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Assessing Solar Tracker Effectiveness in Diverse Weather Conditions

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***Abstract*— Solar tracking systems aim to optimize solar photovoltaic (PV) panel efficiency by maximizing exposure to sunlight. This paper explores solar tracking, its benefits, and various system types, emphasizing the goal of ensuring panels are perpendicular to the sun's rays. Tracking enhances energy generation potential compared to fixed installations, increasing output by 25-35%. This boosts return on investment and reduces payback periods. In agriculture, solar tracking promotes energy efficiency, productivity, and sustainability. However, long-term benefits, economic feasibility, and environmental impacts require further research. This study proposes evaluating solar panel output under different weather conditions, comparing tracking and non-tracking modes. The analysis concludes that tracking mode generates more power than non-tracking mode. This finding underscores the efficacy of solar tracking technology in maximizing energy production. Overall, adopting solar tracking systems can foster a greener, more sustainable future, particularly in agricultural contexts.*

I. INTRODUCTION

1.1 Solar Energy

The utilization of solar energy dates back millennia, with ancient civilizations such as the Greeks and Romans employing solar architecture to capture and utilize the sun's heat for various purposes [6]. Many early innovations laid the foundation for the solar technologies we have today. One of the most revolutionary developments in solar energy is the widespread adoption of photovoltaic (PV) technology. PV panels, often referred to as solar panels, convert sunlight directly into electricity through the photovoltaic effect [3]. This innovation has transformed the energy landscape by making solar power accessible and economically viable on a large scale. Over the years, intensive research and development efforts have significantly improved the efficiency of solar panels. Breakthroughs in materials science, such as the development of perovskite solar cells, promise even greater efficiency gains in the future [7]. Enhanced efficiency translates into more power generation from the same area of solar panels, making solar energy a compelling choice for meeting energy demands. As solar energy capacity increases, grid integration and energy storage solutions become critical. Research in this area has led to innovations like smart grids, which enable efficient distribution and management of solar-generated electricity [5]. Moreover, energy storage technologies like lithium-ion batteries are making it possible to store excess solar energy for use during cloudy days or at night.

Solar energy is not only economically viable but also environmentally friendly. It produces no greenhouse gas emissions during operation, reducing the carbon footprint associated with energy production [2]. The use of solar power contributes to mitigating climate change and reducing air pollution, thus enhancing overall environmental quality. Beyond its environmental advantages, solar energy also offers economic benefits. The solar industry has witnessed rapid growth, creating jobs and stimulating local economies [1]. As governments worldwide invest in renewable energy, solar power is increasingly becoming an engine for economic development. While solar energy holds tremendous promise, it is not without its challenges. Issues such as intermittency, land use, and the environmental impact of manufacturing PV panels require ongoing research and innovation [4]. Addressing these challenges will be crucial for the continued expansion of solar energy.

1.2 Single-Axis Solar Tracking Mechanism

The quest for sustainable energy sources has led to an unprecedented surge in research and innovation within the field of renewable energy. Solar power stands as one of the most promising and abundant sources of clean energy, offering immense potential for addressing our ever-growing energy needs while mitigating environmental concerns. To maximize the efficiency of solar energy conversion, solar tracking mechanisms have emerged as an essential component of solar photovoltaic systems. Among them, the Single Axis Solar Tracking Mechanism (SASTM) has gained substantial attention due to its cost-effectiveness and significant improvement in energy yield. In recent years, a multitude of research papers and studies have explored various aspects of Single Axis Solar Tracking Mechanisms, highlighting their importance in enhancing solar energy capture. These mechanisms operate by tilting solar panels or arrays along a single axis, typically the east-west axis, to follow the sun's daily path across the sky [8]. This movement ensures that the solar panels are optimally oriented to receive sunlight at nearly perpendicular angles, thereby increasing energy generation. Numerous research findings underscore the benefits of SASTMs.

Solar power occupies a significant position among global renewable energy sources due to its abundant energy eventuality. Accordingly, its donation to electricity generation is steadily adding . still, carrying peak effectiveness from fixed solar photovoltaic(PV) panels is a redoubtable task due to their limited capability to constantly tap into solar energy(10). To attack this issue and alleviate energy effectiveness losses, the application of solar shadowing systems has surfaced as an exceptionally effective result. These systems enable nonstop adaptation of the panels ’ position to align with the sun’s line, optimizing energy immersion and enhancing overall performance(8,9). Photovoltaic energy has shown a eventuality for cost reduction and better conversion effectiveness, and it's believed to come one of the primary source of energy force in the future [11]. solar energy is anticipated to come cheaper than conventional energy sources in the near future, due to two main factors nonstop development of photovoltaic technology, and fossil energies raising prices.

II. MATERIALS AND METHODS

2.1 Materials used:

Table 1. List of materials used in the fabrication

S. No.	Particular’s Name
1.	Solar panel
2	Arduino Uno
3	DC motor
4	LDR sensor
5	Resistance
6	Motor driver
7	Jumper wire
8	Battery
9	Digital Multimeter
10	Tilt sensor

2.2 Following Steps were taken for the fabrication and performance evaluation of SASTM

- Designing of the structure in autocad software
- Collecting different components as per the need of the project
- Fabrication of the basic supporting structure
- Feeding the program in Arduino uno through Arduino IDE
- Assembling of all the desired components on the structure i.e. solar panel, sensors, motor Battery, Arduino Uno
- Placing the project in direct solar radiation
- Measuring the amount of short–circuit current and open circuit – voltage with the help of a multimeter in different weather conditions (clear sky and cloudy sky) by tracking and non-tracking mechanism
- Calculating the Fill Fator (FF)
- Comparing different fill factors for different conditions

2.3 Designing of the structure in AutoCAD

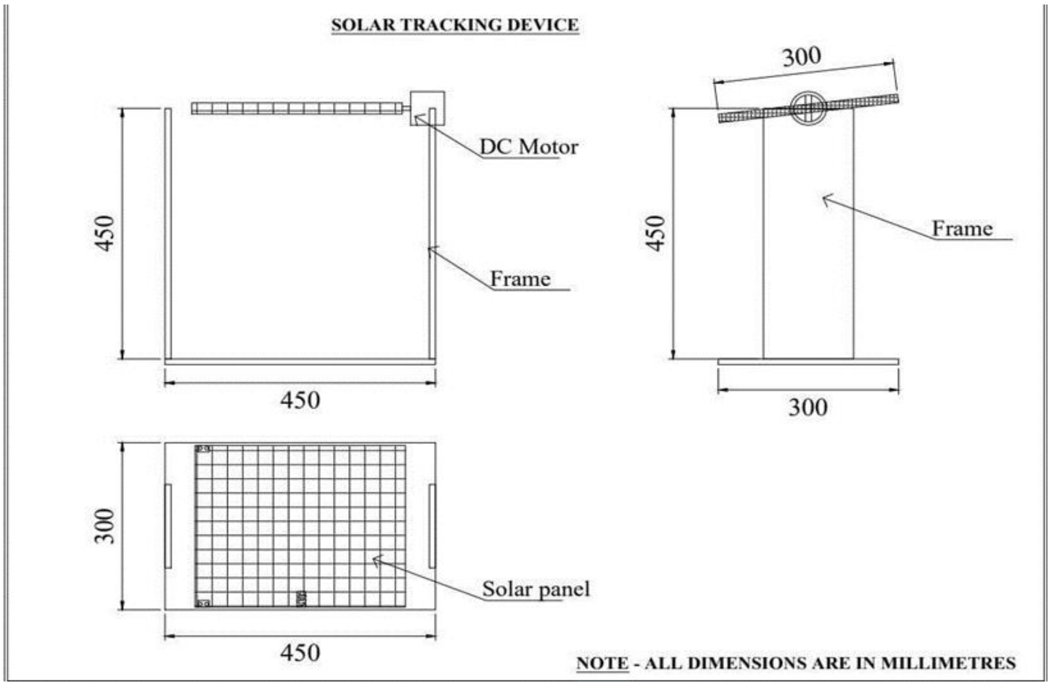

Fig.1. Structural of SASTM

2.4 Theoretical and Mathematical Background

2.4.1 Fill Fator (FF)

A solar photovoltaic module's efficiency is commonly measured by the Fill Factor (FF). It measures the real highest power that may be achieved [12]. The FF is described as the proportion of the highest power of the solar cell to the total(multiplication) of Voc and Isc, which are described as follows:

$$FF(\%) = (Pmax)/(V_{oc} \times I_{sc}) \quad (2.1)$$

2.4.2 Short Circuit Current (I_{sc})

Short circuit current, also known as "fault current" or "maximum fault current," refers to the maximum current that can flow through a circuit when a fault or short circuit occurs. A short circuit is an unintended connection between two conductors, typically with very low or zero resistance, which causes a significant increase in current flow. It is crucial for designing and protecting electrical systems, as it determines the magnitude of current that protective devices like circuit breakers or fuses need to handle [13].

2.4.3 Open Circuit Voltage (V_{oc})

Open circuit voltage, often abbreviated as "OCV" or "Voc," refers to the voltage across a circuit or component when there is no load or current flowing through it. In other words, it is the voltage measured across the terminals of a device when it is disconnected from any external circuit. It is an important parameter in understanding the behavior of power sources like batteries, solar cells, and generators. It represents the voltage potential of the source when no current is drawn from it [14].

III. RESULTS AND DISCUSSIONS

3.1. Observations recorded in clear sky & partially cloudy sky weather condition by tracking and non-tracking mechanism

Short circuit current & open circuit voltage had been measures with help of multimeter in different weather condition in tracking and non-tracking mechanism. The measure value is being discussed in following tables:

Table 1. Measurement of the (Voc) and (Isc) of solar panel in partially cloudy weather (non- tracking), Date- 2 august, 2023

S. No.	Time	Voltage (Voc)	Current (Isc)
1	10:00AM	19.67V	0.28A
2	11:00AM	19.72V	0.62A
3	12:00PM	18.65V	0.26A
4	01:00PM	19.85V	0.41A
5	02:00PM	18,54V	0.11A
6	03:00PM	18.74V	0.13A
7	04:00PM	18.74V	0.16A
8	05:00PM	18.26V	0.08A

Table 2. Measurement of the (Voc) and (Isc) of solar panel in partially cloudy weather (tracking), Date- 1 August, 2023

S. No.	Time	Voltage (voc)	Current (Isc)
1	10:00AM	19.65V	0.16A
2	11:00AM	19.48V	0.20A
3	12:00PM	18.36V	0.22A
4	01:00PM	19.07V	0.35A
5	02:00PM	19,44V	0.31A
6	03:00PM	19.57V	0.41A
7	04:00PM	17.86V	0.07A
8	05:00PM	17.56V	0.09A

Table 3. Measurements of the (Voc) and (Isc) of solar panel in clear sky (tracking), Date- 25 July, 2023

S. No.	Time	Voltage (voc)	Current (Isc)
1	10:00AM	19.24V	0.22A
2	11:00AM	19.79V	0.54A
3	12:00PM	19.44V	0.46A
4	01:00PM	19.86V	0.63A
5	02:00PM	19,40V	0.52A
6	03:00PM	19.05V	0.34A
7	04:00PM	19.62V	0.30A
8	05:00PM	19.17V	0.25A

Table 4. Measurement of the (Voc) and (Isc) of solar panel in clear sky (non- tracking), Date- 26 July, 2023

S. No.	Time	Voltage (Voc)	Current (Isc)
1	10:00AM	19.08V	0.11A
2	11:00AM	19.69V	0.22A
3	12:00PM	19.84V	0.09A
4	01:00PM	19.01V	0.30A
5	02:00PM	19,02V	0.21A
6	03:00PM	19.24V	0.25A
7	04:00PM	18.18V	0.18A
8	05:00PM	18.05V	0.15A

3.2 Calculation to find fill factor in different weather conditions by tracking and non-tracking mechanism

The fill factor is calculated by equation (1)

Table 5. Fill factor of the partially cloudy sky by the non-tracking mechanism

S.no	Time	Pidel (Voc× Ios)	FF(%)
1	10:00AM	5.50	16%
2	11:00AM	12.22	7%
3	12:00 PM	4.84	16%
4	01:00 PM	8.13	24%
5	02:00 PM	2.03	6%
6	03:00 PM	2.43	8%
7	04:00 PM	2.99	9%
8	05:00 PM	1.46	5%

Table 6. Fill factor of the partially cloudy sky by tracking mechanism

S. no	Time	Pidel (Voc× Ios)	FF(%)
1	10:00AM	3.14	9%
2	11:00AM	3.89	11%
3	12:00 PM	4.03	13%
4	01:00 PM	6.92	20%
5	02:00 PM	7.97	25%
6	03:00 PM	8.02	24%
7	04:00 PM	1.25	4%
8	05:00 PM	1.58	5%

Table 7. Fill factor for clear sky by tracking mechanism

S.no	Time	Pidel (Voc× Ios)	FF(%)
1	10:00AM	4.23	12%
2	11:00AM	10.68	30%
3	12:00 PM	1.15	26%
4	01:00 PM	12.51	37%
5	02:00 PM	10.08	20%
6	03:00 PM	1.71	18%
7	04:00 PM	1.99	17%
8	05:00 PM	1.56	14%

Table 8. Fill factor for clear sky by non-tracking

S.no	Time	Pidel (Voc× Ios)	FF(%)
1	10:00AM	2.09	**6%**
2	11:00AM	4.33	**13%**
3	12:00 PM	9.12	**26%**
4	01:00 PM	6.65	**20%**
5	02:00 PM	5.89	**18%**
6	03:00 PM	4.81	**13%**
7	04:00 PM	3.27	**11%**
8	**05:00 PM**	**2.70**	**9%**

3.3Comparison of fill factor in different weather condition by (Tracking and Non-tracking) mechanism.

Table 9. Comparison of fill factor in clear sky by tracking and non-tracking

S. no.	FF(%) (non-tracking mechanism)	FF(%) (tracking mechanism)
1	6%	12%
2	13%	30%
3	26%	26%
4	24%	37%
5	18%	20%
6	14%	18%
7	11%	17%
8	9%	14%

Table 10. Comparison of fill factor in cloudy sky by tracking and non-tracking mechanism

S. no.	FF(%) (non-tracking mechanism)	FF(%) (tracking mechanism)
1	16%	9%
2	7%	11%
3	16%	13%
4	24%	20%
5	6%	25%
6	8%	24%
7	9%	4%
8	5%	5%

3.4 Graphical representation of comparison of fill factor for clear sky and cloudy sky (tracking mechanism) and clear sky and cloudy sky (non-tracking mechanism)

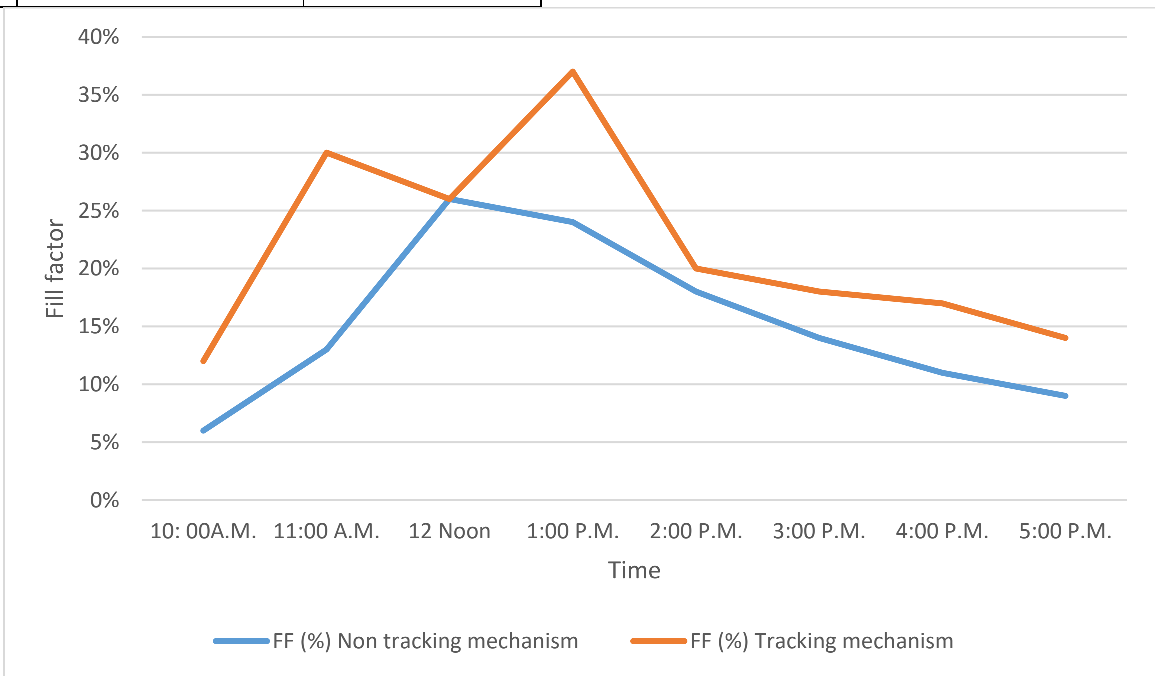

Fig.1. Comparative graph of fill factor in the clear sky by tracking and non-tracking mechanism

The values of fill factor is always high in clear sky by tracking mechanism where as the values of fill factor is always less in cloudy sky by non tracking for every interval of time. This is due to the fact that tracking the solar radiation will automatically increases the voltage and circuit generated by the solar panel

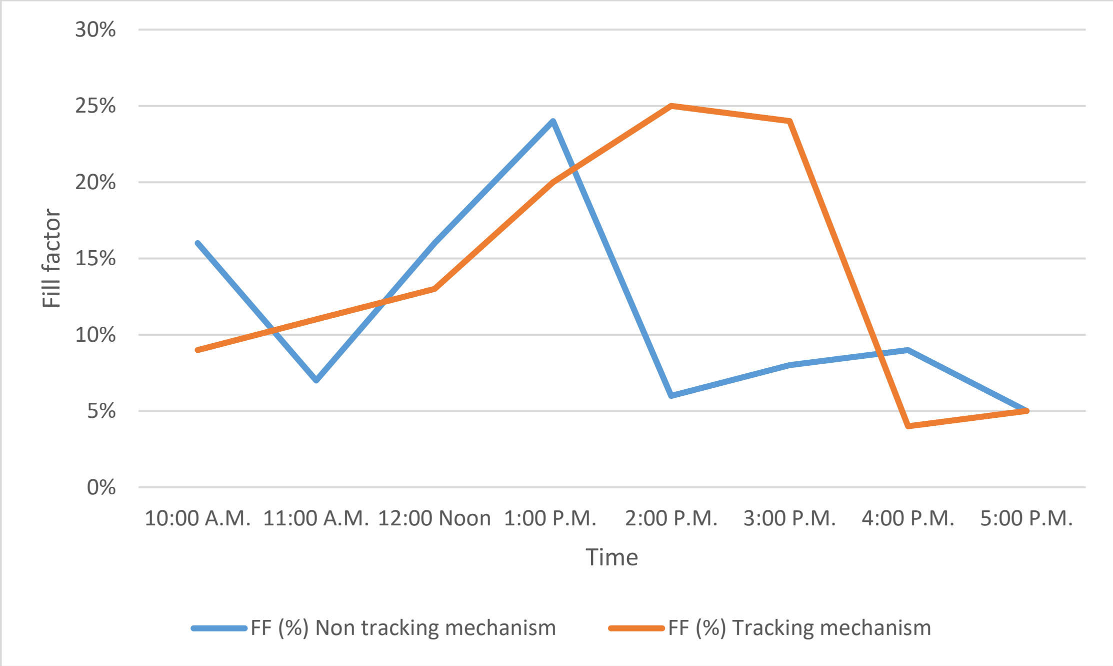

Fig. 2 Comparative graph of fill factor in partially cloudy sky by tracking and Non-tracking mechanism

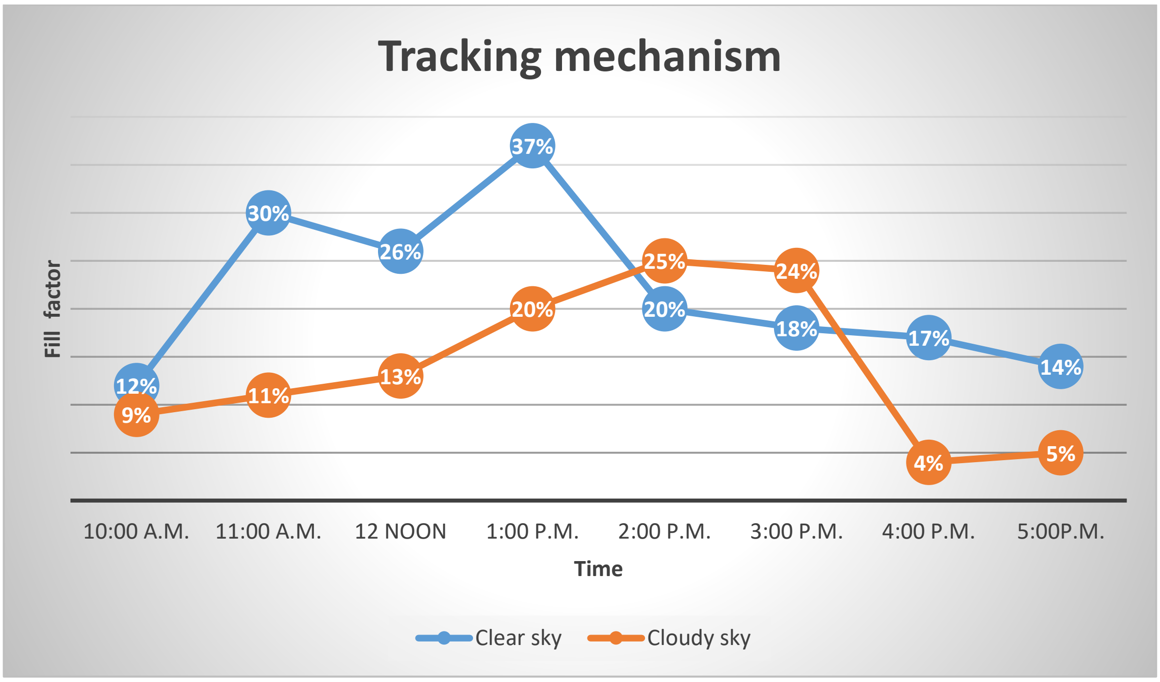

Fig.3 Comparative graph of fill factor in the clear sky and cloudy sky by tracking mechanism

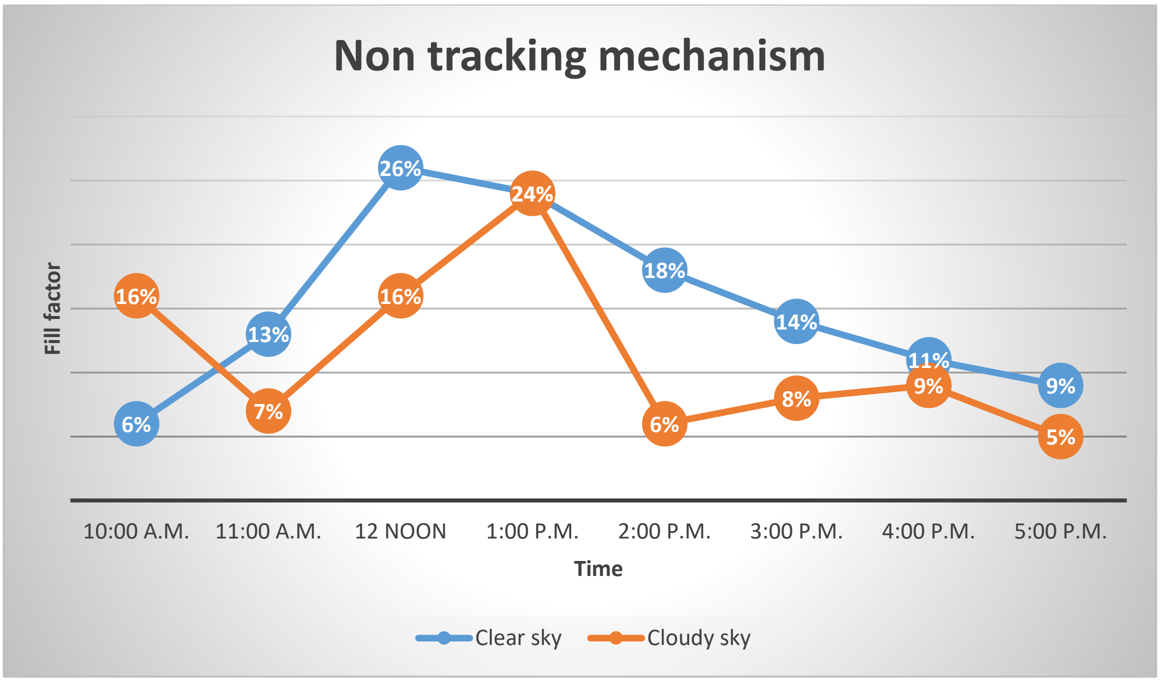

Fig.4 Comparative graph of fill factor in the clear sky and cloudy sky by Non tracking mechanism

IV. CONCLUSIONS

Fill factor has been calculated by observing different voltage and current in different weather condition on the basis of observation tables and graphical representation, this can be concluded that fill factor of clear sky weather is more in tracking condition, in compare to non-tracking condition. This simply means that energy conversion in tracking mode is higher than non-tracking mode. In case of partially cloudy sky, the fill factor has some randomness, that can be seen in table no.4 this is because there is variation in the amount of clouds and density of the clouds too.The maximum amount of voltage and current observed was 19.86V and current 0.63A respectively (Table 3) which was in clear sky weather (tracking mechanism)

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