

# Optimum Design and Implementation of Stand-alone Tracking Photovoltaic Power System based on PLC and Microcontroller

Prof.Dr. Osama Gouda

Department of Power Engineering  
Cairo University  
[d\\_gouda@yahoo.com](mailto:d_gouda@yahoo.com)

Assoc. Prof.Dr. Ghada Amer, Dr.Tamer Elkhodary  
Eng. Mohammed Awaad

Department of Power Engineering  
Benha University  
[Dr\\_ghada11@hotmail.com](mailto:Dr_ghada11@hotmail.com) , [Tamer18@hotmail.com](mailto:Tamer18@hotmail.com) ,  
[awadbhit@yahoo.com](mailto:awadbhit@yahoo.com)

**Abstract** - In order to increase the efficiency of PV system, it is generally used three methods, the first is the increasing of the solar cell efficiency, the second is the energy conversion system included MPPT control algorithm and the third is the using solar tracking system. In solar tracking system, it is used DC motors, special motors like step motors, servo motors, real time actuators, to operate moving parts. DC motors are normally used to operate solar tracking system but it is highly expensive to maintain and repair. In this paper, solar tracking system is proposed. Proposed system designed as the normal line of the solar cell always runs parallel the ray of the sun. This paper presents the development of an effective approach for design, simulation and control of a Stand-alone Photovoltaic (PV) power system elements which are; proposed solar tracking system uses DC motor which is controlled by a program made by Programmable Logic Controller (PLC), a battery charger controller which is programmed by a microcontroller. Finally, a comparison between fixed PV power systems and a tracking PV power system is made.

**Index Terms**- Renewable energy, PLC, Tracking photovoltaic system.

## I. INTRODUCTION

Due to accessibility and lower cost of renewable energy resources in deserted and far-flung areas, as compared to the conventional solutions, their applications in standalone systems have been increasing. Considering the rapid consumption of fossil energy sources, the hybrid renewable systems are about to have great share in future's energy supply [1]. Alternative energy sources are inherently non-polluting, free in their availability, and continuous [2]. However, their applications in conventional distribution systems are limited due to high initial cost and reliability issues [3-22]. An easy and effective approach in utilizing solar energy is to convert it directly to electrical energy using Photovoltaic (PV) technology [4]. According, it is anticipated that PV systems will become one of the main energy recourses to fulfill the global energy requirement by the end of this century [5]. Other methods such as wind power plants, fuel cells batteries, and solar-heat plants are also considerable and are usually combined with PV units in order to increase system reliability [6]. An important and growing concern has been used to

design and control renewable hybrid systems. Different methods for modeling and controlling power production systems are possible by combination of two or more renewable energy systems [7]. The most important and considerable issues about these environmentally friendly systems are their cost and reliability [8]. Nowadays the PV and wind generators are widely use in many applications such as water pumping, illumination [9], electricity supply in outlying areas [10] and supplying communication systems. To include power shortage capability, diesel generators may be used in parallel [11]. Considering the importance of synchronized operation between diesel generators and renewable supply system, the maintenance costs will be noticeable [12]. However, utilization of renewable hybrid systems offers more reliability than diesel generators, photovoltaic or wind systems [13].

This paper presents an effective methodology for design a control system of photovoltaic systems including their planning and analysis. A PLC program is proposed to control the drive signal of a special DC motor, which has a position sensor inside it, in order to obtain a maximum solar tracking. The tracking experimental model system is designed and built. The system was designed as the normal line of the solar cell always runs parallel the ray of the sun.

## II. CONTROLLED ELEMENTS

The entire system was built is shown in Fig.1. It will be handled in details as the following:

### A. Configuration of Solar tracking system

Solar tracking system consists of a solar cell which is tracking the beams of the sun by a DC motor which contains a position sensor. This position sensor gives a certain number of pulses during the movement of the solar cell from the east, as the starting point (zero degree), to the west (180 degree) as stopping point. When counting this number of pulses, it is found to be equal to 833 pulses. The solar tracking system is designed as the normal line of the solar cell always runs parallel the ray of the sun.

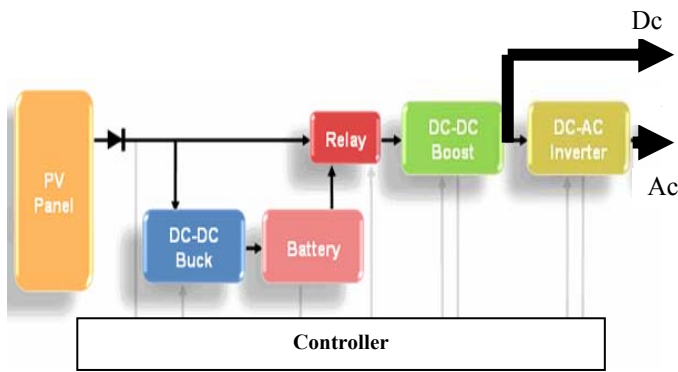


Fig.1 Complete stand-alone photovoltaic power system component

This is done by (1) Adjusting the surface azimuth angle  $\gamma=0^\circ$  when facing the south and (2) The slope of the incident plane with the horizontal  $\beta$  is controlled by moving the DC motor every half an hour by 9 degrees. The motor is moved by control of PLC program. This number of degrees is calculated considering that the system is operated from 7 o'clock AM to 5 o'clock PM (it means that the system operates ten hours daily). So the number of pulses each half hour = 31 pulses and this corresponding to 9 degrees. When the system reaches the 5 o'clock PM, it returns back to the starting point by using a timer. The timer counts the night hours (from 5 o'clock PM to 7 o'clock AM) and then begins to operate the system again for the next day and so on. After moving the cell every 9 degrees, the output voltage of the cell is recorded on the PC via parallel port by MATLAB designed program.

The flow chart of the suggested designed solar tracking system controller algorithm is given in figure (2) where FWD is forward direction and BWD is backward direction.

Fig.3 shows the practical drive circuit of solar tracking controller which consists of two parts;

The first part of the circuit is used to adjust the output of the sensor to be sinusoidal wave with amplitude 1volt P-P. Then this sinusoidal wave entered to an operational amplifier with gain 10 to amplify the signal from 0.5 v to 5 v and then the negative half wave is cut by the diode (D<sub>4</sub>) which allows only the positive half wave to pass. Then entered to a Schmitt trigger which converts the output to pulses and this will be the input to the PLC which counts these pulses.

The second part of the circuit is H Bridge supplied from a 30V dc source and its load is the dc motor. When the relays (K<sub>1</sub> and K<sub>4</sub>) operate, the motor will rotate in clock wise direction and when the relays (K<sub>2</sub> and K<sub>3</sub>) operate, the motor will rotate in counter clock wise direction.

When making run to the PLC program, it has been waited half an hour before the motor is operated in forward direction and at the same time, the number of sensor output pulses is counted. When 31pulses is counted, the motor is stopped and another half an hour will be waited. The program is repeated until the sunset is reached. The number of motor operations is counted by a counter to know the reach to the sunset (180<sup>0</sup>).

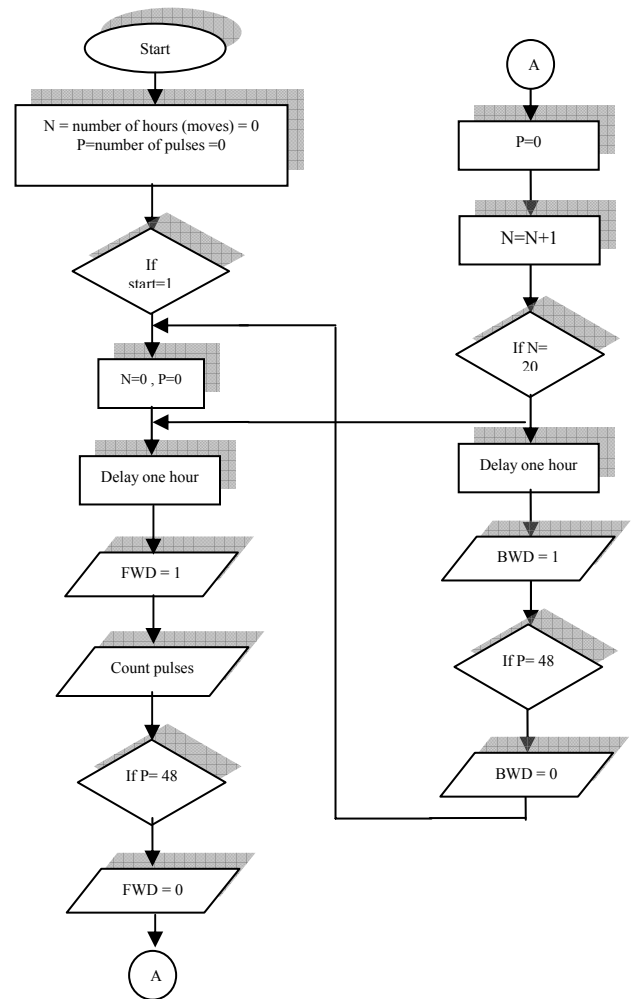


Fig.2 Flow chart of the suggested solar tracking controller algorithm

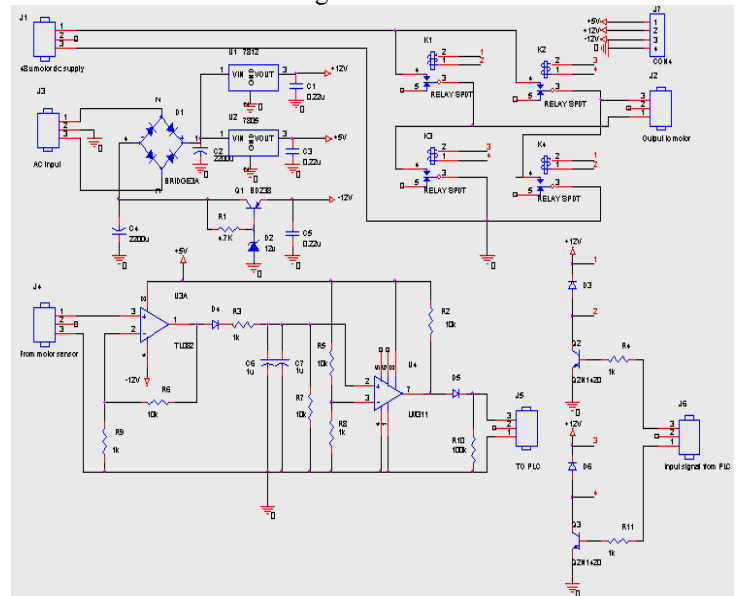


Fig.3 Practical Drive circuit of solar tracking controller

The output of the solar cell is converted to digital signal by analog to digital converter circuit. The digital signal is sent to MATLAB program via parallel port. The output of the solar cell is recorded on the computer each half an hour through a MATLAB program.

## B. Design of the DC/DC Boost Converter

The DC/DC converters are widely used in regulated switch mode DC power supplies. The input of these converters is an unregulated DC voltage, which is obtained by PV array and therefore it will be fluctuated due to changes in radiation and temperature. The DC/DC boost converters are used for the detection and tracking of the point of maximum power produced by PV solar cells module. In these converters the average DC output voltage must be controlled to be equated to the desired value although the input voltage is changing.

The primary criterion for selecting the output filter capacitor is its capacitance and equivalent series resistance, ESR. Since the capacitor's ESR affects efficiency, low-ESR capacitors will be used for best performance. For reducing ESR is also possible to connect few capacitors in parallel. The output filter capacitors are chosen to meet an output voltage ripple specifications, as well as its ability to handle the required ripple current stress. An approximate expression for the required capacitance as a function of ripple voltage requirement,  $\Delta V_o$ , Duty cycle D, switching frequency,  $F_s$  and output voltage,  $V_o$  is given as [15-16]:

$$C_b \geq \frac{V_o * D}{F_s * \Delta V_o * R}$$

## C. Battery Charge Controller

A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries.[17] It prevents overcharging and may prevent against over voltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life.[18,19] The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery recharge. Figure (6) shows the circuit of charge controller. This battery charger is controlled by microcontroller (80C51).[20]

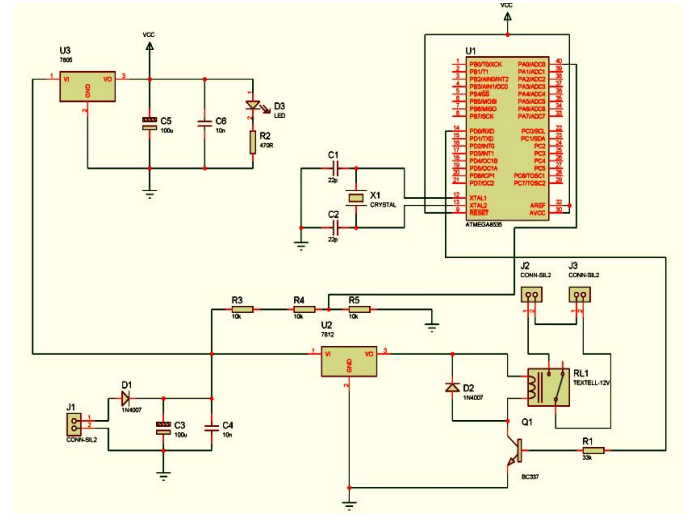


Fig. 6 shows the circuit of charge controller

## D. Solar Power Inverter

A Solar inverter or PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances and possibly a grid. Stand-alone inverters, used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays and/or other sources, such as wind turbines, hydro turbines, or engine generators. There are two configurations for single phase inverter:

- (1) DC to AC half bridge inverter.
- (2) DC to AC Full bridge inverter.

The Inverter output voltage is:

$$V_1 = \frac{m}{2} * V_{dc \text{ peak}}$$

Where:  $V_1$  : fundamental output voltage  
 $m$  : Modulation index  
 $V_{dc \text{ peak}}$  : Peak Dc link

Included as part of the inverter power stage are filter inductors that are placed in series with the three phase outputs of the power stage. The purpose of the inductors is to filter the switching components out of the output currents of the inverter. [21].

$$L_f = \frac{V_{dc} - V_{ab \text{ pek}}}{f_s * \Delta i}$$

Where:  $V_{ab \text{ pek}}$  = peak line to line voltage (v)  
 $F_s$  = Switching frequency (Hz)  
 $\Delta i$  = peak ripple current

### E. Hourly load demand, (kW)

Samples of the daily load curves through the year are given in figures (7),(8),(9),(10) . The figures show the hourly PVBS output power for the recommended day of four months January, April, July and October. This data is associated with Hurgada site.

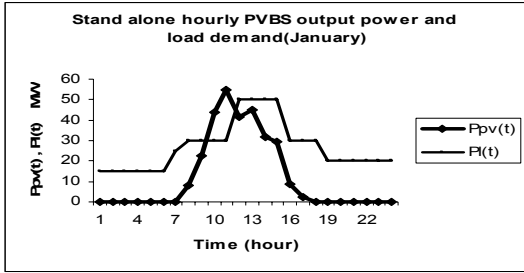


Fig.7 shows hourly PVBS output power and load demand for January.

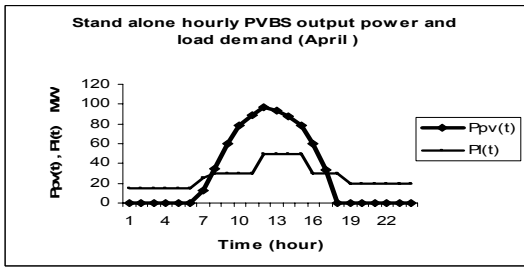


Fig.8 shows hourly PVBS output power and load demand for April.

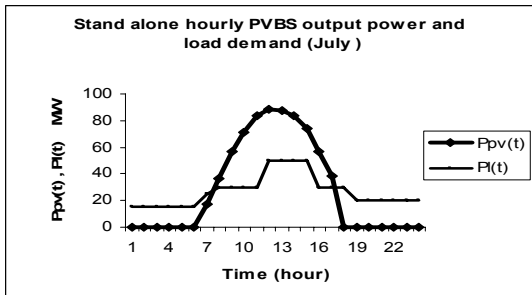


Fig.9 shows hourly PVBS output power and load demand for July.

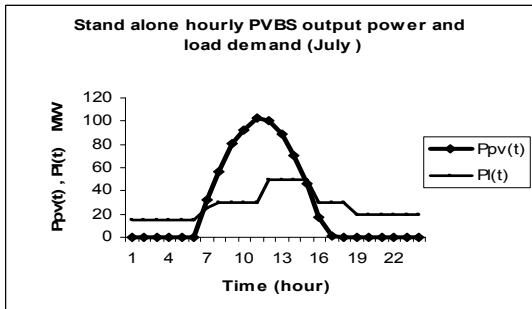


Fig.10 shows hourly PVBS output power and load demand for October.

The hourly output power is calculated and compared with load demand as shown in figures (7),(8),(9),(10). Calculations are done for these months according to the recommended average day for each month [22].In 17<sup>th</sup> January, the output

hourly power of PVBS is calculated and it is found to be greater than the load demand in the period from (10 AM to 11AM). This power is called surplus power. In 15<sup>th</sup> April, the surplus power period is from (8 AM to 6 PM) .In 17<sup>th</sup> July; the surplus power period is from (8 AM to 5 PM). In 15<sup>th</sup> October, the surplus power period is from (7 AM to 2 PM). This surplus power can be stored in the batteries.

### F. Number of inverter units

- Total number of inverter units required to cover the load demand;

$$P_{in} = \frac{P_{io}}{\eta_{inverter}} \quad (\text{input power for inverter})$$

$$I_{in} = \frac{P_{in}}{V_{in}}$$

Number of modules connected in series to make one string

$$\text{gives } V_{in} (N_1): N_1 = \frac{V_{in}}{V_m}$$

$$\text{Number of strings per inverter } (N_2): N_2 = \frac{I_{in}}{I_m}$$

$$\text{Total number of modules per inverter } (N_3): N_3 = N_1 * N_2$$

$$\text{Total inverters needed for PVBS } (N_{Tinverter}):$$

$$N_{Tinverter} = \frac{RSCA}{N_3 * ModuleArea}$$

Where:

$V_m$ : is the module DC voltage at maximum power point.

$I_m$ : is the module DC current at maximum power point.

RSCA: is the required solar cell area.

The Characteristics of the selected inverter are shown in table (1).

Table (1) Characteristics of the selected inverter

Rating	Efficiency $\eta_{in}$	Input voltage $V_{in}$ (dc)	Maximum distortion
500kW	95%	2000 $\pm$ 10%	$\pm$ 5%

The Number of inverters which is needed for the PVBS, TNOIN, can be estimated as follows:

$$TNOIN = \frac{SSCA}{N_3 * Module area}$$

Where:

$N_3$  : The number of PV modules needed for each inverter unit

SSCA: sufficient solar cell area

The module used in this thesis (HIP 200-BA3) solar cell type so the obtained TNOIN is 21inverter

### G. Calculation of battery storage size

The battery storage size which can be integrated with PV is designed to charge the surplus energy during high insolation

period and being discharged to feed the load demand throughout the low insulation periods.

$$BD_s = \frac{B_V}{\eta_B} \text{ KWh}$$

$$B_V = \sum_{t=t_1}^{t_2} (P_{PV}(t) - P_L(t) * PLV) \text{ KWh}$$

There is another part of battery storage is needed to meet the night critical loads.

$$BN_s = \frac{(\text{Night and critical loads} * PLV)}{\eta_B} \text{ KWh}$$

Then total battery size:  $B_s = BD_s + BN_s$

Where:

$BD_s$  : Day size of battery.

$\eta_B$  : Battery efficiency.

$BN_s$ : Night size of battery.

### III. Experiment model results

Figure (11) shows the solar tracker picture of the tracking model built.



Fig.11 shows the solar tracker picture

Figure (12) shows the practical drive circuit of solar tracking controller.

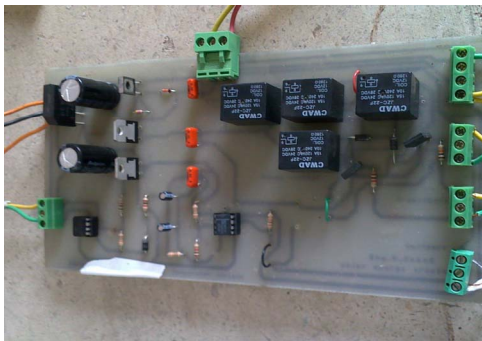


Fig. 12 solar tracking circuit

The output voltage of photovoltaic tracking system is compared with the fixed one as shown in figure (13). As shown in this figure the tracking system gives almost constant output voltage during all the time operation but it is not the same obtained voltage when the system is fixed which the voltage varies with time.

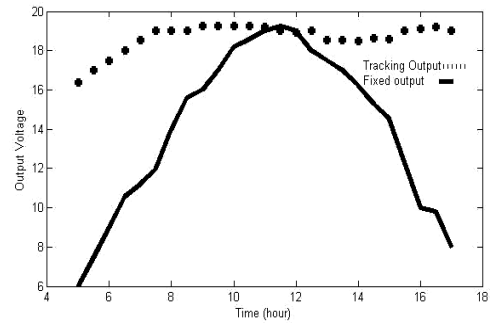


Fig.(13) the output of tracking and fixed solar cell

Figure (14) shows sensor output signal .The modified sensor signal is given in figure (15).

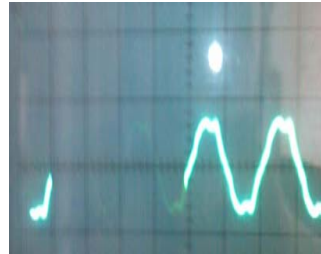


Fig.14 Sensor output signal

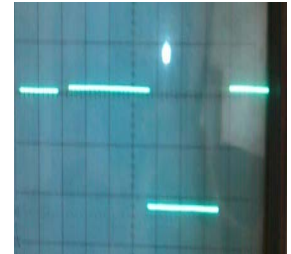


Fig.15 Sensor modified signal

Figure (16) shows the data acquisition card (ADC0804) and figure (17) shows data acquisition card connected to computer via parallel port.



Fig.16 Data acquisition card (ADC0804)



Fig.17 Data acquisition connected to computer

Figure (18) shows PLC connected to tracking motor and drive card .



Fig. 18 PLC connected to tracking motor and drive card



Fig.19 solar Inverter used.

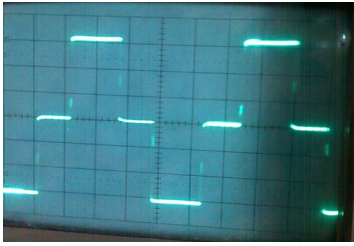


Fig.20 solar inverter output voltage (R load)

Figure (19) solar inverter used in the implemented system and figure (20) shows the inverter output voltage for resistive load.

#### IV. Conclusions

In this paper, it is proposed to develop a solar tracking system. The system was designed as the normal line of the solar cell and always moves to parallel the ray of the sun. A new PLC program has been proposed for solar cell sun tracking. Also a new computer (MATLAB) program has been proposed for storage of the photovoltaic array output voltage on computer via parallel port. Finally the tracking of the sun gives maximum power for solar photovoltaic cell this make the system more reliable. The suggested model can be used in large scale for best utilization of solar energy.

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