THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Design of a Solar Powered Car (Electrical Car), Feasibility and Sustainability in Nigeria Using Imo State Polytechnics Umuagwo Site as a Case Study

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Abstract:
The Design of a Solar Car was carried out, and its reality, feasibility, and workability in Nigeria were visualized. The sustainability was carried out by accessing and quantifying the optimal solar radiation in Nigeria using Imo State Polytechnic Umuagwo Ohaji, Imo State site as a case study. The Solar radiation on a horizontal plan and an inclined plan was calculated and quantified and their various values were compared and it was discovered that the radiation on an inclined plan was higher. The optimal mean monthly global radiation was calculated and adopted.
Due to the constant dynamic nature of a car, the optimal mean monthly daily average tilt angle was calculated and adopted as 15.39^0. The optimal mean monthly average daily tilt angle was used in the design of the car roof, such that the solar panel mounted on it will be inclined at 15.39^0 to ensure the maximum hardness of the optimal solar radiation. The solar energy generated is connected to the batteries via the solar charging controller. The battery connects two 12v by 100Am batteries in series. The batteries generate electric current to the D.C motor connected to the car gear through a pulley system mechanism. The gear powers and controls the movement of the car to any location.

Keywords: *Optimal tilt angle, global monthly radiation, feasibility and sustainability, solar energy generation, irradiation*

1. Introduction

In the research work, the need to visualize the reality of a car powered by solar energy (Solar electric car) and its sustainability in Nigeria was carried out using Imo state Polytechnic Umuagwo, Imo state in Nigeria, as a site for a case study. The challenges for researchers to develop an environmental-friendly type of transportation vehicle for the future have been organized in Australia since 1987 (Zahari Taha et al., 2009). In 2015 cop 21, known as the 2015 Paris ultimate conference in Paris, over 190 countries agreed on climate change by keeping global warming below 20C. They forecast that global emissions will rise from 60% to 70% in 2050 if no action is taken, and 40% of the growing emission is from cars, and the rate of demand for cars is increasing in developing countries (United Nations Climatic Change News, 2021).

The design for Electric vehicles (Solar cars) in the transportation sector has the capability to reduce greenhouse gases emission from global earth warming, increase renewable energy penetration and save fuel costs for transportation (Shigiong Zhon et al., 2019).

An electric vehicle is any electric-driven vehicle that uses one or more electric meter or traction meter for propulsion (Anonymous, 2018). Electric vehicles may be powered through a collection system by electricity from off-vehicle sources or self-contained with a rechargeable battery, solar panel or electric generation to convert fuel to electricity (Anonymous, 2010).

An electric vehicle (electric car) carrying solar panels to power itself is called a solar car (Anonymous, 2018).

This research work focused on the production of a car that can use cleaner energy and reduces to the lowest minimum the emission of greenhouse gases and the use and over dependant on fossil fuel. It further emphasizes how to adequately harness optimal energy from the solar panel on board at the car roof to charge the battery base on the position of the solar panel to sustain the battery while the car is moving without stopping due to battery drainage after a first complete full charging of the battery before used or moving the car.

The monthly average daily optimal tilt angle on an inclined surface was calculated and adopted as 15.39^0 using the formula adopted by Akif Karafi et al. (2015), which was used in the design of a car roof, such that the solar panel mounted on it is inclined at 15.39^0 to the horizontal to ensure proper harness of optimal solar radiation.

2. Material and Method

2.1. Method

There are methods adopted in this research work to aid the understanding of the feasibility and sustainability of a solar car in Nigeria.

- First, the mathematical method adopted in calculating the power generated, solar radiation on a tilted surface, and tilt angle.
- Secondly, the calculation of the construction of the car roof is based on the tilt angle.

In this project work, we focus on the mathematical method of calculating the tilt angle, solar radiation, power generation on a tilted surface and the roof design base on the tilt angle.

2.1.1. Mathematical Method

In this method, some assumptions are adopted in this design calculation.

- As a result of the dynamic nature of a car, a constant tilt angle is calculated and adopted as the mean monthly average daily tilt angle since the car can move from one latitude to the other.
- The average monthly global radiation H of Owerri was adopted as $3.6kwh/m^2/day$ based on the work of Ekwe M.C. *et al. (2018*) of the Nigerian Meteorological Agency.
- The latitude of Imo State Polytechnic is 5.3322^0 N.

The tilt angle β on daily adjustment on rotation along East and West is calculated by the relationship (Akif Karafl *et al*. (2015).

$$\beta = [\emptyset - \delta] \quad (1)$$

∅ = Latitude of the location

δ = Declination angle

The declination angle δ is calculated as shown below:

$$\delta = 23.45\sin\left[360 \times \frac{284+N}{365}\right] \quad (2)$$

N is the day of the year starting from January to December R.A Messenger *et al*. (2003).

The chart of the tilt angle is shown in table 1 below.

Using the value obtained from the tilt angle, the optimal mean monthly average daily tilt angle is calculated as 15.39^0 using monthly average daily tilt angle.

The mean monthly radiation H_T of a tilted surface is calculated by the relationship.

$$H_T = H \times R \quad (3)$$

H = The global radiation on a horizontal surface

R = The ratio of the daily average radiation on a tilted surface (Zang *et al*. 2016.)

R is calculated by the relationship development by Liu & Jordan (1961).

$$R = \left[I \times \frac{H_d}{H}\right] R_d + H_d\left[\frac{1+Cosh_s}{2H}\right] + P\left[\frac{1-Cosh_s}{2}\right] \quad (4)$$

P = The ground reflectance = 0.2

h_s is the hour angle

The hour angle is calculated as follows:

$$h_s = Cos^{-1}[-Tan\emptyset\ Tan\delta] \quad (5)$$

R_d is a functional factor of transmittance of the atmosphere, which depends on atmospheric cloudiness, water vapour, etc.

R_d is calculated by the relationship.

$$R_d = \left[\frac{Cos\,(\emptyset-\beta)\ Cos\delta Sln\ h_s + h_s\left(\frac{\pi}{180}\right) Sin\ \emptyset-\beta)\ Sin\ \delta}{Cos\ \emptyset\ \ Cos\ \delta\ Sin\ h_s + h_s\left(\frac{\pi}{180}\right) Sin\ \emptyset\ \ Sin\ \delta}\right] \quad (6)$$

H_d is the monthly average diffused radiation on a horizontal surface and therefore stated as follows (Page J. K. 1961)

$$H_d = H\,[1.0 - 1.13K_T] \quad (7)$$

K_T is the clearness index of the sky. K_T is calculated by the relationship.

$$K_T = \frac{H}{H_0} \quad (8)$$

H_0 is the monthly average daily extra-terrestrial radiation on a horizontal surface. The extra-terrestrial radiation H_0 on a horizontal surface is calculated by the relationship.

$$H_0 = \frac{24}{\pi} I_{sc}\left[1 + 0.033\ Cos\left(\frac{360N}{365}\right)\right]\left[Cos\emptyset\ Cos\delta\ Sinh_s + \frac{\pi hs}{180} Sin\ \delta\right] \quad (9)$$

π = 3.143.

I_{SC} is the solar constant = $1367w/m^2$

Putting equation 1 into 6, equation 2 into 5, equation 5 into 9, equation 9 into 8, equation 8 into 7, and putting together equations 4, 5, 6, and 7 into equation 3, the result of the monthly global radiation on a tilted surface is computed as shown in table 2 below:

Using the result of the monthly global radiation on a tilted surface (see table 2), the total power generated per photovoltaic panel for a tilted surface and horizontal surface can be calculated by the relationship (Ogunjuyigbe *et al.*, 2016).

$P_{PV.T} = A_{PV} \times H_T \times \Pi_{PV}$ ……………………………………….…..... (10)

$P_{PV.T}$ = Power of the tilted surface
A_{PV} = Area of Panel
Π_{PV} = Efficiency of the photovoltaic panel

$P_{Pv} = A_{PV} \times H \times \Pi_{PV}$ …….....…………………....………………………... (11)

Following equations 10 and 11, the various result of the power generated by a horizontal surface, monthly daily average tilt angle and mean monthly average tilt angle are calculated and computed in table 3.

2.1.2. Design of the Car Roof Calculation

Calculate the Car roof with an inclination angle of 15.39 based on the panel length using the trigonometry ratio method.

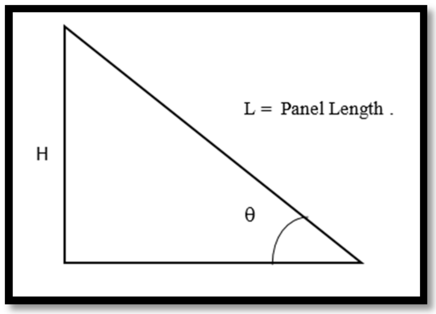

Figure 1

H is the Height from the horizontal
L is the panel length
θ is the tilt angle = 15.39 =β
Using trigonometry rule

$\sin\theta = \frac{H}{L}$ .... (12)

$H = L \sin\theta$ …………………………………………………………………….. (13)

H = 0.43m

2.2. Materials

These are the list of materials selected that suit the design specification with what is available in the local market
300W PV Panel
100Ams 12Volts battery
24 kVolts DC electric motor
Pu-lley
C-hasses of Golf cars with gear system

3. Results and Discussion

Results are presented in the tables below:

S/N	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	28.34	22.85	13.62	1.31	-9.57	-16.71	-17.72	-12.58	-2.39	9.55	20.69	27.44
2	28.26	22.58	13.24	0,92	-9.88	-16.84	-17.64	-12.32	-2.01	9.94	21	27.57
3	28.17	22.3	12.86	0.52	-10.19	-16.97	-17.56	-12.05	-1.63	10.34	21.29	27.69
4	28.08	22.02	12.48	0.13	-10.49	-17.09	-17.47	-11.78	-1.26	10.73	21.59	27.69
5	27.98	21.73	12.09	-0.27	-10.78	-17.21	-17.37	-11.5	-0.85	11.12	21.88	27.92
6	27.87	21.44	11.71	-0.66	-11.09	-17.33	-17.26	-11.22	-0.45	11.51	22.16	28.03
7	27.75	21.14	11.32	-1.05	-11.36	-17.42	-17.15	-10.93	-0.1	11.9	22.44	28.13
8	27.63	20.84	10.93	-1.45	-11.64	-17.51	-17.03	-10.63	0.32	12.29	22.71	28.22
9	27.5	20.54	10.53	-1.82	-11.92	-17.6	-16.91	-10.34	0.72	12.67	22.98	28.3
10	27.4	20.23	10.14	-2.2	-12.19	-17.68	-16.78	-10.03	1.11	13.05	23.24	28.38
11	27.23	19.92	9.74	-2.58	-12.49	-17.75	-16.64	-9.73	1.51	13.43	23.5	28.45
12	27.08	19.6	9.35	-2.96	-12.71	-17.82	-16.5	-9.41	1.91	13.81	23.75	28.51
13	26.93	19.28	8.95	-3.34	-12.96	-17.88	-16.34	-9.3	2.31	14.19	24	28.57
14	26.77	18.95	8.55	-3.71	-13.22	-17.94	-16.19	-8.78	2.71	14.56	24.24	28.62
15	26.62	18.62	8.15	-4.08	-13.46	-17.98	-16.02	-8.45	3.11	14.93	24.48	28.67
16	26.43	18.28	7.68	-4.52	-13.66	-18.02	-15.85	-8.12	3.52	15.3	24.71	28.7

S/N	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
17	26.25	17.95	7.35	-4.82	-13.93	-18.06	-15.68	-7.79	3.92	15.66	24.93	28.73
18	26.06	17.6	6.94	-5.18	-14.16	-18.06	-15.49	-7.46	4.32	16.02	25.15	28.75
19	25.87	17.26	6.54	-5.54	-14.38	-18.1	-15.31	-7.12	4.72	16.38	25.36	28.77
20	25.67	16.91	6.14	-5.9	-14.6	-18.11	-15.11	-6.77	5.13	16.73	25.57	28.78
21	25.47	16.56	5.8	-6.4	-14.84	-18.12	-14.91	-6.43	5.53	17.08	25.77	28.78
22	25.66	16.2	5.33	-6.59	-15.01	-18.12	-14.7	-6,07	5.94	17.43	25.97	28.77
23	25.04	15.84	4.93	-6.94	-15.21	-18.11	-14.49	-5.72	6.34	17.78	26.15	28.76
24	24.82	15.48	4.52	-7.29	-15.4	-18.09	-14.27	-5.36	6.74	18.12	26.34	28.74
25	24.59	15.11	4.12	-7.62	-15.59	-18.07	-14.05	-5	7.14	18.45	26.51	28.72
26	24.36	14.73	3.72	-7.96	-15.77	-18.06	-13.82	-4.64	7.55	18.78	26.68	28.68
27	24.12	14.37	3.31	-8.29	-15.9	-18.01	-13.58	-4.27	7.95	19.11	26.84	28.64
28	23.85	14	2.91	-8.62	-16.11	-17.96	-13.34	-3.9	8.35	19.44	27	28.6
29	23.63		2.51	-8.94	-16.27	-17.91	-13.09	-3.53	8.75	19.76	27.16	28.54
30	23.37		2.11	-9.26	-16.42	-17.85	-12.84	-3.15	9.15	20.07	27.3	28.48
31	23.11		1.71		-16.57	-17.79		-2.77		20.39		28.42

Table 1

Taking the efficiency of the panel = 856
Area of the panel = 1.63

S/N	M	R	H_T	P_{PV}
1	JAN	8.24	152.52	210.91
2	FEB	8.38	168.77	233.38
3	MARCH	9.08	175.79	243.56
4	APRIL	8.99	171.89	237.7
5	MAY	8.77	162.33	224.48
6	JUNE	8.84	142.59	197.18
7	JULY	8.59	116.57	161.2
8	AUGUST	8.75	119.26	164.92
9	SEP	9.04	135.51	187.39
10	OCT	8.84	153.55	212.34
11	NOV	8.07	154.86	214.15
12	DEC	7.69	147.34	203.75

Table 2

By adopting an average monthly tilt angle as optimum, we have the following:

S/N	MONTHS	Rd	R	H_T	P_{PV}
1	JAN	1.15	8.21	151.97	210.15
2	FEB	1.09	8.37	168.57	233.11
3	MARCH	0.96	9.06	175.4	243.55
4	APRIL	0.92	8.94	170.93	236.37
5	MAY	0.85	8.64	159.93	221.16
6	JUNE	0.82	8.69	140.17	193.83
7	JULY	0.83	8.48	115.07	159.12
8	AUGUST	0.89	8.69	118.44	163.78
9	SEP	0.96	9.01	135.06	186.77
10	OCT	1.06	8.85	153.72	212.57
11	NOV	1.14	8.05	154.48	213.62
12	DEC	1.18	7.64	146.38	202.42

Table 3

Volume of PV = [$0.057m^3$]
Area = $1.627m^2$

S/N	MONTHS	Average Pass (N)	Average Tilt Angle	δ δ	hs hs	H $ms/m^2/day$	H $MJ/m^2/day$	K_T	Hd $MS/\mu_t/1$	Rd 1.
1	JAN	16	26.18	-20.85	87.96	18.51	34.09	0.54	7.22	1.21
2	FEB	46	18.23	-13.32	88.73	20.14	35.98	0.56	7.4	1.1
3	MARCH	75	7.72	3.56	90.33	19.36	38.03	0.51	8.2	0.99
4	APRIL	106	-4.4	9.5	90.89	19.12	37.51	0.51	8.1	1.01
5	MAY	136	-13.48	18.81	91.82	18.51	36.35	0.51	7.84	1.07
6	JUNE	167	-17.75	22.33	92.2	16.12	35.55	0.45	7.93	1.12
7	JULY	198	-15.7	21.04	92.06	13.57	35.74	0.38	7.74	1.1

S/N	MONTHS	Average Pass (N)	Average Tilt Angle	δ δ	hs hs	H ms/m²/day	H MJ/m²/day	K_T	Hd MS/μ_t/1	Rd 1.
8	AUGUST	228	-9.29	13.3	91.26	13.63	36.8	0.37	7.93	1.03
9	SEP	259	3.91	3.34	90.31	14.99	37.35	0.4	8.21	1
10	OCT	289	15.18	-9.85	89.07	17.37	36.24	0.48	7.95	1.06
11	NOV	320	24.38	-19.1	88.15	19.19	34.36	0.56	7.05	1.18
12	DEC	350	28.45	-23.09	87.72	19.16	33.32	0.58	6.6	1.26

Table 4

S/N	Months	H	H_T	H_T
		Global Radiation on a Horizontal Surface H	Global Radiation on a Vertical Surface Per Monthly Tilt Angle H	Global Radiation on an Inclined Surface for Mean Monthly (optimal) Tilt Angle (15.39)
		MJ/m²/day	MJ/m²/day	MJ/m²/day
1	JAN	15.51	152.52	151.97
2	FEB	20.14	168.77	168.57
3	MARCH	19.36	175.79	175.4
4	APRIL	19.12	171.89	170.93
5	MAY	18.51	162.33	159.93
6	JUNE	16.13	142.59	140.17
7	JULY	13.57	116.57	115.07
8	AUGUST	13.63	119.26	118.44
9	SEP	14.99	135.51	135.06
10	OCT	17.37	153.55	153.72
11	NOV	19.19	154.86	154.48
12	DEC	19.16	147.34	146.38

Table 5

If you compare the result of the global radiation of solar energy on a horizontal surface and that of an inclined surface, you will find out that the degree of irradiation is higher on an inclined surface than on a horizontal surface. Since the monthly tilt angle is not constant, it varies from day to day to month. The roof of a car cannot be adjusted daily on a monthly basis, which is why we adopted the mean monthly tilt angle, in which the result of its irradiation is almost the same compared with the result of each monthly radiation of each monthly tilt angle. The loss of energy irradiation is infinitesimal per day compared to the monthly differences.

S/N	Months	Total Power Generated by a Horizontal Surface	Total Power Generated by Monthly Tilt Angle	Total Power Generated by Mean Monthly (Optimal) Tilt Angle
		P_{pv1}	P_{pv2}	P_{pv3}
1	JAN	21.12	174.03	173.4
2	FEB	22.98	192.57	192.34
3	MARCH	22.09	200.58	200.13
4	APRIL	21.82	196.13	195.03
5	MAY	21.12	185.22	182.48
6	JUNE	18.4	162.7	159.93
7	JULY	15.48	133.01	131.29
8	AUGUST	15.55	136.08	135.14
9	SEP	17.1	154.62	154.1
10	OCT	19.82	175.2-	175.39
11	NOV	21.9	176.7	176.26
12	DEC	21.86	168.11	167.02

Table 6

Table 3 shows the total power generated by a horizontal surface and the inclined surfaces (tilt surface). From this table, you can see:

- The power generated by the inclined surface (tilt surface) is higher than the horizontal surfaces,
- The total power generated by the monthly tilt surface (monthly tilt angle) and the mean monthly tilt angle are almost the same and
- The difference is infinitesimal compared to daily power generation

4. Conclusion

The use of the Mean Monthly Average Daily Tilt Angle as the optimal tilt angle gives a better result, which is almost closer to the Average Daily Tilt Angle of each month of the year and the optimal tilt angle gives the optimal power generated and the optimal total global irradiation, which is better and constant, compared to the result gotten in varying the tilt angle of the solar panel on board at the car roof.

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