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Design and Implementation of Solar Tracker with Optimimum Maximum Power Point Tracking for AFV Applications

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Abstract:
To meet the ever increasing global energy demand, sustainable energy sources has to be utilized to the maximum possible extent. Solar Photo-voltaic (PV) generation is the most promising solution among the available renewable sources of energy. In order to increase the energy yield from PV generation, the panels has to be exposed to the maximum direct solar insolation. This project mainly focuses to implement Solar PV generation to power a part of Armoured Fighting Vehicles (AFV). Owing to the fact that the vehicles are under constant motion and has a space constraint, the mounting of solar panels proves to be challenging. An efficient and accurate two axis sun tracker is implemented in this project to overcome these challenges and to greatly increase the energy yield throughout the day. In addition to this, a novel model predictive based maximum power point tracking method is implemented in this project to enhance the speed of convergence in tracking the maximum power point. A single-ended primary-inductance converter (SEPIC) is used as charge controller to mitigate the power quality disturbances like input DC current ripple and harmonics.

Keywords: Photo- voltaic, renewable energy, SEPIC, solar tracker.

I. INTRODUCTION

The world population is increasing day by day and the demand for energy is increasing accordingly. Oil and coal as the main source of energy is expected to end up from the world during the recent century which explores a serious problem. Today the demand of electricity in India is increasing and is already more than the production of electricity. We can feel this fact from the electricity cuts during summer. Luckily sun throws so much energy over India, that if we can trap few minutes of solar energy falling over India we can provide India with electricity for whole year. Most parts of India get 7 KWh/sq-metre of energy per day averaged over a year. A solar cell (also called a photovoltaic cell) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect.

A solar panel is a set of solar photovoltaic modules electrically connected and mounted on a supporting structure. The majority of modules use wafer- based on cadmium silicon cells or thin-film cells based on cadmium telluride or silicon. Electrical connections are made in series to achieve a desired output voltage and in parallel to provide a desired current capability. Several types of solar cells are available. Mono-crystalline solar cells, Polycrystalline solar cells, Amorphous Silicon solar cells, Cadmium Telluride solar cells.

A solar tracker is a device for orienting a solar photovoltaic panel, day lighting reflector or concentrating solar reflector or lens towards the sun. Solar power generation works best when pointed directly at the sun, so a solar tracker can increase the effectiveness of such equipment over any fixed position. The solar panels must be perpendicular to the sun's rays for maximum energy generation. Deviating from this optimum angle will decrease the efficiency of energy generation from the panels. An active tracker uses motors to direct the panel toward the sun by relying on a sensing circuit to detect light intensity. There are two main ways to mount a solar panel for tracking: single axis and dual axis. Single axis trackers usually use a polar mount for maximum solar efficiency.

Polar trackers have one axis aligned parallel to the axis of rotation of the earth around the north and south poles. When Compared to fixed mount, a single axis tracker increases the output by approximately 30%. The second way is a two axis mount where one axis is a vertical pivot and the second axis is the horizontal. This method increases the output by approximately 36% compared to stationary panels. The PV cell exhibits a non-linear output current and voltage relationship. There is a maximum power point (MPP) under any solar irradiance level, where the output power of a PV cell is maximised. There are three possible approaches for maximizing the solar power extraction in medium and large scale PV systems. For the small-scale systems, the use of MPP tracking only is popular for economical reasons.

The various methods including the power-matching scheme, curve-fitting technique, perturb-and-observe method, and incremental conductance algorithm have been proposed for tracking the MPP of solar panels. The main aim of this project is to generate the maximum power from solar panel by continuously tracking the sun rays.

The purpose of the project is to implement a system to continuously track the sun rays with the help of the solar panel and grasp the maximum power from the sun by rotating the solar panel according to the sun rays direction. The block diagram of the proposed system is shown in Fig. 1. This project presents a comparative study of high performance tracking of maximum power using MPPT techniques namely Perturb & Observe (P&O), Fuzzy systems and Model Predictive Control based algorithms.

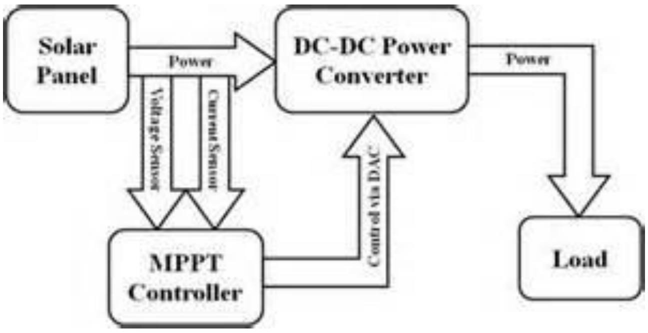


Figure.1. Schematic Block Diagram

II MODELING OF PHOTOVOLTAIC SYSTEM

A photovoltaic cell is basically semiconductor diode whose p-n junction exposes to light [6]. Photo voltaic cell is made from different types of semiconductors using different manufacturing processes. The mono-crystalline and polycrystalline are generally used in commercial level. When light fall on the cell it generate the charge carriers that originate the electrical current if the cell is short circuited. The single diode model of a PV cell is depicted in Fig. 2.

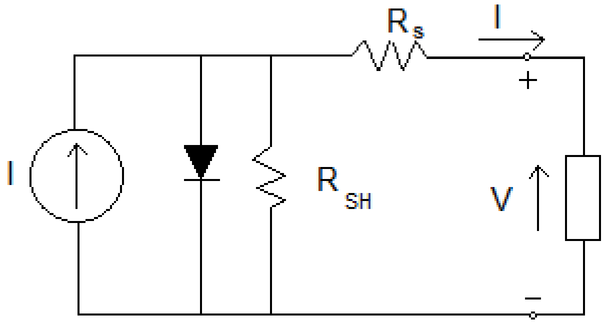


Figure.2. Single diode model of a PV cell

In this model we consider a current source (I) along with a diode and series resistance (R_s). The shunt resistance (R_{sh}) in parallel is very high, has a negligible effect and can be neglected.

The output current from the photovoltaic array is

$$I = I_{sc} - I_d \quad (1)$$

$$I_d = I_o \left(e^{qV_d/kT} - 1\right) \quad (2)$$

Where I_o is the reverse saturation current of the diode
q is the electron charge
k is the Boltzmann constant ($k = 1.38*10^{-19}$ J/K)
T is the junction temperature in Kelvin (K)
From the equation (1) and (2)

$$I = I_{sc} - I_o \left(e^{qV_d/kT} - 1\right) \quad (3)$$

Using suitable approximation,

$$I = I_{sc} - I_o \left(e^{q((V+IRs)/nkT)} - 1\right) \quad (4)$$

Where I is the photovoltaic cell current
V is the PV cell voltage
n is the ideality factor.

III MAXIMUM POWER POINT TRACKING

MPPT is the tracking system used in solar energy by matching the load impedance with the PV panel impedance. MPPT is used to improve the efficiency of the solar panel. MPPT is an algorithm that is included in the charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called 'Maximum Power Point' or Peak Power Voltage. MPPT is a fully electronic system that varies the electrical operating point of the modules are able to deliver maximum available power. In the source side we are using a DC converter connected to a solar panel in order to enhance the output voltage so that it can be used in many applications such as motor load. There are different methods used to track the maximum power point. Few of the most popular techniques are

1. Perturb and Observe
2. Incremental conductance method
3. Fractional short circuit current
4. Fractional open circuit voltage
5. Fuzzy logic control
6. Neural networks

The choice of the algorithm depends on the time complexity the algorithm takes to track the MPP, implementation cost and ease of implementation. P&O, Fuzzy method and Model predictive based control algorithms are compared and studied.

A. Perturb and Observe Method

Perturb and Observe (P&O) is the simplest method. In this we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to MPP it doesn't stop at the MPP and keeps on perturbing on both the directions [5]. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. However this method does not take account of the rapid change of irradiation level. The flow chart of the P&O algorithm is shown in Fig. 3.

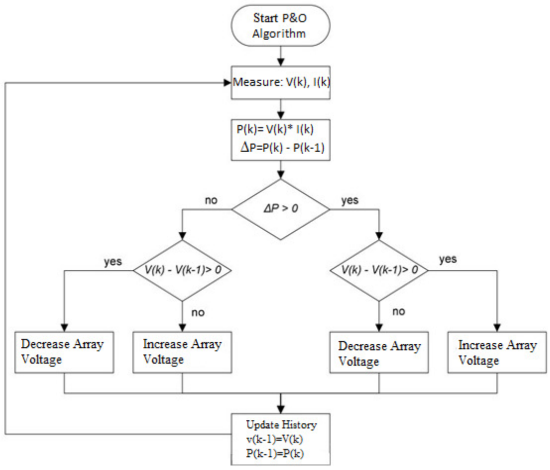


Figure. 3. Flowchart of Perturb & Observe algorithm

The sub block for the P&O algorithm is given in Fig. 4.

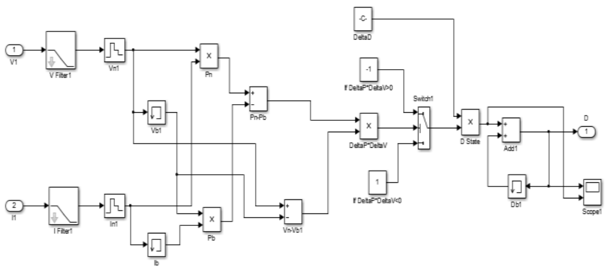


Figure.4. Sub-block model for the conventional P & O MPPT controllers

B. Fuzzy Logic Control

This method uses fuzzy logic to have a faster controller response and to increase system stability once reached the MPP. The tracking of the MPP will be divided into two phases. The first phase is to improve the response of the MPPT controller, the second phase is the fine phase where the step is very small, thus ensuring the system stability and decrease the maximum oscillations around MPP. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing any mathematical models, and handling non linearity. The fuzzy logic controller generally consists of three stages: Fuzzification, Inference and Defuzzification. During Fuzzification, numerical input variables are converted into linguistic variables based on a membership function. These variables are then compared to a set of pre-designed values during inference method, in order to determine the appropriate response. Defuzzification is for converting the fuzzy subset of control from inference back to values. The block diagram of FLC is shown in Fig. 5.

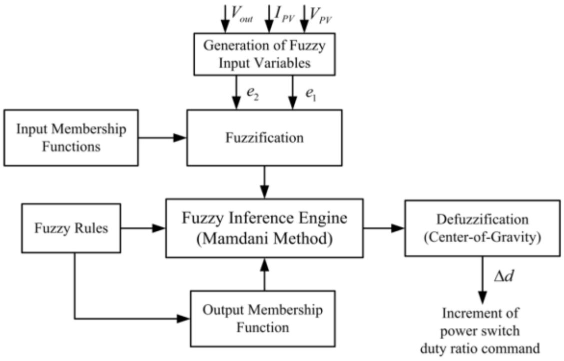


Figure. 5. Block Diagram of Fuzzy Logic Control

The inputs to a MPPT fuzzy logic controller are usually an error X1 and change in the error X2. The output of the FLC is usually a change in the duty ratio of the power converter, D. Once X1 and X2 are calculated and converted to the linguistic variables, the fuzzy logic controller output, which typically a change in duty ratio D of the power converter , can be looked up in a rule base [3], [7]. The rules for the FLC are viewed in rule base table as shown in Fig. 6.

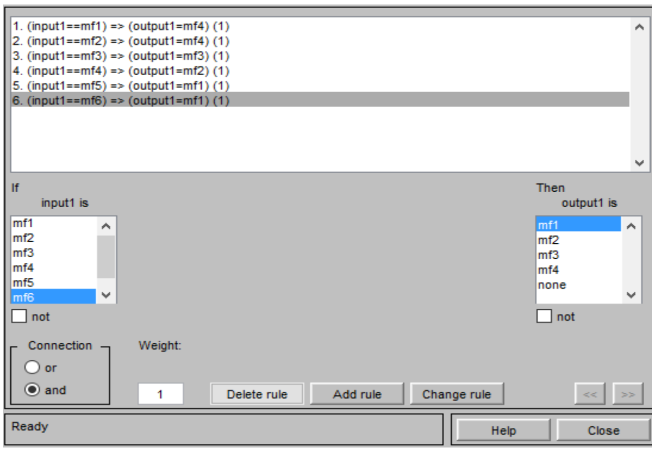


Figure.6. The rules base for FLC

In this proposed system, six membership functions and six rules are formed. For fefuzzification, the centroid of area(COA) is used. The output of the fuzzy is given to the phase lock loop (PLL) block and then the output pulse generated from this MPPT technique is given to the power semiconductor switch of the SEPIC converter. The input and output of the membership functions are shown in Fig. 7 and Fig.8.

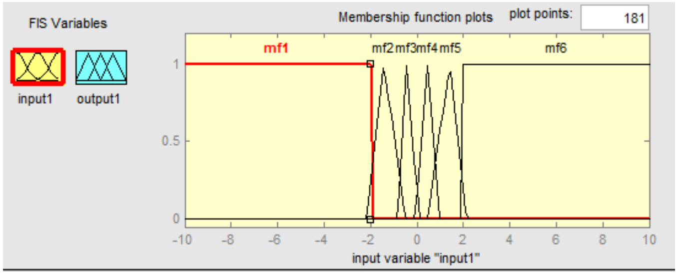


Figure. 7. The input membership function for FLC

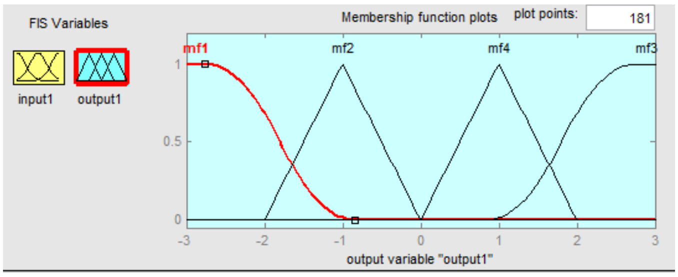


Figure.8. The output membership function for FLC

The sub block of the FLC is shown in Fig. 9.

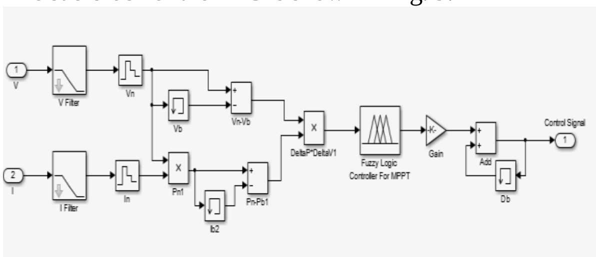


Figure.9. Simulink model for the fuzzy logic MPPT controllers

C. Model Predictive Based MPPT method

The Model Predictive Control (MPC) methods for control of power converters have been under development recently. MPC has improved performance in comparison with the traditional methods. The proposed method is unique. It directly predicts the behaviour of the PV module in the future steps using a digital observer [1]. The MPC predicts the future by few steps. Step 1 includes predicting the voltage. The algorithm calculates the two possible future PV voltage values.

$$V_{pv}(K+1)' = V_{pv}(K) + \Delta V \qquad (5)$$

$$V_{pv}(K+1)^2 = V_{pv}(K) - \Delta V \qquad (6)$$

Where ΔV is a voltage step set by the system designer based on the PV module rating.

Step 2 includes predicting the power. The prediction of power is done by PV characteristics of module around operating point V_{pv} (K). This is done by the digital observer model, modeled using Thevenin's circuit. The elements of Thevinin's circuit are equivalent voltage V_{eq} and equivalent resistance R_{eq} of the module.

$$R_{eq}(K) = -\frac{V_{pv}(K) - V_{pv}(K-1)}{I_{pv}(K) - I_{pv}(K-1)} \qquad (7)$$

$$V_{eq}(K) = V_{pv}(K) + R_{eq}(K)\, I_{pv}(K) \qquad (8)$$

Where V_{pv}(K-1) and I_{pv}(K-1) are the values of the PV module voltage and current from the previous sampling time. Step 3 involves the Evaluation of Cost function. The predicted power for two cases will be used to evaluate cost function.

$$J^{\{1,2\}} = P_{pv}(K+1)^{\{1,2\}} - P_{pv}(K) \qquad (9)$$

To increase power in each step, predicted power result in large value of J. The advantage of model predictive method are low oscillations, better performance with fast time response, fast convergence [10]. The sub block for MPC MPPT controllers is shown in Fig.10.

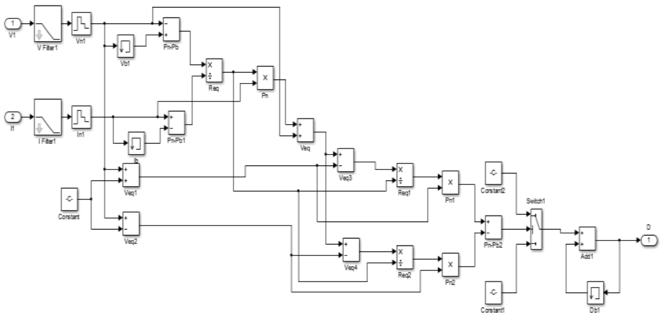


Figure. 10. Sub-block model for the Model Predictive MPPT controllers

IV. SEPIC CONVERTER

The single ended primary inductance converter (SEPIC) is a DC/Dc converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. The SEPIC converter allows a range of DC voltage to be adjusted to maintain a constant voltage output. The SEPIC converters can increase or decrease the voltage. The advantages of SEPIC converter are lower input current ripple [2] , lower switch voltage operation, higher efficiency operation with the lowest input voltage.

V. SIMULATION RESULTS

The proposed project consists of a solar PV panel with different MPPT algorithms and a SEPIC converter. Simulations are carried out MATLAB2013a/ SIMULINK software. Matlab proves to be dynamic software for power electronic simulations. The mathematical modeling of PV array is shown in Fig. 11. From the Fig. 11, it can be seen that the output voltage and the current of the PV array is 60V and 10 A respectively. Table 1 shows the Input and output parameter values of PV modules.

Table.1. Input and output parameter values of PV module & SEPIC converter

Parameters	Values	Units
Solar irradiation	400	KW/m^2
Temperature	25	ºC
SEPIC converter inductance value	22e-3	H
SEPIC converter capacitor value	1e-6	F

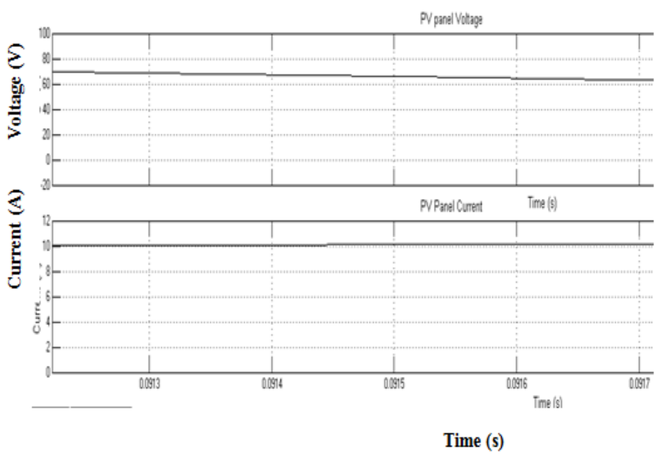


Figure. 11. Output Voltage and Current waveforms of PV array

The output voltage and current waveform for P&O , Fuzzy Logic Control and Model Predictive Control is shown in Figs below.

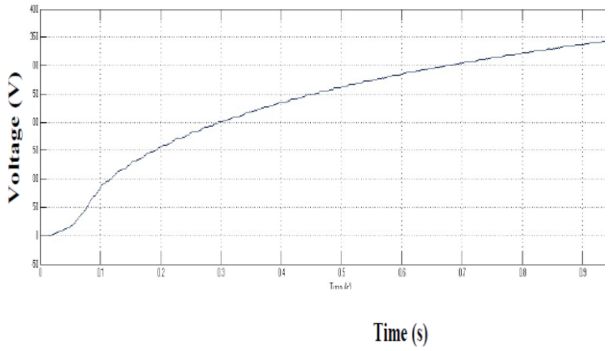


Figure.12. OUTPUT Voltage waveform for P & O MPPT controllers

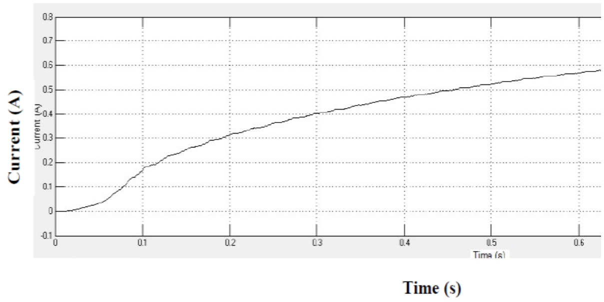


Figure. 13. OUTPUT Current waveform for P & O MPPT controllers

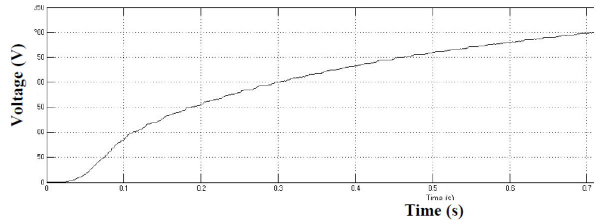


Figure. 14. OUTPUT Voltage waveform for FLC MPPT controllers

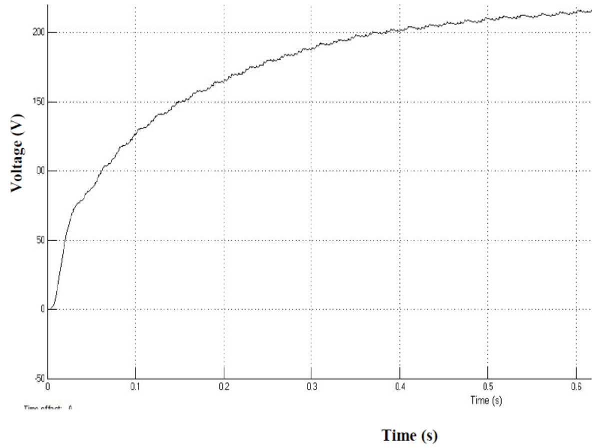


Figure.15. OUTPUT Voltage waveform for MPC MPPT controllers

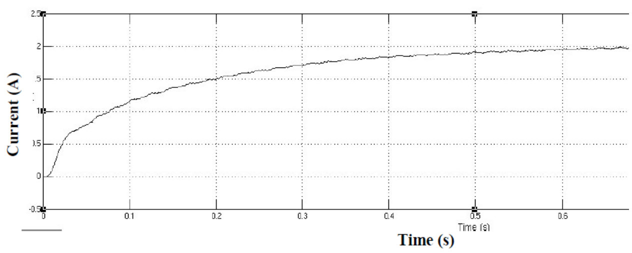


Figure.16. OUTPUT Current waveform for MPC MPPT controllers

VI. CONCLUSION

It is seen that when compared with traditional P&O fails to track MPP when the irradiation changes rapidly. The Fuzzy logic controller is based on the experience of the operator. It has a very good performance. It improves the response of PV systems. It not only reduce the time in response to the continued maximum power point but it also eliminates the fluctuations around this point. The MPC converges of the maximum power point faster and exhibits the low oscillation around MPP in steady state with maximum power point extraction for same irradiation and temperature when compared to P&O and Fuzzy logic control.

Table.2 Simulation Results of Various MPPT Techniques

MPPT TECHNIQUES	VOLTAGE (V)	CURRENT (A)	POWER (W)
PURTURB & OBSERVE	350	0.7	245
FUZZY LOGIC CONTROL	350	1	350
MODEL PREDICTIVE CONTROL	225	2	450

HARDWARE EXPLANATION:

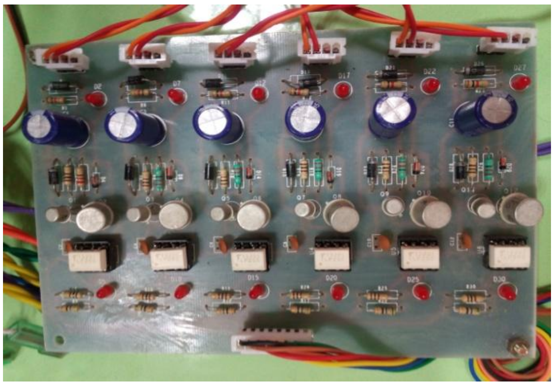
- Input supply:- AC and solar
- Rectifier: It is converted into AC TO DC Supply.
- Driver circuit: -It can be used to amplify the 5V pulses to 12V for using transistor technology and provided isolations for using opto-coupler. It has two functions,
- Amplification
- Isolation
- Pulse generator: - Here we have used PIC microcontroller to make a switching signal.

Controller board:

• By using controller board PWM pulses are generated. PIC controller is used to generate the pulses. 5V DC supply is given to the PIC controller board. Generated PWM will be below 5V. To operate the MOSFET need to give 9-12V pulses. Driver circuit is used here to increase the pulses amplitude.

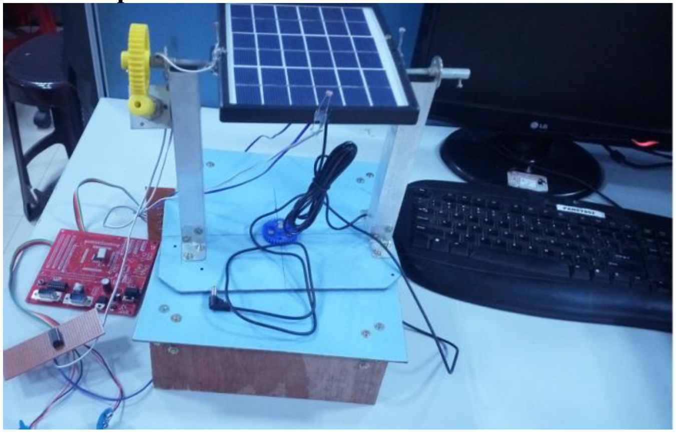
Driver circuit:

• To driver circuit below 5V pulses are given. Role of the driver circuit is Amplification and isolation. Transistors are used to amplify the pulses and optocoupler IC is used to provide the isolation between main circuit and controller circuit. 12V supply is individually used to operate the transistors and optocoupler.



Sepic circuit

Solar setup



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