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Dynamic Monitoring and Analysis of Dual-Axis movement of SPV Power Plant Parameters under various Atmospheric Conditions

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ABSTRACT- This research paper presents comprehensive insight into the testing of a 1 KW sun tracking photovoltaic (PV) performance. The study uses a state-of-the-art real-time string monitoring system to allow this analysis while covering an extensive variety of atmospheric conditions. The design of the 1 KW solar tracker system incorporates a tracking sensor circuit, motor driver circuit, string monitoring system, and solar tracker control circuit. Solar tracking systems boost energy generation by adjusting the angle of PV panels to optimum sunlight exposure. The effectiveness of such devices can, however, be severely impacted by atmospheric changes. In a photovoltaic (PV) facility, we have successfully developed and placed into use a real-time system for monitoring certain strings. The system collected data on key parameters such as current, voltage, and temperature, providing insights into the health and efficiency of each string. Our study encompassed various atmospheric conditions, including clear skies, cloudy days, and fluctuating solar radiation. A DAQ system developed communicate with observations such as the voltage and current of photovoltaic arrays and the voltage and current of DC motors. When comparing the dual-axis tracking system to the static PV system, a maximum of 48% more electricity can be extracted. Both days with clear skies and days with clouds provide satisfactory results. The supply for the tracker control circuit comes from PV cells. Therefore, there is no need for any auxiliary supply, such as a battery.

Keywords: DAQ, DAST, PV, LDR, DAS, SPV.

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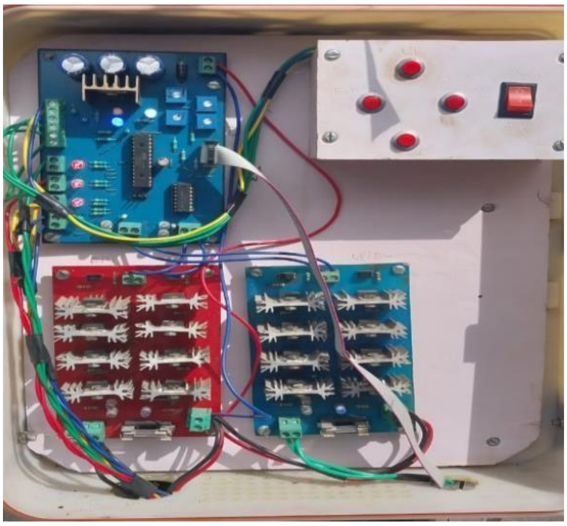
1. INTRODUCTION

This paper offers a comprehensive overview of the intricate process involved in designing and implementing the electrical circuits that form an integral part of both the dual-axis sun tracker (DAST) and the string monitoring systems. The dual-axis sun tracker circuitry is a complex assembly encompassing several key components, such as a dedicated 5V power supply circuit that serves the control system, a circuit housing Light Dependent Resistor (LDR)- based sensors, and an adept H-bridge motor driving circuit. Data Acquisition (DAQ) circuit, meticulously devised to facilitate the seamless transmission of vital measurements. These encompass a spectrum of essential parameters, including the photovoltaic (PV) array's voltage, current, as well as critical readings derived from the DC motor [1]. A dual-axis tracking system's DAQ (Data Acquisition) circuit is essential for gathering and processing sensor data, which allows for accurate control of the system's movements. Sensors which track factors like temperature, position angles, and sunlight intensity can communicate with this circuit. These sensors' analogue signals are transformed into digital data by the DAQ circuit so that they can be processed for tracking control by a microcontroller or computer [2].

2. ELECTRICAL SYSTEM

The dual-axis sun tracking photovoltaic (PV) system amalgamates mechanical and electrical subsystems shown in *figure 1*. This system encompasses key components such as PV cells, an LDR sensor circuit, a power supply to facilitate the operation of tracker control mechanisms, and a dedicated string monitoring circuit. The LDR sensors control mechanisms, and a dedicated string monitoring circuit. The LDR sensors detect variations in sunlight intensity and relay the signal to a comparator. This comparator subsequently directs the motor driving circuit to initiate the rotation of the PV panel. The solar panels used in this work are capable of generating 335W power each. The specifications of a panel provided by vender at standard test conditions (100 mW/Cm^2. at air mass 1.5 and at 25 ^{0}C cell temperature) are present in *table 1*.

(a) Complete Assembly



(b) Electrical Subsystem

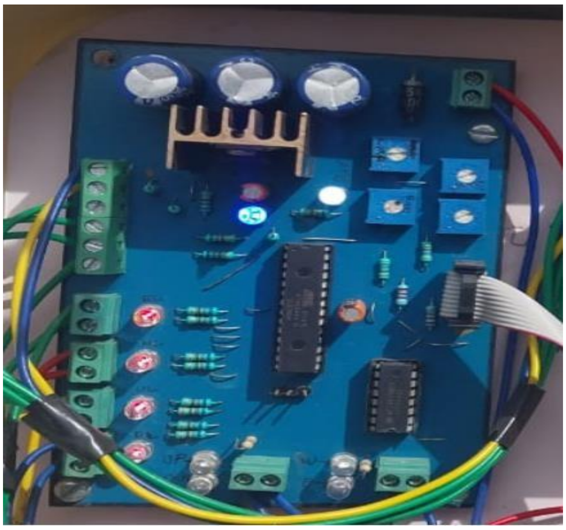
Figure 1: Sun tracking system (335x3 watt)

Table 1: Specifications of 335Wp Solar Photovoltaic Modules

Type	UTL 335W PV module
Rated power	335W
Open circuit voltage (Voc)	45V
Short circuit current (Isc)	9.10A
Voltage at maximum power (Vmpp)	37.03V
Current at maximum power (Impp)	8.79A
Total number of cells	72
The electrical properties deviate no more than +/-3% from the specified values under Standard Test Conditions (1000W/m^2, 25°C, AM 1.5).	

3. SOLAR TRACKER CONTROL CIRCUIT FOR DAST

The control circuit for the sun tracking system holds significant importance as it enables the operation of dual-axis tracking. In this designed circuit, a pair of LDR sensors is employed to facilitate the rotation of the DC motor for East-West movement, while another set of two LDR sensors facilitates the tracker's motion from West to East. The positioning of the LDR sensors is visually represented in *figure 2*.



(a) Fabricated Control Circuit

(b) Visual Representation of LDR Sensors

Figure 2: Fabricated control circuit & Visually representation of LDR sensors

The motor driving signal output circuit in a dual-axis solar tracker circuit is responsible for generating the appropriate control signals that drive the DC motors responsible for adjusting the solar panel's orientation. The microcontroller (such as ATmega8) generates digital output signals based on calculations from the sun tracking algorithm. These signals determine the required direction, speed, and duration of motor movement to achieve accurate solar panel positioning. Solar tracker circuit has been shown in *figure 3*.

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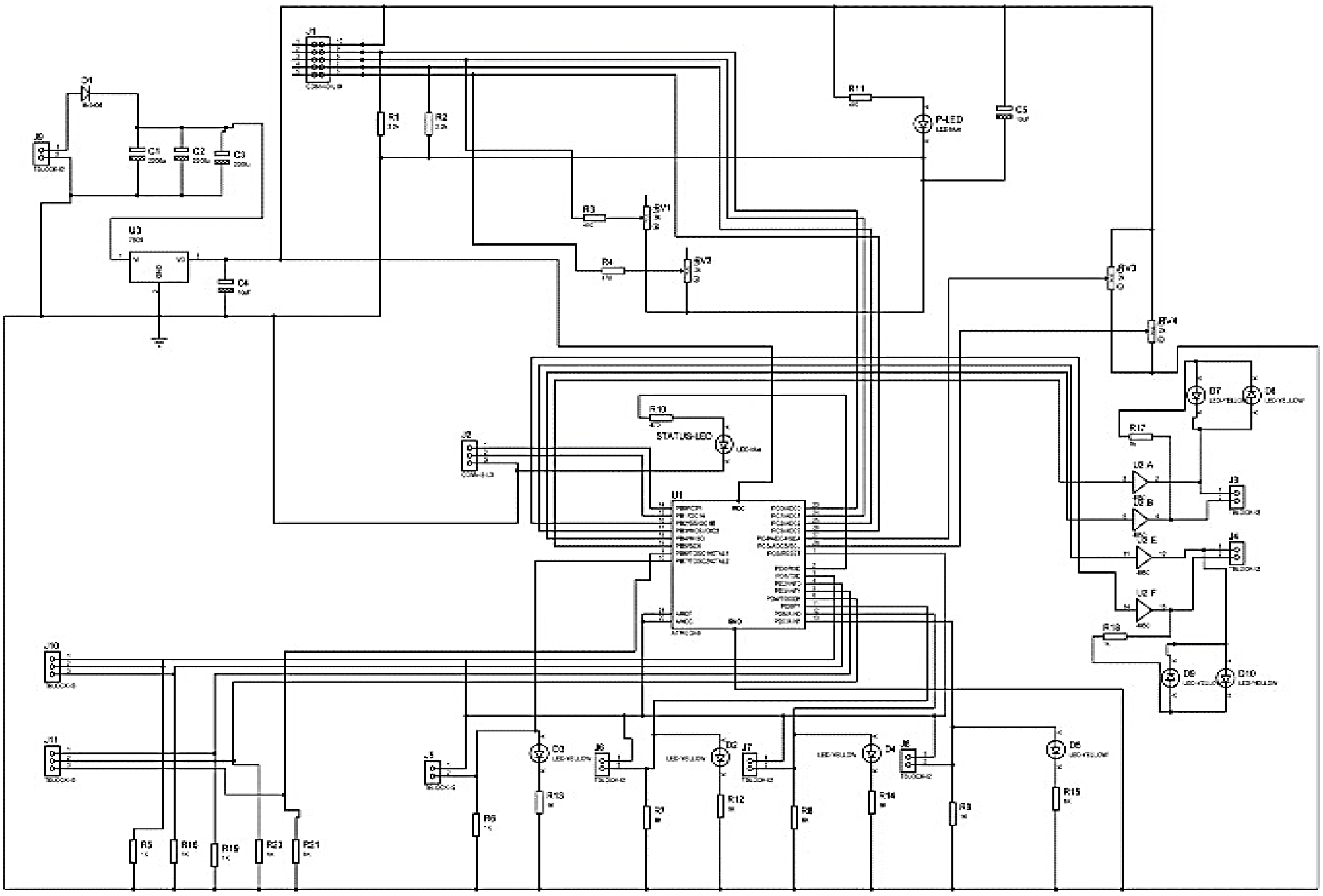

Figure 3: Solar Tracker Control Circuit for Dual Axis

4. MOTOR DRIVER CIRCUIT FOR DAST

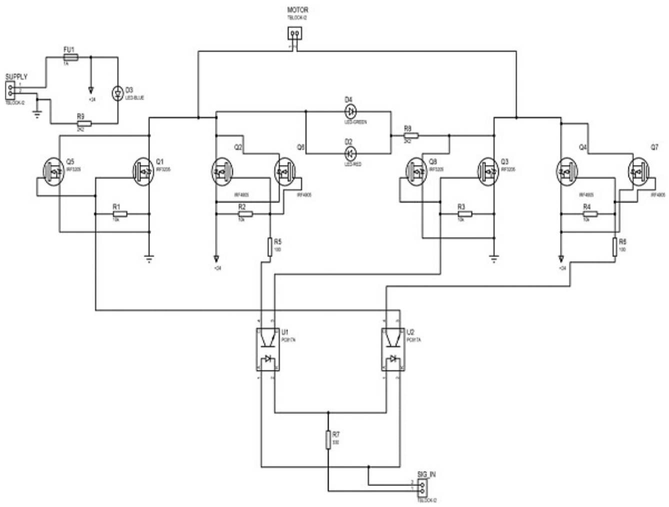

Figure 4: Circuit Diagram of Dual Axis Solar Circuit Tracking Motor Driver Circuit

In a DAST system, the motor driver circuit holds a pivotal role in controlling the movement of the solar panels as they track the sun's position in both the azimuthal and elevation directions. The motor driver circuit is responsible for supplying the appropriate power and signals to the motors that control the movement of the panels. *Figure 4* has been shown the motor driver circuit for DAST [3-4].

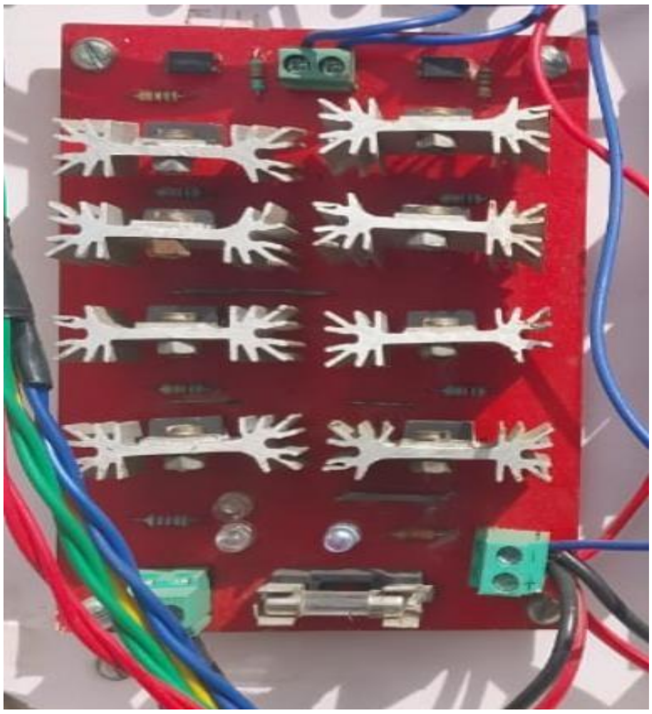

Figure 5: Fabricated motor driver

5. STRING MONITORING SYSTEM FOR DUAL AXIS SOLAR TRACKER

String monitoring in Solar PV systems are divided into two main levels: 1. SPV Plant level. 2. Base station Monitoring Level. Monitoring at plant level includes a Data Acquisition System (DAS). Supervisory monitoring of string voltage and current comes under Base Station Monitoring level. In the Plant level data acquisition system gathers data from DC link, weather sensors (temperature and insolation) and provides the same to PC based monitoring for operational purposes [9]. Plant level monitoring is responsible for reporting voltage and current values of each string. The String monitoring includes Performance ratio and Efficiency. In the proposed system, DAQ is used for plant level monitoring.

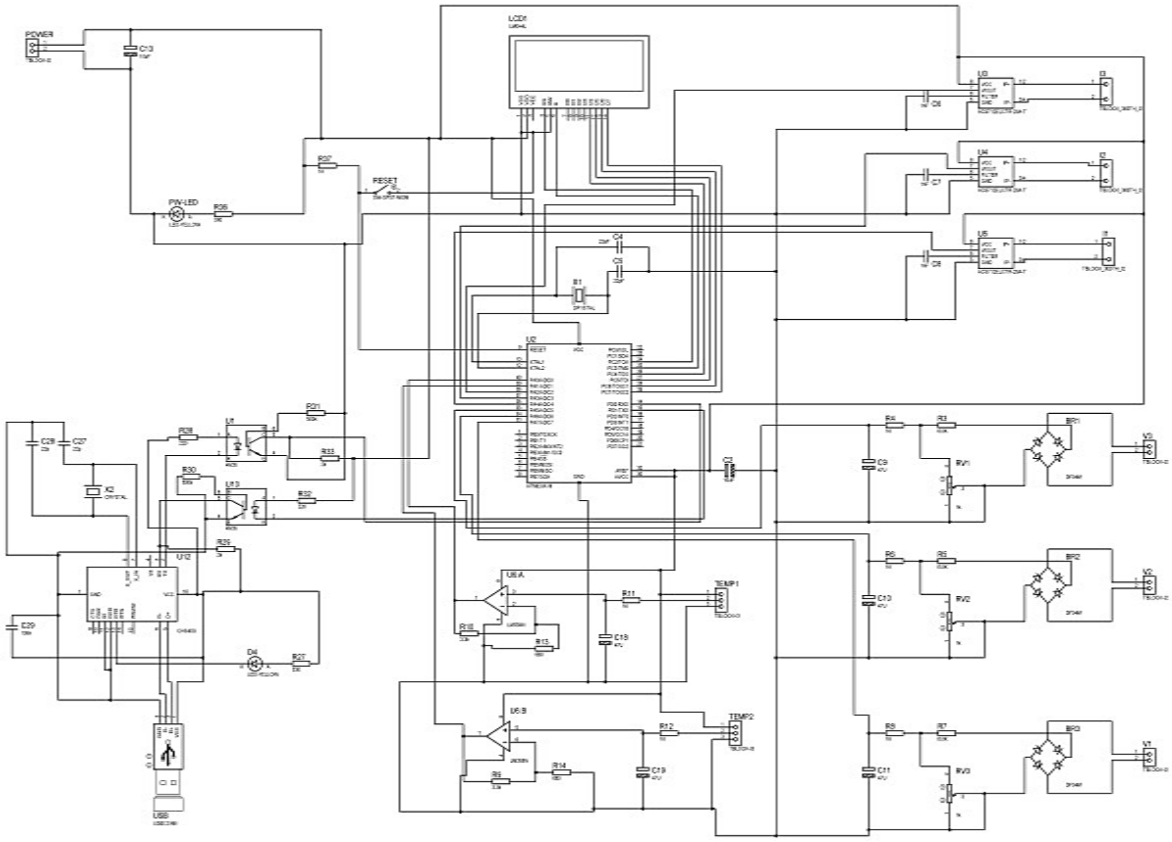

Figure 6: Circuit Diagram for Dual axis solar tracking String Monitoring system

In DAST Data Acquisition (DAQ) system or string monitoring system, the ATmega32 microcontroller is a central processing unit for controlling, monitoring, and processing data from the solar tracking system. XTAL1 and XTAL2 pins are used to connect an external crystal oscillator for generating the microcontroller's clock signal. The ACS712 Hall-effect current sensor circuit plays an important role in a Dual Axis Solar Tracking Data Acquisition (DAQ) system by accurately sensing and measuring the current flowing through various components, such as solar panels & motors [6]. It is comprising of three hall effect sensors. First hall effect current sensor is used for measuring the PV string current, second for current measurement of X- motor for East-west movement, and the third sensor for measurement of current taken by the Y-motor during elevated rotation. Fabricated Circuit Diagram for Dual axis solar tracking String Monitoring system has been shown in the *figure 7*. The DF04M DC voltage rectifier is a fundamental component in a Solar Tracker DAQ circuit [10]. Its role in converting solar panel-generated AC voltage to stable DC voltage enhances the accuracy, compatibility, and reliability of the voltage data captured by the DAQ system, enabling effective monitoring and analysis of solar panel efficiency.

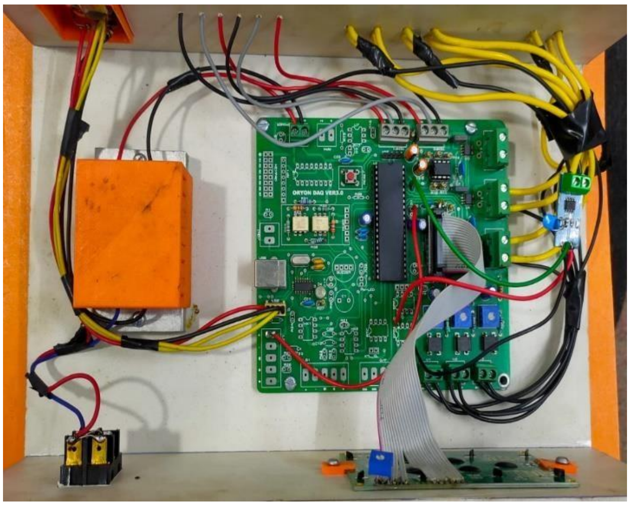

Figure 7: Fabricated Circuit of DAST String Monitoring system

6. TRACKING SENSOR CIRCUIT FOR DUAL AXIS SOLAR TRACKER

A tracking sensor circuit in a DAST is a crucial component that helps determine the optimal position of the solar panels based on the sun's position. This circuit uses various sensors to collect data about the sun's direction and intensity, enabling precise adjustment of the solar panels to maximize energy capture. Photovoltaic (PV) cells or light-dependent resistors (LDRs) are commonly used to measure light intensity [11]. These sensors detect the sun's position by sensing the direction of the highest light intensity. Circuit diagram is shown in the *figure 8*.

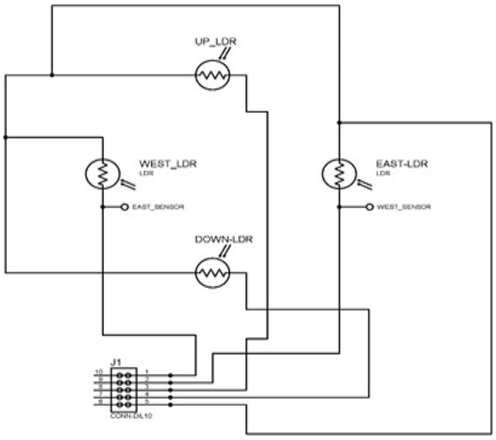

Figure 8: Tracking sensor circuit

Figure 9: Fabrication of Tracking sensor circuit

Figure 10: Hardware Set up of Data Acquisition (DAQ) or String Monitoring System with a 200- watt load

7. DC-MOTOR SYSTEM

The sun changes its position throughout the day, whole year. To track the exact position of the sun, a solar tracking system require two degrees of freedom. Therefore, in solar tracking system, two DC motors and gear system are used. Geared DC motors are preferred because of their low speed and high starting torque [12]. The first DC motor is used for azimuthal rotation and second on is used for elevated rotation as shown in *figure 11*. The shaft of DC motors is connected to warm gear transmission system. These DC motors are mounted in a tangential position of the circular gear as shown in *figure 11*. In this experimental analysis, we integrated two motors: the first one controlled motion along the X-axis with a robust power output of 90 watts, while the second one was assigned to maneuver the Y-axis and featured a power capacity of 60 watts.

(a) Motor X

(b) Motor Y

Figure 11:1KW Tracker System utilizes two 12V DC motors within its dual-axis tracking mechanism

8. PERFORMANCE ANALYSIS OF DUAL AXIS TRACKING SYSTEM ON CLEAR SKY DAY, UNDER CLOUDY DAY & PARTIALLY CLOUDY CONDITIONS

8.1 Clear Sky Day

The data collection was done via designed string monitoring circuit shown in *figure 10*. The DAQ system was connected with CPU via USB. The data collection was done via designed string monitoring circuit. The experiment was performed in a clear sky day on date 15-7-2023. For this experiment 180-watt DC bulb load was connected to each PV system. The variation in powers of dual axis PV tracker and static PV system are shown in *figure 12*. It can be seen that the power produced by both PV system is almost same between the time intervals 10.20 a.m. to 1.00 p.m. It was observed that dual axis tracking PV system produced 47% more power compare to static PV system on given day.

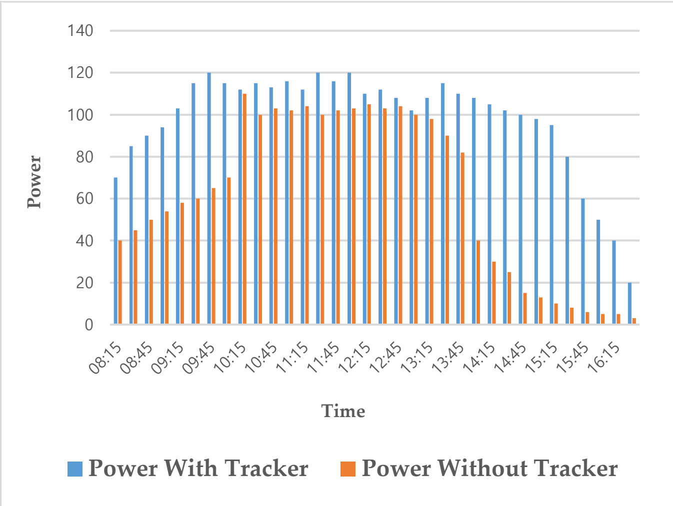

Figure 12: Fluctuation in power produced by PV systems on date 15-07-2023

8.2 Under Cloudy Day

The efficiency of dual axis tracking system under the cloudy atmoshpheric situation was observed on given date 22-07-2023. The data was collected via DAQ circuit. The power generated by DAST PV system is shown in blue color and the variation in power generated by static PV system shown in green color. Effect of clouds is clearly visible in *figure 13* from 1.00 p.m. onwards. It has been observed that the efficiency of SPV system with dual axis sun tracker is 23% more as compared to static PV system's efficiency on this day.

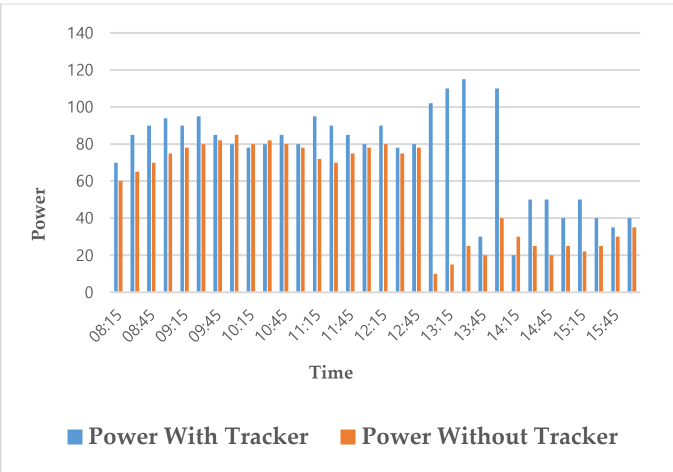

Figure 13: Fluctuation in power produced by both PV systems under cloudy day

8.3 Partial Cloudy Day

Figure 14 shows the variations in power of tracking PV system and static PV system under partial cloudy day till 1:00 pm after that sky becomes clear. The data collection was done from 9:00 a.m. to 3:30 p.m. The increase in efficiency of SPV system due to tracking has been observed to be 36% more as compared to fixed SPV system.

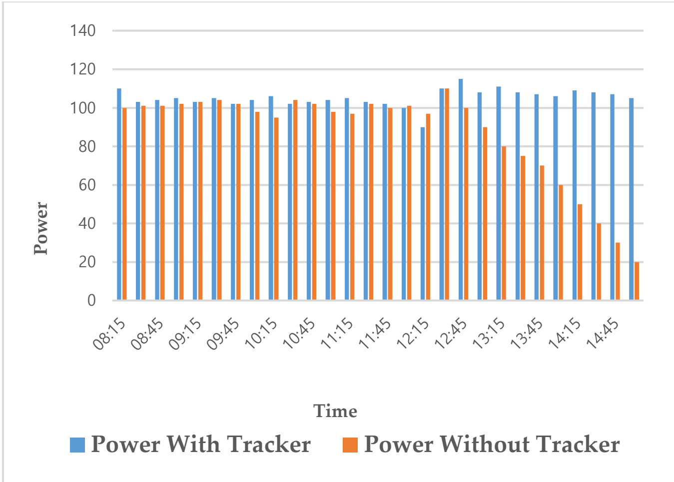

Figure 14: Fluctuation in power in both PV systems under cloudy to clear sky day

9. CONCLUSION

The tracking system and designed circuits provide satisfactory results & all the circuits are cost effective. The efficiency and proper monitoring of the current solar photovoltaic power plant is increased as a result, and new implementation strategies must be developed. String monitoring is another important area for monitoring and fault diagnosis of thousands of panels installed in any large-scale solar PV power plant. According to the above findings, the dual axis tracking system can extract up to 45–48% more electricity than a static photovoltaic system. Both on days with clear skies and clouds, the findings continue too good. PV cells provide the electricity for the tracker control circuit. Consequently, no additional supply, such as a battery, is required.

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