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Recommendation Proposal

Design and Development of Single Axis Type Automatic Tracking Mechanism for Solar Devices

Submitted by

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PART - I - GENERAL INFORMATION

1.	**Project Code**	
2	**Project Title**	Design and development of single axis type automatic tracking mechanism for solar devices.
3	**Name of Department Where the project was undertaken** **a) Name of Department** **b) Location of Project**	Department of Electrical and Other Energy Sources Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli Department of Electrical and Other Energy Sources Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli
4	**Name of Scientist**	Er. N. K. Palte, Instrument Mechanic
5	**Name of Co-scientists**	Er. R. N. Palte, Senior Research Assistant Dr. A. G. Mohod, Associate Professor Dr. Y. P. Khandetod, Professor and Head
6	**Objectives**	1. To design and develop continuous single axis type automatic tracking mechanism for solar devices 2. To evaluate performance of newly developed tracking mechanism.
7	**Year of start**	Yr. 2014-15

PART - II - TECHNICAL INFORMATION

1. Background of Project:

1.1 Justification:

Energy is the prime factor for the development of a nation. An enormous amount of energy is extracted, distributed, converted and consumed in the global society daily. 85% of energy production is depends on fossil fuels. The sun is a very large, inexhaustible source of energy. In rural sector it may be the promising source of energy/fuel as tremendous increase in prices of LPG cylinders for household cooking, drying operations.

1.2 Need of solar tracking system

Energy capture efficiency of solar collector is affected by the design of the system and the method of mounting the collector. For existing solar panels, which are without any control systems typical level of efficiency varies from 4% to 10% - a level that should enhance for wide application. To increase energy capture efficiency of the solar collector, it should be placed such that it **always receives maximum intensity of light**.

Kelly & Gibson, 2009 observed that with single axis solar tracking mechanism about 30% more energy output is obtained than fixed tilt in sunny climate. Messenger & Ventre, 2012 conducted the study and concluded that with two axis solar tracking mechanism energy output of about 50% and 20% more is obtained in summer and winter respectively than fixed tilt in clear sky conditions. They also reported that energy output of about 35% and 5% more is obtained in summer and winter respectively than fixed tilt in cloudy conditions.

Existing solar tracking systems are time base, sophisticated software base and sensor base. These systems are more expensive and need expertise to operate. Majorly available solar tracking systems are designed for large capacity solar energy harvesting systems and not for small size systems. Some of them are semi-automatic, which needs manual interventions.

Solar energy harvesting systems for domestic purpose viz. solar cooker, parabolic dish, parabolic through etc. are proven technologies, but still it is not popularized among the public, because without tracking systems it needs continuous manual assistance. So to make these solar energy harvesting systems hassle free, and popular among the public, solar tracking systems are required. Public demands the system, which should automatically track the sun. The tag line for promotion of this system could be ***'Fix it and Forget it'.***

1.3 Methodology

The aim of this project is to utilize the maximum solar energy through solar panel/ Concentrating solar thermal devices using solar tracking mechanism. For this an automatic sun tracking system is proposed. This project will help the solar power generating equipment/concentrating solar thermal devices to get the maximum sunlight automatically thereby increasing the efficiency of the system. The solar panel/collector, tracks the sun from east to west automatically for maximum intensity of light, making the system hassle free.

2. Technical Details of Project:

2.1 Design of single axis tracking mechanism:

The circuit is designed using motor driver IC; which can handle 4A current @ 12 volts DC. Also 2 (two) more LDR sensors (LDR3 & LDR4) are connected parallel to East side sensor (LDR2) to overcome the practical problem to sense the sun rays at early hours in the morning.

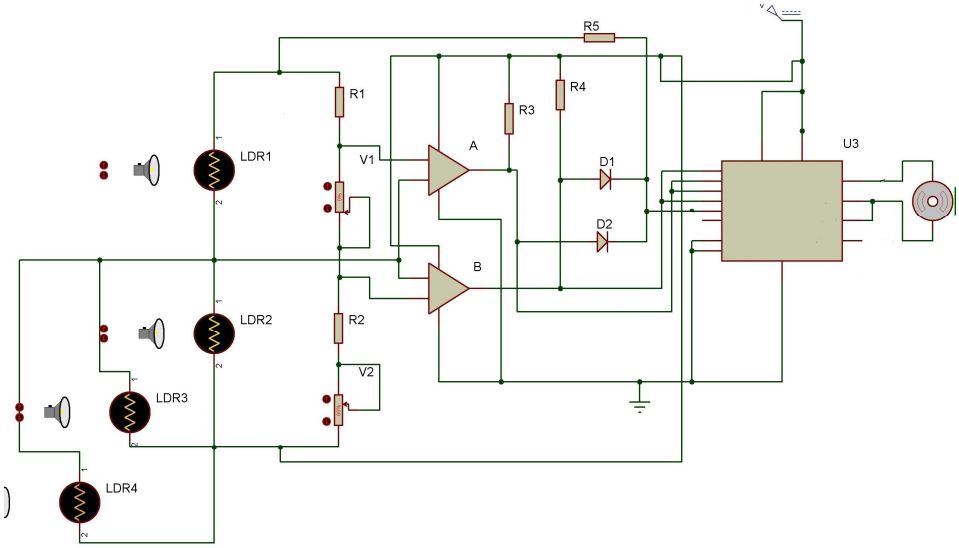


Fig. 1 - Circuit of solar tracker system

2.2 Component fabrication and procurement.

To design Printed Circuit Board (PCB) of the Solar Tracker circuit, Graphical Layout Editor software is used. PCB and component layout of solar tracker circuit is as shown in Fig 2 and Fig. 3.

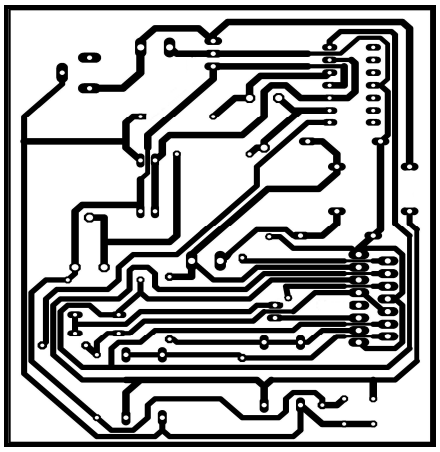


Fig. 2 - Printed Circuit Board Layout

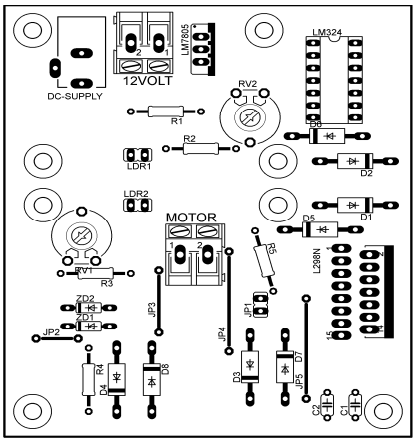


Fig. 3 - Components Layout

2.3 Design of Solar Tracker Circuit Encloser:

The size of newly designed PCB is (7.62 x 8.89) cm and maximum height of the component mounted on PCB is 3.81 cm. Solar Tracker Circuit Encloser with partition plate between two sensors is fabricated as shown in Fig 4. Two sensors (LDR1 & LDR2) are placed on opposite side of partition plate as shown in Fig 5. Additional one sensor is placed

on east-side wall of the encloser and other is placed at bottom of the encloser as shown in Fig 6. The Solar Tracker Unit is installed on axis of rotation of Tracking Structure keeping partition plate co-incident with axis of rotation as shown in the Fig 8.

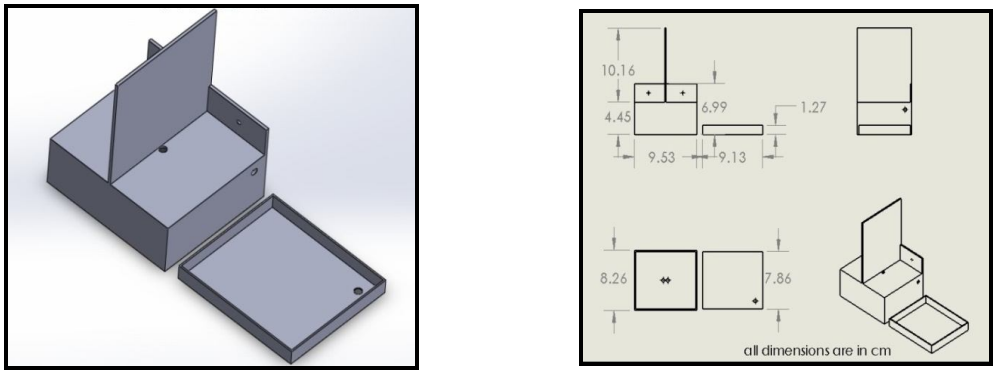


Fig 4. Solar Tracker Unit Encloser

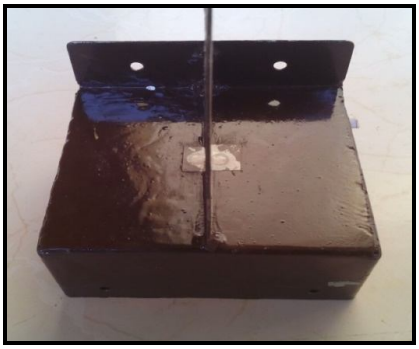
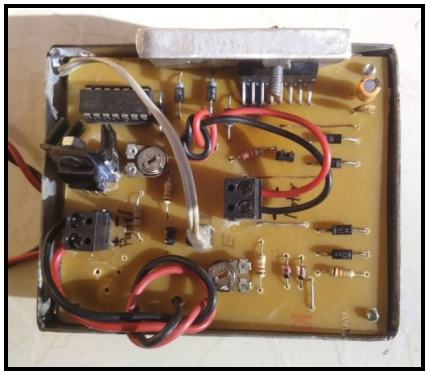


Fig 5. Placement of sensors (LDR1& LDR2)

Fig 6. Placement of additional sensors (LDR3 & LDR4)



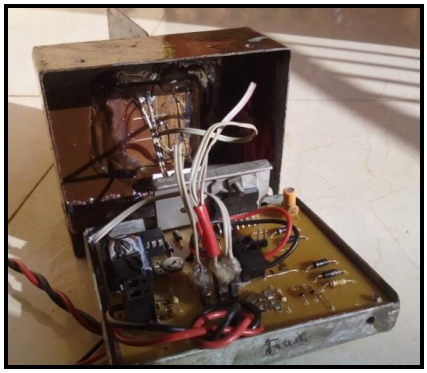


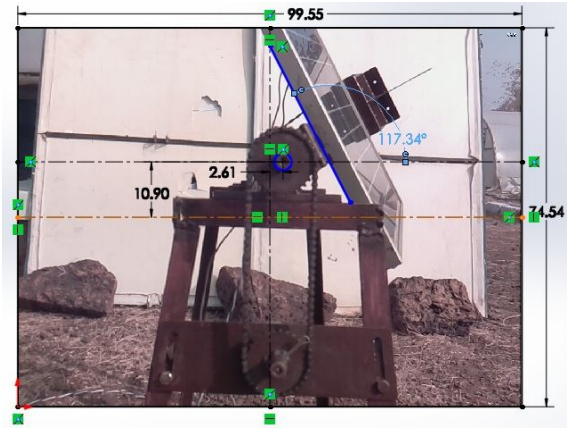
Fig 7. Solar Tracker Unit (Circuit and Encloser)

Fig 8. Installation of Solar Tracker Unit on 10 watt photovoltaic panel

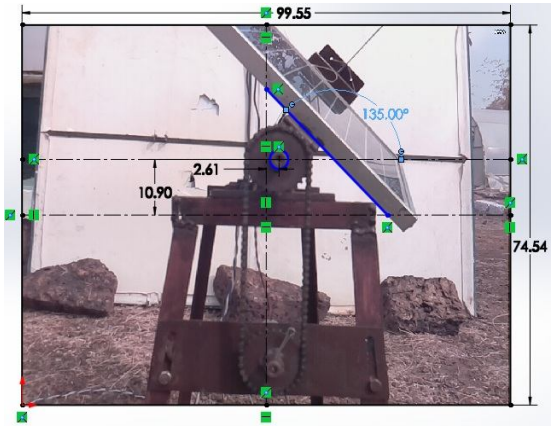
3. Performance evaluation of solar tracker unit –

3.1 Testing on 10 watt panel during year 2015-2016:-

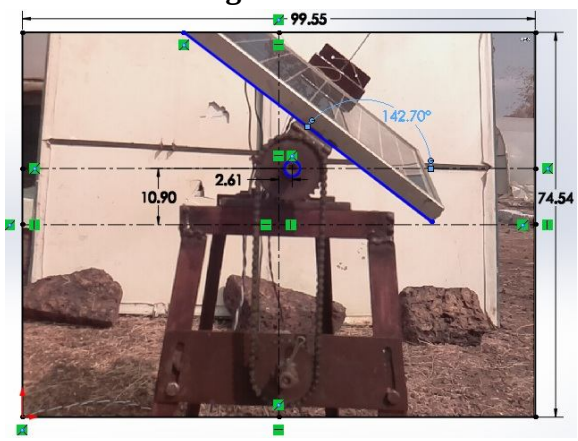
To measure the angle of rotations for 1 hour, photos were snapped at interval of 60 minutes, keeping the camera undisturbed. Snapped photos then processed in Solidworks-2015 software to find the angle of rotations within 60 minutes.



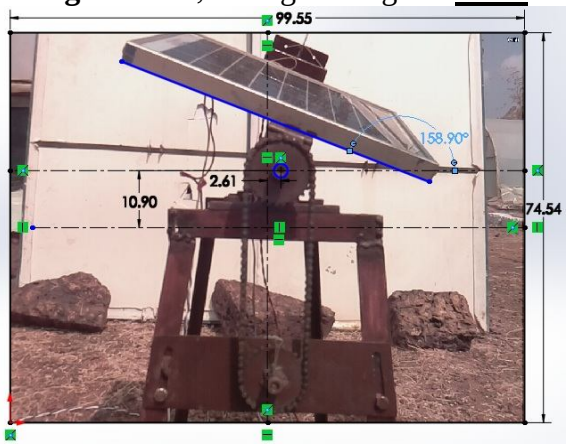
Time of snap = 8.15 am;
Angle = 117.34^0



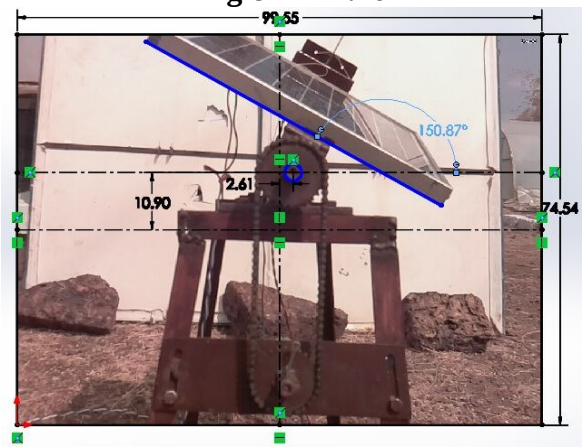
Time of snap = 9.15 am;
Angle = 135^0; Change in angle = **<u>17.66^0</u>**



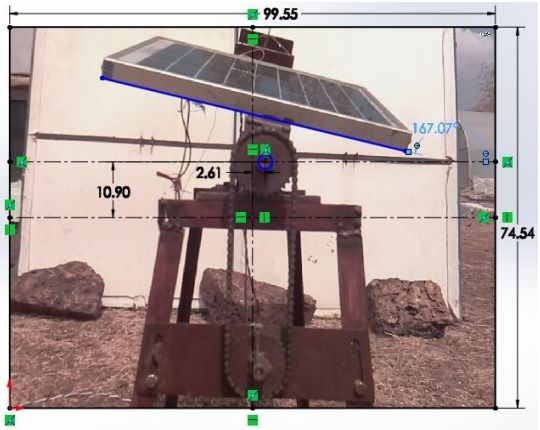
Time of snap = 9:56 am;
Angle = 142.70^0



Time of snap = 10.56 am;
Angle = 158.90^0; Change in angle =**<u>16.20^0</u>**



Time of snap = 10.28 am;
Angle = 150.87^0



Time of snap = 11.28 am;
Angle = 167.07^0; Change in angle = **<u>16.20^0</u>**

Fig 9. Measurement of angle per hour by tracked photovoltaic panel

Table 1. Evaluation of system on 10 watt solar panel during Yr. 2015-2016.

Time hrs.	Tracked Panel volt	Fixed panel Volt	Temperature ^{0}C	Solar insolations Watt/m^2	% increase in voltage
7:00	4.71	3.25	14	--	35.65%
7:15	16.01	8.01	15	2	101.29%
7:30	18.52	12.64	17	4	48.49%
7:45	19.32	16.15	20	12	19.77%
8:00	19.83	17.71	23	34	12.02%
8:15	19.54	18.81	26	60	3.91%
8:30	19.86	18.98	27	86	4.64%
8:45	19.93	19.23	29	120	3.62%
9:00	20.00	19.42	30	158	2.99%
9:15	19.89	19.45	31	196	2.26%
9:30	19.84	19.46	32	237	1.95%
9:45	19.70	19.47	34	273	1.18%
10:00	19.87	19.44	34	315	2.24%
10:15	19.75	19.40	36	349	1.85%
10:30	19.65	19.35	35	382	1.53%
10:45	19.68	19.28	37	408	2.09%
11:00	19.60	19.20	38	432	2.11%
11:15	19.64	19.16	38	452	2.51%
11:30	19.81	19.21	38	466	3.14%
11:45	19.80	19.18	38	476	3.26%
12:00	19.97	19.41	35	481	2.86%
12:15	20.10	19.39	36	487	3.66%
12:30	20.14	19.30	36	496	4.37%
12:45	20.05	19.25	37	489	4.15%
13:00	20.09	19.29	36	488	4.15%
13:15	20.04	19.24	36	486	4.15%
13:30	19.93	19.11	37	486	4.31%
13:45	20.04	19.21	37	485	4.31%
14:00	19.95	19.17	38	471	4.10%
14:15	20.01	19.25	37	461	3.96%
14:30	20.03	19.29	37	441	3.85%
14:45	19.88	19.20	38	415	3.56%
15:00	20.04	19.31	37	401	3.82%
15:15	20.01	19.26	36	374	3.88%
15:30	20.01	19.24	37	346	4.00%
15:45	20.11	19.27	36	310	4.37%
16:00	20.13	19.14	36	271	5.16%
16:15	20.24	19.06	35	251	6.23%
16:30	20.12	19.16	33	208	4.98%
16:45	20.05	18.88	32	177	6.19%
17:00	20.17	18.61	32	136	8.41%

Time hrs.	Tracked Panel volt	Fixed panel Volt	Temperature ^{0}C	Solar insolations Watt/m^2	% increase in voltage
17:15	20.06	18.10	31	110	10.79%
17:30	19.44	16.84	30	75	15.47%
17:45	18.13	14.73	29	44	23.22%
18:00	14.51	11.34	26	25	27.56%
18:15	10.49	8.63	25	--	19.64%

- It is observed that output voltage from stationary and tracked panel varied. The variations are maximum at early morning hours (i.e. from 7:00 hrs to 8:00 hrs) and late evening hours (i.e. from 17:00 hrs to 18:00 hrs.
- As per data logged, for rated power output, voltage of tracked panel was reached to 16 volts at around 7:00 to 7:15 hrs. and same was reached at 8:00 to 8:15 hrs for fixed PV panel.
- Also tracked PV panel voltage was drop below 16 volts at around 17:45 to 18:00 hrs. and same was dropped at 17:30 to 17:45 hrs for fixed panel.
- **So the tracked PV panel harvest the solar energy for extra 1 ½ hrs.**
- Percentage increase in Rated Power Output = 20%

3.2 Testing on 80 watt solar panel during Yr. 2016-2017:-

For testing of solar tracker unit on commercially used solar panel of 80 watt system, structure was fabricated as shown in fig. 9.

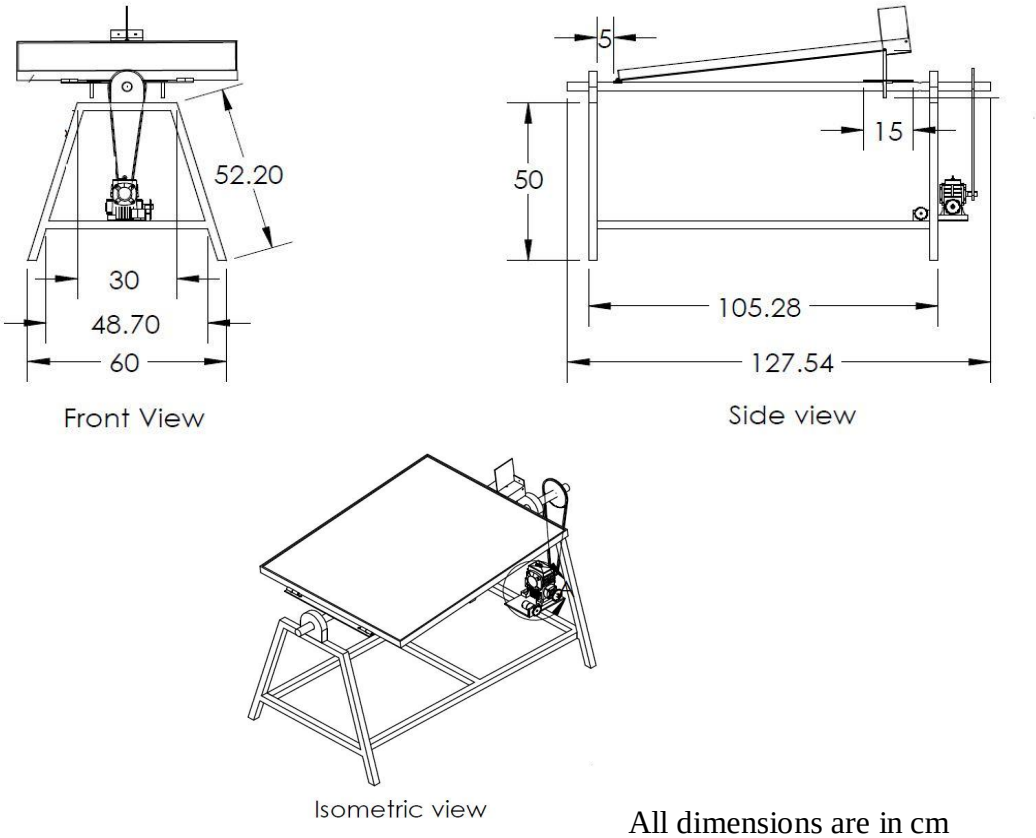


Fig 10. Structure for installation of Solar Tracker Unit on 80 watt photovoltaic panel

Specifications of PV panel –

Power (max) = 80 watts

V_{open} = 21.45 volts

I_{sc} = 4.85 A.

Size of panel – (85 x 60) cm.

Weight of panel – 6.5 kg.

Specifications of motor used for tracking are -

Speed - 10RPM, 120 kg-cm torque

12V DC motors with Metal Gearbox and Metal Gears

Load current = upto 7.5 A (Max)

12 volts @ 2A DC power adaptor is used to power the tracking circuit.

Specification of gear box –

Make – Machinery Ltd.

Ratio – 15:1

Type – Worm gear (right angled)

Motor shaft and gear box input are directly coupled therefore motor and gear box input ratio is 1:1. Gear box output and tracking shaft ratio is also 1:1. Maximum current required to move or rotate the structure from its stationary position is 1.5 A@12 volts. Thus for this specific structure minimum (12 x 1.5 = 18 watt) power motor is required.

Fig11. Installation of Solar Tracker Unit on 80 watt photovoltaic panel

The performance of solar tracker unit is evaluated by recording the open circuit voltage and short circuit current output of stationary solar panel and tracked solar panel. The current sensor module is used to measure current consume by motor. Data logger is used to log motor's current data at interval of 20 seconds from 7:00 to 18:00 hrs. Short-circuit current of PV panel is measured using digital multimeter at interval of 15 min. from 7:00 to 18:00 hrs.

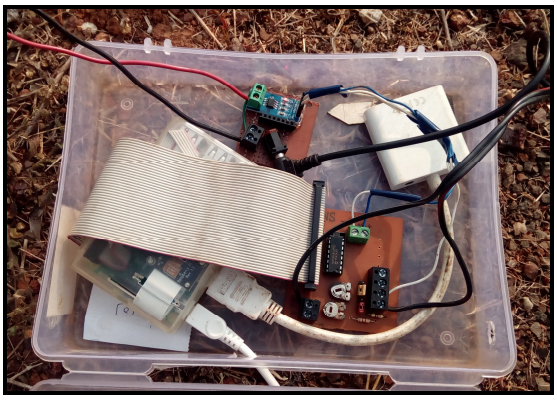
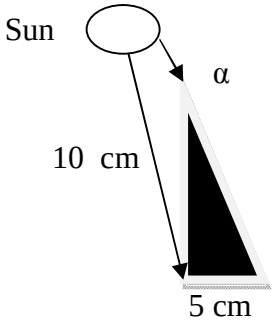


Fig 12 – Experimental setup to record data

Rotation speed of earth/ relative rotation of sun is 1 degree per 4 minutes. System uses encloser box with partition plate of 10 cm. height. LDR are placed very close to either side of partition plate. Sensor has diameter 0.5 cm. To make the tracker motor work, sensor of diameter 0.5 cm should go under the shadow of partition plate.



$\alpha = \tan^{-1}(0.5/10) = 2.86^0 \sim 3^0$

Sun will move by 3^0 in 12 min.

So to track the sun, motor will run atleast 5 times/hr.

Table 2 – Power consumption of tracking motor on 80 watt system

S. N.	Time (hr)	Time for which motor consume current (hh:mm:ss)	Time (seconds)	Avg. Current motor run time (Amp)	Tracking Motor (Wh)
1	7:00-8:00	00:06:20	380	1.419	1.80
2	8:00-9:00	00:07:00	420	1.138	1.59
3	9:00-10:00	00:06:00	360	1.096	1.32
4	10:00-11:00	00:06:20	380	1.096	1.39
5	11:00-12:00	00:07:00	420	1.048	1.47
6	12:00-13:00	00:07:00	420	1.231	1.72
7	13:00-14:00	00:06:40	400	1.200	1.60
8	14:00-15:00	00:06:20	380	1.197	1.52
9	15:00-16:00	00:05:00	300	1.185	1.18
10	16:00-17:00	00:07:20	440	1.036	1.52
11	17:00-18:00	00:06:20	380	1.055	1.34
Total	**11 hrs**	**01:11:20**	**4280**	**1.155**	**16.47**

Tracking motor current readings are recorded on 17th Jan. 2017. Sun rise time – 7:17 hr (IST), Sunset time – 18:21 hr (IST). When motor is not running or in OFF condition the electronic components of the circuit consumed average current of 200 mA.

Table 3 - Performance evaluation of tracking system on 80 watt system

S. N.	Time (hr)	Tracking motor (Wh)	Tracked Panel (Wh)	Fixed Panel (Wh)	Gross Gain (Wh)	Net Gain (Wh)	Solar intensity (Watts/m^2)
A	B	C	D	E	F = D - E	G = F - C	H
1	7:00-8:00	1.80	4.15	3.58	0.56	1.23	46.20
2	8:00-9:00	1.59	44.62	26.00	18.62	17.03	239.00
3	9:00-10:00	1.32	66.49	46.22	20.27	18.95	441.25
4	10:00-11:00	1.39	77.13	65.70	11.43	10.05	654.50
5	11:00-12:00	1.47	81.38	77.79	3.58	2.12	785.50
6	12:00-13:00	1.72	85.46	85.25	0.21	-1.51	838.75
7	13:00-14:00	1.60	88.53	84.33	4.19	2.59	828.00
8	14:00-15:00	1.52	84.60	71.38	13.22	11.71	688.50
9	15:00-16:00	1.18	65.31	48.94	16.36	15.18	480.25
10	16:00-17:00	1.52	41.53	23.59	17.94	16.42	280.50
11	17:00-18:00	1.34	6.89	4.98	1.91	0.57	68.33
Total	**11 hrs**	**16.47**	**646.07**	**537.77**	**108.31**	**91.86**	

Tracked position PV panel and fixed position panel wattages are measured on 20th Jan. 2017. Sun rise time – 7:17 hr (IST), Sunset time – 18:23 hr (IST).

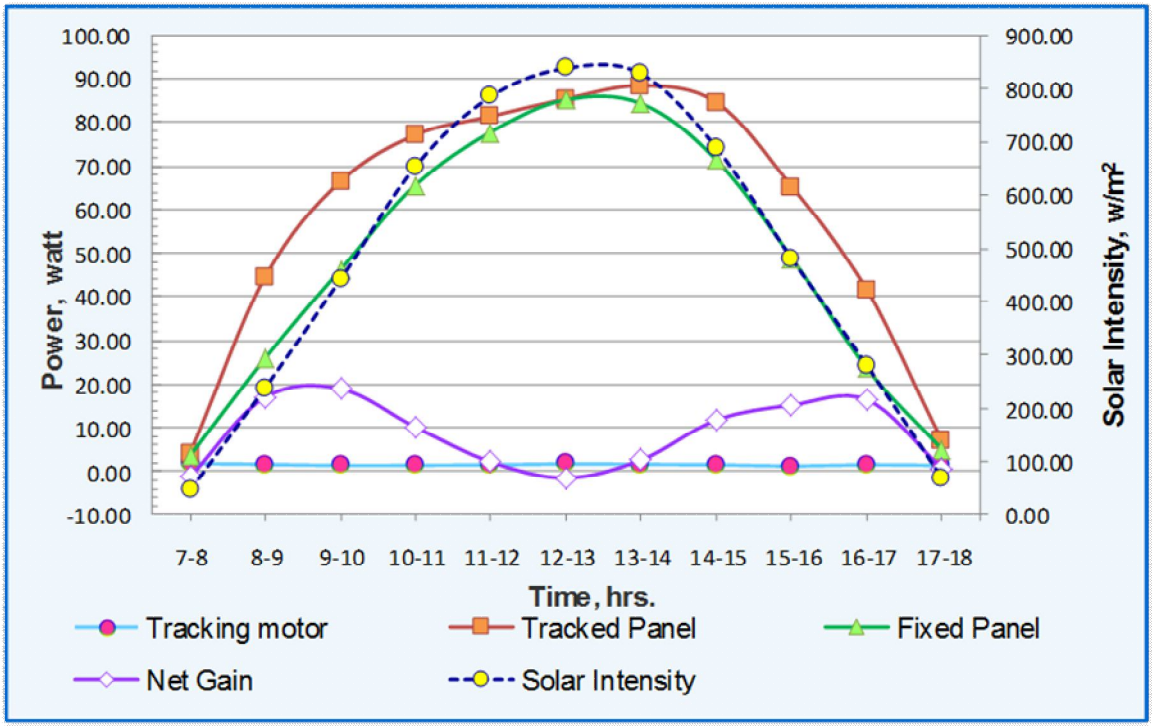


Fig 13. Effect of solar intensity on energy generation by stationary and tracked panel

- Power required for motor to rotate the PV panel from 7:00 to 18:00 hr. is 16.47 watts (avg.) for a day.
- Power output from tracked 80 watt - PV panel from 7:00 to 18:00 hr. is 646.07 watts for a day which was depends on solar intensity.
- Power output from fixed 80 watt - PV panel from 7:00 to 18:00 hr. is 537.77 watts for a day.
- Net energy gain is 15%.

4. Evaluation of cost economics

The cost economics for stationary and tracked panel on 80 W systems is worked out considering the cost incurred for installation of systems. Similarly the estimate is made for installation of 1 kW, considering structural stability and torque generated during rotation of solar PV panel.

4.1 Cost for installation of tracker system on 80 W system

Table 4 - Total installation cost for stationary and tracked panel on 80 W system –

Sr. No.	Specification	Rate	Weight	Requirement	Stationary Panel		Tracked Panel	
					Weight (kg)	Cost (Rs.)	Weight (kg)	Cost (Rs.)
1	**80 Watts** PV Panel	5000/-	6.5 kg	1 no.	6.5	5000	6.5	5000
2	**Frame** for holding PV panel and for stand– G.I. 1" sq. pipe	300/- per 20 ft	5.5 kg/ 20 ft	4350 mm = 15 ft.	-	-	4.2	225
3	**Center Rod** – Hollow pipe – G.I. 1.0", thickness 1.5 mm	300/- per 20 ft	5.5 kg/ 20 ft	1275.4 mm = 5 ft	-	-	1.4	75
	Total weight of rotating parts =				**6.5**		**12.1**	
4	**Stand Frame** – G.I. 1" sq. pipe	300/- per 20 ft	5.5 kg / 20 ft	7881.2 mm = 25 ft	-	-	6.9	375
5	Pedestal **Bearings** - 1"	250/-	-	2 nos.	-	-	-	500
6	**Gearbox** - Worm Gear ratio - 15:1	2500/-	-	1 no.	-	-	-	2500
7	Chain and sprockets	300/-	-	-	-	-	-	300
8	Solar tracking device	500/-	-	1 no.	-	-	-	500
9	Metal Gear Motor	600/-	-	1 no.	-	-	-	600
11	Fabrication and labour charges 30% on item no. 2,3,4					-	-	203
	Total installation cost					**5000**		**10278**

4.2 **Cost for installation on 1kW system**

4.2.1 **Structure for installation of tracker system on 1 kW system –**

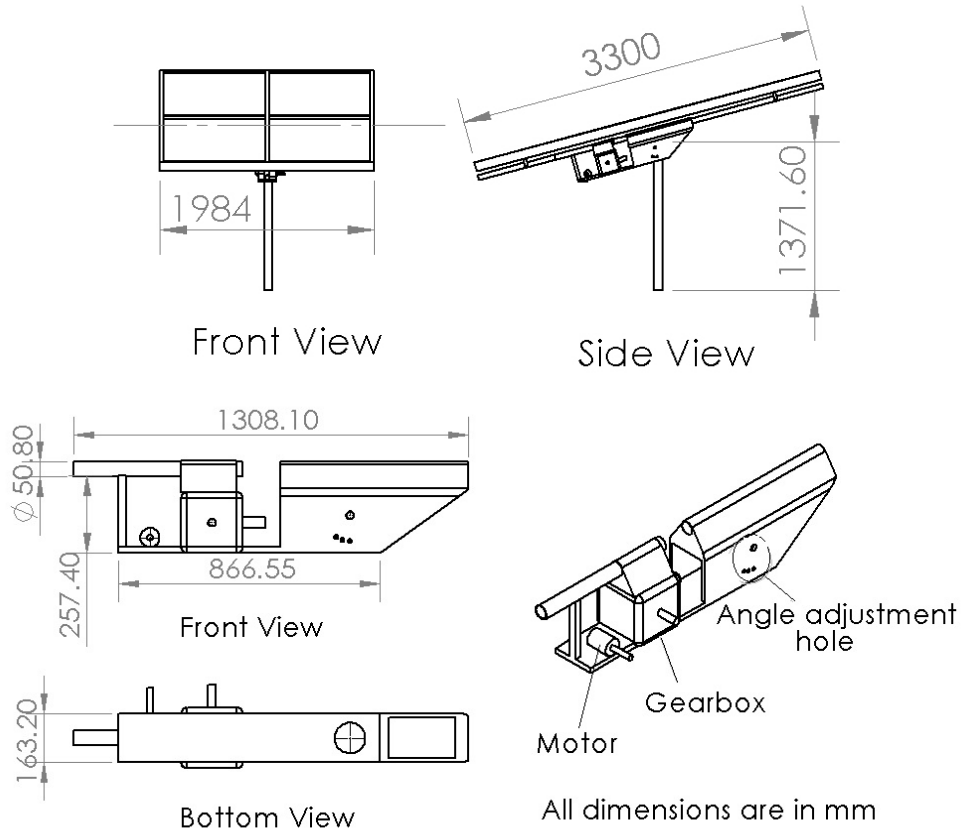


Fig 14. Structure for installation of Tracker system on 1-kW photovoltaic panel

Table 5 - Total installation cost for Tracked system on 1 kW systems -

Sr. No.	Specification	Rate	Weight	Requirement	Weight (kg)	Cost (Rs.)
1	**250 Watts** PV Panel	12500/-	19.5kg	4 nos.	78	50000
2	**Frame** for holding 4 PV panels – G.I. 1.5" square pipe, thickness 1.5 mm	650/- per pipe (20 ft)	8 kg / per pipe (20 ft)	15852 mm ~= 52 ft	20.8	1690
3	**Center Rod** – Hollow pipe - G.I. 1.5", thickness 2.2 mm	750/- per pipe (20 ft)	9 kg / per pipe (20 ft)	3963 mm ~= 13 ft	5.85	488
	Total weight of rotating parts =				**105**	
4	**Center Assembly**- 4 sq.ft. MS sheet of thickness 3 mm + Hollow pipe - G.I. 2.0", thickness 2.2 mm				-	1500
5	**Bearings**-1"	125/-	-	4 nos.	-	500
6	**Gearbox** - Worm Gear ratio - 15:1	2500/-	-	1 no.	-	2500
7	Chain and sprockets	500/-	-	-	-	500
8	Solar tracking device	500/-	-	1 no.	-	500
9	Metal Gear Motor	600/-	-	1 no.	-	600
10	Miscellaneous	-	-	-	-	500
11	Fabrication and labour charges 30% on item no. 2,3,4					1103
	Total installation cost for Tracked system					**59881**

4.2.1.1 Analysis for torque required to rotate 1kW system structure -

To determine torque required for rotating 1 kW system structure of around 105 kg, structure is design in Solidworks-2016 and Motion analysis is carried out.

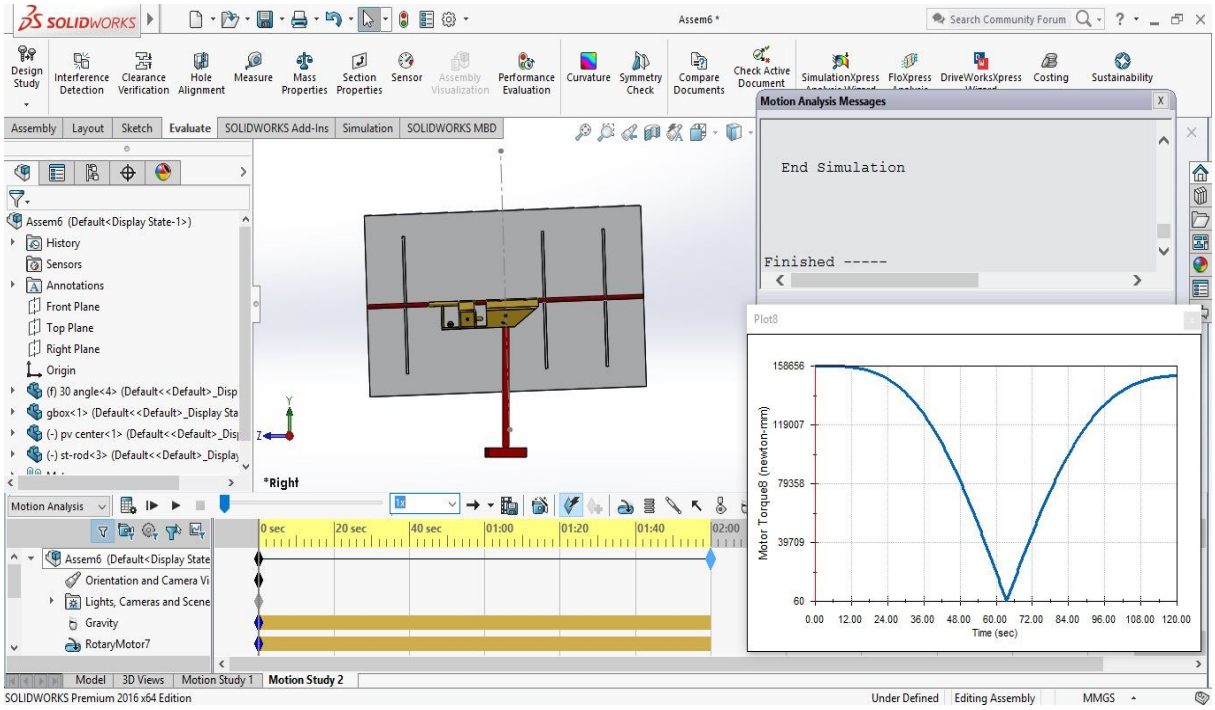


Fig 15. Motion Analysis – 1kW panel – 160^0 rotation in 2 min at inclination of 2^0

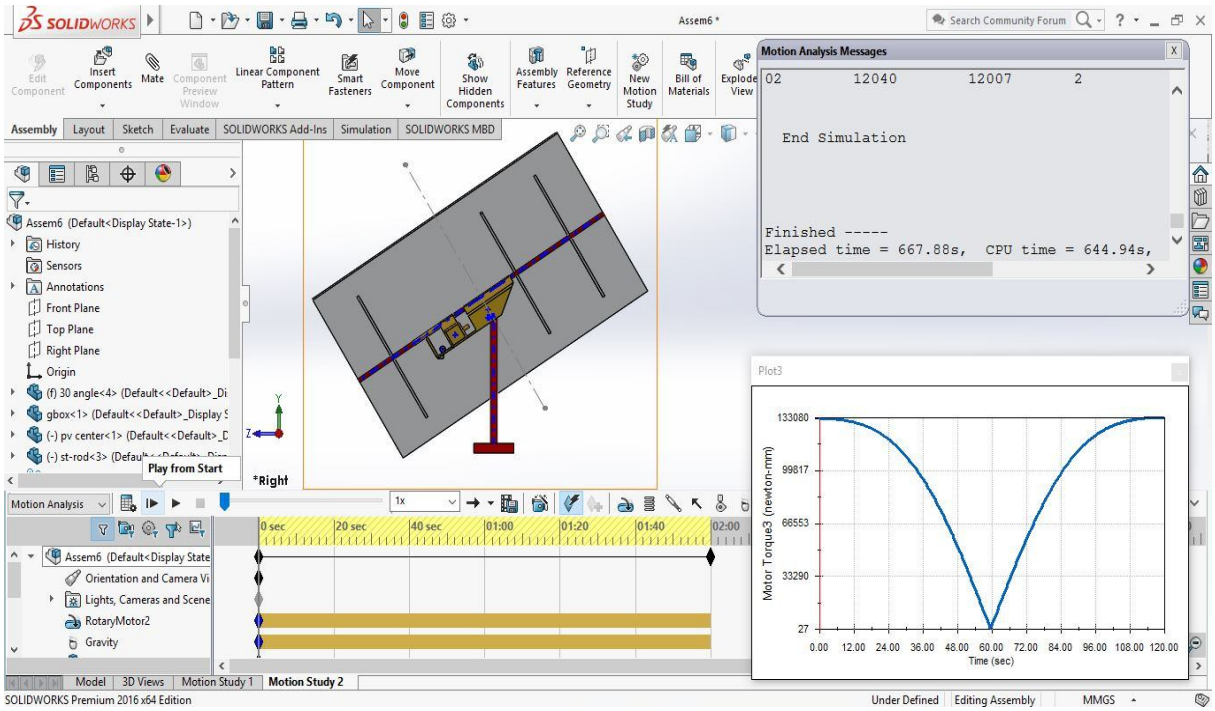


Fig 16. Motion Analysis – 1kW panel – 160^0 rotation in 2 min at inclination of 32^0

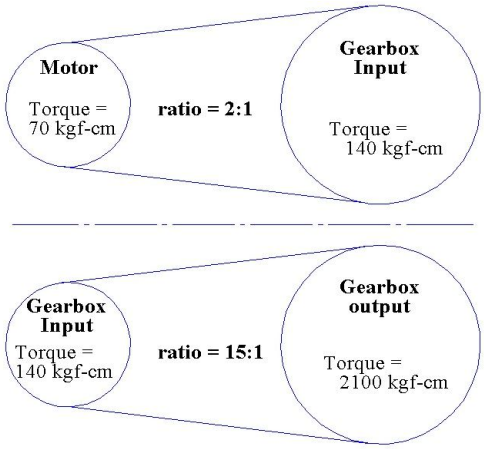


Fig 17. Gear ratio and Torque calculation

- Motor shaft - gearbox input ratio = 2:1, gearbox ratio = 15:1 and gearbox output - tracking shaft ratio = 1:1.
- Motor torque at 12 volts @ 3 A (max) = 70 kgf-cm (6.86 N-m)
- So the **torque at output shaft** of gearbox = motor torque x gear ratio = 2100 kgf-cm **(205.94 N-m).**
- Torque requires to rotate structure is determine by using **Motion Analysis in Solidworks 2016 3D CAD software**
    - 80 W panel (approx. 15 kg weight) at inclination of 2^0 = 0.54 N-m
    - **1 kW** panel (approx. 105 kg weight) at inclination of $\mathbf{2^0}$= 158.67 N-m
    - **1 kW** panel (approx. 105 kg weight) at inclination of $\mathbf{32^0}$= 133.08 N-m

4.2.2 Structure for installation of 1-kW stationary system -

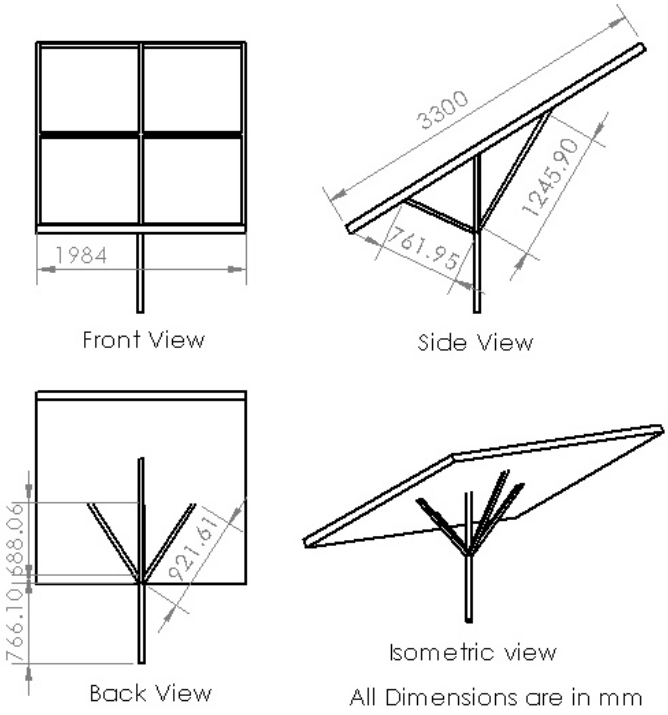


Fig 18. Structure for installation of on 1-kW stationary system

Table 6 - Total installation cost for Stationary panel on 1 kW systems

Sr. No.	Specification	Rate	Weight	Requirement	Weight (kg)	Cost (Rs.)
1	**250 Watts** PV Panel	12500/-	19.5kg	4 nos.	78	50000
2	**Frame** for holding 4 PV panels – G.I. 1.5" square pipe, thickness 1.5 mm	650/- per pipe (20 ft)	8 kg / per pipe (20 ft)	15852 mm ~= 52 ft	20.8	1690
3	**Center Rod** – Hollow pipe – G.I. 2.0", thickness 2.2 mm	750/- per pipe (20 ft)	9 kg / per pipe (20 ft)	1524 mm ~= 5 ft	2.25	188
4	**Supports for PV frame** – G.I. 1.5" square pipe, thickness 1.5 mm	650/- per pipe (20 ft)	8 kg / per pipe (20 ft)	3992 mm ~= 13 ft	5.2	422
5	Miscellaneous	-	-	-	-	500
6	Fabrication and labour charges 30% on item no. 2,3,4					690
					Total installation cost for stationary system	**53490**

4.2.3 Cost Evaluation of stationary and tracked panel on 80 W and 1 kW systems

The installation cost and energy gain (Rs./year) for stationary and tracked panel on 80 W and 1 kW systems are compared and payback period is calculated.

Table 7. – Comparative cost of stationary and tracked panel on 80 W and 1 kW systems

S.N.	Particulars	80 W system		1 kW system	
		Stationary Panel	Tracked Panel	Stationary Panel	Tracked Panel
1	Installation cost (Rs.)	5000	10278	53490	59881
2	Energy generated (kwh/day)	0.54	0.65	6.7	8.0
3	Energy gain by tracked panel (kwh/day)	-	0.11	-	1.3
4	Energy generated per year (approx. 300 days) kwh / year	162	195	2010	2400
5	Energy gain by tracked panel (approx. 300 days) kwh / year	-	33	-	390
6	Cost of energy gain, Rs./ year	-	330	-	3900
7	Payback period of tracker cost (years)	-	16	-	**1.64**

5. Discussions

- As per the Motion Analysis done in Solidworks-2016 existing gearbox and motor (used for 80 W panel) can also be used to rotate 1 kW structure having approx. weight of 105 kg.
- Payback period of extra tracking mechanism cost for 1 kW system is 19 months.

- Power consumed by tracking motor and required motor's wattage can be lowered by changing input and output gear ratio of gearbox.
- By proper gear arrangement and mechanical structure the single axis automatic solar tracking mechanism can be used in solar harvesting devices i.e. parabolic solar cooker, Scheffler dish, parabolic trough, Fresnel lens collector etc.

Recommendation –

Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli developed single axis automatic solar tracking mechanism is recommended to increase output of solar photovoltaic panel.

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