Design and implementation of a Smart PV Generation System using Proteus Software

K.M. Abo-Al-Ez, A. Y. Hatata, M.S. Kandil

Abstract— Smart Grids are intelligent power networks that utilize resources efficiently and involve a greater degree of remote and automatic processes than previously. Future smart grids will have an increased amount of renewable energy systems. The solar energy systems will have a considerable share of the future energy market. Accurate design of the photovoltaic (PV) system is essential for reliable and controllable operation within the smart grids. The smart and efficient operation of a PV generation system for both off-grid and grid-connected operation requires four main functions that need to be developed accurately. These functions include: the solar tracking system, the DC-DC converter with maximum power point tracking (MPPT) algorithm, the battery control charger, and the DC-AC power inverter controller. This paper presents the design and simulation of a smart PV generation system using proteus software. According to the proposed design a practical system is built and connected to a PV panel. Different measurements are taken or different radiation levels. A comparison between measurement and simulation results shows a very good agreement.

Index Terms— PV, maximum power point tracking, DC-DC converter, proteus software.

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1 INTRODUCTION

In recent years, there is unprecedented interest in renewable energy sources which provide electricity without giving rise to any carbon dioxide emission. PV cells, wind generators, biomass plants and fuel cells represent the most interesting and practical renewable energy systems. Solar energy is an attractive option because of its reliability and availability. Egypt is a lucky country, because it has shining sun during summer and winter, therefore the incident radiation must be used for environmental and economic trends. PV generation system is static, quite, free of moving parts and these make it have little operation and maintenance costs. The system can be installed near or in load location and it has low environmental impact. The main applications of PV systems are either standalone systems as water pumping, domestic purposes, street lightening, military and space, or grid connected configurations. Accurate design of the photovoltaic system is essential for reliable and controllable operation within the future smart grids. The smart and efficient operation of a PV generation system for both off-grid and grid connected operation requires four main functions that need to be developed accurately: the solar tracking system, the DC-DC converter with maximum power point tracking (MPPT) algorithm, the battery control charger, and the DC-AC power inverter controller. This paper addresses the design issues of those components using the proteus software. A practical system is built and connected to a PV panel on the rooftop of the Labs building, located in the faculty of engineering, Mansoura University. The currents, voltage and power are measured for different radiation levels and at different temperatures. The practical characteristic curves are compared to the simulation ones to show the accuracy of the design.

2. Solar tracking system

Solar tracking is the process of sensing and following the position of the sun. Real-time tracking would be necessary to follow the sun effectively, so that no external data would be required in operation. The use of tracking technology allowing solar modules to follow the course of the sun optimizes the incident angle of sunlight on their surface and consequently improves their performance and increase electricity production [1], [2]. A tracking mechanism is often incorporated into the solar arrays to keep the array pointed towards the sun [1]. When compared to the price of the PV solar panels, the cost of a solar tracker is relatively low. Since the sun moves across the sky though the day, this is far from an ideal solution [2].

Fixed PV modules at the optimum angle typically yields an improvement of around 15% compared with simply laying them flat [3]. Trackers, on the other hand, adapt to both the daily passage of the sun and potentially the changing seasons too. The end user will prefer the tracking solution rather than a fixed ground system because the efficiency increases by 30 to 40% (more money) [4]. Sun-tracking systems are usually classified into two categories: passive (mechanical) and active (electrical) trackers [1]. Passive solar trackers are based on thermal expansion of a matter (usually Freon) or on shape memory alloys. Tests have shown that passive trackers are comparable to electrically based systems in terms of performance. Although passive trackers are often less expensive, they have not yet been widely accepted by consumers [4]. Major active trackers can be categorized as microprocessor and electro-optical sensor based, PC controlled date and time based, auxiliary bifacial solar cell based and a combination of these three systems. Electro-optical solar trackers are usually composed of at least one pair of ant parallel connected photo resistors or PV solar cells which are, by equal intensity of illumination of both elements, electrically balanced so that there is either no or negligible control signal on a driving motor [1].

The main components of solar tracking system, as explained in

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figure. 1, include: sensors, power supply, microcontroller, motor driver (H-bridge) and dc motor.

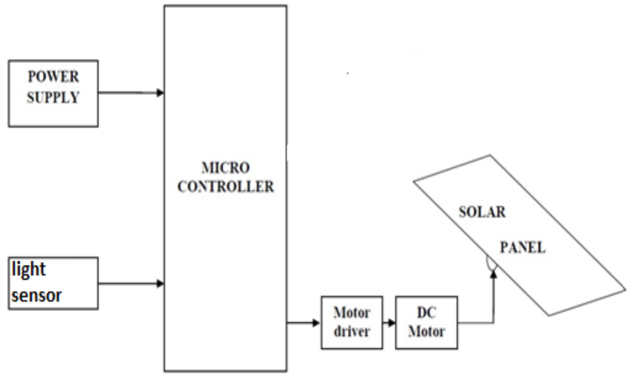


Fig.1 Solar tracking by light sensor

Motors are used to drive the solar tracker to the best angle of exposure of light. Some of the widely used motor types are: stepper motors, DC motors, and servo motors [1], [2]. There are different types of microcontrollers that can be used with solar tracking systems. Among these types, the PIC16F877A microcontroller based on the AVR enhanced RISC architecture is the widely used one [1]. This microcontroller is designed to optimize power consumption versus processing speed. The H-bridge is formed of MOSFETs, which are connected to relays. The relays are used to drive the motor. The relays are preferred because they use absolutely no current when the contacts are closed, and they use current only on the coils which trigger the closing when the solar cells produce a voltage. The integrated solar tracking system is built using proteus software. The system block diagram is shown in figure. 2.

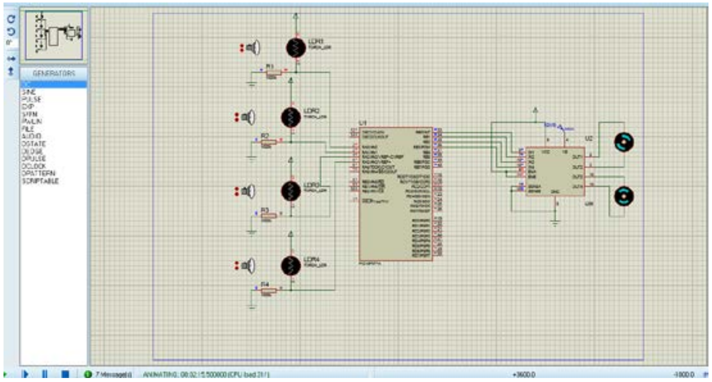


Fig.2 Simulation circuit of solar tracking system

3. DC-DC converter with MPPT

A buck DC-DC converter with maximum power point tracking (MPPT) is used in the proposed design. There are several maximum power point tracking methods that are used for PV system operation. Among those methods, the Perturb and Observe (P&O) method is the most widely used [5], [6]. In this method the controller adjusts the voltage by a small amount from the array and measures power, if the power increases, further adjustments in the direction are tried until power no longer increases [5]. The solar cell voltage is initially increased. If the output power increase, the voltage is continually increased until the output power starts decreasing. Once the output power starts to decrease, the cell voltage is decreasing until maximum power is reached. This process is continued until the MPP is attained. This results in an oscillation of the output power around the MPP, as shown in figure 3. A flowchart of the modified P&O algorithm is shown in figure 4 [6].

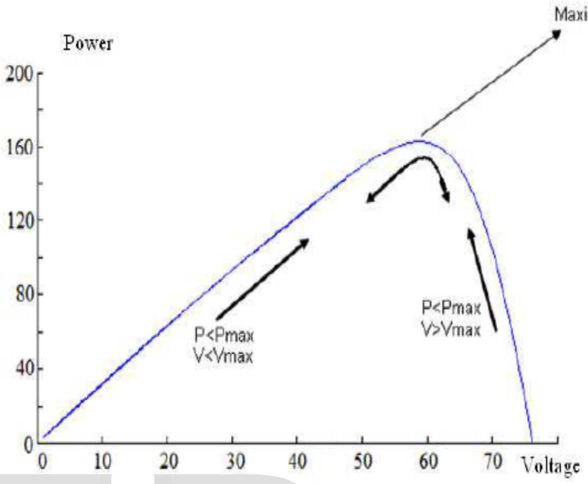


Fig.3 output power using P&O algorithm [5]

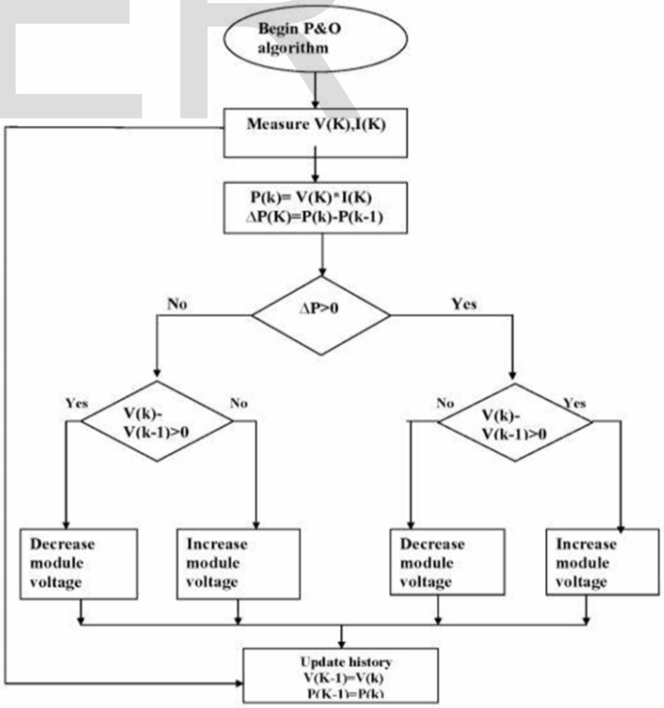


Fig.4 Perturb and observe (P&O) algorithm flow chart

In summary, the MPPT controller's function is to bring the voltage to the desired level and maintain it at that value. In this paper, the MPPT code is developed using proteus software, and the operational circuit model is shown in figure 5.

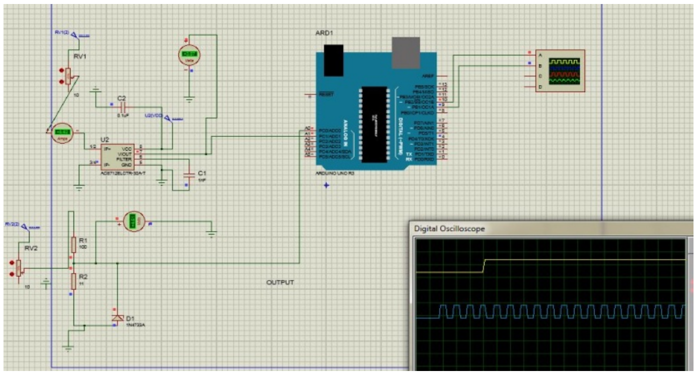


Fig.5 Operational circuit model of MPPT on Proteus

Due to battery charging purpose, a certain DC voltage at output terminals is required to be less than input one [7]. This voltage will be attained using a buck DC-DC converter. The following steps are performed to design that converter [8]:

1- Calculate Maximum Switch Current:

Maximum duty cycle: $D = \frac{V_{out}}{V_{in}}$

Inductor Ripple Current: $\Delta I = \frac{(V_{in(max)} - V_{out}) \times D}{f_s \times L}$

A good estimation for the inductor ripple current is 20% to 40% of the maximum output current:

$\Delta I_l = (0.2 \text{ to } 0.4) \times I_{out(max)}$.

Maximum switch current $I_{sw\,(max)} = \frac{\Delta I_l}{2} + I_{out(max)}$

2- Select Inductor:

$$L = \frac{V_{out} \times (V_{in} - V_{out})}{\Delta I_l \times f_s \times V_{in}}$$

Where f_s is switching frequency

3- Select Rectifier Diode :

To reduce losses, use Schottky diodes.

$I_f = I_{out(max)} \times (1 - D)$

4- Calculate power dissipation of the diode:

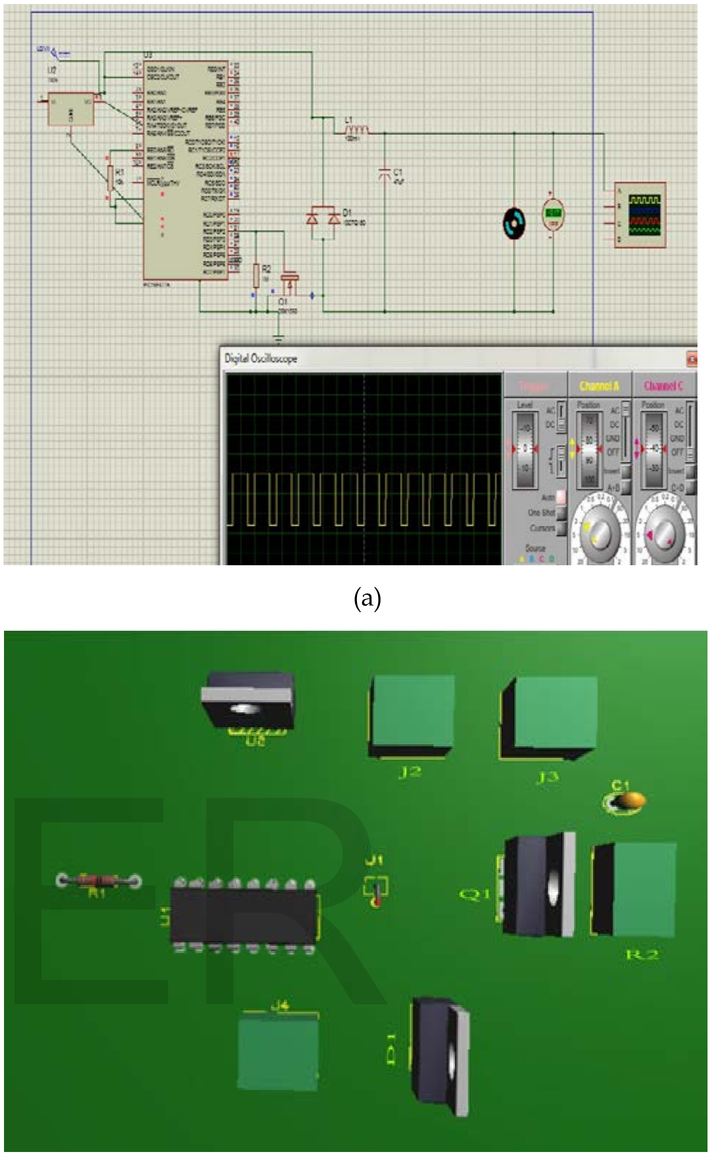
$P_D = I_f \times V_f$

5- Output Capacitor:

$$C_{out(min)} = \frac{\Delta I_l}{8 \times f_s \times \Delta V_{out}}$$

In this study we take V_{out} =240 V, and V_{in} =1000 V, so that the maximum duty cycle is equal to 0.24. The selected inductor is equal to 4.5x10-7 H, whereas the output capacitor is 2.4x 10^{-4} F. The power dissipation of the diode is found to be: 11.4 W

The buck DC-DC converter operation based on the previously mentioned design steps is also developed and simulated in proteus software, and the operational circuit model is shown in Figure 6. The components are assembled and a practical test is implemented. The test components are shown in Fig.7.



(a)

(b)

Fig.6 Design and simulation of a buck DC-DC converter using proteus

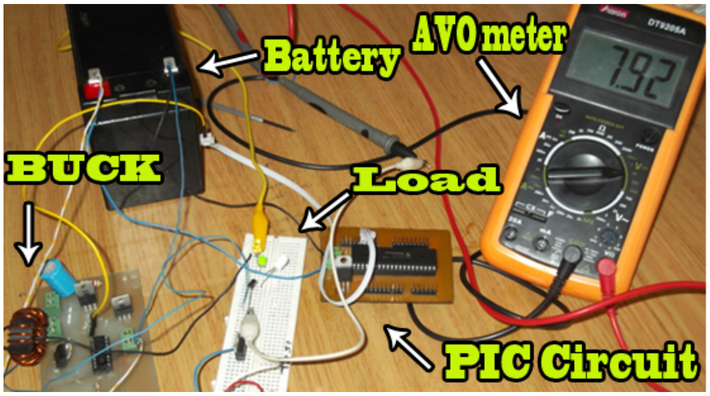


Fig.7 Buck DC-DC converter practical output

For many dc applications the operational load voltage is about 220V_dc. The PV panels cannot supply 220 V_dc in all cases, as the output may not be more than 50 volts. So boost DC-DC converter can be used to satisfy this case. To design a boost DC-DC converter, the following calculations are performed [8-9]:

1- Minimum Duty Cycle: $D_{min} = 1 - \frac{V_{i\,max}}{V_{o\,min}} = 60\%$

2- Maximum Duty Cycle: $D_{max} = \frac{V_{i\,min}}{V_{o\,max}} = 85\%$

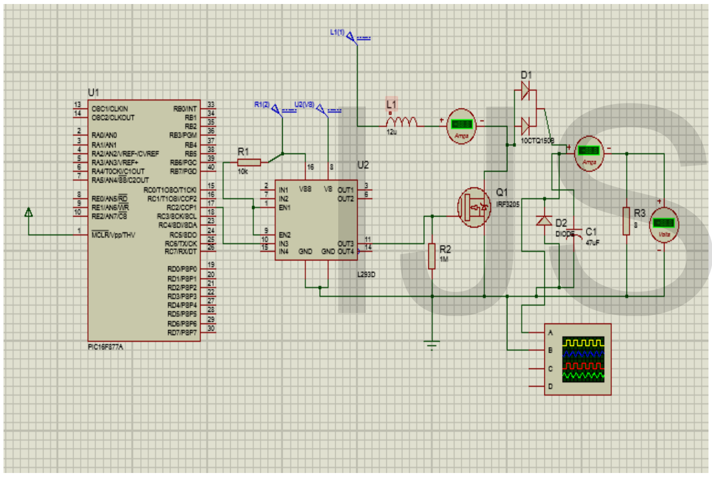
3- Minimum inductor size: $L = \frac{D * V_{in} * (1-D)}{2 * f * I_{out}} = 2304\ \mu H$

4- Peak inductor current: $I_{pk} = \frac{V_{in\,max} * D}{f * L} = 0.1333\ A$

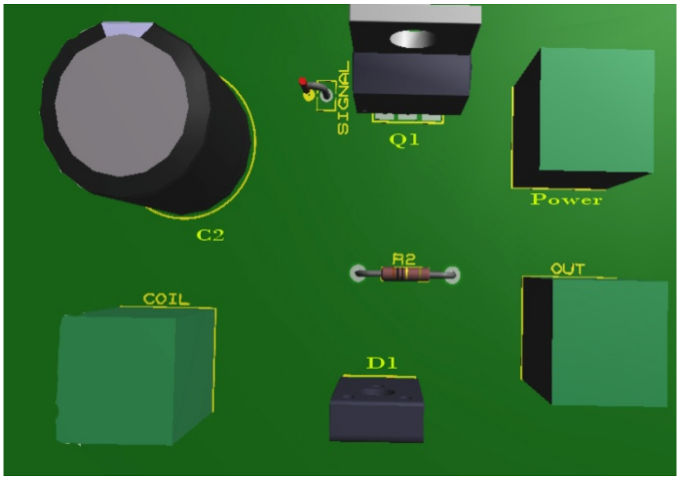
5- Minimum Capacitor: $C_{min} = \frac{I_{out}}{V_{ripple} * f} = 6.3999\ \mu F$

6- Minimum Schottky Diode: -60 V & 0.13 A

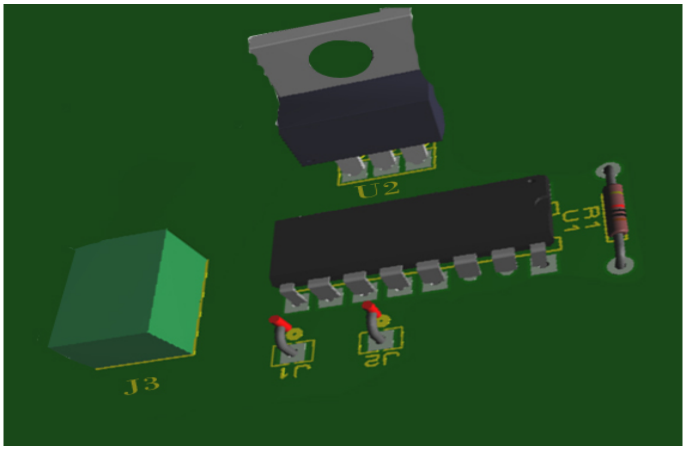
The boost DC-DC converter operation based on the previously mentioned design steps is also developed in proteus, and the operational circuit model as shown in figure 8. A practical test is developed based on the design as shown in figure 9.



(a)



(b) Boost Power Circuit



(c) Boost Control Circuit

Fig.8 Design and simulation of a boost DC-DC converter using proteus

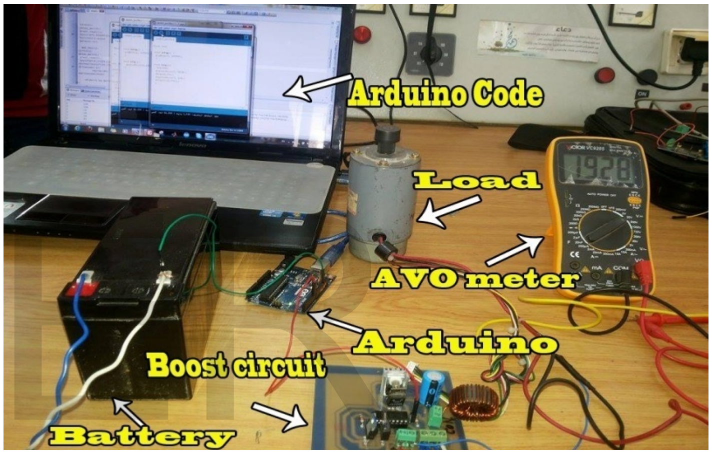


Fig.9 Boost converter practical output

The DC - DC converter is the basic component for regulating output power of PV cells. It regulates the voltage and current transferred from the solar panels to the battery. Most panels are designed at 12 volt, but the output is always between 16 and 20 volts. If there is no regulation the batteries may be damaged during overcharging. Most batteries need around 14 to 14.5 volts to get fully charged. For the batteries safety control chargers are required.

4. Battery control charger

A charge controller is an essential part of nearly all power systems that charge batteries. The function of a charge controller is to block reverse current and prevent battery overcharge. Some controllers also prevent battery over discharge, protect from electrical overload, and/or display battery status and the flow of power [10], [11]. Charge controllers come in three general types, with the Maximum power point tracking (MPPT) based charge controllers are the most common [12]. State of charge (SOC) estimation is a fundamental challenge for battery use. The SOC of a battery, which is used to describe its remaining capacity, is a very important parameter for a control strategy. As the SOC is an important parameter, which reflects the battery performance, so accurate estimation of the SOC can not only protect battery, prevent over discharge, and improve the battery life but also allow the application to make rational control strategies to save energy [13]. However, a battery is a chemical energy storage source, and this chemical energy cannot be directly accessed [14]. This issue makes the estimation of the SOC of a battery difficult. Accurate estimation of the SOC remains very complex and is difficult to implement, because battery models are limited and there are parametric uncertainties. Many examples of poor accuracy and reliability of the estimation of the SOC are found in practice [15]. The SOC is one of the most important parameters for batteries, but its definition presents many different issues. In general, the SOC of a battery is defined as the ratio of its current capacity to the nominal capacity. The nominal capacity is given by the manufacturer and represents the maximum amount of charge that can be stored in the battery [14]-[16].

The Coulomb counting method measures the discharging current of a battery and integrates the discharging current over time in order to estimate SOC. SOC is calculated by the following equation [17]:

$$SOC(t) = SOC(0) - \frac{1}{Ah_{nom}} \int_0^t I_m(t)dt$$

Where:

SOC(t) = the starting value of State of charge

Im(t) = the measured current.

There are several factors that affect the accuracy of Coulomb counting method including temperature, battery history, discharge current, and cycle life. The design and simulation using proteus is shown in figure 10.

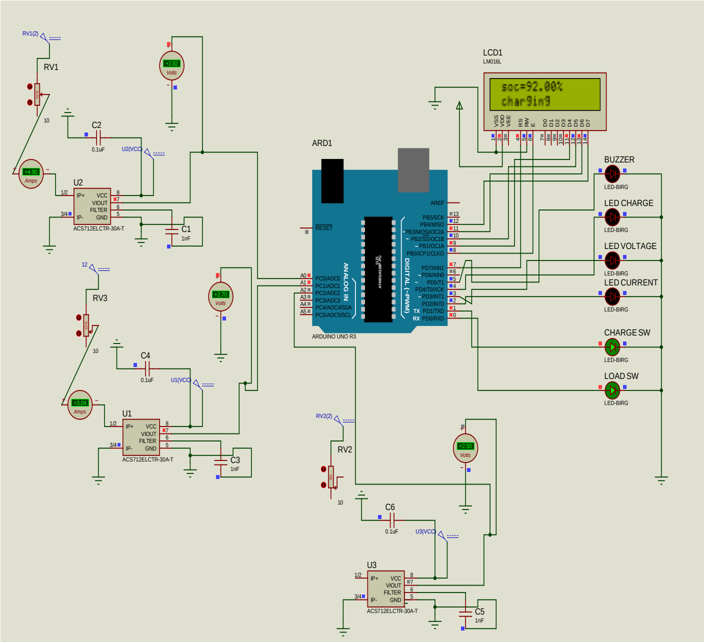


Fig.10 Design and simulation of the battery control charger

5. DC - AC Power Inverter

The main objective of static power converters is to produce an AC output waveform from a DC power supply. A voltage source inverter (VSI) is one that takes in a fixed voltage from a device, such as a dc power supply, and converts it to a variable-frequency AC supply. Voltage-source inverters are divided into three general categories: Pulse-width Modulated (PWM) Inverters, Square-wave Inverters, Single-phase Inverters with Voltage Cancellation and each one has its own characteristics and usage [7], [8]. Any power electronic circuits require some interface circuits for running the switches and control them easily. The used power electronic switches differ due to their ratings and simplicity of control. Inverter simulation is not simple like converter as it requires at least two pulses with some switching logic. Using proteus the inverter circuit and its controller is designed and tested as shown in figure 11. The practical circuit was built in the lab as shown in figure12.

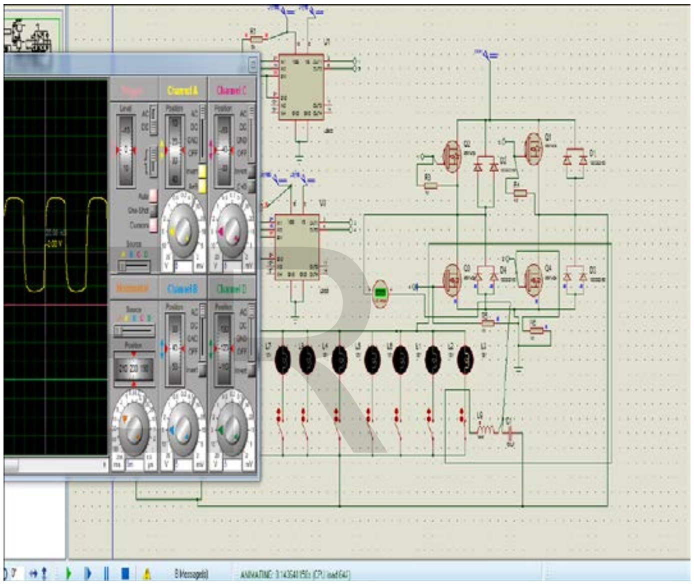


Fig.11 Design and simulation of the DC-AC inverter and its controller

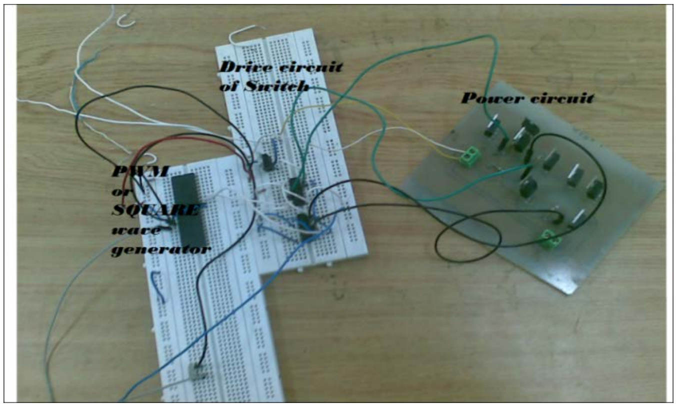


Fig.12 The practical inverter circuit.

The complete components of the smart PV generator operation was built and connected to the PV array. The P-V curves are drawn based on the measured data when using the PV array on the roof top of the electrical engineering laboratory building. The power and voltage are measured at the maximum power points for different solar radiations. A comparison between the measured voltages for different radiation levels and those obtained from the MATLAB simulation model is shown in Table 1 whereas the comparison between the power values of the two cases is shown in Table 2.

Table.1 Comparison between Measurements and Simulation Voltages (at temperature = 29°C)

Radiation (W/m^2)	Simulated using Matlab V_{mp} (V)	Measured V_{mp} (V)	Error %
1000	17.6	18.4	-4.35
900	17.4	18.3	-4.92
800	17.3	16.5	4.85
700	17.1	16.4	4.27
600	16.8	15.9	5.66
500	16.6	15.7	5.73
400	16.3	15.5	5.16
300	15.8	15.01	5.26
200	15.2	14.4	5.55
100	14.2	13.4	5.97

Table.2 Comparison between Measurements and Simulation Power (at temperature = 29°C)

Radiation (W/m^2)	Simulated using Matlab P_{max} (W)	Measured P_{max} (W)	Error %
1000	127.6	133.4	-4.35
900	113.8	118.8	-4.21
800	100.0	95.37	4.85
700	86.5	82.95	4.28
600	73.0	69.0	5.80
500	59.8	56.5	5.84
400	46.8	44.5	5.17
300	34.1	32.4	5.25
200	21.8	20.65	5.57
100	10.1	9.5	6.31

The comparison between the experimental and simulated results shows the closeness between them. The percentage error in voltages ranges between 4.27 to 5.97, whereas the error in power ranges between 4.21 to 6.31. This shows the effectiveness of the proposed design.

6. Conclusions

This paper addresses the issue of designing the smart PV generation system components using the proteus software. The solar tracking system, the DC-DC converter with maximum power point tracking (MPPT) algorithm, the battery control charger, and the DC-AC power inverter controller, are accurately designed in order to choose their practical circuit parameters. The components are assembled and connected to a PV panel. The measured PV characteristics obtained by the practical system are closely matching to the ones obtained from simulation with a small error percentage. In conclusion, the designed model is effective for simulation study and analysis of the operation of smart PV generation system.

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