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AN IMPLEMENTATION TECHNIQUE OF OPTIMIZED SOLAR POWER GENERATION USING TWO-DIMENSIONAL TRACKING SYSTEM BASED ON TAMIL CALENDAR

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Abstract
The availability of solar energy is abundant in India. Nook and corner of each and every village in our country get electricity by converting the solar power into electric power. The use of electricity is increasing day by day. Hence optimization in the production of electricity is always an interest to engineers A comparative study with other existing techniques involved in the solar power generation has been made and the findings shows that our method has slight improvement than other techniques. This two-dimensional tracking system rotates the solar panel in both directions every time positioning the panel towards sun for maximum flux reception. Two stepper motors are used to rotate the panel in east to west direction and a DC motor is rotating the panel in north - south direction based on the data taken from Tamil calendar for focussing the panel towards Sun throughout the year. In this experimental study A (12 V I , 0.5 amps solar panel is rotated, and the power delivered from the system is compared with other systems. It is clearly established that this two-dimensional tracking system which use no sensors has generated considerable amount of power with reduced cost. This solar power generation system can be incorporated in a domestic microgrid. In this paper, an implementation method of optimizing solar power generation technique is explained.

Key words : Two dimensional tracking, Tamil calendar, maximum flux, solar power generation

1. Introduction

The relation between the locations of sun towards earth, plays a very good role in the amount of electric power generation in a solar power generation system. The sun moves towards north for 6 months from the south, and when in crosses the earth equatorial plane, this time is called as epoch or a starting of time period, that time is considered for the starting date for any calendar year. Tamil calendar consider the date on which, the sun is crossing the Tamil land, as the first day of new year. An sample calendar day sheet giving sun rise and sun set is given in Figure 1. On that day sun will be very straight towards east in Tamil land. Figure 2 shows the movement of Sun with respect to the equatorial plane of earth

Solar power is available plenty in India due to its geographical location and is a natural power available for all the living creatures in the world. It is a renewable energy with no dust or pollution. it is necessary to enhance the usage of solar power generation in a large scale in India with better technologies which are harmless to living species. In this paper, the solar power generation is carried out to the optimum level by the use of Tamil calendar. Using two-dimensional tracking technique, the solar panel is rotated not only from east to west, but also rotated from in the horizontal direction from north to south and vice – versa for getting maximum solar flux all the time. This paper explains the implementation technique with block diagram, circuit diagram, components used in the circuit, connections, operation procedure, algorithm, data collected, etc. These real data are compared with other solar power generation methods and the its superior advantage. MATLAB simulation has been used for chart preparations which indicate the graph of solar electric power generation over the period of one day.

2. Related Works

Solar radiation reaches its maximum of 6.6 kilowatts per square meter in February month and minimum of 4.7 kilo Watts per square meter in a day in November month at Perunthurai town of Tamil Nadu state in India [1]. Tamil calendar is a solar calendar which can be used for optimizing solar power generation using a method for tracking sun for maximum power [2]. No sensor is used for tracking the movement of the sun [3]. For optimizing solar power generation, Overall distribution and Weighted Differential Evolution algorithms are used in combination.]4] .
Tracking system should move the panel to a position towards an angle in which maximum electrical output power is generated.[5].
Active algorithm and chronological algorithm are combined to produce a hybrid algorithm which will produce the maximum power at all time [6]. Generating maximum power at shadowing conditions is the purpose of the controller in a tracking system [7]. Particle swarm optimization algorithm must be restarted, whenever there is a change in the illumination on the panel for maximum output [8].

The Particle swarm optimization algorithm initializes a population and updates them using velocity and position equations for producing optimum power [9]. High efficiency solar panel reduces the heat loss during the generation electric power.[10].
Monte Carlo algorithm and Particle Swarm Optimization algorithm are combined to produce maximum power in solar power tower system [11]. The optimization software HOMER is used in the solar tracking system for optimizing power generation [12]. South facing passive type of solar trackers will rotate the panel from east to west. [13]. Electric power is generated using a thermochemical process through use of solar rays.[14]. A improvement has been proposed in the existing smart grid system. As the population is always increasing day by day, the number of houses, offices, schools, colleges, buildings, and industries are also increasing, because of this, the existing grid system can not address the required power requirements. So a new smart grid power system is necessary [15].

A model for smart grid has been proposed for energy storage at high power level. Power purchase is very normal in today's high electric power requirements. There is a need for changes in today's power transfer system from one grid to another grid. Scientists are trying to transform the conventional power distribution system into today's digital technology age.[16].

An implementation method of modern technique for smart micro grid has been proposed for improving the safety, efficiency and reliability. Smart micro grid uses wireless communication technology for transferring data between micro grid and the distribution grid. This method is very much economical and very fast in operation. The author has used PROTES simulator for implementing smart micro grid and has provided that the proposed system is low cost compared with existing systems. SMS method is used for data transfer between distribution grid operator and the utility operator. [17]

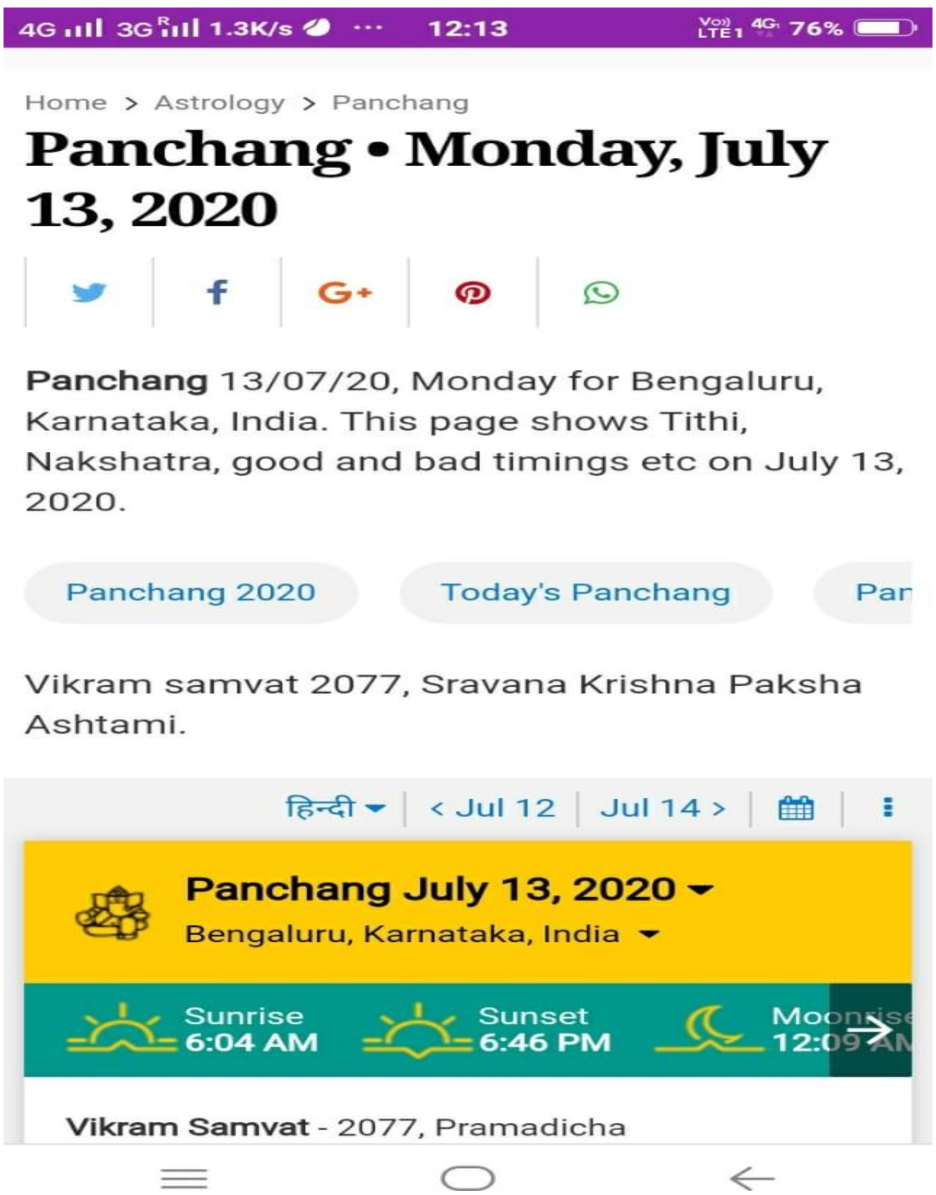

Figure 1. Calendar shows rising time and setting of Sun for a day

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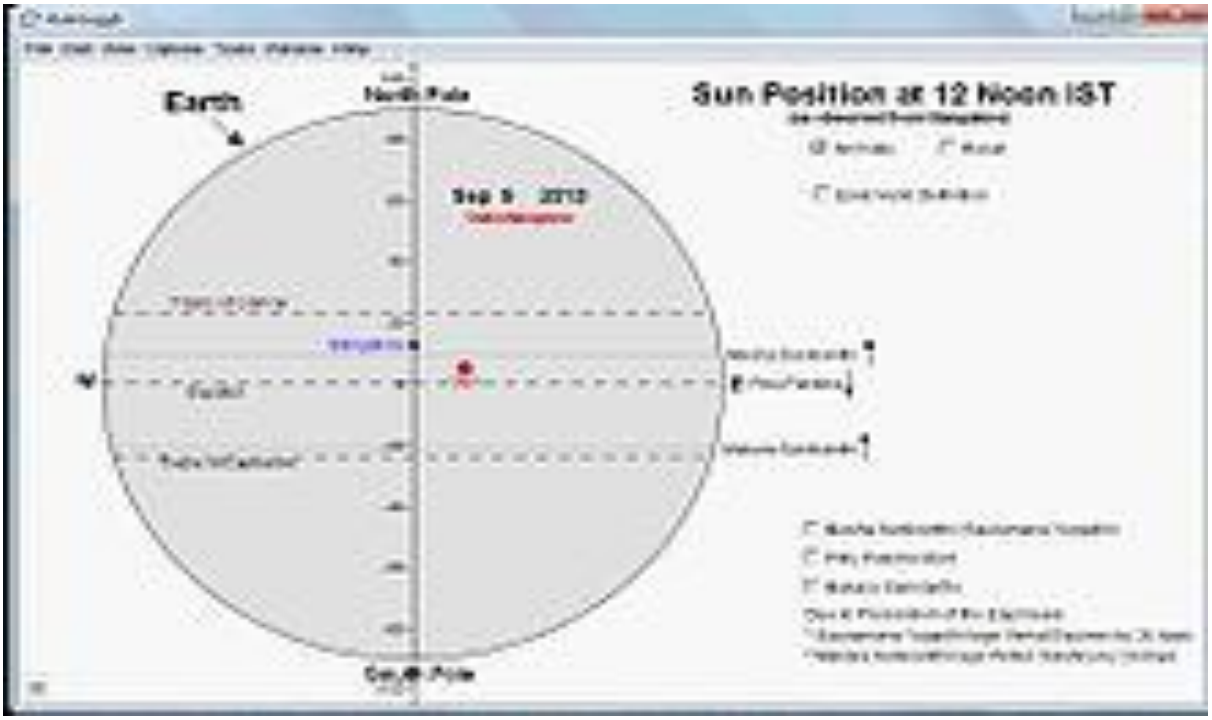

Figure 2. The movement of Sun with respect to the equatorial plane of earth over a period of one year.

3. Experimental setup

Our objective is harvesting more power output from solar panel by rotating the panel in alignment with Sun trajectory by using data from native calendar, when compared to a solar panel which is of stationary. The building block diagram of the circuit is shown in figure 3.

The following parts are used in implementation of optimum solar power generation
1. DC Power supply 5V, 12V
2. Stepper motor driver L293D Quadruple Half-H Drivers
3. Stepper motor – 2Nos Nema17 4.2 Kg-cm 2-phase 4-wire Stepper Motor for 1.8Deg /Step
4. DC motor –12V Geared Reduction Motor Reversible High Torque Turbo Worm Gear Box
5. RTC DS1307 with crystal 32.768KHz
6. PIC16F877A
7. LCD 2X16
8. Cables and Mechanical fixtures to support and rotate

Description of circuit is as follows

DC Power supply Output rating 5V / 3A and 12V / 4A
5V supply to logic circuit
12V supply for stepper and DC motor driver supply and flash programming

L293D :
Wide Supply-Voltage Range: 4.5 V to 36 V
Separate Input-Logic Supply
Internal ESD Protection
High-Noise-Immunity Inputs

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Stepper Motor :
Gear box attached. Reduction ratio 720:1

DC Gear motor
Gear reduction ratio. Reduction ratio 100:1

DS1307 :
Real-time clock (RTC) counts seconds, minutes, hours, date of the month, month, day of the week, and year with leap-year compensation valid up to 2100

PIC16F877A :
Enhanced Flash Microcontroller
Enhanced Flash program memory typical 100,000 erase/write cycle
Data EEPROM memory typical 1,000,000 erase/write cycle
Data EEPROM Retention > 40 years
Self-reprogrammable under software control
In-Circuit Serial Programming™ (ICSP™) via two pins
Single-supply 5V In-Circuit Serial Programming
Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
Programmable code protection
Power saving Sleep mode
Selectable oscillator options
In-Circuit Debug (ICD) via two pins

LCD :
2 Line 16 characters Alpha numeric display

Motors are mounted on mechanical fixtures and connected with reduction gear trains
to achieve accurate angular movement. Cables are connected between motor and driver board.
The gear reduction ratio for east - west stepper motors (M_EW1 and M_EW2) are kept at 720:1.The motor step angle (M_EW1 & M_EW2) is 1.8^0 and has to be supplied 200steps for one complete rotation. For 720 revolution of motor shaft, one rotation is achieved at load gear.

For every minute the load gear will rotate approximately 0.25 degree (180/720 degree)
(0.0043633 radian). The exact value will be calculated from the sunrise and sunset time from
the native calendar.
The day duration is calculated in minutes i.e the time between sunrise and sunset in minutes.
The angle of rotation per minute (cdsaew) for that day, for that installed location,
in east west direction is obtained by dividing π by this day duration in minutes and is used
to calculate the number of steps required. For reduction ratio of 720:1 half revolution of motor shaft will give an angular displacement of 0.25 degree i.e 0.0043633 radian in load gear.
For half rotation of shaft of stepper motor, 100 steps are required, if step angle is 1.8^o degree.
Number of steps required for one minute angular displacement = (100 / 0.0043633) * cdsaew.

For North South angular movement, calculation is done per day basis.
On June 21st the sun is positioned in maximum north.
On December 21st the sun is positioned in maximum south.
The current date is obtained from RTC.
The days in a year are grouped into four quarters
The four quarters are mentioned below.
1. March 21st to June 20th - 92 days North
2. June 21st to September 20th – 92 days North
3. September 21st to December 20th – 91 days South
4. December 21st to March 20th – 90 days / 91 if leap year South
The first two quarters are northern cycle
The last two quarters are southern cycle
For each quarter the displacement for current date is calculated as follows.
The total number of days (totday) is calculated as the number of days from the

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starting date of the quarter in which the current date is placed, till the current date.

The angular movement of each quarter of the year is approximately 23.5° i.e 0.41015 radian north / south. The current day displacement (cdangns) is calculated as follows (0.41015 / total days in the quarter) * totday (North / South) according to the quarter. An offset angle (NSOFFSET) which is defined according to the distance from equator is obtained from the native calendar. This will equal to longitude of that location. This value will be added or subtracted depending upon where installation is located, either in northern or southern hemisphere. For instance, if the location is in 10° north from equator, on March 21st total days (totday) = 0, and cdangns = 0, as the location in northern hemisphere, the value of NSOFFSET is subtracted and result is -10° i.e 10° south, and the panel will be moved 10° south to track and follow SUN movement in north south tilt angle of that location.
We consider tropical area in our calculations.

Motor driver step input signals are transmitted from controller, to obtain panel movement in desired direction.

LCD display is used to display the status and data details at every time.

Firmware:

The microcontroller could be programmed in circuit and during installation the data collected from the native calendar is programmed into the flash. The current date & time is also programmed into the RTC through microcontroller. The programme is developed according to the flow chart given below and stored into the flash. The circuit diagram is shown in figure 4.

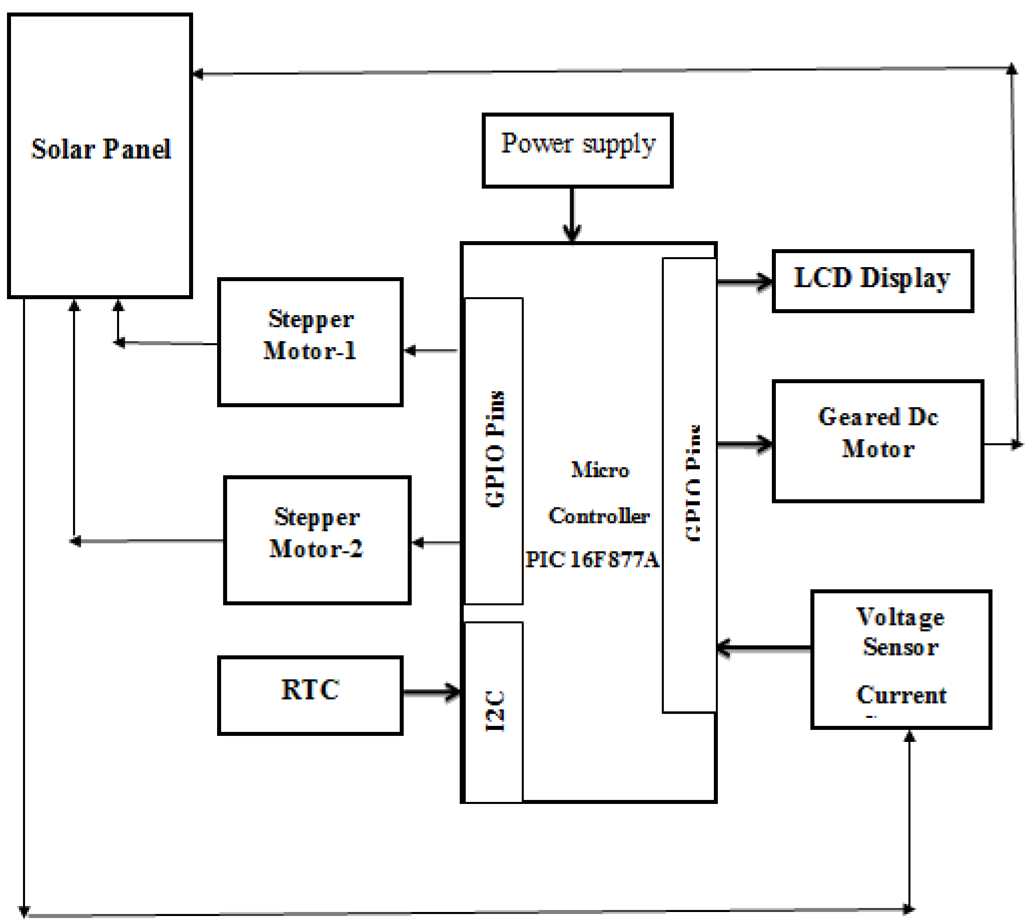

Figure 3. The building block of two-dimensional solar panel rotation for optimizing power generation.

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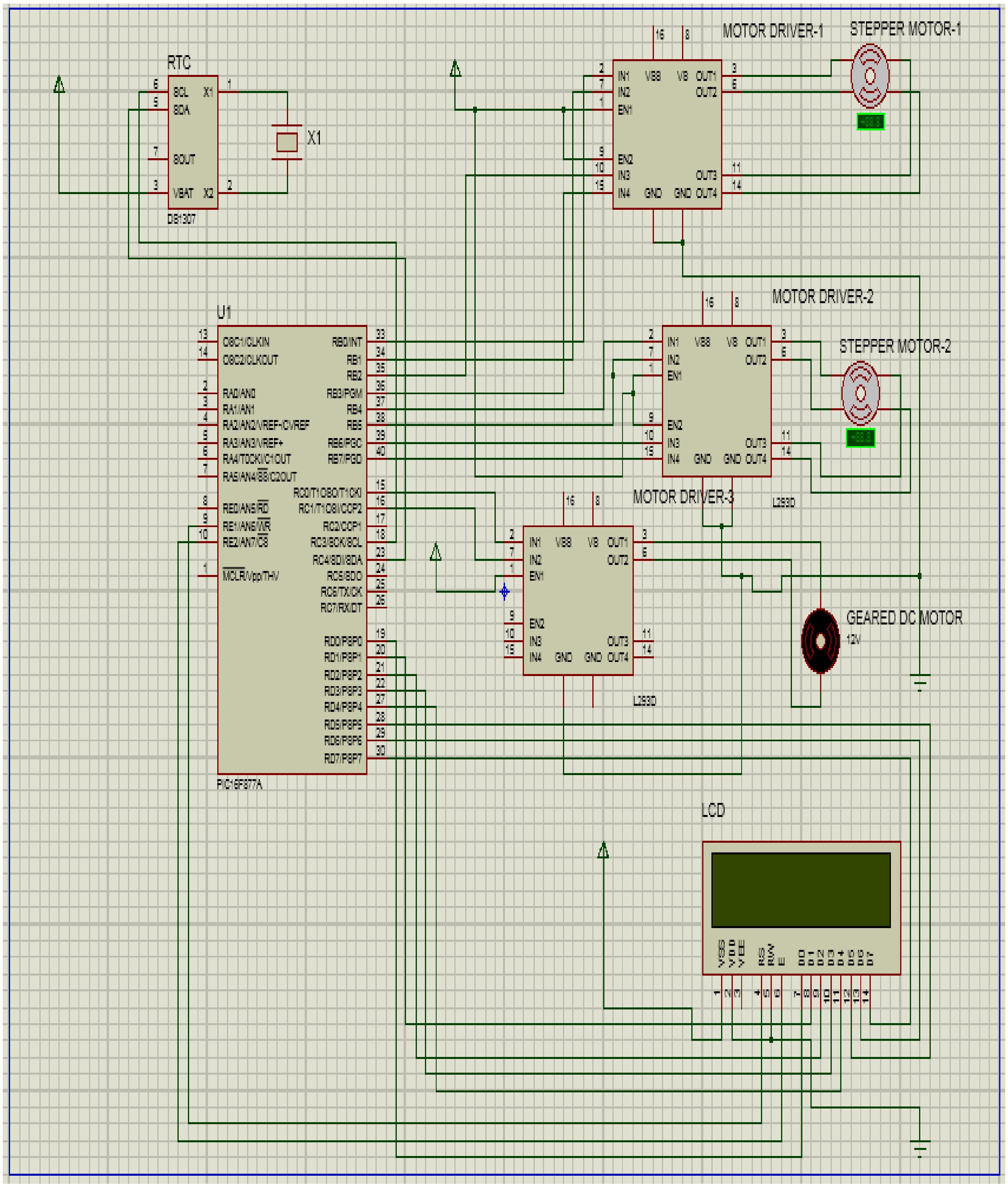

Figure 4. **Circuit diagram of two-dimensional solar panel rotation circuit for optimizing power generation.**

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Figure 5. Experimental setup of two-dimensional solar panel rotation circuit for optimizing power generation.

Advantages :

The proposed system uses inbuilt RTC and the data collected from the native calendar, stored in flash. When compared to solar light tracking method, this could work even in cloudy environment, and there is no chance of false tracking. When compared to gps based systems, our system has minimum hardware, hence less expensive. Also software is not complicated.

The native calendar is reasonably accurate as it is used in hundred of years. The data available are taken practically in the location, which will take into consideration of the geographical condition, the elevation from sea level and nearby mountain like elevated topology which would change the sunrise or sunset time of that particular location. They have been utilized for agricultural and ceremonial purpose. The data in native calendar is used as a lookup table for our calculations and we are able to achieve best results. The experimental setup is shown in figure 5.

Algorithm and flowchart

Algorithm:

Step1: Power on the logic board.

Step2: Initialize all variables and set default values.

Step3: Update reset status display.

Step4: Check home status, if not in home, move panel to east-west and north-south home.
Update home position status.

Step5: Update home position display.

Step6: Get rtc values.

Step7: Check date & time validity if not valid, update error date time display and goto step6
Else update date time display.

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Step8: Check current date variable = rtc date variable if false goto step10.

Step9: Check current date north-south position status variable, if true goto step12 else goto step11.

Step10: Set current date variable = rtc date variable.

Step11: Calculate current day step angle for north-south direction using the data in flash and assign to variable. Flash has the data collected from the native calendar including sun rise and sun set time and offset from equator. Move panel to current date north-south angle. Update north-south position status and display.

Step12: Calculate current day east-west step angle using data from flash.
Set current day east-west step angle variable.
Update current day east-west step angle status.

Step13: Read rtc and set current time variable = rtc time

Step14: Check time legal, if false goto step2.
Update current date and time, display.

Step15: Check current time, if time is not earlier than sun rise time goto step19.

Step16: Check home position status, if false goto step2.

Step17: Check current day north-south position staus, if false goto step6.

Step18: Check current day east-west step angle status, if false goto step6.
Else goto step13.

Step19: Check current time is between sunrise and sunset time, if false goto step23.

Step20: Calculate time between current day sunrise time to current time in minutes.
Calculate the east-west angle and set calculated east-west angle variable.

Step21: Check current east-west angle variable = calculated east-west angle variable.
If true goto step13.

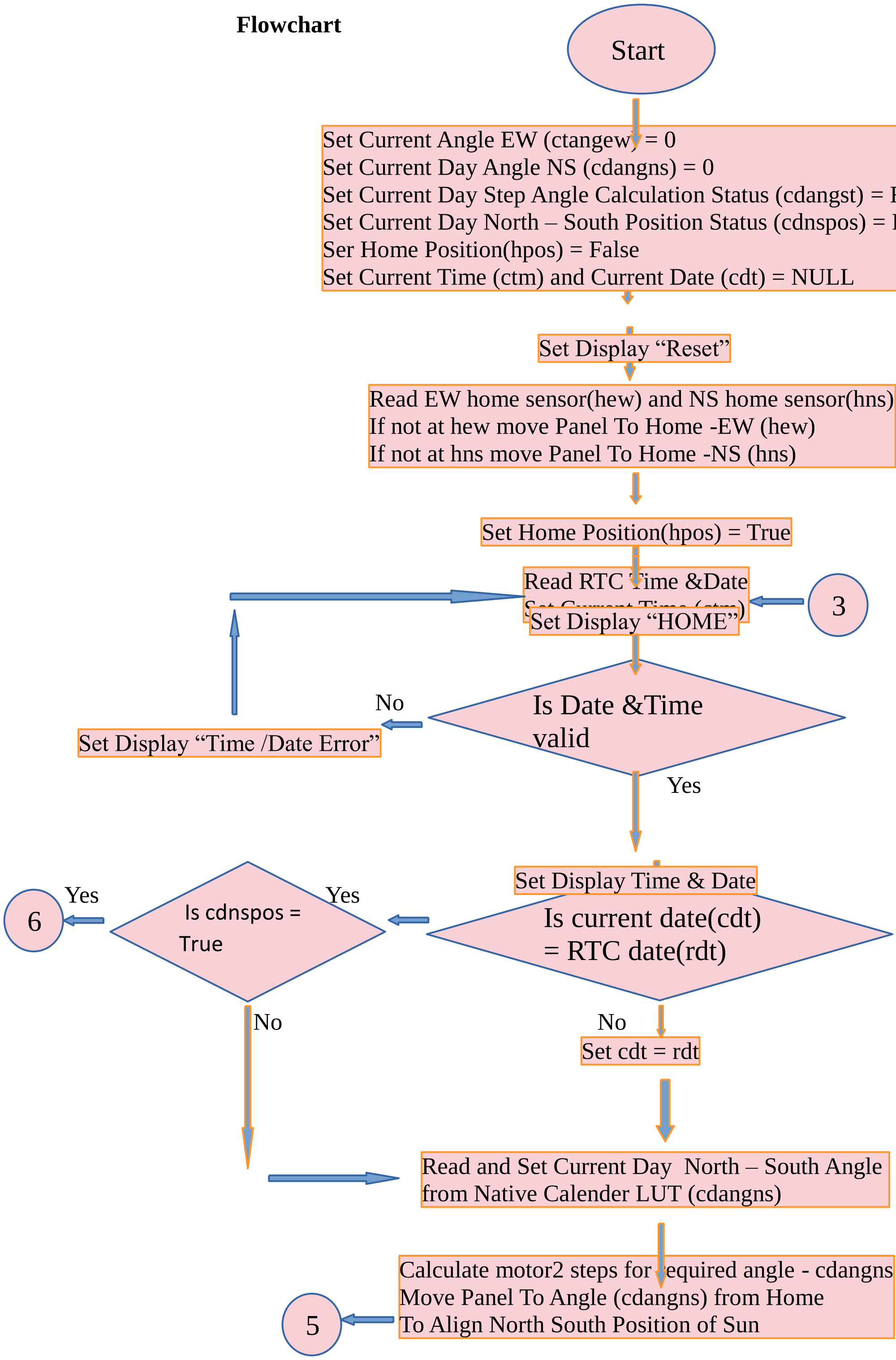
Step22: Calculate the difference between current east-west angle and calculated east-west angle.
Calculate the number of steps for east-west rotation using current day east-west step angle.
Move the panel east-west as per the steps.
Set current east-west angle variable = calculated east-west angle variable.
Goto step13.

Step23: Read rtc

Step24: Check current date = rtc date, if true update wait display and goto step23.

Step25: Goto step2.

Flowchart


Start
Set Current Angle EW (ctangew) = 0
Set Current Day Angle NS (cdangns) = 0
Set Current Day Step Angle Calculation Status (cdangst) = False
Set Current Day North – South Position Status (cdnspos) = False
Ser Home Position(hpos) = False
Set Current Time (ctm) and Current Date (cdt) = NULL
1
Set Display "Reset"
Read EW home sensor(hew) and NS home sensor(hns)
If not at hew move Panel To Home -EW (hew)
If not at hns move Panel To Home -NS (hns)
Set Home Position(hpos) = True
Read RTC Time &Date
Set Display "HOME"
3
No
Is Date &Time valid
Set Display "Time /Date Error"
Yes
Set Display Time & Date
Is current date(cdt) = RTC date(rdt)
Yes
Is cdnspos = True
Yes
6
No
No
Set cdt = rdt
Read and Set Current Day North – South Angle from Native Calender LUT (cdangns)
Calculate motor2 steps for required angle - cdangns
Move Panel To Angle (cdangns) from Home
To Align North South Position of Sun
5

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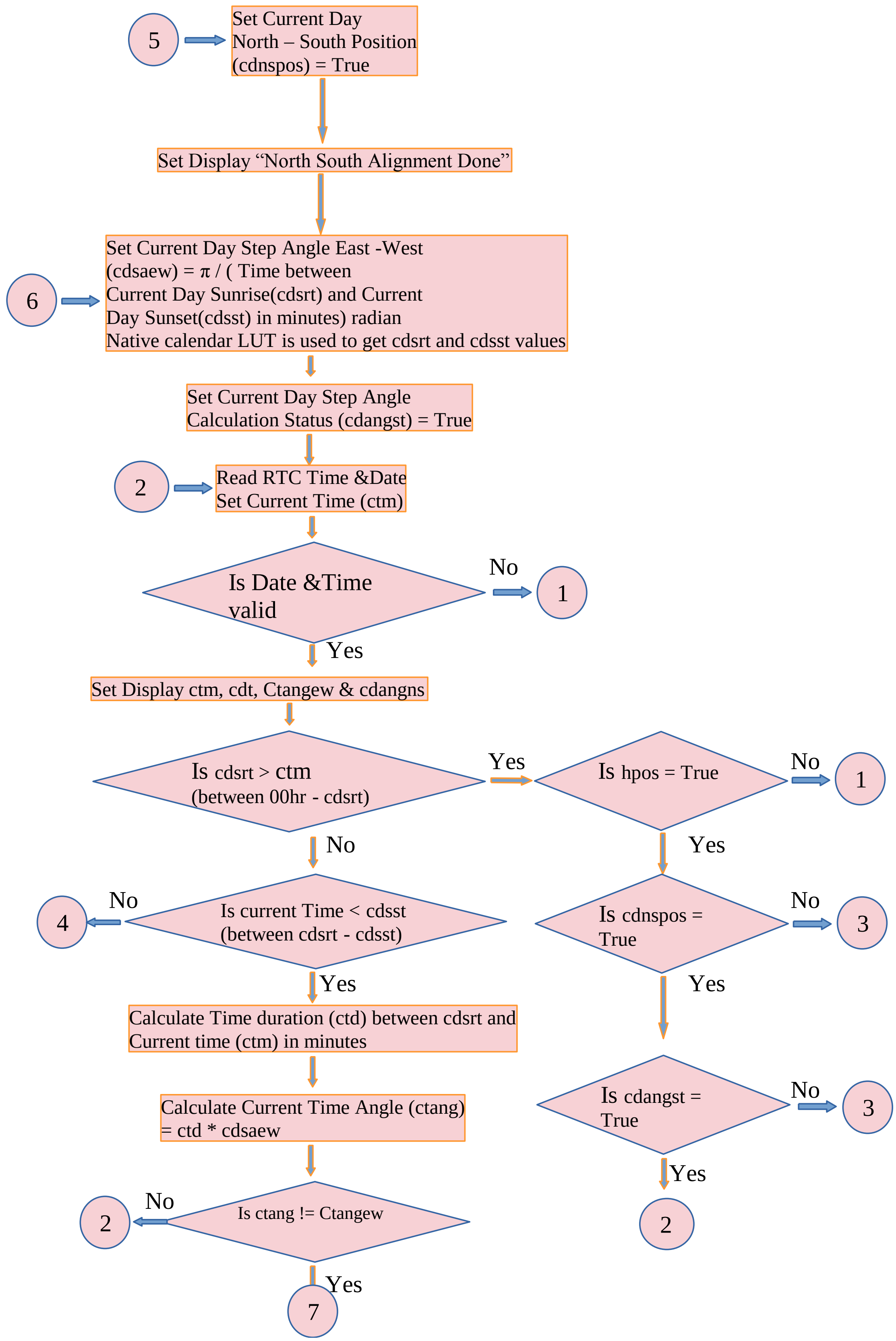

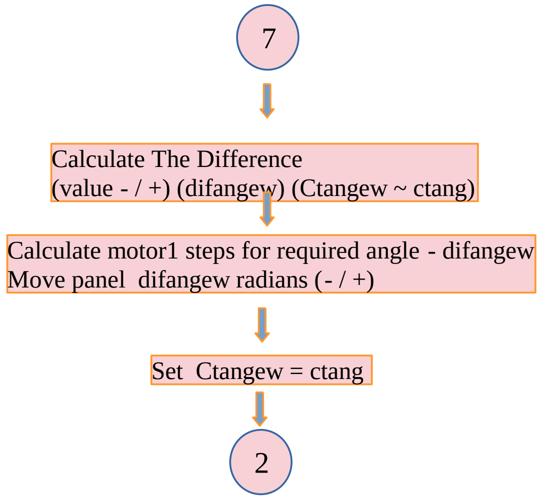

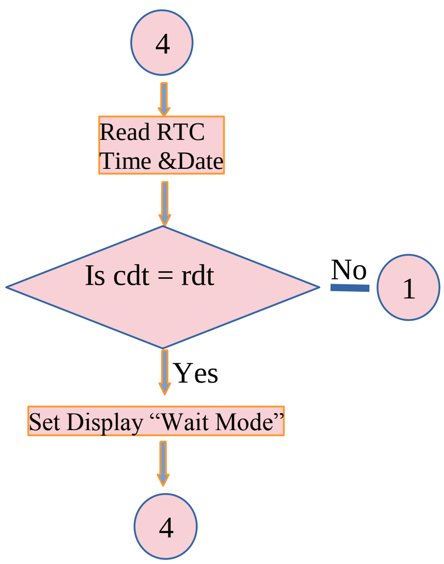

4. Mathematical calculations with result and graph

Mathematical model

To calculate the work done and power required for rotating the panel for π radians in 12 hours

The overall work done W is divided into three components.

W = W1 + W2 + W3

W1 is the work done to set the panel into movement with angular velocity of π / 43200 radian sec^{-1} from rest.

W2 is the work done against the static frictional force.

This is the product of torque to overcome the static frictional force, radius of rotating arc and initial angular displacement.

W3 is the work done to overcome kinetic frictional force.

This is the product of torque to overcome the kinetic frictional force, radius of rotating arc and remaining angular displacement.

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The force is applied to the gear attached to the pivot.

Input data:

Mass of solar panel (M) = 5Kg (Including shaft mass)

Length of rotating arm (Radius) (R) = 1 Meter

Total circular displacement (Θ) = π Radians

Total time to rotate (T) = 12 Hrs = 43,200 Sec

Calculation1:

Angular velocity of rotation (Ω) = π / 43200 Radian / Sec

= 7.2722×10^{-5} Radian / Sec

Work done to move the panel from rest to Rotational Speed:

$= \frac{1}{2} \times I \times (\Omega)^2$

where I is inertia, Ω is final angular velocity

$I = \frac{1}{2} \times M \times R^2$

$= \frac{1}{2} \times 5 \times (1)^2$

= 2.5 Kg - Meter^2

$\Omega = 7.2722 \times 10^{-5}$

$\Omega^2 = 5.2884 \times 10^{-9}$

Work(W1) = $\frac{1}{2} \times 2.5 \times 5.2884 \times 10^{-9}$

= 6.6106×10^{-9} Jouls

Calculation2:

We consider coefficient of static friction and kinetic friction of steel gear where the force is applied to rotate, as 0.6.

we calculate the static frictional force

= M x g x 0.6

where g is gravitational acceleration = 9.8 M - Sec^{--2}

M = 5Kg

Force(F2) = 5 x 9.8 x0.6

= 29.4

This force act only at start and opposing to bring object from rest to movement. So we consider this act during the first(start) unit of time(1 sec).

The work done at this second is calculated as follows.

Work(W2) = τ_s x Θ_i

where τ_s is torque and Θ is angular displacement

τ_s = F2x R

= 29.4 X 1

= 29.4

$\Theta_i = ½ \times (\Omega_f + \Omega_s) \times t$

where Ω_f is final angular velocity and Ω_s is start angular velocity. t is consider as 1 sec.

Ω_f is 7.2722×10^{-5}

Ω_s is 0

Θ_i is initial angular displacement

So $\Theta_i = ½ \times (7.2722 \times 10^{-5} + 0) \times 1$

= 3.6361×10^{-5} radian

So W2 = $29.4 \times 3.6361 \times 10^{-5}$ Jouls

= 106×10^{-5} Jouls

Calculation3:

After establishing the required angular velocity, to maintain that velocity, the kinetic friction force has to be overcome.

Coefficient of kinetic friction for steel is consider as 0.6

Kinetic friction force F3 = 0.6 x M x g

= Force(F3) = 0.6 x 5 x 9.8

= 29.4 N

Θ_r is remaining angular displacement

$\Theta_r = \pi - \Theta_i$

$= \pi - 3.6361 \times 10^{-5}$ radian

= 3.1415 radian

W3 is the work done for rotating over the remaining angular displacement

W3= τ_r x Θ_r

τ_r = F3 X R

= 29.4 x 1

= 29.4 N - meter

W3 = 29.4 x 3.1415 Jouls

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= 92.3601 Jouls

Calculation4:

Overall work done W

= W1 +W2 +W3

= 6.6106 x 10^{-9} + 106 x 10^{-5} + 92.3601

= 92.3611 Jouls

This is the work done in 43200 sec

So power used per second P = W / Time

= 92.3611 / 43200 sec

= 2.1379 mW

Additional consideration:

The frictional force could be lowered by using suitable lubricants.

Frictional coefficient may vary from material to material and the result may vary.

The gravitational force which act against the movement from 0 to π/2 radians is almost nullified by the gravitational pull down during the rotation from π/2 to π radian.

The wind force may be supporting or opposing and not considered.

Temperature and humidity may affect the result

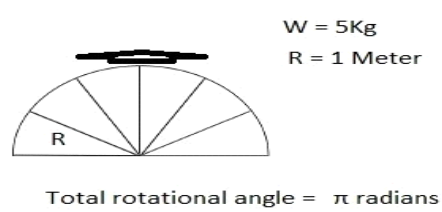
and could change the final value by ±10% from the calculated

value.

The motor efficiency may be between 70 - 80%

This will increase the final power required by 30%

So the average power required is around 3mW.



Data for solar power generation were collected on 6/1/2020 at Tirupati , Andhra Pradesh for rotating the solar panel and keeping it in a static position.

The average difference in Power is 253.6 mW

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Power generation was taken for the load of 250Ω.

The power utilized to rotate the panel = 3mW.

Ratio = 3 /253.6 = 0.011829

Readings and Graph

Readings were taken for a full day at Tirupati, Andhra Pradesh in India for a whole day. These readings were taken for a load of 770-ohm load connected at the output terminals. These readings are given in the following table. Voltage and current readings were taken in Voltage and milli amperes respectively, and power is calculated using the following equation.

P = V X I watts

Table 1. Readings of Solar Power generation with and without tracking system at Tirupati, Andhra Pradesh, India on 6.1.2020. Comparison of power generation is given by MATLAB generated graph in figure.6.

	Solar panel at Static Position			Panel is tracking Sun Position		
TIME	Voltage in Volts	Current in MA for 250 Ohm	Power IN Milli Watts	Voltage in Volts	CURRENT in MA FOR 250 Ohm	POWER IN Milli Watts
7.40 AM	12.5	50	650	17.5	70	1225
7.50 AM	13.5	54	729	18	72	1296
8 AM	15	60	900	18.5	74	1369
8.30 AM	17.5	70	1225	19	76	1444
8.30 AM	17.5	70	1225	19	76	1444
8.40 AM	17.5	70	1225	19	76	1444
9 AM	18	72	1296	19	76	1444
9.5 AM	18	72	1296	19.5	78	1521
9.10 AM	18.5	74	1369	19.5	78	1521
9.30 AM	18.5	74	1369	20	80	1600
9.40 AM	18.5	74	1369	20	80	1600
10 AM	18.5	74	1369	19	76	1444
10.5 AM	18.5	74	1369	19	76	1444
10.30	19.2	76.8	1474	19.6	78.4	1537
11 AM	19.2	76.8	1474	19.6	78.4	1537
11.35 AM	19.2	76.8	1474	19.6	78.4	1537
12 NOON	19.2	76.8	1474	19.6	78.4	1537
12.30 PM	20	80	1600	20.2	80.8	1632
12.40 PM	20	80	1600	20.2	80.8	1632
1.10 PM	20	80	1600	20.2	80.8	1632
1.35 PM	19.5	78	1521	20	80	1600
2 PM	19.5	78	1521	20	80	1600
2.30 PM	19	76	1444	19.6	78.4	1537
3 PM	19	76	1444	19.6	78.4	1537
3.30 PM	18.9	75.6	1429	19.6	78.4	1537
4 PM	17.5	70	1225	19	76	1444
4.30 PM	15.4	61.6	949	19	76	1444
5 PM	6.5	26	169	18	72	1296
5.15 PM	4	16	64	15.5	62	961
5.20 PM	4	16	64	13.5	54	729

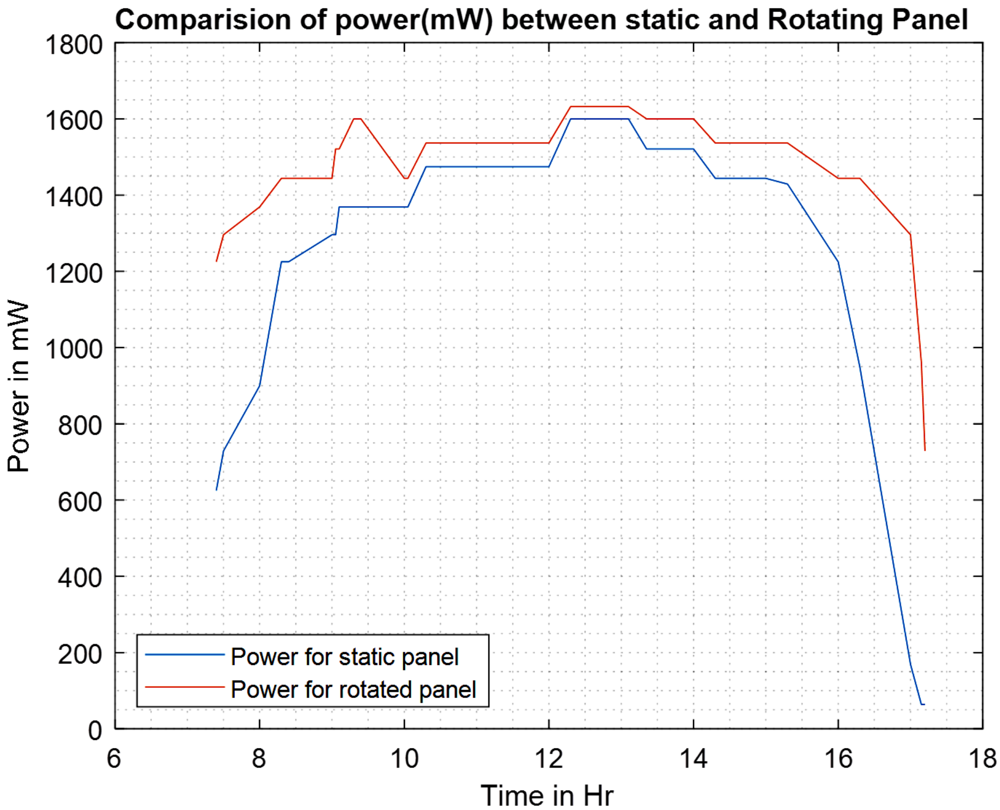

Figure 6. Solar power generation with and without tracking system at Tirupati, Andhra Pradesh, India on 6.1.2019.

5. Conclusion

In this paper, solar power generation readings have been used which have been taken at SV Engineering College, Tirupati, Andhra Pradesh, India, by implementing a solar panel rotating model and real values have been used for calculating the electrical power spent for rotating solar panel. A graph has been drawn using those readings with the help of MATLAB Software. It is compared with the generated powers, with rotation and without the rotation of tracking system. It is found out that when this type of solar tracking is used, more extra power is generated. By tracking the maximum solar rays all the time, this method is optimizing photo voltaic power generation. In future IOT can be used for rotating motor using wire - less communication system.

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