

Design and implementation of Smart Relay Based Two-axis Sun Tracking System

Dr. jawad Radhi Mahmood
Dept. of Electrical Engineering
University of Basrah
Basrah, Iraq
Jr_alamiri@yahoo.com

Haider Muhammed
Dept. of Electrical Engineering
University of Basrah
Basrah, Iraq
Haider_5566@yahoo.com

Abstract— Solar power is environment friendly power source, but it is characterized by being highly dependent on the irradiation level witch is function of the sun position in the sky. To overcome this situation and extract maximum power from the sun, the PV array must be kept nearly perpendicular to the sun during the daytime.

In this paper, a smart relay based sun tracking system has been designed and implemented to keep the PV array perpendicular to the sun during the day hours.

1. INTRODUCTION

Current trends in electric energy generation are moving towards the utilization of the environment friendly sources of energy, represented by the wind and solar energy ones as a supplementary energy resources. The solar based one is the more attractive because it is characterized by being free, incur no fuel cost, abundant, limited less, distributed all over the world, pollution free, and require little maintenance.

Every day, the sun rises in the east, moves across the sky, and sets in the west. If one could get a solar cell to turn and look at the sun all day hours, then it could receive the maximum amount of sunlight possible and convert it into the more useful energy form (electricity). The current of the solar module is very sensitive to the isolation of the sun. Small tilt in the solar module make the current drop rapidly. At each hour, the earth rotates 15 degree about its axis [1], therefore the solar module must be tilt 15 degree every hour to make line of sight with the sun otherwise the output power of the module decreases.

To get the maximum from the sun, many tracking techniques have been developed and still are being developed. [2,3,4,5,6].

2. PHOTOVOLTAIC CELL OPERATION AND CHARACTERISTIC

Photovoltaic cell consists of semiconductor material, which converts sunlight into DC current using the photovoltaic effect. The conversion process passes through two phases. In the first phase, absorption of sun light generates an electron-hole pairs. In the second phase, the electron and holes are separated (by the internal electric field) to the negative and positive terminal thereby generating electrical power [7].

2.1 PHOTOVOLTAIC CELL EQUIVALENT CIRCUIT AND MATHEMATICAL MODEL

The most general model is the one so called one diode model . This model is shown in Fig.1[8]. It consists of current source (directly proportional to solar irradiation), diode (stands for the intrinsic P-N junction), shunt resistance (R_{sh}), and series resistance (R_s).

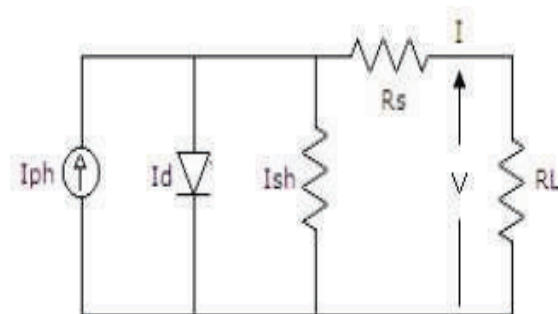


Figure 1. The equivalent circuit of a solar cell

Where I and V stand for terminal current and voltage respectively of the solar cell, I_{ph} is the light generated current, I_d is the diode current, R_s and R_{sh} are the series and parallel resistances of the cell.

The mathematical model which relates the various parameters of the equivalent circuit is given by the following expression:

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

$$I_{ph} = \frac{I_{scr} * [1 + \alpha * (T_c - T_r)] * S}{S_r} \quad (2)$$

$$I_d = I_o \left[e^{\frac{q * (V + I * R_s)}{A * k * T}} - 1 \right] \quad (3)$$

$$I_o = I_{or} * \left(\frac{T}{T_r} \right)^{\frac{3}{A}} * e^{\left[\left(\frac{q * E_g}{k * A} \right) * \left(\frac{1}{T_r} - \frac{1}{T_c} \right) \right]} \quad (4)$$

$$I_{sh} = \frac{V + I * R_s}{R_{sh}} \quad (5)$$

$$I = I_{ph} - I_o * \left[e^{\frac{q * (V + I * R_s)}{A * k * T}} - 1 \right] - \frac{(V + I * R_s)}{R_{sh}} \quad (6)$$

Assuming high R_{sh} , equation 6 can be rewritten as:

$$\frac{(I_{ph} - I + I_o)}{I_o} = e^{\frac{q * (V + I * R_s)}{A * k * T}} \quad (7)$$

$$\frac{q * (V + I * R_s)}{A * k * T} = \ln \left(\frac{I_{ph} - I + I_o}{I_o} \right) \quad (8)$$

$$V = \frac{A * k * T}{q} * \ln \left(\frac{I_{ph} - I + I_o}{I_o} \right) - I * R_s \quad (9)$$

Where α is the current-temperature coefficient, T_c is the cell operating temperature, T_r is the reference temperature, S is the solar radiation, S_r is the reference solar radiation, q is the electron charge, A is the ideality factor, k is Boltzman constant, I_o is the diode saturation current, I_{or} is the diode reference saturation current, and E_g is the band gap power.

2.2 PHOTOVOLTAIC ARRAY MATHEMATICAL MODEL

The photovoltaic array takes the structure shown in Fig.(2). As it is clear, it consists of N_p parallel connected strings, where each string consists of N_s series connected photovoltaic cells.

Applying Kirchhoff's current law:

$$I = N_p * I_{ph} - N_p * I_d \quad (10)$$

$$I_d = I_{ph} - \frac{I}{N_p} \quad (11)$$

$$I_o * \left[\left(e^{\frac{q * V_d}{A * k * T_c}} - 1 \right) \right] = I_{ph} - \frac{I}{N_p} \quad (12)$$

$$I_o * e^{\frac{q * V_d}{A * k * T_c}} = I_{ph} - \frac{I}{N_p} + I_o \quad (13)$$

$$\frac{q * V_d}{A * k * T_c} = \ln \left(\frac{I_{ph} - \frac{I}{N_p} + I_o}{I_o} \right) \quad (14)$$

$$V_d = \frac{A * k * T_c}{q} * \ln \left(\frac{N_p * I_{ph} - I + N_p * I_o}{N_p * I_o} \right) \quad (15)$$

$$\text{But } V_d = \frac{V}{N_s} + \frac{I * R_s}{N_p} \quad (16)$$

$$V = \frac{N_s * A * k * T_c}{q} * \ln \frac{N_p * I_{ph} - I + N_p * I_o}{N_p * I_o} - \frac{I * R_s * N_s}{N_p} \quad (17)$$

$$V = \frac{N_s * A * k * T_c}{q} * \ln \left(1 + \frac{N_p * I_{ph} - I}{N_p * I_o} \right) - \frac{I * R_s * N_s}{N_p} \quad (18)$$

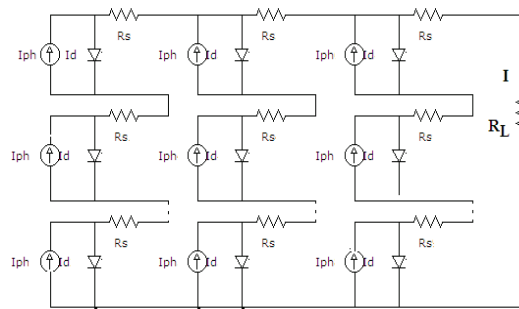


Figure 2. Photovoltaic array structure.

2.3 PHOTOVOLTAIC CELL BEHAVIOUR AS A FUNCTIONS OF SOLAR IRRADIATION

From equations (2) to (18), it is seen that the PV characteristic is function of the level of solar irradiation and cell temperature.

Fig.(3) declares that the output power of the PV array increases as the solar irradiation increases. The open circuit voltage slightly decreases as the irradiation increases. The short circuit current is largely increases as the irradiation increases.

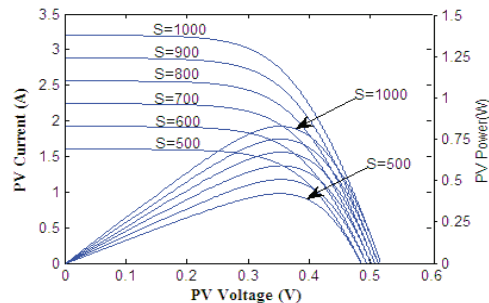


Figure 3. I-V characteristic and P-V characteristic under different irradiation..

3. PROPOSED SUN TRACKING SYSTEM

The proposed tracking system is shown in Fig.(4) and its functional block is shown in Fig.(5). It consists of sensing unit, smart relay based processing unit, and two single phase induction motor based driving units..



Figure 4. Prototype image.

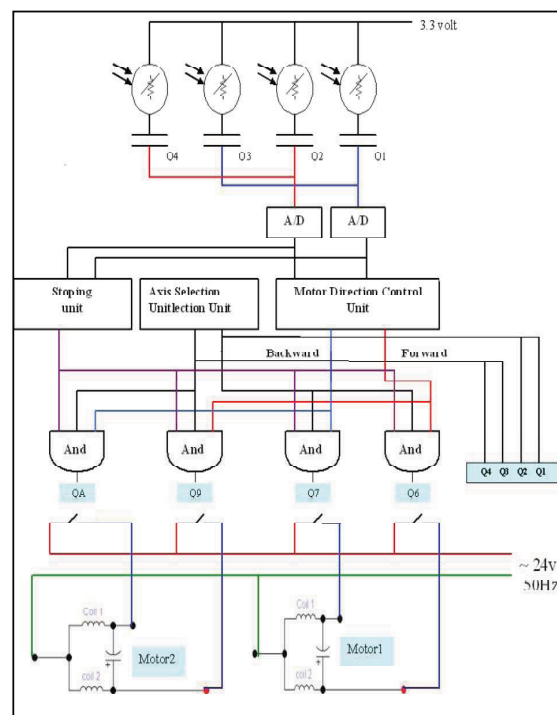


Figure 5. Functional block of the proposed tracker.

3.1 PHOTO-RESISTOR BASED SENSING UNIT

This unit involves four cadmium sulfide photo resistors arranged as shown in fig.(6). R1 and R3 are dedicated to monitor the sun travel from east to west during the day, where as R2 and R4 are dedicated to monitor the movement from north to south during the seasons of the year. In this unit, each photo resistor produces a mA current signal proportion to the incident light on its surface.

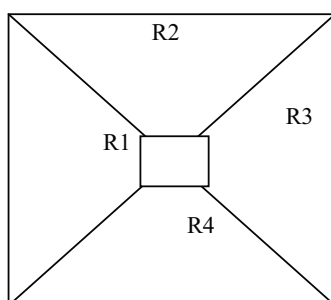


Figure 6. Sensing resistors distribution.

3.2 THE PROCESSING UNIT

This one is the brain of the tracking system. It consists of a Schneider SR3B261BD smart relay and SR3XT43BD A/D extension unit. The A/D extension unit involves two analog to digital conversion channels. The smart relay has been programmed (using function block diagram language shown in Fig.(7)), to achieve three functions. These are, the axes selection, motor direction control, and the stopping.

3.2.1 AXIS SELECTION FUNCTION

This function block allows the smart relay CPU to evaluates the axis sensors and determine the direction of rotation. Every 15 minutes, it manipulates the horizontal axis first and then the vertical one.

3.2.2 TRACKING STOPPING UNIT

This one has been added to stop the tracking process during night and low light hours. When the current output of the sensors are less than a certain level, this unit forces the driving motors to be in off states..

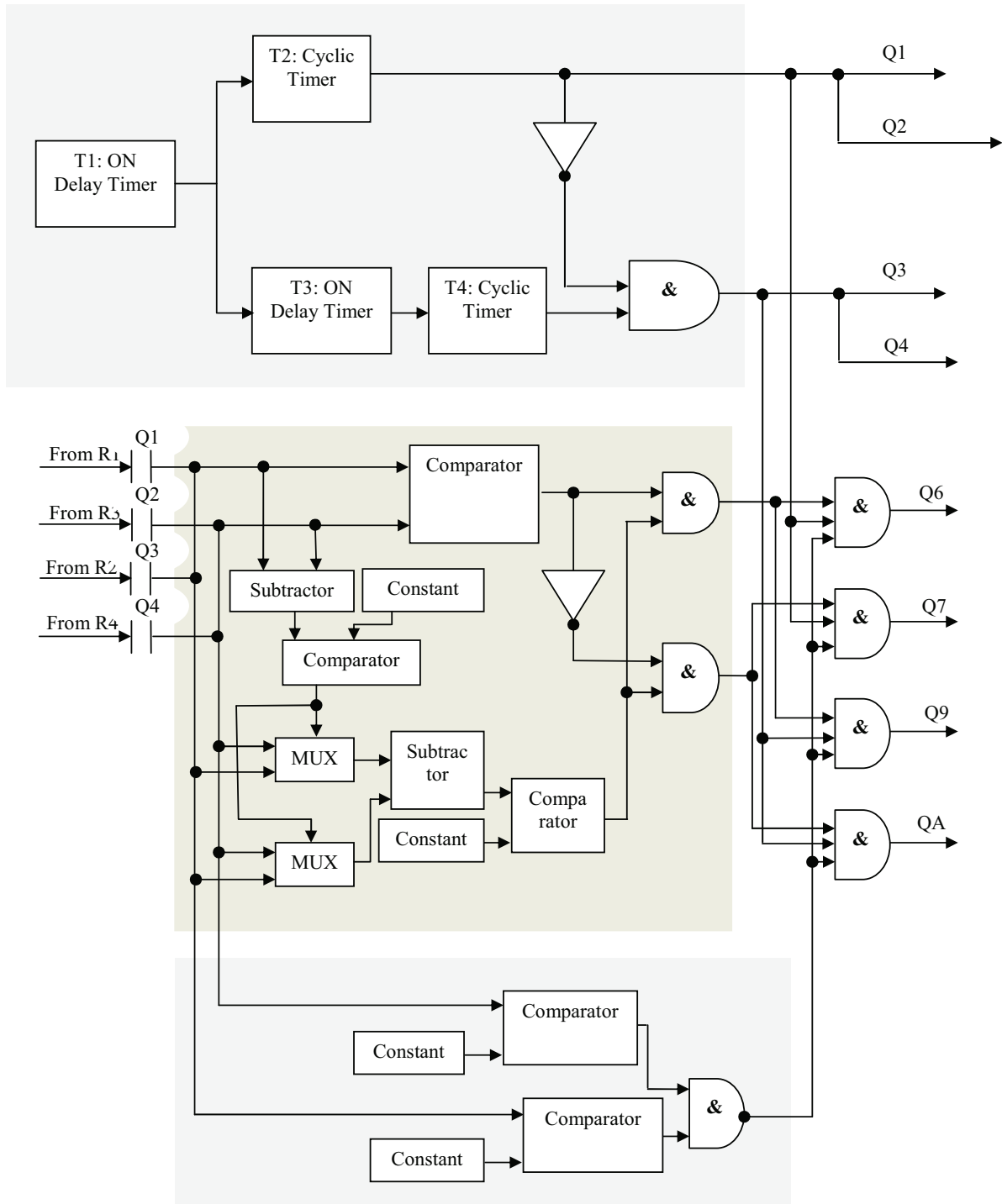


Fig.(7): Function block diagram representation of the control algorithm proposed.

3.2.3 MOTOR DIRECTION UNIT

This one is responsible for driving the solar panel in the direction of the sensor for which the current signal is the maximum one through issuing the correct direction command,

4. RESULTS

In this paper, smart relay based controller (SR3B261BD) has been used to control the motion of two-axis sun tracking surface. The present study was conducted to monitor the performance of the system and measure the power on moving photovoltaic module in **Iraq, Basra**. The results are compared with stationary solar panel and also with single axis sun tracker tilt by (45°). Preliminary measurements indicated that the use of two axis sun tracker would increase daily energy (**42%**) more than the stationary solar panel and (**1%**) more than the single axis. The designed system operates smoothly with precise positioning about (7.5°) per half hour. Fig. (8) shows the measured time functions of power, voltage, and current for stationary PV module and Fig.(9) shows that under two axis sun tracker.

5. REFERENCES

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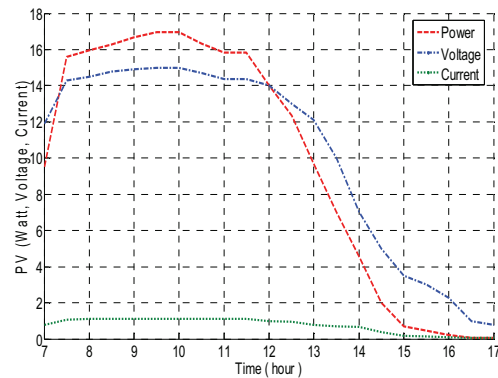


Figure 8. Measured time functions of power, voltage, and Current of stationary PV.

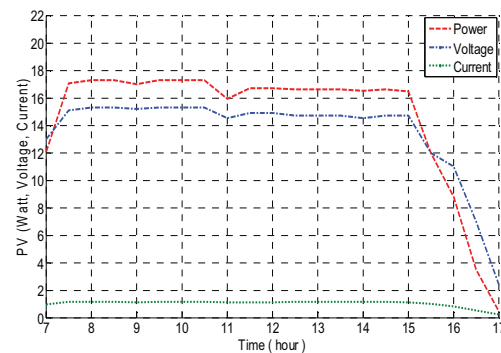


Figure 9. Measured time functions of power, voltage, and current of two-axis sun tracker.