Design and Stability Analysis of Solar Panel Supporting Structure Subjected to Wind Force

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Abstract

This paper deals with the design and stability analysis of a solar panel supporting structure used as a fuel station in green automobile engineering. The present work is a part of the project named "Sun 2 Car" of Mahindra Reva Ltd and the design is used by the company to meet their industrial needs. The design of solar panel supporting structure and the effects of wind force on its structural stability is discussed in this paper. The measures for preventing the overturning of the structure are also discussed. Due to the wind force, a reaction force is experienced on the structure and the structure will retain its stable state, only if this reaction force is compensated by the force due the self-weight of the structure. The structure under consideration is able to hold 8 solar panels of 1kW capacity each and can withstand the wind velocity experiencing at different locations of India. This structure can use anywhere in India (calculations are based on wind zones of India), and can freely place anywhere as the base has no holding arrangements. The design is optimized for easy assembly, dismantle and transportation.

Keywords

Solar Panel supporters, Solar cars, Steel structures, Wind zones of India

Nomenclature

C.G : Centre of Gravity of structure in y axis w.r.t base coordinate system. (from test model),m

α : Angle of inclination of roof w.r.t horizontal direction of wind , Degrees

P_{wind} :Wind Pressure acting on roof of the structure, N/m^2

V : Design wind velocity or speed, m/s.

V_b : Basic wind speed of the Zone under consideration, m/s

l ,b : Length and Width of the roof of the structure on which solar panels are mounted, m

A : Actual area or total area of roof, m^2

A_e : Effective area or Projected Area,m^2

C : Overturning couple due to the wind force, Nm

F_{wind} : The wind force acting on the roof of solar panel structure, N

F_R : Reaction force acting on the structure due to C, N

F_1 : Reaction force experienced on each base leg of structure due to C, N

W : Total weight of structure including solar panels, N

W_1 : Weight experienced in each base leg of structure, N

H : The distance between point of application of load and base point of structure, m

a : The distance between C.G and base point of structure, m

h : Distance between the centre of gravity of structure at a particular angle and the point of application of load , m

x : It is the distance between the primary touching points of the base legs, m m : Total mass of the structure including solar panels, kg.

g : Acceleration due to gravity= 9.81 m/s^2

k_1 :Risk coefficient or probability factor. For all general building and structures with a wind velocity of 55m/s, it is 1. Various values are given in table.2

k_2 : Terrain, height and structure size factor. For terrain category 2 and class A structures, it is Unity. Values of this coefficient is given in table.3

k_3 : Topography factor. Its value is taken as unity, if the slope of ground is < 3^0.

n : Total number of solar panels.

1. Introduction:

Sun is the ultimate source of energy, almost all forms of energy is either directly or indirectly related to it. It has been saying that the energy released from sun in one second is more than that what mankind had used since the dawn of civilization [1].

Solar energy is a promising type of sustainable energy which is inexhaustible and abundant. Till now, we were not able to tap the full potential of this "green energy."

As we know, the oil price is going up and its availability, in other side, is going down. The world is now in a verge of energy crisis and is the time to think about a suitable substitute to these conventional petroleum derivatives. Even though, it is very hard to develop a suitable substitute for I.C engines, which are widely used in automobiles today, it is essential to develop such a one while considering the future energy crises due to the unavailability of fossil fuel energy.

Mahindra REVA had made a stepping stone in this field, who developed a true working model of a car with solar energy as fuel. **Mahindra Reva Electric Vehicles Private Limited**, formerly known as the **Reva Electric Car Company**, is an Indian company based in Bangalore, involved in designing and manufacturing of compact electric vehicles. "Born Green" is an operating philosophy that Mahindra REVA strongly adheres to. It consists of a conscious effort to minimise environmental impact across all business areas. Mahindra REVA has several International patents in the field of diagnostics, telematics and energy management systems numbering 14 granted patents and36 'active' applications. [2]

Their project named as "Sun 2 Car" is a promising one in the R&D development of future green automobile technology. Recently they released the new generation solar cars- NXG and NXR. By considering the scope and future, they are planning to provide solar fuel stations across the country. As a part of their fulfilment, we designed the structure as mentioned in abstract.

2. Formulation of generalised stability condition of structure for wind force

The arrangement of solar panels in structure is similar to double sloped roof trusses, for which the expression for wind pressure is given by

$$P_{wind} = 0.6 \times V^2 \quad (1)$$ [3]

Wind force=Wind Pressure x Effective area of panel

$$F_{wind} = P_{wind} \times A_e \quad (2)$$

A_e = Total area of sloped roof x Sine of angle of inclination

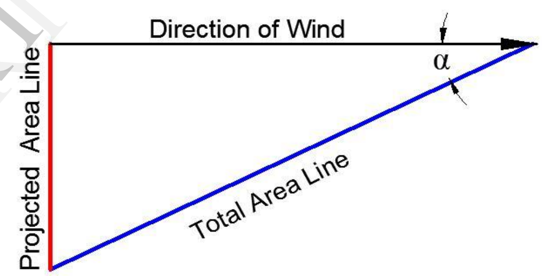


Figure. 1: Arrangement of Slopped Roof

From Fig. 1,

$$\sin \alpha = \frac{\text{Projected area line(red)}}{\text{Total area line (blue)}}$$

∴ Projected area line = Total area line x Sin α

$$\therefore A_e = A \times \sin \alpha \quad (3)$$

Substituting equation (3) in (2)

$$F_{wind} = P_{wind} \times A \times \sin \alpha \quad (4)$$

Due to this wind force, the structure experiences an overturning effect. This overturning couple is expressed as

$$C = F_{wind} \times h \quad (5)$$

This overturning couple imparts a reaction force at the base of the structure. This reaction force can be calculated by using the following expression.

$$F_R = \frac{C}{x} \quad (6)$$

The structure is symmetric along any vertical plane. In this model, we consider either left or right half of the structure along the vertical plane. So, the reaction force, F_R is expected to distribute in all the base legs equally, in either left or right portion. In general, if there are 'n' base legs which is arranged symmetrically about the vertical plane, reaction acting on one leg is given by the expression,

$$F_1 = \frac{F_R}{(n/2)} \quad (7)$$

The structure will retains its stable state only if it is able to compensate this reaction force with its self-weight. Let,

Weight of the structure, W = m x g (8)

This weight is equally distributed in all base legs of the structure. So, if the structure have 'n' base legs, the weight experienced for a single leg is given as,

$$W_1 = \frac{W}{n} \quad (9)$$

∴For stability of structure due to wind force, the general condition can obtain equating the equations (7) & (9).

$F_1 \leq W_1$

$\mathbf{W \geq 2\ F_R}$

Minimum condition for stability is

$\mathbf{W = 2\ F_R}$

i.e., the weight of the structure should be twice of the reaction force of wind.

This is the generalised stability condition of structure for wind force.

3. Test model and experimental methodology

3.1 Test model

Using one of the most popular CAD Modelling software CREO 2.0, the test model of solar panel supporting structure was created with proper material, here mild steel. It is shown in fig. 2, also various parameters are given.

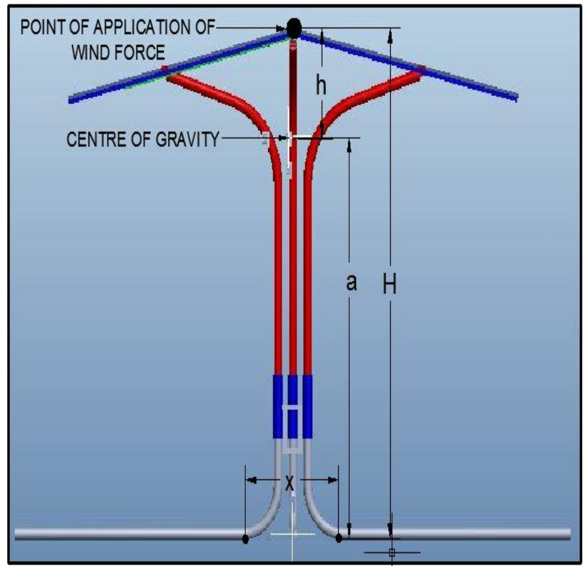


Fig. 2: Test Model with Parameters

3.2Specifications of model:

Length of roof, l = 4m

Width of roof, b = 2m

Total area of sloped roof, A = 8 m^2

Total mass of the structure, m = 425 kg

Total Height of the Structure, H = 3.123m

Distance between the primary touching points of the base legs,x = 1 m

3.3 Assumptions:

i. The structure is symmetric about any vertical plane.
ii. The wind load is acting in horizontal direction.
iii. Depth / thickness of panels is ignored.
iv. Wind load is acting with a constant velocity.
v. Structure is placed in horizontal position.
vi. Only wind force is acting on the structure. Other force are out of scope of this study.
vii. The wind force is acting at the tip of the structure.

3.4 Method of conducting experiment:

In this study, Wind Zone-1 is considered. The wind velocity is chosen as 55 m/s, as per IS: 875 Part3, wind zones of India. Wind zones are illustrated in Fig.3

i. The roof angle is changing in equal steps.
ii. Determine the position of C.G of the structure using "mass property tool" of software.
iii. Measure the distance between C.G and base point of structure, a.
iv. Measure the distance between point of application of load and base point of structure, H.
v. Distance between C.G and point of action of load is calculated by reducing H from total height of structure.
vi. Observations are tabulated and calculations are made, as given in Table.1

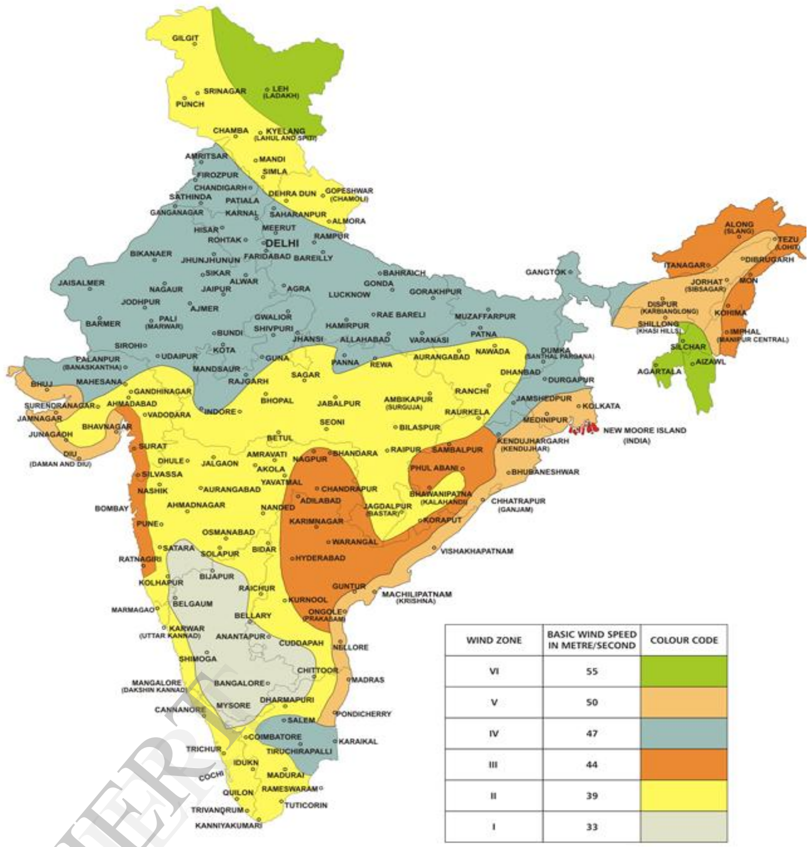


Fig.3: Wind zones of India

4. Calculations, Results and Analysis

$P_{wind} = 0.6 \times V^2$

Design velocity, V can be calculate by using the equation

$V = k_1 . k_2 . k_3 . V_b$

k_1 = Risk coefficient or probability factor. For all general building and structures with a wind velocity of 55m/s, it is 1. Various values are given in table.2

k_2 = Terrain, height and structure size factor. For terrain category 2 and class A structures, it is 1. Values of this coefficient is given in table.3 Category 2 terrain contain is contained with scattered obstructions having heights usually between 1.5m to 10m above ground surface. Class A are the structures and/or their components such as cladding, roofing etc. having maximum dimensions is less than 20m above ground surface.

k_3 = Topography factor. Its value is taken as unity, if the slope of ground is < 3^0.

V_b = Basic wind speed of zone VI = 55 m/s

∴ V = **55 m/s**

∴ P_{wind} = 1815 N/m^2

Wind Force, F_{wind}

$= P_{wind} \times A \times \sin\alpha$

Here, the angle of inclination is considered as 5^0.

∴ F_{wind} = 1265.42 N

Over turning couple, $C = F_{wind} \times h$

(Value of 'h' is taken from the Table.1)

= 722.554 ≈ 722.60 Nm

Reaction force, $F_R = \frac{C}{x}$ N

$\therefore$ F_R = 722.60 N

Weight of the structure, W = m x g N

Substituting the values,

$\therefore$ W = 4170 N

Applying stability condition,

$W \geq 2\ F_R$

4170 ≥ (2 x 722.552)

4170 ≥ 1445.108

The condition is satisfied.

The structure is able to withstand the wind load with a velocity of 55 m/s and 5^0 angle of inclination. Therefore, the structure is stable.

Table.1: Total Reaction Force for All Wind Zones.

α (^{0})	a (m)	h= H-a (m)	F_R =(P x A x h x Sin α) / x (N)					
			ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6
0	2.61390	0.509	0	0	0	0	0	0
1	2.60113	0.522	132.254	109.3	96.58	84.64	66.5	47.61
2	2.58878	0.535	271.11	224.05	197.97	173.5	136.31	97.6
3	2.57680	0.546	414.91	342.9	302.99	265.55	208.62	149.37
4	2.56513	0.558	565.18	467.08	412.72	361.71	284.17	203.46
5	2.55226	0.571	722.6	597.19	527.68	462.46	363.33	260.14
6	2.54018	0.583	884.85	731.28	646.16	566.3	444.91	318.55
9	2.50396	0.619	1406.01	1161.99	1026.74	899.84	706.96	506.16
12	2.46853	0.654	1974.35	1631.69	1441.76	1263.58	992.72	710.76
15	2.43392	0.689	2589.29	2139.91	1890.83	1657.15	1301.92	932.15
20	2.37748	0.745	3699.76	3057.66	2701.75	2367.85	1860.28	1331.92
25	2.32308	0.799	4902.99	4052.06	3580.4	3137.91	2465.27	1765.08
30	2.27115	0.852	6185.52	5112	4516.96	3958.73	3110.14	2226.79
35	2.22213	0.901	7503.82	6201.54	5479.65	4802.45	3772.99	2701.37
40	2.19911	0.923	8614.61	7119.51	6290.8	5513.35	4331.51	3101.26
45	2.15505	0.968	9938.64	8213.75	7257.67	6360.73	4997.25	3577.91

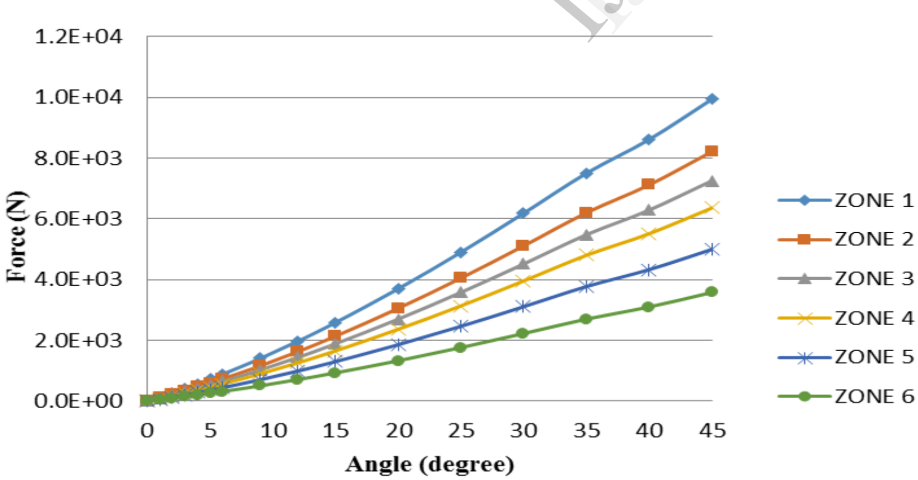
Table.2 [4]: Calculation of K_1

Class of structure	Mean probable design life of structure (years)	k1 factor for Basic Wind Speed					
		33	39	44	47	50	55
All general buildings and structures.	50	1.0	1.0	1.0	1.0	1.0	1.0
Temporary shed, structures	5	0.82	0.76	0.73	0.71	0.70	0.67
Building and structures presenting a low degree of hazard to life and property in the event of failure.	25	0.94	0.92	0.91	0.90	0.90	0.89
Important buildings and structure such as hospitals, communication towers, etc.	100	1.05	1.06	1.07	1.07	1.08	1.08

Table.3 [4]: Calculation of K_2

Height (z) (m)	Terrain and Height Multiplier (k_2)			
	Terrain category 1	Terrain category 2	Terrain category 3	Terrain category 4
10	1.05	1.00	0.91	0.80
15	1.09	1.05	0.97	0.80
20	1.12	1.07	1.01	0.80
30	1.15	1.12	1.06	0.97
50	1.20	1.17	1.12	1.10
100	1.26	1.24	1.20	1.20
150	1.30	1.28	1.24	1.24
200	1.32	1.30	1.27	1.27
250	1.34	1.32	1.29	1.28
300	1.35	1.34	1.31	1.30
350	1.37	1.36	1.32	1.31
400	1.38	1.37	1.34	1.32
450	1.39	1.38	1.35	1.33
500	1.40	1.39	1.36	1.34
Note: For intermediate values of height z and terrain category, use linear interpolation				

Fig 4: Graph of Reaction Force vs. Angle of inclination



Conclusion

The design of solar panel supporting structure is done and the effects of wind force on its structure stability is analysed. Due to the wind force, a reaction force is experienced on the structure and the structure will retain its stable state, only if this reaction force is compensated by the force due the self-weight of the structure.

From the graph shown in figure.4, we can calculate the required amount of weight to withstand the wind force. The calculations are based on wind zones of India and can freely place anywhere as the base has no holding arrangements. The design is optimized for easy assembly, dismantle and transportation.

In future, this structure will be used as the fuel stations to meet the energy requirement of solar cars, as it can be used for domestic purpose, commercial purpose.

References

[1]. M.S.S Murthy, "The Unseen Sun", Science Reporter, November 2010 (Vol.47, ISSN: 0036-8512), NISCAIR-CSIR Publication, pp.8-12.

[2]. www.mahindrareva.com, "About Us" web portal

[3]. Dr.Ramachandra , Virendra Gehlot, "Calculation of wind load", Design of Steel Structure (Based on IS: 800-2007) (Vol.1, 13th edition-2011, ISBN: 978-81-7233-654-7) Scientific Publishers (India), pp.742-751

[4]. IS: 875 Part-3, 1987, Indian Standard Institute.

[5]. N.Subramanian, "Wind load calculations", Design of Steel Structures (7th impression 2011, ISBN: 10-0-19-567681-5), Oxford University Press, pp.209-216.