, specific yield, PV penetration get increases for all climatic zones which are minimum

TABLE 18. PV: Peimar SG290MFB Analysis for different climatic condition with and without monthly optimum tilt angle.

Parameters	New Delhi		Patna		Jaipur		Srinagar		Hyderabad		Panajim	
		OTA		OTA		OTA		OTA		OTA		OTA
Rated Capacity (kW)	36	36	36	36	36	36	36	36	36	36	36	36
Capital Cost ($)	2143	2143	2143	2143	2143	2143	2143	2143	2143	2143	2143	2143
LCOE ($/kWh)	0.00274	0.00217	0.00293	0.00237	0.00258	0.00209	0.00325	0.00254	0.00260	0.00210	0.00269	0.00239
Total Production (kW)	58,042	73,433	54,226	67,300	61,645	76,262	48,955	62,556	61,161	75,813	59,076	66,683
Specific Yield (kWh/kW)	1,612	2,040	1,506	1,869	1,712	2,118	1,360	1,738	1,699	2,106	1,641	1,852
PV Penetration (%)	1,413	1,787	1,320	1,638	1,500	1,856	1,191	1,522	1,488	1,845	1,438	1623

TABLE 19. Economic Analysis with and without OTA for six climatic zones.

Parameters	With OTA	Without OTA
LCOE ($/kWh)	0.00209-0.00254	0.00258-0.00325
Total Production (kW)	62,556-76,262	48,955-61,645
Specific Yield (kWh/kW)	1,738-2,118	1,360-1,712
PV Penetration (%)	1,522-1,856	1,191-1500
Simple Payback (yr)	1.45-1.59	1.54-1.76
Return On Investment (%)	59.1-64.9	52.9-61.1
Internal Rate of Interest (%)	63.1-68.8	56.8-65.0
Net Present Value ($)	18,661-20,591	16,545-19,315
Annualized Saving ($)	1,646-1,795	1,482-1,697

TABLE 20. Comparison of Emission using only Grid and Grid PV with OTA.

Emission	Grid	Grid-PV with OTA					
		New Delhi	Patna	Jaipur	Srinagar	Hyderabad	Panajim
CO2 kg/year	2597	817	867	799	815	811	773
SO2 kg/year	11.3	3.54	3.76	3.46	3.54	3.51	3.35
NO2 kg/year	5.51	1.73	1.84	1.69	1.73	1.72	1.64

TABLE 21. Emission reduction using Grid-PV with OTA in comparison to only Grid.

Emission	Grid-PV with OTA					
	New Delhi	Patna	Jaipur	Srinagar	Hyderabad	Panajim
CO_2 kg/year	68.54	66.61	69.23	68.61	68.77	70.23
SO_2 kg/year	68.67	66.72	69.38	68.67	68.93	70.35
NO_2 kg/year	68.60	66.60	69.32	68.60	68.78	70.23

for Jaipur and maximum for Srinagar. The variation of these parameters with and without OTA are shown in Table 19 and with OPTA variation is more proving useful to install PV-Grid at OTA for maximum benefit. Payback indicate number of years it takes to recover an investment. The payback is the number of years it takes for the cumulative income to equal the value of the initial investment.

The comparison of emission with Grid-PV at OTA and only Grid is shown in Table 20. The emission CO2, SO2, NO2 with only Grid is more in comparison to Grid-PV. It is found that for six climatic conditions in India reduction for CO2, SO2, NO2 varies from 66.61% to 70.23%, 66.72% to 70.35 %, 66.60% to 70.23% respectively, proving useful to install Grid-PV at OTA, see Table 21.

IV. CONCLUSION

In this research, the techno-economic performance of grid-connected PV with and without optimum tilt angle rooftop solar PV building with constant load in the six climate zones of India was examined. The main conclusions can be stated as follows:

(i) The results show that incident average measured solar radiation on PV-Grid significantly increases with OTA in all six zones. The maximum increase is seen in Jaipur with 1.04 kWh/m^2/day while the average increase is 0.7 kwh/m2/day. The average clearness index is 0.58, 0.54, 0.61, 0.50, 0.59 and 0.57 respectively.

(ii) Grid-PV system is found to be economical in six climatic zones. Energy sold to the grid with OTA is greater than without OTA and it is highest (30,339 kWh) for Arid region and lowest (27,405 kWh) for Montane region with peak load of 1.10 kW.

(iii) For six climatic zones LCOE varies from 0.00209 to 0.00254 $/kWh with OTA and it varies from 0.00258 to 0.00325 $/kWh without OTA, showing using OTA in PV LCOE get decreases from 18.99 % to 21.84%.

(iv) Total PV production, Specific Yield, PV Penetration, Simple Payback, Return on investment, Internal Rate of Interest, Net Present Value, Annualized Saving varies from 62,556-76,262, 1,738-2,118, 1,522-1,856, 1.45-1.59, 59.1-64.9, 63.1-68.8, 18,661-20,591, 1,646-1,795 at OTA and it varies from 48,955-61,645, 1,360-1,712, 1,500-1,191, 1.54-1.76, 52.9-61.1, 56.8-65.0, 16,545-19,315, 1,482-1,697 without OTA for different climatic zones.

(v) Energy sold to grid increases on OTA PV-Grid in comparison to without OTA PV-Grid and it varies from 4.20% to 13.37% and increase is highest and lowest for Montane and Tropical Wet climatic zones respectively.

(vi) Energy purchase from grid decreases on OTA PV-Grid in comparison to without OTA PV-Grid for all climatic zones except Arid and it is same for semi-arid.

(vii) Using OTA PV-Grid simple payback year is decreased by 5.84% to 9.65 %. Net present value increased by 33 % while ROI increased by 24.3 %.

(viii) CO2, SO2 and NO2 emission for different climatic zones get reduce using Grid-PV with OTA which is beneficial for reducing pollution in these zones.

Future research is focused on installation of Grid-PV at monthly optimum tilt angles for different climatic zones and perform analysis experimentally.

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