DESIGN AND DEVELOPMENT OF SUPPORT STRUCTURE FOR SOLAR PANEL TILTING MECHANISM

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Abstract*—*The existing sources of energy such as coal, oil, etc, are not adequate to meet the ever increasing demands. These are also depleting and may be exhausted at the end of the century or the beginning of the next century. As the so-called 'Climate Change' is worsening month by month and abrupt/extreme weather events are becoming more frequent everywhere, more and more people are feeling the need to get away from the usual fossil fuel (coal, oil, gas) generated electric power supply. In many states there is perennial shortage of power and in many areas the problem is really acute. So people are exploring ways to install solar PV system for their home, office or industrial premises. To develop alternatively to meet the situation solar energy is most suitable to overcome the future needs, in which solar rays from the sun falls on the photovoltaic cell to generate the electricity. So to fall solar rays support structure for photovoltaic cell is to be designed properly. The main aim is to design the support structure, transmission mechanism and tilting of the panel automatically on the daily basis depending on the wind pressure, so analysis and manual adjustment in the seasonal tilt and design considerations of the solar firm is focused in this paper.

IndexTerms*— *solar cells, output power, estimated load, material selection, moment of inertia, bending moment

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1. INTRODUCTION

A solar power plant is based on the conversion of sunlight into electricity, either directly using photovoltaic's (PV), or indirectly using concentrated solar power (CSP).concentrated solar power systems use lenses, mirrors, and tracking systems to focus a large area of sunlight into a small beam. Further there were various alternatives to the existing day lighting systems and one of them is Solar Tube. Solar light is directly converted into electricity using devices based on semiconductor materials, we call it **PHOTOVOLTAIC'S.** 'Photo' means light and 'voltaic' means electricity. From year 2000, solar energy entered the era in which environmental issues and economic issues renewed the public interest in solar energy. It is the era in which the solar market has transformed from a local market to a global market. In the new millennium Germany took the lead with their progressive feed-in tariffs policy, leading to a large national solar market and industry.

2. ASSEMBLIES OF PHOTOVOLTAIC SOLAR CELLS

Assemblies of solar cells are used to make solar modules which are used to capture energy from sunlight. Photovoltaic's is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from sun light. Because of earth rotation certain suitable tilting mechanism is to be adapted in congenial to the earth rotation to fall sun rays continuously on photovoltaic cell throughout the day.

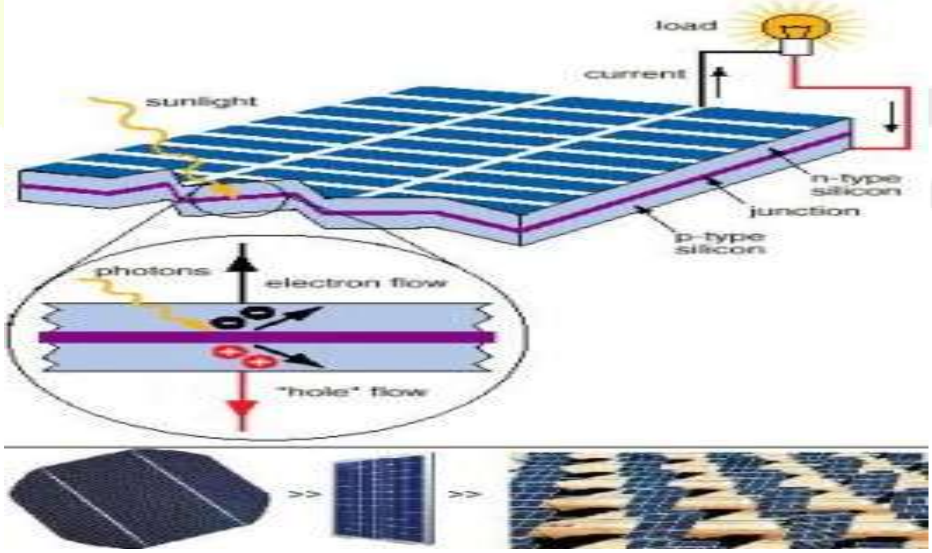

Fig1. Photovoltaic cell

Selection of materials and its costs, materials characteristics matched to the efficient spectrum of available light for solar cells and design of tilting mechanism for efficiently conversion of wavelengths of solar light that reaches the Earth surface is the critical area.

3. DESIGN CONSIDERATIONS OF A SOLAR FIRM:
3.1 Important considerations of solar PV systems that must be kept in mind.
1. Sizing the solar PV system
2. Solar insulation at your location
3. Panel efficiency& Panel cost – How much area is needed for a 1 kW solar PV plant
4. Ambient temperature
Shade free area
6. Panel orientation
7. Weight of the PV plant
8. Batteries and inverter

3.2. SELECTION OF THE SOLAR PANELS AND SOLAR TUBE:
With the estimated amount of the output wattage polycrystalline silicon has been selected based on the given dimensions below.
3.2.1 Selection of solar panel (polycrystalline silicon type)

Fig.3. Polycrystalline SI type solar panel

Dimensions-
Length - 1581 mm
Breadth - 809 mm
Thickness -40 mm
Weight- 19.5 kg
Wattage produced- 250w

3.4.2 Selection of a solar tube:
So, firstly, consider a beam which tends to withstand this sixteen panels thus opposing the forces acting on it without fail. First consideration in this process is what is the maximum length of the tube? 8 panels each side gives a total of 16 panels on a tube.
So = 8 x 810 mm = 6480 mm = 7m

3.4.3 Consideration material and loads that are acting on the tube as follows
Wind load: The maximum wind force acting on the each panel is around 8080N these loads are acting on all the panels normally due to this load there will be some deflection in the panel in certain extreme condition due to poor design the structure may break.
Self weight of the tube: The panels weighs around 20kgs are placed on the beam so it should sustain total weight of all the panels on either side of he beam and Hinged support load from the bottom and welding pressure
Beam material: which is selected should sustain the weights of all the panels and wind load and its self weight
i.Aluminiu: relatively soft, durable, lightweight, ductile, and malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. It is nonmagnetic and does not easily ignite. A fresh film of aluminium serves as a good reflector (approximately 92%) of visible light and an excellent reflector (as much as 98%) of medium and far infrared radiation. The yield strength of pure aluminium is 7–11 MPa, while aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminium has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded.
Aluminium atoms are arranged in a face-centered cubic (fcc) structure. Aluminium has stacking-fault energy of approximately = 200 mJ/m^2.
ii.Stainless steel: Stainless steel is notable for its corrosion resistance, and it is widely used for food handling and cutlery among many other applications. Stainless steel does not readily corrode, rust or stain with water as ordinary steel does. However, it is not fully stain-proof in low-oxygen, high-salinity, or poor air-circulation environments. There are various grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and corrosion resistance are required.

Power output of a 1 kW solar PV plant

Power output of your solar PV plant is a complex thing that depends upon so many variables – insulation, panel orientation, tilt angle, temperature and so on. But in India, we have some indicative data for guidance.

The CUF for many solar friendly Indian states is in the range 18-20 [for example, Gujarat (18), Andhra Pradesh (20), Uttarakhand (19)] and the average output of 1 kW plant in these states lies in the range 4.3 – 4.8 kWh. Annual units expected from a plant (kWh) = Plant size in kW x CUF x 365 x 24

(Please note that this is a state average and can vary significantly at different location seven within a state.)

TIP: Just look at the daily insulation in kWh on any day – it tells you electricity units produced on that day. So a 1kW system in Delhi may produce on a winter cold day (3kWh x 1) 3kWh of power on that day. On summer days the same system could give you (6kWh x1) 6kWh. [This is just an illustrative example]

5.0. OUTPUT POWER ESTIMATION OF THE SOLAR INSTALLATION:

5.1 Planned based on an average 3 bedroom flat as shown below

lights 12 x 15W = 180W
Fan 5 x 70W = 350W
Tv 1 x 60W = 60W
a/c's 3 x 1000W =3000W
geyser 1x 1000 W =1000W
Mixies 1 x 400 W =400W
Total wattage : 4990W
Load factor :0.5
Required wattage :2495
Number of flats in building: 40
Wattage for building 99800 planned wattage 100000 W

(Extra:-After optimizing for 400 buildings of such size in an area, total wattage required is 40000000W)

5.2 Estimation of panels on the tube

no. of panels/tube = 16
total no. of panels required = 400
no of tubes required = 25
next even no. = 26
number of rows = 2
number of tubes per row = 13
total wattage planned = 100000
wattage per panel = 250 W
no. panels required = 400

5.3 Estimation Load:

1. Wind load estimation: Wind analysis here has been done based on the data presented in the Hyderabad's environmental portal.

Designing time warranty is 25 years.
Maximum wind speed as per the past 25 years = 90 KM/hr = 90,000 m/3600 seconds
Equivalent pressure of air is 25m/s
Wind pressure is = 400 N/m^2
Calculating the force acting on one single panel:
Area of the panel is = 1.26 m^2
Force on one panel = 400 x 1.26 = 505 N
2. Weight of the panel is 19.5 kg =19.5 x 9.81 =191 N
3. Weight of the tube is = 1078N
Total Load acting on the tube
= (16x505) N+191N+1078N=8080N+191+1078=9500N =>10000N (approx)
Therefore W = 10000N/7 = 1428 or 1500N or 1.50 KN
Max BM (M) = $(Wl^2)/8$ = 1.50 x 49/8 = 9.18 k N-m
Torque T = 4KN x 1.58/2 KN-m = 3.16 M^2
Equivalent BM:

A bending moment which, acting alone, would produce in a circular shaft a normal stress of the same magnitude as th emaximum normal stress produced by a given bending moment and a given twisting moment acting simultaneously.

Me = $\frac{1}{2}\left[M+\sqrt{[M^2+T^2]}\right]$ = 7.24 kN-M
Assumed bending stress on the beam as f = 10 KN/cm^2
M/I = f/y => M/f = I/y = Z (where Z is the section modulus)
Therefore,

M/f = 100 X 7.24 / 10 = 72.4 cm ^3
Next step is to find out the section modulus for various cross-sections as shown below:
Firstly a tube of a certain cross-section is randomly selected from the TATA catalogue (as shown in the figure) and calculated its required section modulus. Then based on the previously assumed value the material quantity is said to be increased or decreased as shown below.
180 x 180 x 4= I/y = 1421.7 cm ^ 4/ 7.16 cm ^ 3 = 200 cm ^3(this can be further reduced as shown below)
200 x 200 x 4 = I/y= 3238.12 / 8.74 = 370 cm ^ 3(can be reduced further)
150 x 150 x 4= I/y= 801/6 = 133.4 cm ^ 3(can be reduced further)
130 x 130 x 4 = I/y = Z= 634/5.16=126 cm^3 (This material is sufficient so this tube is OK)
From the catalogue below 130 x130 x 4 are the required dimensions of the beam that has been selected

SHS B x B mm	Thickness mm	Sec Area A cm^2	Unit W Kg/m	Moment of Inertia		Radius of Gyration		Elastic Modulus		Torsional Constants		Outer Surface
				I_{xx} cm^4	I_{YY} cm^4	r_{xx} cm	r_{YY} cm	Z_{xx} cm^3	Z_{YY} cm^3	J cm^4	B cm^3	Area per m m^2
113.5x113.5	4.80	20.28	15.92	393.30	393.30	4.40	4.40	69.30	69.30	637.45	103.89	0.429
	5.40	22.60	17.74	432.58	432.58	4.38	4.38	76.23	76.23	708.69	114.41	0.426
132x132	4.80	23.83	18.71	634.39	634.39	5.16	5.16	96.12	96.12	1018.30	144.11	0.503
	5.40	26.60	20.88	700.11	700.11	5.13	5.13	106.08	106.08	1134.25	159.18	0.500
150x150	4.00	22.95	18.01	807.82	807.82	5.93	5.93	107.71	107.71	1273.46	161.38	0.579
	5.00	28.36	22.26	982.12	982.12	5.89	5.89	130.95	130.95	1569.09	196.38	0.574
	6.00	33.63	26.40	1145.91	1145.91	5.84	5.84	152.79	152.79	1856.18	229.44	0.569
	8.00	43.79	34.38	1443.00	1443.00	5.74	5.74	192.40	192.40	2405.78	290.12	0.559
180x180	4.00	27.75	21.78	1421.74	1421.74	7.16	7.16	157.97	157.97	2224.31	236.76	0.699
	5.00	34.36	26.97	1736.87	1736.87	7.11	7.11	192.99	192.99	2747.93	289.40	0.694
	6.00	40.83	32.05	2036.52	2036.52	7.06	7.06	226.28	226.28	3259.23	339.65	0.689
	8.00	53.39	41.91	2590.73	2590.73	6.97	6.97	287.86	287.86	4246.16	433.32	0.679
220x220	5.00	42.36	33.25	3238.12	3238.12	8.74	8.74	294.37	294.37	5083.17	440.67	0.854
	6.00	50.43	39.59	3813.36	3813.36	8.70	8.70	346.67	346.67	6034.53	520.18	0.849
	8.00	66.19	51.96	4894.99	4894.99	8.60	8.60	445.00	445.00	7897.48	668.99	0.839
	10.00	81.43	63.92	5887.19	5887.19	8.50	8.50	535.20	535.20	9549.15	796.48	0.829
250x250	6.00	57.63	45.24	5672.00	5672.00	9.92	9.92	453.76	453.76	8920.44	680.77	0.969
	8.00	75.79	59.50	7315.65	7315.65	9.82	9.82	585.25	585.25	11702.07	879.31	0.959
	10.00	93.43	73.34	8842.29	8842.29	9.73	9.73	707.38	707.38	14248.15	1054.68	0.949

Table.1. Tata hollow square tube catalogue

Beam specifications:

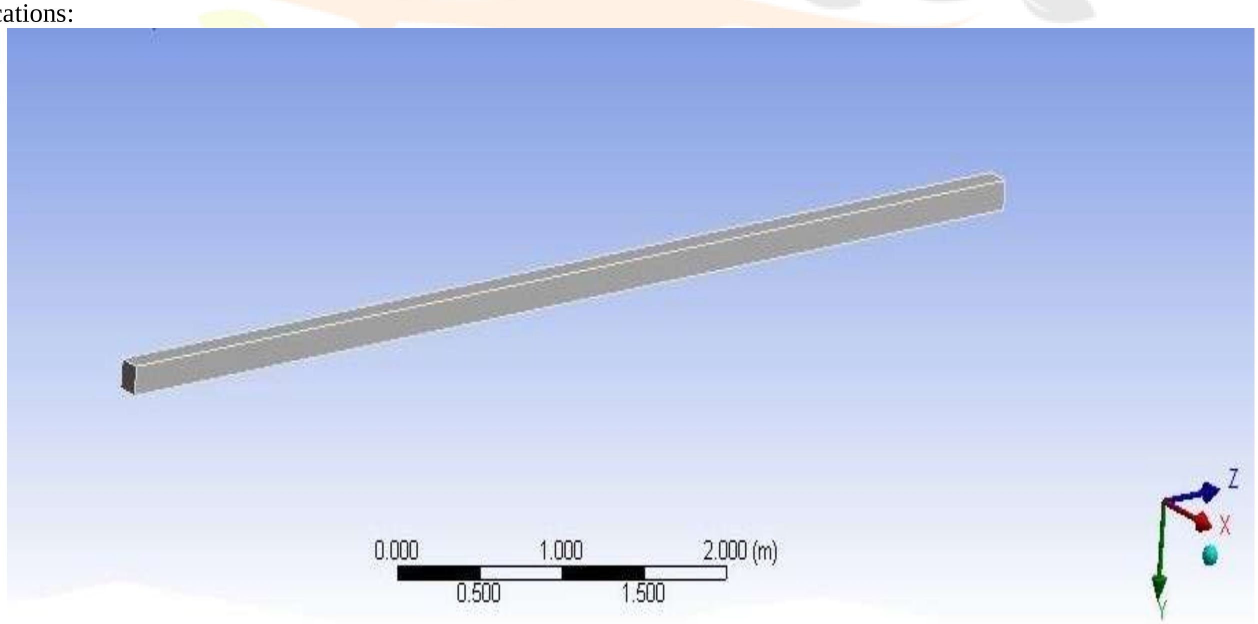

Fig 4. Stainless steel square tube

Beam(tube) type is Solid square tube/beam
Material – Stainless steel (cold rolled)
Length of the beam = 7m
Width of the beam = 80mm
Thickness = 1.6 mm
Inner width = 76.8 mm
Inner depth = 26.8mm
Dimensions = 132 x 132 mm
Thickness = 4.80 mm
Section area = 23.83 cm2
Unit weight = 18.71 kg/m

Moment of inertia-

* Ixx - 634.39 cm4
* Iyy - 634.39 cm4

Radius of gyration-

* rxx - 5.16 cm
* ryy - 5.16 cm

Elastic modulus-

* Zxx - 96.12 cm3
* Zyy - 96.12 cm3

For T section:

Max BM= 375 NM= 3750 kg cm

I/y= Z= 3.5 cm ^ 3

Unbalanced torque assumed is 5%

Force required for twist is 5kg

These are all completely the theoretical estimations made in the selection of the tube

6.0 DEFLECTION AND BENDING MOMENT DIAGRAMS

6.1 Aluminium using ANSYS

A bending moment is the reaction induced in a structural element when an external force or moment is applied to the element causing the element to bend. The most common or simplest structural element subjected to bending moments is the beam.

Fig 5 a) Deflection of aluminium tube

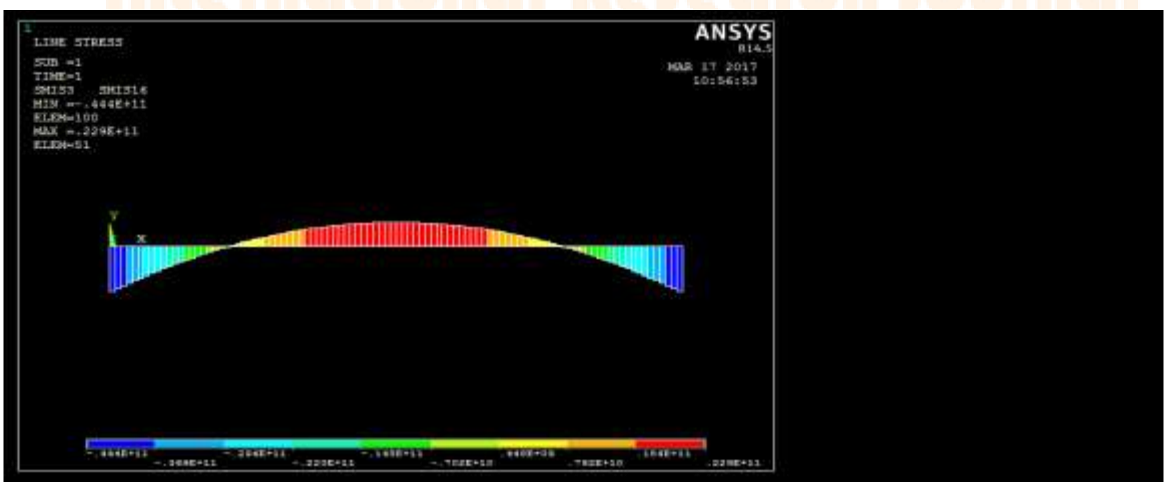

Fig 5 b). Bending moment of aluminium tube

6.2 Stainless steel using ANSYS

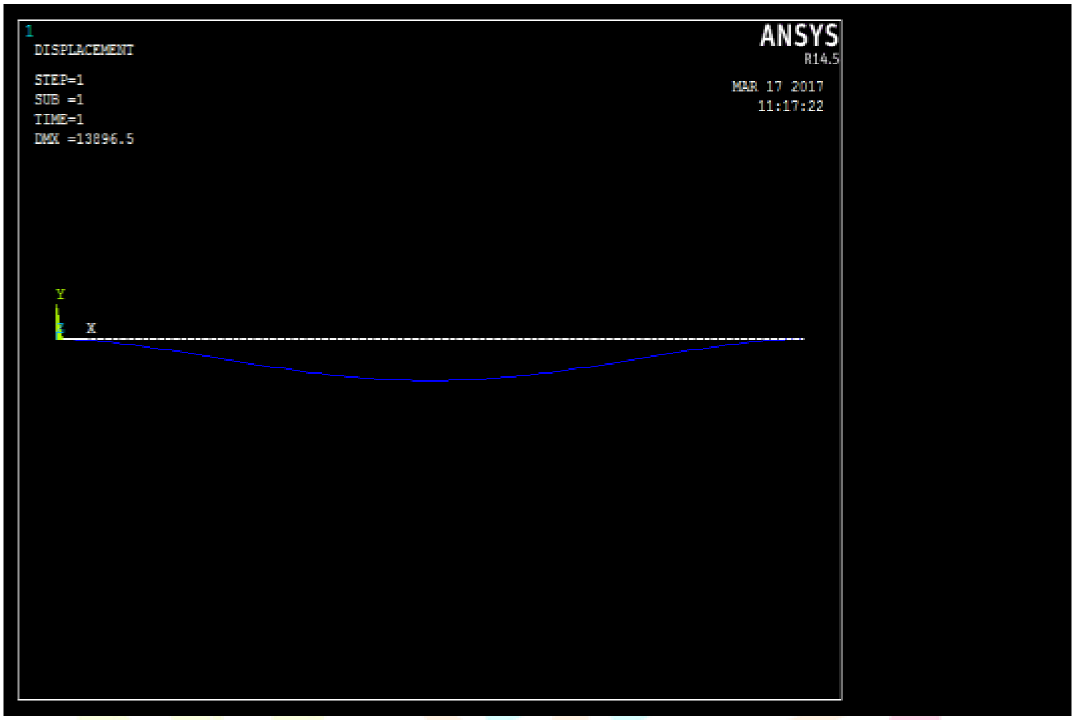

Fig 6 a) Deflection of steel tube

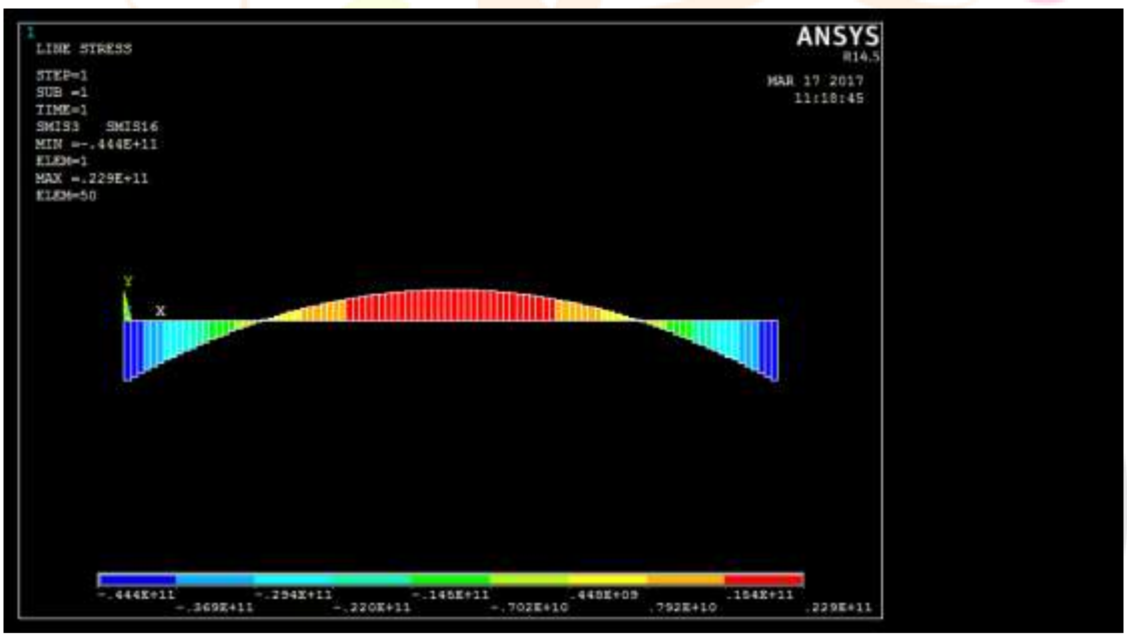

Fig 6 b). Bending moment of steel tube

Generally stainless material type beam is selected because it is corrosion resistive and it have the low deflection and bending moment also I can sustain more amount of load.

7. ARRANGEMENT OF PANELS:

The optimal way to arrange solar panels to collect the maximum solar power is in the usual boring linear arrays, as in Marc Brandsma's answer. Ideally, these arrays will track the motion of the sun so that the panels are always exactly perpendicular to light from the sun.

Note that finding the optimal fixed orientation is not entirely trivial, since the atmosphere will let through different amounts of sunlight depending on the angle relative to the ground and local atmospheric conditions. But to a pretty good approximation, the best fixed orientation is just to put solar panels on south facing slopes in the Northern hemisphere.

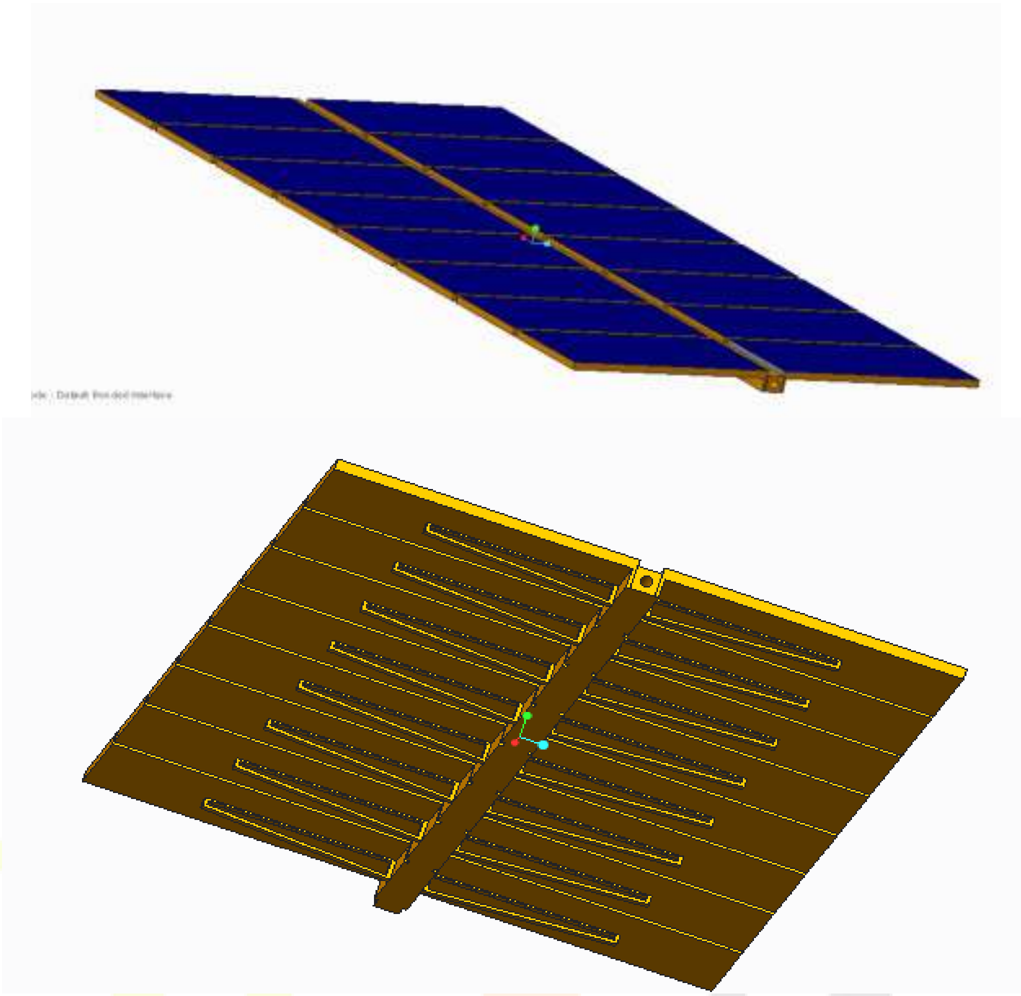

Fig 7. Solar Panels arrangement

No of panels on each beam : 16

8 panels are placed on either side of the beam and are places on a L-support which is welded to the beam and panels are placed on it and a hinged support is given from the bottom which gives rise to the transfer of loads on the panels to the beam. the stresses, deflection due to them can be neglected.

The panel had clearance of about 0.005m with the edges they can be tilted along with the beam and they have a circular hole on its peripheral side area to which bearings are attached by that power can be transmitted to the beam easily.

8.0 DAILY TILTING MECHANISM:

8.1Tilting considerations:

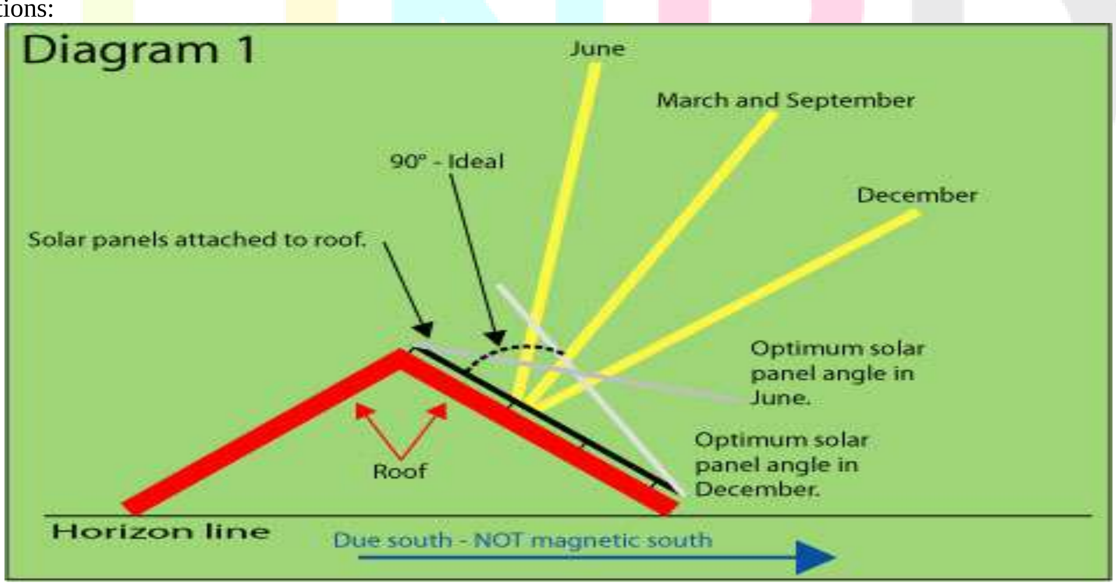

Fig 8. Solar panel tilting

Latitude	Summer ang	Winter angle
25°	2.3	41.1
30°	6.9	45.5
35°	11.6	49.8
40°	16.2	54.2

The tilt angle of the photovoltaic (PV) array is the key to an optimum energy yield. Solar panels or PV arrays are most efficient, when they are perpendicular to the sun's rays. The default value is a tilt angle equal to the station's latitude plus 15 degrees in winter or minus 15 degrees in summer.

If roof faces east-west rather than north-south, it have a few options. Solar panels facing east or west won't get as much light as those on a southern-facing roof. One solution is to compensate by increasing the solar collector area, either using more panels or larger collectors.

Considering the drive required for the daily tilt it is assumed that the panels are being rotated till the sun rays are constantly falling on them right from the sunrise in the morning till the sun set. So12 hours has been assumed as the incident time of the sunlight from the morning till evening.

Time assumed is 6am to 6 pm with an angle of tilt of 240 degrees

The tilting is done as per the following procedures.

8.2 Tilting of the tube:

Output is :240 degrees

Total time is :12 hours

Assumed no. of movements/day are=12 x 4= 48 times

For every hour 4 tilts are been made. Hence the tilts are been made for every 15mins.

Every moment = 5 degree/ every 15 min

Gear ratio is 1:70

Type of gear is worm self locking gear

Input shaft is 1 rev

8.2.1 Selection of required drives for tilting.

DRIVES: A worm gear is gear train where one of the meshing gears is worm and another one is a spur gear.

For power transmission, input torque is applied to the worm and it rotates and transmits the torque to the spur gear. As a result the gear rotates.

Fig 9 .Self locking worm gear

A self-locking worm gear is a type of worm gear that does not allow the interchange ability of the input and output gears like in spur gear trains (can interchange the driving gear and the driven gear) For this type of gear, the worm always acts as a driving gear and the spur gear as a driven gear- vice versa is not possible. If you try to run it otherwise, it will lock automatically.

Estimated results:

Gear ratio is 1:70

Type of gear is worm self locking gear

Input shaft is 1 rev

8.2.2 Selection of the motor to produce the required tilt

Stepped motor: Stepper motors are DC motors that move in discrete steps. They have multiple coils that are organized in groups called "phases". By energizing each phase in sequence, the motor will rotate, one step at a time. With a computer controlled stepping you can achieve very precise positioning and/or speed control. For this reason, stepper motors are the motor of choice for many precision motion control applications. Stepper motors come in many different sizes and styles and electrical characteristics.

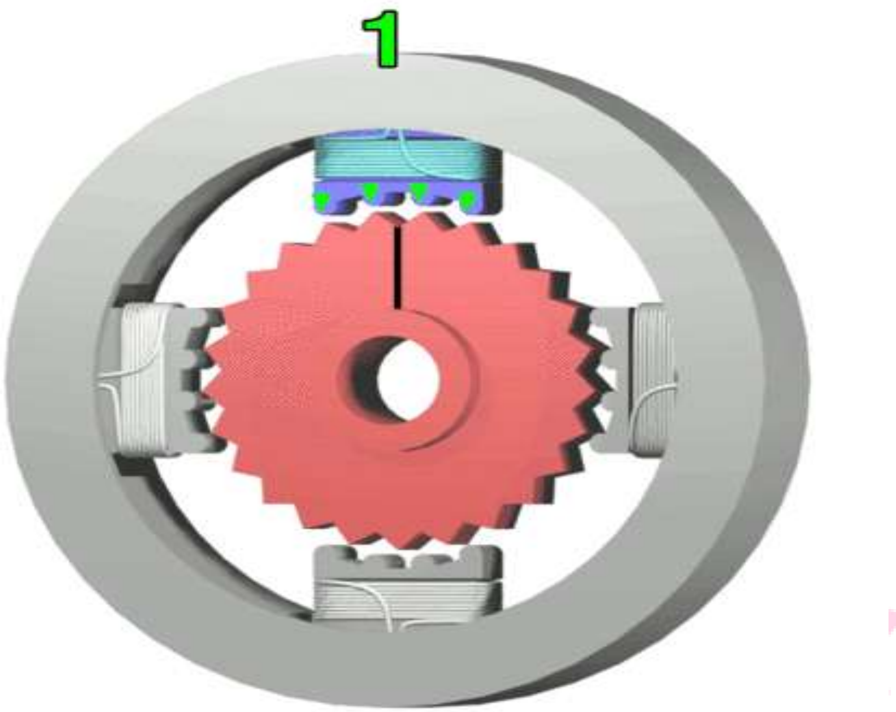

Fig 10: Stepped motor

Specifications:
input motor speed 60 rpm
motor h.p required 0.018 hp
wattage of motor 13.20
selected motor 40w/60 rpm
synchronous motor

9. SEASONAL ADJUSTMENT:

A zero tilt angle means that the face of the panel is aimed directly overhead. A positive tilt angle means that the panel faces more towards the equator. In the northern hemisphere that would mean tilting so it faces towards the South.

In Hyderabad = 17.5 degree inclination
North up
South down

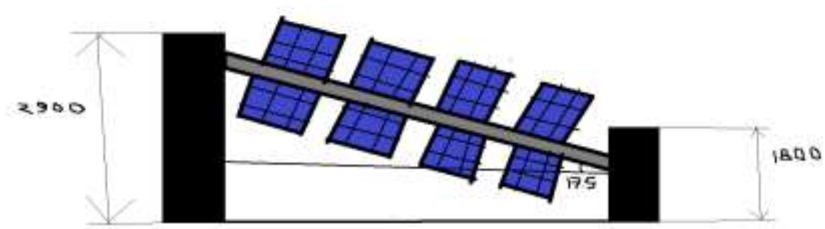

Fig.11 Solar tube arrangement for seasonal tilt

There is of course deviance throughout the seasons, but ideally solar panels should be facing as close to true North as possible to reduce the impact that the Winter seasons have on efficiency. Once again referring to the graph above, one can see that even North Easterly and North Westerly facing panels will be largely operating at around the 90% of their rated outputs. However, once angles start approaching East North East or West North West orientation, the numbers start reducing rapidly

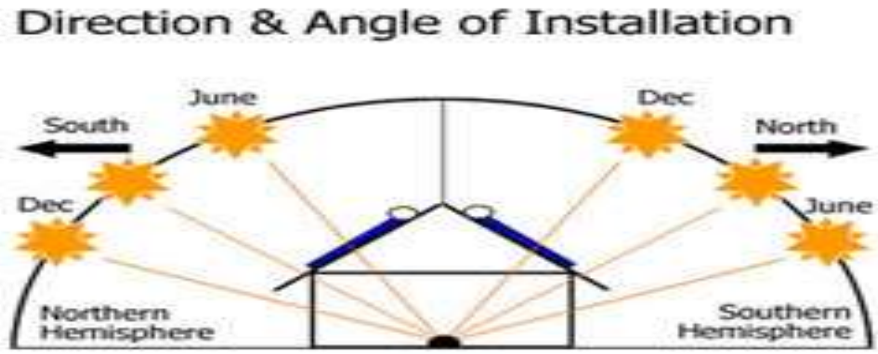

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Fig 12. Direction and angle of installation

Estimated Seasonal adjustment:-
In Hyderabad = 17.5 degree inclination
North up
South down
Height at Left side = 2900 mm
Height at Right side = 1800 mm

10. Estimated overview of the tilting mechanism

As per considerations all the set of rows of the tubes are said to be controlled and are been tilted by a single motor. So, the following data gives a brief overview of the planned power transmission of the firm.

Type of the motor is DC stepper motor
Specifications of the motor:
input motor speed : 60 rpm
motor h.p required : 0.018 hp
wattage of motor : 13.20
selected motor : 40w/60 rpm
synchronous motor
-Number of sprockets on the motor shaft are: 2
-Power transmission data:
force required to slide is :136.511 kg
Diameter of journal assumed : 50 mm
torque at journal :3412.776 kg mm=3.412776 kg m
sprocket ratio top to bottom is : 3
torque required at the bottom sprocket: 1.138 kg m
torque at the bottom for 26 tubes :29.577 kg m
sprocket ratio gearbox to bottom axis :2
torque at the output axis gear box :14.789 kg m
reduction ratio of gear box : 70
input torque at gear box : 0.21 kg m

11. CONCLUSION:

This paper gives general estimated data regarding the theoretical analysis of the solar supporting structure which fulfills the three criteria's such as low cost, higher efficiency, tilting mechanism. It just gives us a theoretically estimated results but the efficiency can be further increased by adding seasonal tilting mechanism and also by providing coded sensors such as pyranometer, light detecting sensors, storm detecting sensors, humidity and rain sensors.

There might be some losses during the chain transmission or due to the breakage of some tooth on the sprockets which may reduce the overall efficiency of the firm. As the efficiency of the gears are better than the sprockets and the chains and also the accuracy of the design is more, we can modify the design by installing worm gears with self locking mechanism to transmit the energy.

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