CHAPTER 5

HARDWARE IMPLEMENTATION AND CASE STUDIES

5.0 INTRODUCTION

In this chapter, a brief description of the PV system design, hardware design of charge controller, details of data logger and interfacing circuits are presented. The software aspects and flow charts have been explained. The case study of PV based lighting system with the proposed MPPT algorithm has been described. The wireless irrigation system with a charge controller has also been described. At the end, discussion and conclusions are presented.

5.1 EXPERIMENTAL EVALUATION OF A PV SYSTEM

An experimental setup of PV system evaluation is shown in Fig. 5.1. The four important components used in the measurement of system are as follows:

(i) PV Module: Commercially available PV module with a peak output power of 39 Wp (peak watt), short circuit current (I_{sc}) of 2.6 A, open circuit Voltage (V_{op}) of 21 V under standard test conditions of irradiance (G = 1000 W / m^2) and nominal operating cell temperature (NOCT) of 25°C were used for the experimental setup.

(ii) Pyranometer: Model no. DLSR 8704 with specification of wavelength range 400 to 1100 nm, irradiance measurement range 0 to 1200 W/m^2 and output voltage range 0 to 1 V was used for the measurement of irradiance.

(iii) Data Logger System: The data logger system was developed using PIC18F8722 board. The data of temperature and irradiance along with time stamp were collected and stored on a multimedia memory card (MMC).

(iv) V-I curve tracer: MATLAB software was used to simulate the PV module under test as explained in Chapter 4.

Fig. 5.1  Block diagram of PV system evaluation
5.2 DESIGN OF DATA LOGGER SYSTEM

The important components of data logger are PIC18F8722, real time clock, sensors, ADC and memory interface. The brief description of these components are given below:

(i) PIC 18F8722 is a microcontroller IC manufactured by Microchip. It has a 10-bit inbuilt ADC, enhanced USART, PWM and a host of other features such as priority levels for interrupts, single-supply, in-circuit serial programming and nano-watt technology. The board used for the data logger system is shown in Fig. 5.2.

(ii) **Real time clock:** This is the internal clock/calendar of the system which keeps the time and date stamp on collected data. The voltage necessary for the operation is provided by a standard lithium 3V button cell. The I2C protocol for communication with the microcontroller has been used. The specifications are: two wire I2C interface, hour : minutes : seconds, AM/PM, day month, date – year, leap year compensation, accurate calendar up to year 2100 A.D., battery backup, 1Hz output pin and 56 bytes of non-volatile memory available to user.
The schematic diagram for interfacing the real time clock is shown in Fig. 5.3.

(iii) Temperature Sensor

The schematic diagram of the temperature sensor is shown in Fig. 5.4, where DS1820 is a temperature sensor and the output signal is directly interfaced with the PIC microcontroller for further processing.

(iv) ADC interface and signal conditioning circuit

The circuit diagram for interfacing the signal conditioning system is shown in Fig. 5.5. The zener diodes at the input and output of the buffer circuit give the
protection against spikes. The output of the OPAMP buffer circuit makes the signal compatible to PIC microcontroller.

![Circuit diagram for interfacing the analog signal](image)

**Fig. 5.5** Circuit diagram for interfacing the analog signal

(v) **Multimedia memory card (MMC) interface**

The multimedia memory card has been used for storing data. The memory card being used is a Transcend make and having memory of 2 Gb memory card. The schematic diagram of the MMC card connections is shown in Fig. 5.6.

![Schematic diagram for interfacing the MMC](image)

**Fig. 5.6** Schematic diagram for interfacing the MMC

The flowchart of the data logger system for temperature and irradiance measurements is shown in Figs. 5.7 (a) and 5.7 (b), respectively.
Initialize ADC, USART, MMC

Initialize library and create new File

Skip ROM for temp. measurement

Isolate fraction and make it 4-DIGIT decimal Integer

Handle whole part of the temperature

Check for negative temp.? 

Yes

Sign correction

No

Separate whole and fractional part and convert to string

Append the file on MMC

Fig. 5.7 (a) Flow chart for temperature measurement
5.3. MEASUREMENT OF REAL TIME IRRADIANCE AND TEMPERATURE DATA

The data of irradiance and temperature were collected at city of Alandi, Pune for 12 hours duration in the interval of every one minute. The graph between time and irradiance data is shown in Fig. 5.8 (a). The graph between time and temperature is shown in Fig. 5.8 (b). These data have been used for the simulation of input in Chapter 4.
5.4 PV SYSTEM WITH BATTERY BACKUP

The solar energy is an unreliable source of energy, though it is available in abundant. It fluctuates with time and is not available during night or when the sky is cloudy. Therefore, it is necessary to use the backup source for PV systems in stand-alone applications, where a backup source of energy is needed to compensate the balance power demand of the load. Batteries are generally used as a backup source in such applications. To reduce the cost of the system, the ratings of the batteries are designed optimally. Batteries feed the load when the PV output power is less than the load demand and is charged when the PV output power is more than the load demand. In applications where batteries are used, it is critical to prevent over-charging or deep discharging of the batteries to enhance the battery life and to ensure good performance. This is achieved using charge controller, which is discussed in the following sections.
5.4.1 Set Points for Battery Charging

The charge controller senses the state of charge (SOC), i.e., voltage and decides either to disconnect it from the source (PV module in this case) to prevent it from over charging, or to disconnect the load (from the battery output) to prevent deep discharging of battery. This feature is very useful for unpredictable loads. The commonly used set points are:

(i) **Voltage regulation set point (VR)**: It is the maximum voltage up to which a battery can be charged (without getting overcharged). When this voltage is reached, the controller disconnects the battery from the source.

(ii) **Voltage regulation hysteresis (VRH)**: It is the difference between VR and the voltage at which the controller re-connects the battery to the PV source and starts charging.

(iii) **Low voltage disconnect (LVD)**: It is the minimum voltage up to which the battery can be allowed to discharge, without getting deep discharged. The charge controller disconnects the load from the battery terminals as soon as the battery voltage reaches LVD, to prevent it from deep discharging.

(iv) **Low voltage disconnect hysteresis (LVDH)**: It is the difference between LVD value and the battery voltage at which the load is reconnected to the battery terminals.

5.4.2 PV Charge Controller

The schematic of the charge controller for a PV system is shown in Fig. 5.9. The diode D1 is the blocking diode. MOSFET1 and MOSFET2 are used as switches to disconnect the PV from the load or battery depending on the conditions explained in section 5.4.1.

![Fig. 5.9 Schematic of a PV system with a battery backup](image-url)
The output of microcontroller cannot drive the gate of the MOSFET and hence gate drive circuits are used. The schematic of the drive circuit for MOSFET1 and MOSFET2 are shown in Figs. 5.10 and 5.11, respectively (Mohan et al. 2003, Rashid 2001).

![Fig. 5.10 Circuit of gate control for MOSFET -1](image1)

![Fig. 5.11 Circuit of gate control for MOSFET -2](image2)

The power supply required for the internal operations is generated using the control circuitry shown in Fig. 5.12. The power generated from the PV module is supplied from battery in absence of sun light.

![Fig. 5.12 Generation of 5V internal supply from PV system](image3)
The system level connection for standalone PV system for a DC water pump load is shown in Fig. 5.13. The initial high starting current is provided by the battery. The charge controller automatically controls the flow of energy to DC water pump for optimization of energy consumption from the solar cell.

Fig. 5.13  PV system for DC water pump (motor) load with battery backup

Fig. 5.14  PV System for AC load with battery backup
The output of the PV system is converted to AC using inverter for an AC load. The system level connection for standalone PV system for an AC load application is shown in Fig. 5.14.

5.5 CASE STUDIES

In this section various case studies for specific applications of lighting system and wireless irrigation system are discussed. The applications are developed using the proposed hybrid MPPT algorithm and comparison for improvement is made with the other existing algorithms.

5.5.1 Photovoltaic Electronic Ballast for Lighting System

The lighting system was designed for a stand-alone system, where the electrical transmission line cannot be commonly provided. The electronic ballast is a simple switch inverter having low harmonic sinusoidal output voltage waveform. It has benefits of high efficiency and low harmonic distortion. There are basically two types of ballasts namely magnetic ballast and electronic ballast. The magnetic ballast uses a core and coil assembly transformer that provides a minimum function for operating the lamp. Hence, it is not as efficient as the electronic ballast. The electronic ballast operates at high frequencies, which causes the electromagnetic interference (EMI). To increase the efficiency and minimize the EMI, electronic ballasts are operated from 20 KHz to 45 KHz frequencies. Electronic ballast design is more common due to its superior performance. The output of electronic ballast has 10% to 15% more light. It has no irritating AC line frequency hum and the high frequency switching and does not flicker to the human eyes (Ribarich 2006). The initial cost of electronic ballast is higher than the magnetic ballast, but payback of electronic ballast will come in the long run. Operating the ballast at higher frequency has the advantage of increased efficiency, longer lifetime, control over lamp power and smaller and lighter ballast.

The UC3872 is a resonant lamp ballast controller optimized for driving cold cathode fluorescent, neon and other gas discharge lamps (Unitrode 1999). The resonant power stage develops a sinusoidal lamp drive voltage, which minimize switching loss and EMI generation. Lamp intensity adjustment is done with a buck regulator, which is synchronized to the external power stages resonant frequency. It is best suited for the automotive and battery powered applications. The circuit for soft start and circuit for
open lamp have been incorporated to minimize component stresses. Open lamp detection is enabled at the completion of a soft start cycle. The chip is optimized for smooth duty cycle control to 100%. Other features include under voltage lockout, accurate minimum and maximum frequency control. Fig. 5.15 shows a complete circuit of lighting system using the UC3872 resonant lamp ballast controller.

The IC: UC3872 provides all drive control and housekeeping functions. The buck output voltage (center-tap transformer) provides the zero crossing and synchronizes the signal. This IC with resonant lamp ballast was chosen because it typically draws less than 1µA current and has a wide operating range of 4.5V to 24V. A resistive model is used for simulating the fluorescent lamp. The photovoltaic electronic ballast is simulated using PSIM with P&O MPPT, variable step MPPT and the proposed hybrid MPPT algorithms for the same input irradiance test pattern. An improvement of 7.63% and 1.51% has been obtained for the proposed hybrid algorithm with respect to P&O MPPT and Variable step MPPT algorithms, respectively, for the efficiency.

The FFT of the high frequency sinusoidal output of the resonant inverter circuit is shown in Fig. 5.16 (a) and the FFT of the sinusoidal output of the high frequency SPWM is shown in Fig. 5.16 (b). From these figures, it is observed that the harmonics
contents are reduced with resonant converter. This switching losses are reduced due to zero crossing switching (Goudar et al. 2011d).

![Graph of Output Voltage vs Frequency for inverter output with resonant converter](image1)

**Fig. 5.16 (a)** FFT of the inverter output of electronic ballast with resonant converter

![Graph of Amplitude vs Frequency for inverter output with SPWM converter](image2)

**Fig. 5.16 (b)** FFT of the inverter output of electronic ballast with SPWM converter

### 5.5.2 Photovoltaic Based Distributed Wireless Irrigation System

The cost of running wires in any landscaping application is enormous and there is a lot of problem in the maintenance of the system. The abundant of availability of solar energy during the day time can provide a wireless system for irrigation, which makes the system an ideal, efficient and economical. The modular photovoltaic system and load profile matching can make it very much suitable for distributed wireless irrigation system. The block diagram of the proposed wireless irrigation system application is shown in Fig. 5.17.
Fig. 5.17  Block diagram of the proposed wireless irrigation system

The proposed wireless irrigation system can be visualized in three different sections namely, PV side, controller side and the load side. The PV side has a battery back up to compensate power during the period of less or non availability of insolation. The control algorithm harvests the PV and battery energy to the load through the control module explained in section 5.4.2. The control side consists of small wireless sensor nodes to sense the humidity and temperature, and to communicate with a Base Station (BS) located over a short distance from the sensor nodes (Wallace 2010). The BS then sends the sensed data to the microcontroller for necessary action and generates control signals. Node mobility, node failures and environmental obstructions cause a high degree of dynamics in WSN. If a node fails, new routes need to be formed to address the topology changes. This may require more power and hence design of power management algorithms becomes an important aspect. A sensor network should be self-organized if the sensor nodes are randomly distributed in a region. The power consumed in a sensor network increases with the increasing distance between source and destination. It is recommended to use networks with multiple nodes like a mesh
configuration. The proposed microcontroller PIC16F877 is used to receive and IC-PIC16F873 for transmitting the data. The load side consists of water pump which is driven by microcontroller through driver and relay circuits to supply the water depending on the conditions of water level of tank or the humidity and temperature conditions of the soil. The wireless connectivity is proposed to overcome the constraints of wired connectivity, ease of operation and a feasibility of automation to irrigate maximum area during the period of maximum insolation.

Wireless sensors sense the moisture of different areas in the field and continuously transmit the data to the microcontroller of the master unit. If the sensed moisture is less than the required value, the microcontroller will open the valve of that particular area. If the water level is less in the water tank, the master microcontroller will turn ON the water pump (motor) whose power source is PV module (Goudar et al. 2011e). The flow chart of the sensor module and the master module is shown in Fig. 5.18 (a) and Fig. 5.18 (b), respectively.

![Flowchart for sensor module](image1)

**Fig. 5.18 (a) Flowchart for sensor module (b) Flow chart for master module**

The schematic of the Zigbee module and the Zigbee transmitter is shown in Figs. 5.19 and 5.20, respectively. Transmitted information from transmitter module is received by the master module through Zigbee on pin no. 3 which is behaving as receiver pin. The received information is send to PIC 16F877 with the help of transmitter and receiver pin (C6 and C7).
Fig. 5.19 Schematic of zigbee module
Fig. 5.20 Schematic of Zigbee transmitter
Fig. 5.21 Schematic of zigbee receiver
The output of float valve is given to the input port A of PIC 16F877. Output Port D of PIC 16F877 is used for LCD. Output port B of PIC 16F877 is used for Stepper motor to operate the valve. ULN 2003 relay driver is used for operating the relay to turn ON and OFF the DC motor water pump vide control pin C0.

The schematic of the Zigbee receiver is shown in Fig. 5.21. The PIC 16F877 receives information from Zigbee regarding the condition of the field and temperature range, which is displayed on LCD. If the temperature is above certain level then PIC will check the water level of tank using float valve and if water is not sufficient then DC motor is turned by relay driver (ULN 2003) for filling the tank.

5.6 DISCUSSION AND CONCLUSION

To check the suitability of developed PV system few specific applications were tested as case studies. The complete stand-alone lighting system has been implemented and simulated in PSIM using the proposed MPPT algorithm in conjunction with resonant converter. It has been found to have the advantage of high efficiency and low harmonic distortion. Circuit of charge controller and interfacing circuit of data logger have been designed. All the components of PV system are independently designed with circuit boards so that it is easy to change the interface board as per the application A distributed wireless irrigation system has been implemented with the developed charge controller.