

Design and Analysis of Solar Carport Canopies with Maximum Power Generation for Electric Vehicle

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Abstract: *Solar energy is an abundant and sustainable form of the renewable energy system; its potential is beyond our expectations and calculations. Being a sustainable energy source, solar energy becomes the fundamental necessity for meeting the energy requirements at present and future. In this paper, an optimum solar power generation system is proposed based on the Monolith, Duo-pitch, and Barrel Arch Canopies at different tilt (angle formed b/w horizontal Surface and the solar panel) angles by using the Helioscope Software developed by Folsom Labs for electric vehicles charging. Through the simulation results, it is proposed that maximum power can be generated at Monolith canopy at a standard geometrical angle. The proposed technique is validated on Sukkur city of Sindh province in Pakistan. Furthermore, the detailed study on the payback period, vehicle charging cost, and an annual reduction in CO₂ emission is discussed in detail.*

Index Terms— *Electric vehicles (EV); carport canopies designing; green environment; Pollution-free energy; Mitigation of fossil fuel.*

I. INTRODUCTION

EVs (plug-in electric vehicles) can be charged through electricity provided by a charging station. A variety of technologies available in conventional vehicles. However, EVs have different capabilities such as low running cost, less maintenance and carbon emissions do not exist in these vehicles. The functioning of these vehicles is based on charged batteries and individual purpose motors [2]. A typical conventional car annually emits 4600kg carbon, to deplete the ozone layer and causes severe problems for human health. According to a survey in Pakistan, if 2.3 million registered vehicles could be converted into an electric vehicle, which can result in a reduction of overall demand for fossil fuel up to 40%. [1]. Almost five years ago, 4% of total electricity in Pakistan was generated from renewable energy resources, whereas the other 96% of electrical energy was generated through conventional methods. According to a report published by energy-pedia, Pakistan aims to achieve 50% of total grid energy from renewable resources by 2030 to power their electric locomotives and Homes. To generate sustainable energy for charging EVs the best locations are canopies of fuel Station, public Parking CNG stations.

In 2030, the population of Pakistan will be increased to around 260 million, which can result in severe issues of transportation and energy crisis. Pakistan is lying in such a blessed tropical region, which has a high potential for renewable resources. However, due to the economic crisis in Pakistan, there is a gap in energy generation and energy demand. More than 40 million Pakistani population live in rural areas where they suffer from transportation, and load shedding issues. Electric vehicles could be a miracle for them b/c they have an easy source to charge their vehicles by installing solar carport shades at any location. However, 30% of the population in Pakistan lives in cities; the major issue of citizens is the parking of vehicles, according to a survey every car holder paying \$30 on each month to park their vehicle at shade. The parking stations are prime locations for Installation of solar photovoltaic (PV) system, the generated power from these parking lots can also utilize charging EVs and lightning [16,17 and 21]. According to new implemented bill Pakistan will shutoff 1500 CNG stations and convert these into electric vehicle charging stations by the end of 2021. So, this project focuses electric vehicle charging station by installing Carport Canopies and comparison of maximum power generation b/w three major types of canopies (Monopitch, Duopitch and Barrel Arch).

II. LITERATURE REVIEW

- PMR Almeida PV Magazine: In USA Solar Star 579MW Power Plant has been harvested by the use of the technique to charge electric vehicles and utilize power for commercial use; authors analyzed that 1665 GW of energy can be generated annually, and it is the most significant history in the United States of America, this project is installed on 10 kilometers [4,18].
- Habib: From this study, the effect of temperature and relative humidity was observed to demonstrate the effectiveness of a PV module. It is also observed that the relationship between efficiency and temperature is higher compared to the relationship between effective cloudy weather and relative humidity [16].
- F Umar: A Case Study is also done in Punjab province at Islamia University Bahawalpur, Pakistan. The geometrical locations of Bahawalpur occur at second most abundant solar insolation in Pakistan. This project can generate 23.3 MW annually, and the installed capacity of this project is 17.3 kW [3].

- *Khalid*: This research presents that from February to mid of November radiation is greater than 200 W/m² in Sindh and also available in rich amount thought country and there is a huge potential for solar based power generation thought the year. in an area of about 100 m², 44.8MW to 82.5 MW power can be generated during whole month in all these regions, basically this research work presents a clue to install solar based charging stations in Sindh Pakistan [19].
- V.K.B Ponnam: The author addresses a multi-objective optimization technique for obtaining simultaneous Electric Vehicles Charging System & DG placement and sizing. The problem is formulated to optimize real power losses, Average Voltage Deviation Index, and Voltage Stability Index of the electrical distribution system [1].
- M. E. Bendib: This research work presents, a smart grid system consisting of solar panels and a battery bank is presented for an electric vehicle. For the integration of green power in our system, solar panels are used to charge the accumulator while the power exchange between the vehicle and the grid is realized by power wireless transfer [24].

III. VARIOUS TYPES OF LOSSES IN CARPORT CANOPIES

A. Types of Carport Canopy

- Single Row Carport Canopy
- Double Row Carport Canopy

In this research study, the authors proposed the most common type, double row carport because it takes small space for installation, low cost of cabling and small iron frame. In this proposed design, the authors discussed various canopies performance and suitability for electric vehicles regarding charging at optimized power levels through solar panels such as Mono-pitch, Duo-pitch, and Barrel Arch. In this paper, a 200 Watt, 250 solar panels to generate 50kWh is to be designed with the help of helioscope Software.



Fig. 1. Design of various carport canopies roof structures

B. Losses Occurred in Carport Canopy System

Various losses occur during converting solar radiation in electrical power, as depicted in Figure 2. However, two significant factors are discussed below:

- Irradiation level
- Temperature.

Moreover, PV module efficiency and performance are degraded by increasing temperature, the standard temperature of solar PV module considered as 25°C, but proposed project site is hot and dry so ambient temperature of Solar module is increase too much, so from following equation temperature of the solar module is calculated with the help (1).

$$T_m = e_i(e^{a+bw_s}) + T_a \quad (1)$$

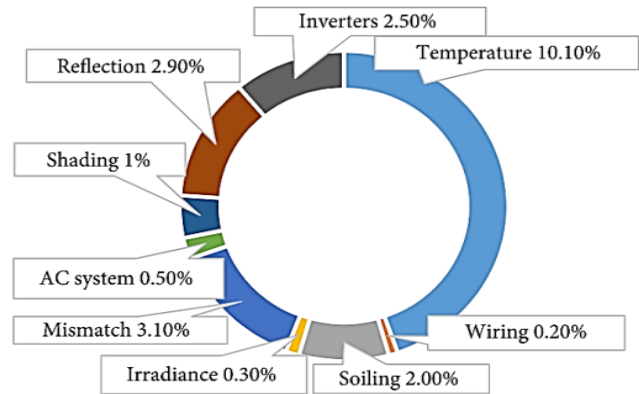


Fig. 2. Various losses in the design of carport canopy

Where T_m is the solar Panel temperature (°C), T_a is the ambient Environmental temperature (°C), e_i the irradiance of the solar module (Watts/m²), w_s speed of wind (m/s), a is upper limit coefficient, b is the coefficient of wind at which temperature of module drops. The calculation with different tilt angles indicated the maximum efficiency drop due to rise in temperature beyond ambient temperature is around 11.2 %. Results of Figure 2 are obtained at 15°, Monopitch without shading in hot climate of Sukkur and showed the efficiency drop due to temperature of 10.10%.

IV. MODELING OF A CANOPY STRUCTURE FOR CHARGING STATION AT PROPOSED SITE

In this case, various factors have been considered and can be discussed as follows:

A. Structure and Sizing of carport Canopy

Generally, the most common size of carport canopies is chosen 14m² to 20m², but in this scenario, authors choose 34*24m², which provides shade to 816m² carport shades for the generation of maximum power and utilization of carport canopies at maximum efficiency.

B. Modeling of Carport Canopy without shading Effect

A 50kW solar carport canopy installed at Sukkur on 180° South facing, where the maximum annual generation could be around 84.5 MWh (See Figure 1).

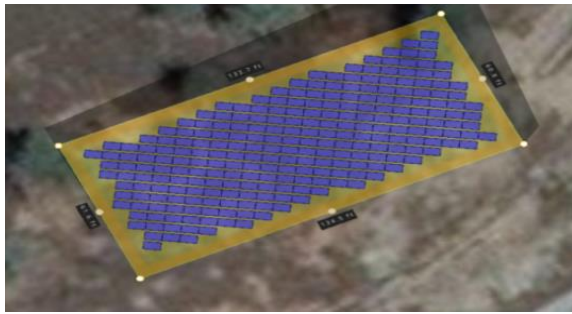


Fig. 3. Mono-pitch canopy

C. Modeling of Carport Canopy with shading Effect

A 50kW solar carport canopy is installed at a location of Sukkur at 180° South facing, where the maximum annual power generation depends upon the shading effect, but here estimated generation can be around 35 MWh (See Figure 2).

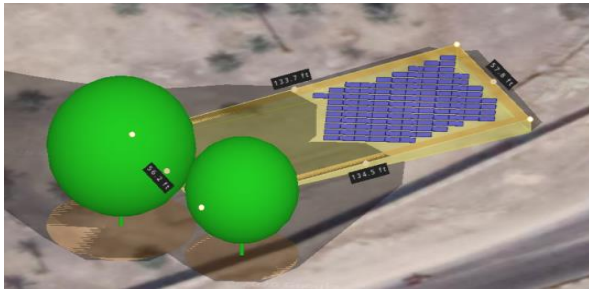


Fig. 4. Shading of nearby Objects

V. SPECIFICATIONS OF PROPOSED SYSTEM

In this research work, authors have done a series of multiple simulations for sizing and maximum efficiency of carport parking lots based on the solar photovoltaic (PV) system at proposed locations Sukkur at various tilt angles and various times. Authors also have done detailed shadow analysis, total losses, and vehicle charging capacity, and annual generated energy by use of Helioscope software.

TABLE I: Data analysis parameters Sukkur

Parameters	Values	
Sukkur geometrical Slope angle	27.7°	
Sukkur solar isolation	2031 kWh/m ² /year	
Ground coverage ratio (GCR)	1.04	
Inter row spacing	0.304m	
Carport height	25 ft.	
Model of Temperature	Sendia model	
Transposition model	Perez model	
	Rack type	Carport.
Temperature model parameters	A	-3.56
	B	-0.075
	Temperature delta	3.0°C
Weather model condition	TMY, 10 km grid (Metronome)	
Average ambient temperature	30.4°C	

TABLE II: Specifications of PV module

Module Parameters	Values
Peak Max Power watts (3SUN)	200
Maximum Generated voltage (V _{max} , V)	36.2
Maximum Power Current (I _{max} , A)	5.52
Open-circuit voltage (V _{oc} , V)	45.2
Short-circuit current (I _{sc} , A)	5.93
PV Module efficiency (%)	18.2

VI. RESULTS AND DISCUSSIONS

In this section, analysis has been conducted by authors at the proposed location Sukkur for power generation at different tilt angles of 5°, 10°, 15°, and 27.7°. Beyond that, the results are also calculated at a standard geometrical angle to differentiate between generated power at different tilt angles. However, authors have fixed carport canopy at 180° south.

A. Mono-pitch Canopies Sukkur Region

In this study, a single surface with a single slope was designed (See Figure 1). Therefore, a comparison is carried out with shading of Trees and nearby objects at different tilt angles.

Monopitch without shading the results vary from angle to angle. Moreover, the power generation at 5° is around 78.27 MWh, and the maximum occurs at 27.7° is 84.13 MWh annually (See Figure 5). From the results, it was observed through the without shading effects, and it is cleared that at 27.7° the production is quite enough to charge electric vehicles.

Monopitch with shading the results of shading effect were observed that at tilt angles 5° the generated power was 32.13 MWh, and at a geometrical angle 27.7° is around 58.71 MWh (See Figure 6), from these results it is clear that these results are less than without shading effects and in this scenario shading loss has been observed around 0.9 %.

B. Duo-pitch Canopies Sukkur Region

In this case, Duo-pitch carport canopy with and without shading effects has been analyzed. From the design perspectives, Duo-pitch carport canopy has two rows (See Figure 1), one facing south at 180°, and the other is facing north at 360°. Duo-pitch without shading it is analyzed that at different tilt angles, minimum generation occurs at 5° is 75.53MWh and at 27.7° is 67.32 MWh (See Fig 7).

Duo-pitch carport canopy when including shading effect maximum generation obtained at 5° is 53.74 and generation at 27.7° is 39.75 (See Fig 8), and the shading effects losses vary from 1.8-3.2%.

C. Barrel Arch Canopies Sukkur Region

The techno-economic analysis has been estimated for Barrel arch Canopies with and without shedding effects; Barrel arch carport canopy has a curved structure (See Figure 1) each point on the surface of barrel arch has different tilt angles.

In this structure, authors have chosen three rows which form the curved shape with an angle of 360° facing north. Barrel Arch without shading results are calculated from the proposed station at 5° maximum generation occurs is 72.84 and at 27.7°

is 53.22MWh (See Figure 9). Barrel Arch when shading effect is included, the results become at 5° is 48.37MWh and at 27.7° is 41.07 MWh (See Figure 10) shading counted as 2.2-5.0 %.

D. Comparison Analysis of Various Canopies

Before starting any project, various factors such as payback period, financial investment, environmental impacts, and benefits need to estimate. In this case study, detailed data are collected and analyzed in two different ways, including shading effect and without shading effect on designing solar carport canopies at Sukkur on solar-based carport canopies. The cost is compared with the up tariff from Water and Power Development Authority Pakistan (WAPDA). Therefore, overall project cost and the payback time (See Table 3, 4, 5, and Figure 11). Two well-known Pakistan government registered vendors calculated the overall estimated cost of this project. Based on this analyzed structure and forecasted data, the total amount of project can be paid back in 10 Years in case of monolith canopy.

TABLE III: Components, cost, and payback periods (Monopitch)

Components	Cost and Payback
Per watt Cost of Solar Module (\$0.70/W)	\$37,500.00
Cost of iron structure (\$4.95/sq. ft.)	\$43,213
Total cost (\$)	\$80,713.00
Annual generated power	84870kWh
WAPDA per unit charges	\$0.09
Annual cost of solar power (\$)	\$7,638.30
Time	Year
Payback duration (years)	10.56

TABLE IV: Components, cost, and payback periods (Duo-pitch)

Components	Cost & Payback
Per watt Cost of Solar Module (\$0.70/W)	\$37,500.00
Cost of iron structure (\$4.95/sq. ft.)	\$43,213
Total cost (\$)	\$80,713.00
Annual generated power	75530kWh
WAPDA per unit charges	\$0.09
The annual cost of solar power	\$6,797.20
Time	Year
Payback duration (years)	11.87

TABLE V: Components, cost, and payback periods (Barrel-arch)

Components	Cost & Payback
Per watt Cost of Solar Module (\$0.70/W)	\$37,500.00
Cost of iron structure (\$4.95/sq. ft.)	\$43,213
Total cost (\$)	\$80,713.00
Annual generated power	72840KWh
WAPDA Per Unit Charges	\$0.09
The annual cost of solar power	\$4,886.60
Time	Year
Payback duration (years)	12.31

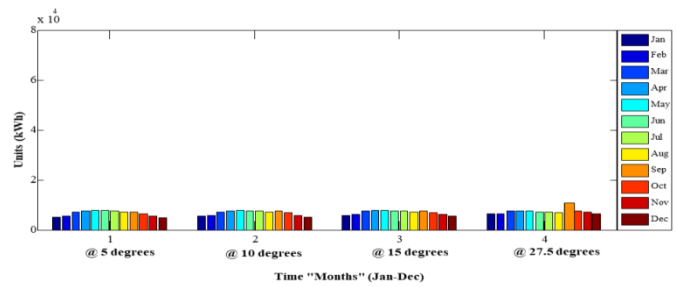


Fig. 5. Power generation at different tilt angles (kWh) without shading (Mono-pitch)

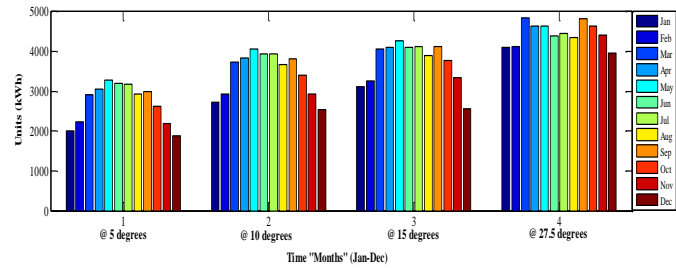


Fig. 6. Power generation at different tilt angles (kWh) with shading (Mono-pitch)

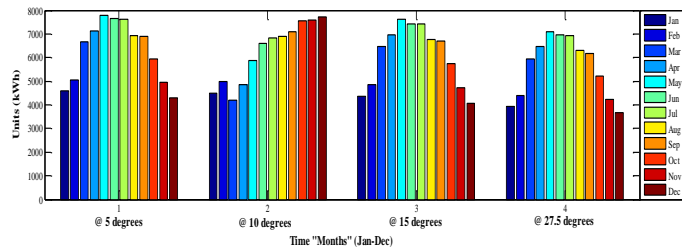


Fig. 7. Power generation at different tilt angles (kWh) without shading (Duo-pitch)

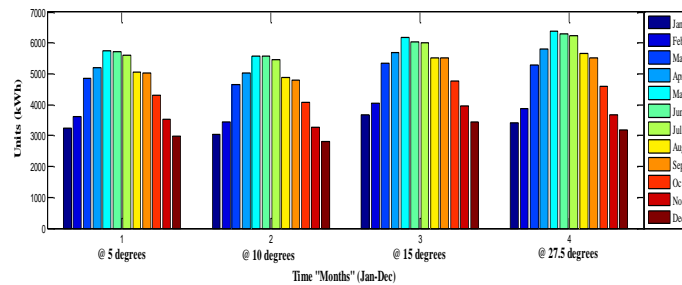


Fig. 8. Power generation at different tilt angles (kWh) with shading (Duo-pitch)

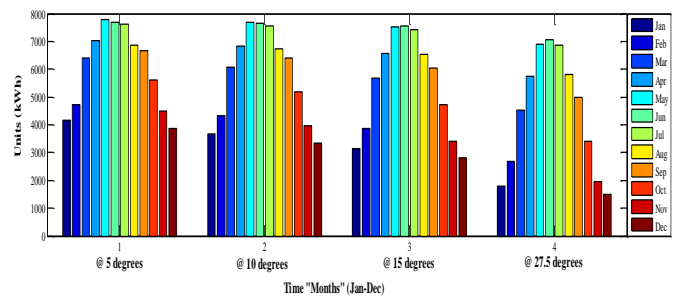


Fig. 9. Power generation at different tilt angles (kWh) without shading (Barrel arch)

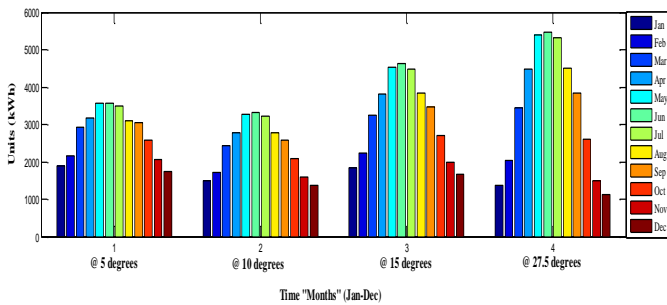


Fig. 10. Power generation at different tilt angles (kWh) with shedding (Barrel arch)

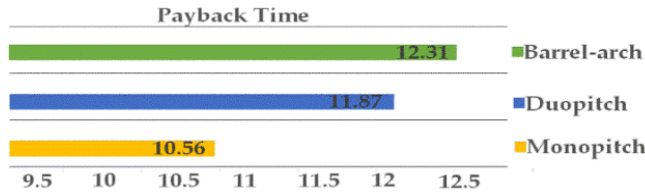


Fig. 11. Payback period

VII. CONCLUSION

Solar Photovoltaic technology is widely used for cost-free energy and environment-friendly power generation. The best place for Installation carport canopy is public and private parking in urban areas, this will charge electric vehicles.

- From this research, authors conclude that solar canopies provide excellent quality of shelter, provides power for cleaning and washing vehicles and an uninterrupted supply to charge vehicles and nearby traffic control signals.
- Provides cost-free power, large area covering shelter especially feasible for refugees and for those persons who arrange temporary events at different locations
- By installing solar PV carport canopies, annual generated electricity from conventional sources is minimized.

After a detailed data analysis and comparison of the designed canopies, it has been concluded that for the monolith canopies design, maximum power can be generated at a 27.7° tilt angle. Whereas, Duo-pitch design can generate 77.10% energy as compared to the monolith, and barrel arch design canopy can yield only 64.36 % as compared to mono-pitch and Duo-pitch.

ABBREVIATIONS

- T_m = Solar Panel temperature ($^\circ\text{C}$),
 T_a = Ambient Environmental temperature ($^\circ\text{C}$),
 e_i = Irradiance of the solar module (Watts/m²),
 w_s = Speed of wind (m/s),
 a = Upper limit coefficient,
 b = Coefficient of wind at which the temperature of module drops.

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