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Comparison of Tracking Algorithms Employed in Solar Harvesting Systems

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Abstract: Objectives: Intelligent solar energy harvesting systems employ controllers and sensor arrays to track the sun, in conjunction with power converters to output steady, usable power. This paper aims to provide a comparative study between key existing algorithms, as well as provide a potential alternative to some of them . Methods/Analysis : Multiple existing algorithms for this control scheme were all executed on a custom dual-axes servo driver solar tracker, feeding a boost converter, under controlled and identical conditions. Findings: With inferences drawn by comparing the transient parameters of their respective response curves, conclusions could be drawn as to where the tested algorithm was optimally suited to. The algorithms compared where incremental conductance method, array sorting method and constant voltage tracking method, all executed at the same location under comparable lighting conditions. Novelty/ Improvement: The information garnered can influence cost effective strategies in purchase of solar powered intelligent systems.

Keywords: Solar; Renewable; Tracker; MPPT; Algorithm; Microcontroller; CVT;INC; Control

1. INTRODUCTION

Solar energy harvesting systems, specifically photovoltaic systems have existed for over a hundred years. It is only in recent times that significant advancement towards their efficiency, cost and size has transpired, leading to its strong viability as a renewable, alternative source of energy. In a developing country like India, where power distribution and reliability is often questionable, having a decentralized, stable source of power to independently energize local systems is an invaluable commodity. Further, with the topography of the land, and annual weather conditions (approximately 300 clear, sunny days per year), the estimated solar potential of the country ranges above 700 GW of nominal power.

Only an estimated 2 percent of this is actually being harnessed, with initiatives to increase this capacity only now beginning to take shape. It is thereby vital that during this surge in solar power generation, that the PV panels themselves be optimized and imbued with a certain degree of intelligence. Smarter, optimized generating systems capable of dynamically reacting to varying loads with minimal loss and error would be indispensable, especially when the source is as fickle as the sun. The standard way of optimizing an existing solar panel is to mount it on a solar tracking device, which would follow the

suns travel path throughout the day along the principal meridian, thereby ensuring that the maximum panel surface is exposed to incident radiation. In addition, power converters are a staple requirement in PV generation due to the unavoidably transient nature of the output. Boost and buck-boost converters are a main-stay in most solar generating systems to maintain a steady, usable output. Together, this converter can enable the system to perform MPPT, or Maximum Power Point Tracking, through use of one of the several MPPT algorithms. These algorithms can be separated into static panel tracking algorithms and dynamic panel tracking algorithms. The foremost of each are Incremental Conductance method (INC) and Constant Voltage tracking method (CVT). Past publications have highlighted the favorable response curve of INC method, with regard to its high response time and low overshoot. This paper aims to provide a comparative study based on an analysis of transient parameters of these algorithms, in addition to a proposed alternative algorithm in order to conclude the relative strengths and weaknesses of each, as well as to conclude where the algorithm could most optimally be used. This will be done by executing and evaluating each algorithm under controlled, similar conditions, on a custom built dual-axes servo-driven solar tracking device with an attached test panel. The output would be fed through a designed boost converter and evaluated graphically.

HISTORY

A. Panel tracking systems history

A solar tracker is a device that orients a payload toward the Sun. Payloads are usually solar panels, parabolic troughs, Fresnel reflectors, mirrors or lenses. For flat-panel photovoltaic systems, trackers are used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel. This increases the amount of energy produced from a fixed amount of installed power generating capacity.
Trackers have been employed in almost 90% of all commercial installations that generate output greater than one megawatt from 2009 to 2012. Tracking systems also

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find prevalence in all concentrated solar power (CSP) applications, as it is imperative that these systems be pointed at the Sun to produce energy. The same applies to concentrator photovoltaic (CPV) technology as well. Though mechanical tracking systems for traditional applications are slowly being phased out in favour of larger, more efficient static panel arrays, there is a large scope for mechanical tracking systems to increase the generated output of existing static panels that suffer from space restrictions, dynamic lighting conditions and high output requirement.

B. MPPT algorithms history

Maximum power point tracking (MPPT) is a technique employed primarily in wind and solar power generation in order to maximize the attainable output given transient environmental conditions. Pertaining to the subject of this paper, a solar harvesting system is not in control of the quantity of incident light that it will receive throughout its active-cycle. The power available is therefore inherently variable. Solar irradiance and temperature vary throughout the day contributing to non-linearity of the system, and obstructions such as clouds can severely impact the generation of panel-based systems. Further, it is vital to ensure the maximum power is delivered from the panel, regardless of the ultimate destination. The efficiency of the system must be optimized, relative to the alterations in the load characteristic to ensure that the power transfer is at the highest efficiency. Attaining this point or the "maximum power point" is the process known as MPPT. It is the purpose of the MPPT system to sample the output of the PV cells and make suitable adjustments to obtain the maximum result. These systems are primarily utilized in electric power converter systems, voltage/current conversions, filters, regulators and drives, all within power grids, batteries or motors.

II. MPPT ALGORITHMS

There are numerous types of MPPT algorithms available but in this paper mainly three are discussed based on their different nature. These algorithms are chosen based on nature of application.

A. Modified INC

This is one of fastest algorithm used for MPPT. In this paper, prototype uses two degree of motion and a boost converter. Flowchart of this algorithm is given in Fig. 1

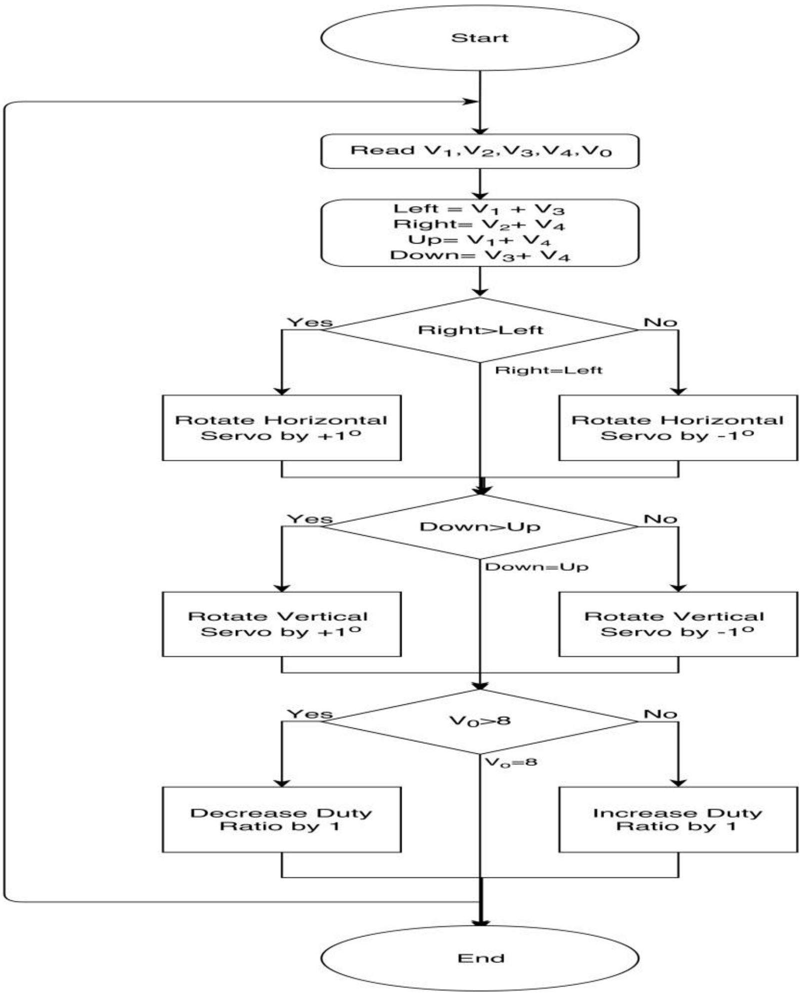

Figure 1 Flowchart of Modified INC algorithm.

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B. Array Sorting

In this paper Array sorting algorithm uses one degree of motion only for altitude angle. Flowchart is shown in Fig. 2

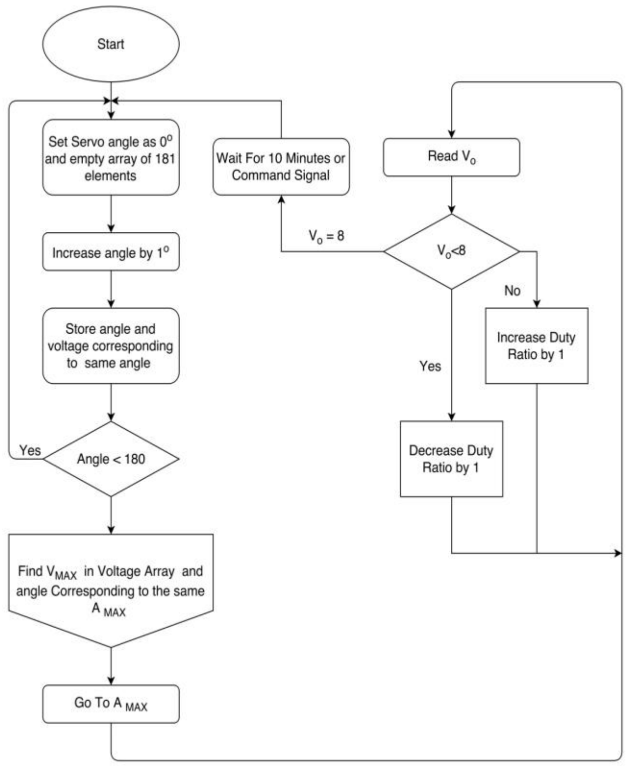

Figure 2. Flowchart of Array Sorting Algorithm

C. CVT

In this paper CVT doesn't need any actuators at all. Output of solar panel is directly given to Boost Converter without any Panel Motion. Flowchart in Fig. 3.

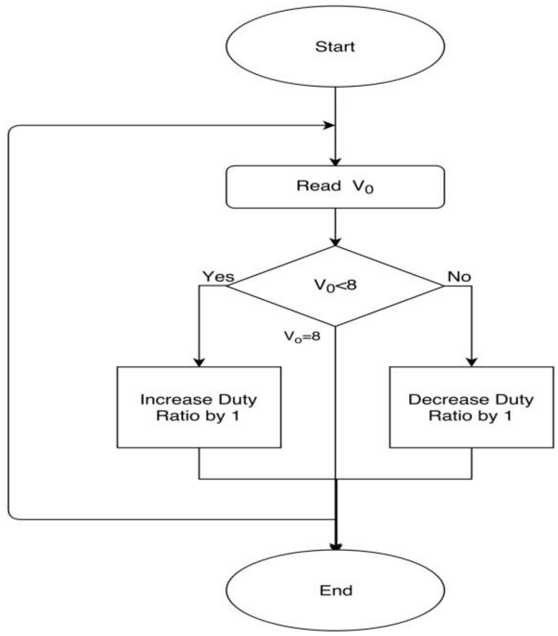

Figure 3. Flowchart of CVT algorithm.

III. SIMULATIONS

Simulation is done in MATLAB/SIMULINK for comparing the characteristics of output of solar panel without and with boost converter, which is duty ratio controlled. In Simulink model output of solar panel is given to the boost converter. There is a provision provided in SIMULINK to vary Irradiance and Temperature.

A. Simulation with constant Irradiance and Temperature

First simulation is done with a constant Irradiance of 1000W/m^2 and a constant temperature of 25 degree Celsius.

B. Simulation with Variable Irradiance and Temperature

Second part of simulation contains same model with different physical operating conditions. In this Model there is variation in Irradiance from 200 to 1000 W/m^2 and Temperature varies from 25 to 26 degree Celsius.

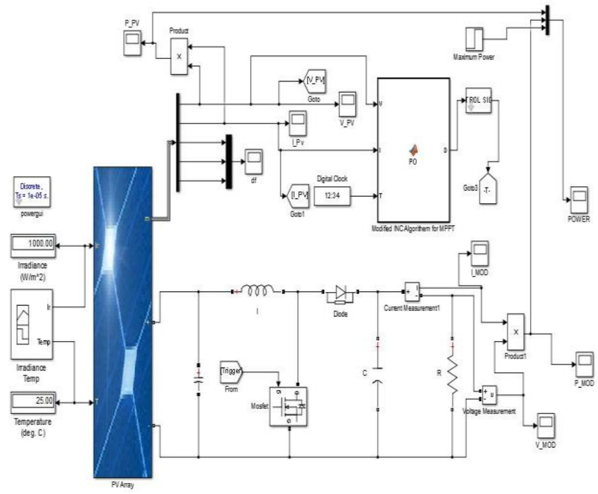

Figure 4. Simulation Model in SIMULINK

11. MATERIALS AND METHODS

A hardware prototype was constructed upon positive confirmation from the simulation. The prototype made is shown in fig 5. All the algorithms discussed are executed on this prototype. The body of the prototype is comprised primarily of acrylic sheet material. This material underwent numerous physical alterations such as cutting, bending, drilling and sanding until the appropriate shape was achieved. The moving section of the prototype relies on the structural stability and mechanical strength of this material. Several scrap pieces of acrylic sheet were also used to precisely position the upper servo motor to receive the shaft through the parallel columns. The base of the prototype consists of a layer of laminated sheet, that was cut by a precision laser cutting tool in order to accommodate the 10 kg Servo motor through it. This layer is mounted onto a 5cm thick thermocaul base to elevate the platform. Thermocaul was chosen for easy modification, allowing a hole for the motor to be excavated with relative ease.

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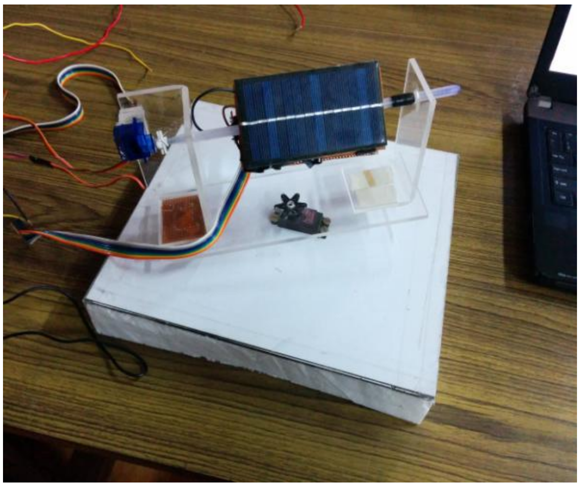

Figure 5 Hardware Prototype

The setup is mechanically driven by two servo-motors. They are of the following specification- Vertical Servo: Mounted on the L-column, this motor is responsible for vertical movements of the panel, and it achieves this by rotating a shaft directly connected to it. Horizontal Servo: Rotates the base of the acrylic section, and is mounted within the prototype base. Servo motors were chosen over traditional DC motors because a closed loop control could be achieved without the requirement of external rotary encoders or gyro-accelerometer pairs. Servo motors also have an extensive in-built library within the Arduino IDE, making them the ideal actuator candidate.

The axle or main shaft employed is a re-appropriated plastic pen casing, hollowed out and warped to required dimension. A screw imbedded deep within one end ensured that the shaft can be tightly attached to the servo shaft.Two large erasers, attached to each other by a strong adhesive, where modified to encircle the shaft, allowing a planar area upon which the varo-board and panels could later be mounted.Two varo-boards were added to the planar eraser surfaces, bound in place by threaded wire. The test-panel and the LDR sensor array are mounted on these boards. The boards were chosen for weight-restrictions, flexibility and availability criteria.

Black tape was used liberally to improve mechanical strength of structural weaknesses, and to also form a make-shift rivet on the far side of the main-shaft, to ensure minimal disconnection of the shaft from the upper motor.

Headers were soldered onto the varo-boards to enable accessible and secure connections of wires from the boost converter and Arduino to the moving shaft. Since the motor sweep only covers 180 degrees, there is no allowance made for wire tangling around either shaft. However, wires were chosen at suitable length to prevent disconnection during operation.

111. RESULTS

Simulation Results:

In this part results obtained are discussed and compared as the paper demands. First Simulations Results are taken and later Hardware results are taken.

C. Simulation with constant Irradiance and Temperature

First discussing simulation Results with constant physical parameters.

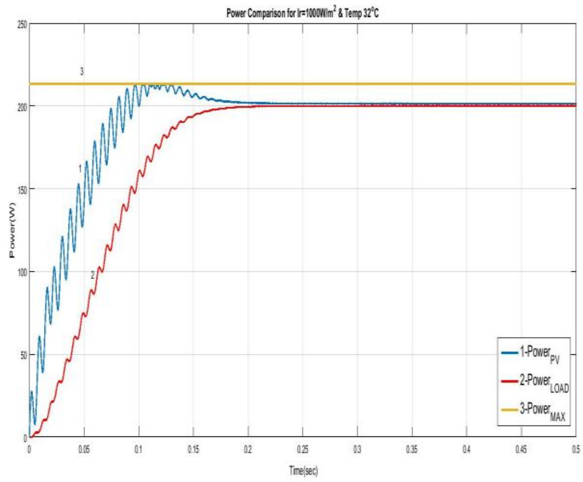

Figure. 6 Simulation Results for Case IV A

In fig 6 it is clear that Boost Converter output caries less transients as compared to direct solar panel output and it settles faster, giving a stable output voltage due to application of boost converter.

D. Simulation with constant Irradiance and Temperature

For Irradiance and temperature variation in fig 7 output comparison comes to be as shown in fig. 8

In this case there are even more transients due to sudden changes in Irradiance Level which is extreme case in Practical life but still proposed system is capable of handling and suppressing the transients leading the system to stability

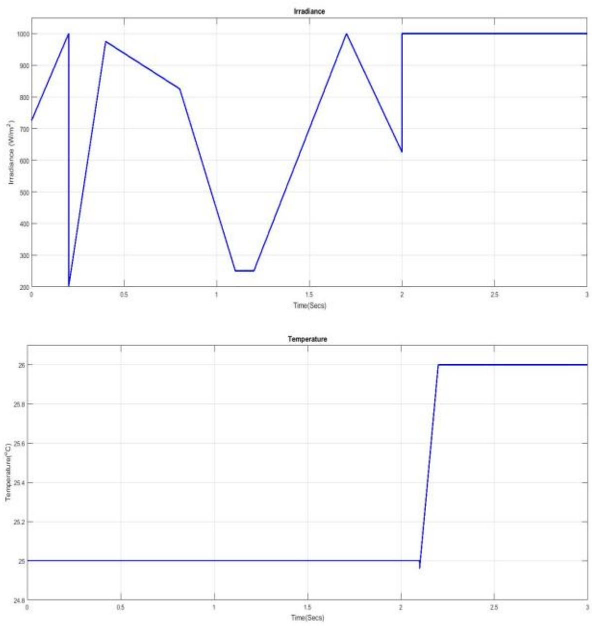

Figure 6 Irradiance and Temperature variation.

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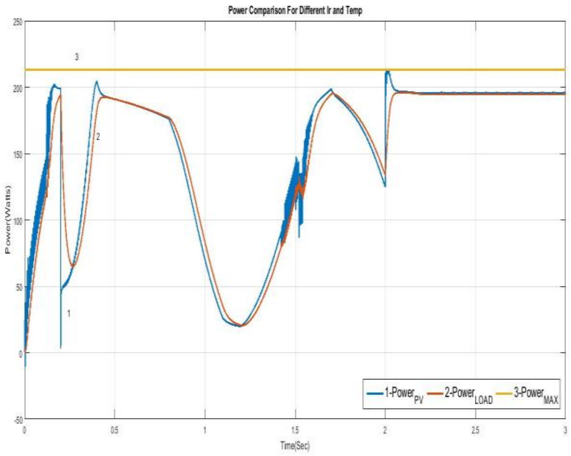

Figure 7. Output Corresponding to Case IV B

HARDWARE RESULTS

Hardware results shown are taken on a single stand alone system and all the results from different algorithms are compared.

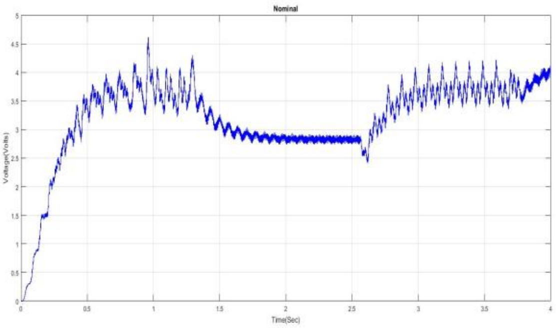

Figure 8 Direct Panel Output

D. Direct Panel Output

In fig 8 output of solar panel is taken without any other peripherals. As expected there are very high transients in output and there is particular set voltage.

E. CVT output

In fig 9 output of constant voltage tracking is shown. It can be observed from fig 9 that there are very high transients present in transients time but after 2.03 seconds output settles at 8 volts

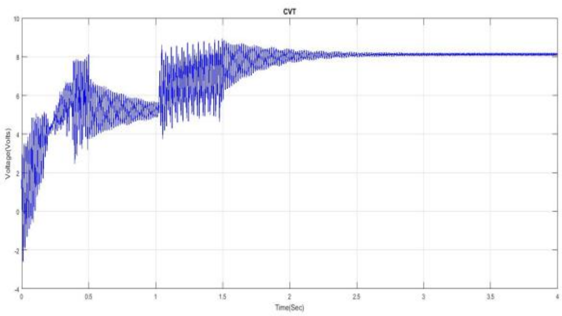

Figure 9 CVT Output

F. Array Sorting Algorithm Output

In fig 10 it is observed that output waveform has transients in rising period but are moderate in nature as compared to the final value and after a settling time of 1.57 seconds waveform settles down to 8 volts

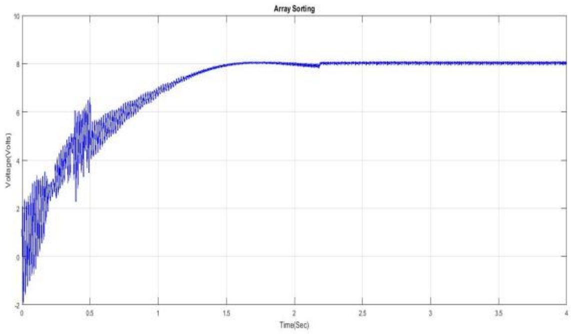

Figure 10. Array Sorting Algorithm Output

G. Modified INC algorithm Output

Here in Fig. 11 there are very low transients present in rising period with settling time of 1.26 seconds waveforms settles down to final value.

H. Comparison of all four cases

In Fig 12 a comparison of all four cases discussed in Parts A to D of this chapter are taken together and compared. Among all the algorithms Modified INC came out to be best for any system with least settling time and least transients during rise period. Array sorting is next best option with moderate transients and settling time. CVT comes last with highest transients and settling time.

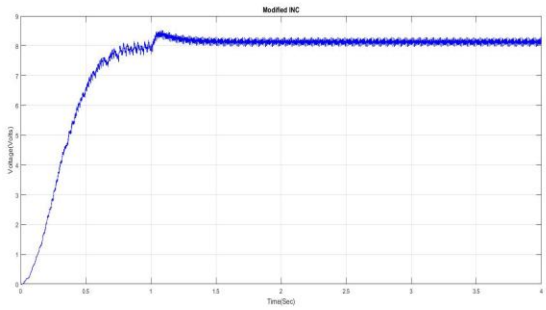

Figure 11 Modified INC algorithm Output

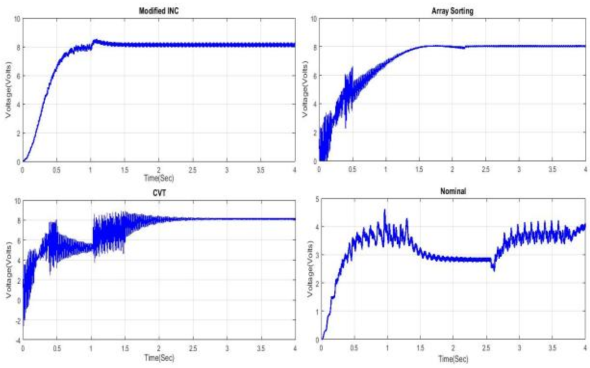

Figure 12 Comparison of Algorithm

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IV. PARTS

Parts required making a simple system are given in table 1.

SI No.	Name of the Part	Quantity
1.	Photodiodes	4
2.	Arduino UNO	1
3.	Solar Panel	1
4.	DC Servo Motor	2
5.	Resistors	4

Table 1 No. of Parts Required

V. DISCUSSION AND CONCLUSIONS

For experimental purposes, the constructed prototype is capable of measuring and recording altitude and azimuth angles, as well as received power at all angles for storage and future reference. The modified INC method (and by virtue of their similar control logic, the Perturb and Observe method) yielded the fastest response time among all tested algorithms, with low settling time and minimum transients and peaks during rise period. This method is highly suitable for highly dynamic conditions, such as panels atop vehicles or ships. The proposed algorithm, the “array sorting” algorithm was much slower than most standard dynamic tracking algorithms, however, since the acquired value was distinct, it allowed for extremely stable, accurate tracking between scanning intervals. Further improvement could be made to the scan cycle, by only including values within a certain threshold of the previously acquired maximum to speed up response time between scans. A cross-reference system could also be implemented to compare archived positional data with current data to serve as a diagnostic check for any discrepancies in the event of equipment failure .While the CVT algorithm exhibited highest transients and slow response time, it proves that MPPT tracking through just the employed power converter (boost converter) is still appreciably higher than a nominal panel. The graphical information garnered can be used to for cost-effect evaluation when considering the purchase of multiple panels or upgrading existing panels with a MPPT algorithm controlled power converter system. This can further be improved by utilizing higher order power converters such as Cuk converter.

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