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Measurement of meteorological data based on wireless data acquisition system monitoring

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ABSTRACT

Estimation of solar energy potential of a region requires detailed solar radiation climatology, and it is necessary to collect extensive radiation data of high accuracy covering all climatic zones of the region. In this regard, a wireless data acquisition system (WDAS) would help to estimate solar energy potential considering the remote region's energy requirement. This article explains the design and implementation of WDAS for assessment of solar energy. The proposed system consists of a set of sensors for measuring meteorological parameters. The collected data are first conditioned using precision electronic circuits and then interfaced to a PC using RS232 connection via wireless unit. The LabVIEW program is used to further process, display and store the collected data in the PC disk. The proposed architecture permits the rapid system development and has the advantage of flexibility and it can be easily extended for controlling the renewable energy systems like photovoltaic system. The WDAS with executive information systems and reporting tools helps to tap vast data resources and deliver information.

1. Introduction

The rapid evolution of renewable energy sources during the last two decades resulted in the installation of many renewable energy power systems all over the world. But the installation cost is still high, so their design optimization is desirable. However, such an effort requires detailed knowledge of meteorological data of the site where the system will be installed, because the corresponding energy production is highly influenced by the climatic conditions. In many cases, meteorological data from many different locations is required in order to evaluate models describing the spatial variability of a renewable energy sources. Thus, the development of automate database management systems is indispensable. Such systems typically consist of microcontroller-based unit for recording the signals of interest, while the collected data are usually transmitted to PC for storage and further processing.

Another application is collecting weather data and module performance data at remotely deployed renewable energy systems, in particularly photovoltaic (PV) installation. Weather data being collected consists of wind speed, wind direction, rainfall, ambient temperature, atmospheric pressure, relative humidity, and irradiance of the sun. The performance monitoring of a PV system, thus, requires that the appropriate weather parameters be recorded. Data acquisition systems are widely used in renewable energy source applications in order to collect data regarding the installed system performance, for evaluation purposes [1]. A real wind and solar potential measurements are used to determine the specifications of an isolated renewable energy sources [2].

Many data acquisition systems have been developed in order to collect and process such data, as well as monitor the performance of renewable energy systems under operation in order to evaluate their performance [3–5]. A data acquisition system has been designed and used for monitoring the performance of both photovoltaic battery charging and water-pumping systems [6,7]. An A/D converter interfaced to a microcontroller-based unit records a set of sensors' signals, while the collected data are stored in a local EPROM. The data collected by the microcontroller are transmitted to a PC, with an RS-232 serial connection, where they are stored for further processing. The same architecture has been implemented for solar irradiation and ambient temperature measurements [8–10]. A different approach has been developed and proposed [11]. A commercial data-logging unit has been used to measure a set of meteorological and operational parameters of a hybrid photovoltaic–diesel system. The collected data are transmitted to a PC through an RS-232 serial interface, where they are processed using the LabVIEW data acquisition software. However, a data-logging unit lacks flexibility compared with a data acquisition card approach, while, in addition, it cannot be used for renewable energy system control. A common characteristic of the design methods described above is that a microcontroller-based data-logging unit is used to measure the signals of interest and interface the collected data to a PC through an RS-232 serial interface.

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However, serial data transmission limits the system performance if an advanced control capability is desired.

An integrated data acquisition system for renewable energy sources systems monitoring has been developed [12]. A set of sensors are used to measure atmospheric and soil conditions, as well as quantities regarding the energy produced by the hybrid photovoltaic/wind generator power system, such as the photovoltaic array voltage and current, the wind generator speed. The collected data are further processed, displayed on the monitor and stored in the disk. All these data acquisition systems have very wide applications, due to the needs of user. For this our designed wireless measurement system will be welcomed with interest also by common users.

Another application of meteorological data, is to generate typical meteorological year (TMY) data. In fact, three methods have been used for generating TMY data set using a 10-year period (1995–2004) of meteorological data from four stations in a tropical environment [13]. So, to validate these methods, the authors compare the monthly average global radiation obtained from TMY methods and 10-year hourly data. Also, the authors compare the variation of monthly average temperature, relative humidity and wind speed obtained from TMY methods and 10-year hourly data.

As air temperature and wind speed are 3-h period data, these were mathematically interpolated to obtain the hourly data. The 10-min average solar radiation was again averaged to give hourly mean of solar irradiance.

However, in our case to avoid the mathematical interpolation, we have designed a wireless data acquisition system (WDAS) to give us experimental hourly data. This improve the precision of the measured data and then the comparison between measured data and those simulated by the models will be more significant.

In the design of a measurement system, we must choose an appropriate precision electronic circuit as well as the different parts constituting the weather sensing, in order to reduce the measurement errors. In fact, the wind-speed at a site can be measured by installing anemometers on top of meteorological (met) towers [14]. The authors consider that a top-mounted anemometer should be located at the windward side of its met tower, raised 5 diameters above the top. This will reduce speed-up error to less than 1%. Other sources of error, accelerated airflow, or speed-up, around the top of met towers can cause incorrect anemometer measurements.

In this context, firstly, we have opted to the wireless system to minimize the errors of measurement due to the connection cables for a classical acquisition systems, where the sensors are situated more than 200 m from the acquisition systems. Secondly, we have chosen an appropriate electronic precision circuits as the interface between the sensors and the measurement station.

The principal purpose of this work is to design a system of data transmission received from the remote stations, to facilitate significantly the reception of data and to minimize the cost of maintenance of these stations.

In this paper, we develop a low cost, autonomous remote weather data acquisition system (WDAS), using readily and easily available equipment to collect and transfer local data to any PC equipped with an Internet connection. The WDAS is used to collect and transfer data to a remote server for storage and processing, using a wireless interface. The data is moved from the remote station to a server that stores and analyzes this data. A set of sensors are used to measure meteorological data (solar radiation, air temperature, relative humidity, pressure, wind speed, and direction). The sensor signals are first filtered and amplified using precision electronic circuits and then are interfaced to a PC, through the PCI bus, using a wireless unit. The collected data are further processed, displayed on the monitor and stored in the disk using the LabVIEW software. This method has the advantages of rapid data acquisition system development and provides an easy-to-use graphical environment that permits the system operators to process easily the collected data. The proposed wireless data acquisition system has no limit, its use on large power capacity renewable energy systems, which is the main objective of such monitoring and control systems.

This paper is organized as follows: a description of WDAS, an analysis of the sensors and the electronic circuits developed are presented in Section 2. The remote and base stations, the weather monitoring application program are described in Section 3 and the experimental results are given in Section 4.

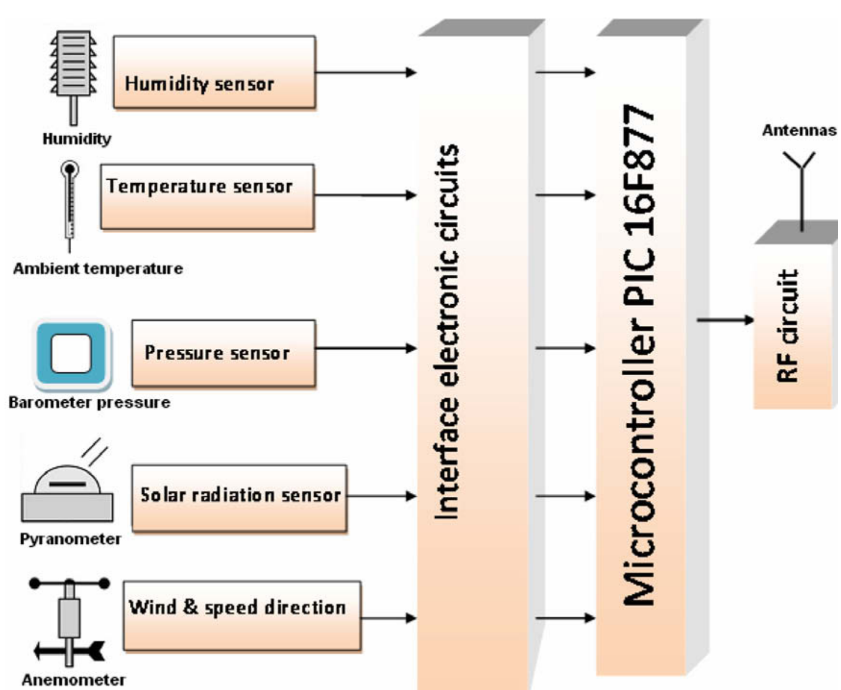

Fig. 1. The sensors and interface electronic circuits in remote station.

2. Description of wireless data acquisition system

The weather station is a field data acquisition system designed to collect and transmit weather data, including rain fall, wind speed, and direction, outdoor temperature, and humidity, and barometric pressure. Requirements for the system are:

- Measure weather-related data.
- Capable of wireless transmittal of data.
- Weather resistant.
- Solar powered.

The system realized is a portable data acquisition system which allows collecting, store, and transmitting data at any location.

The wireless weather station is composed of a remote station and a base station. The remote station is solar-powered and wakes up once a minute to collect and transfer data. The base station receives and buffers the incoming data and then transfers it via an RS232 connection to a PC for processing. Within each of the stations is a dedicated circuit card as well as a separate, RF circuit card.

2.1. Remote station design

The Remote station consists of four functional sections: the sensors, the microcontroller PIC (Parallel Interface Controller)16F877, the RF circuit, and the power supply. The schematic, shown in Fig. 1, shows the block diagram of different sensors used and the microcontroller PIC16F877.

The electronic circuits of the sensors and the interface circuits are shown in Fig. 2.

2.1.1. Solar radiation sensing

The measure of solar irradiation is dedicated to a solar cell pre-calibrated with a pyranometer Kipp and Zonen. The photocurrent

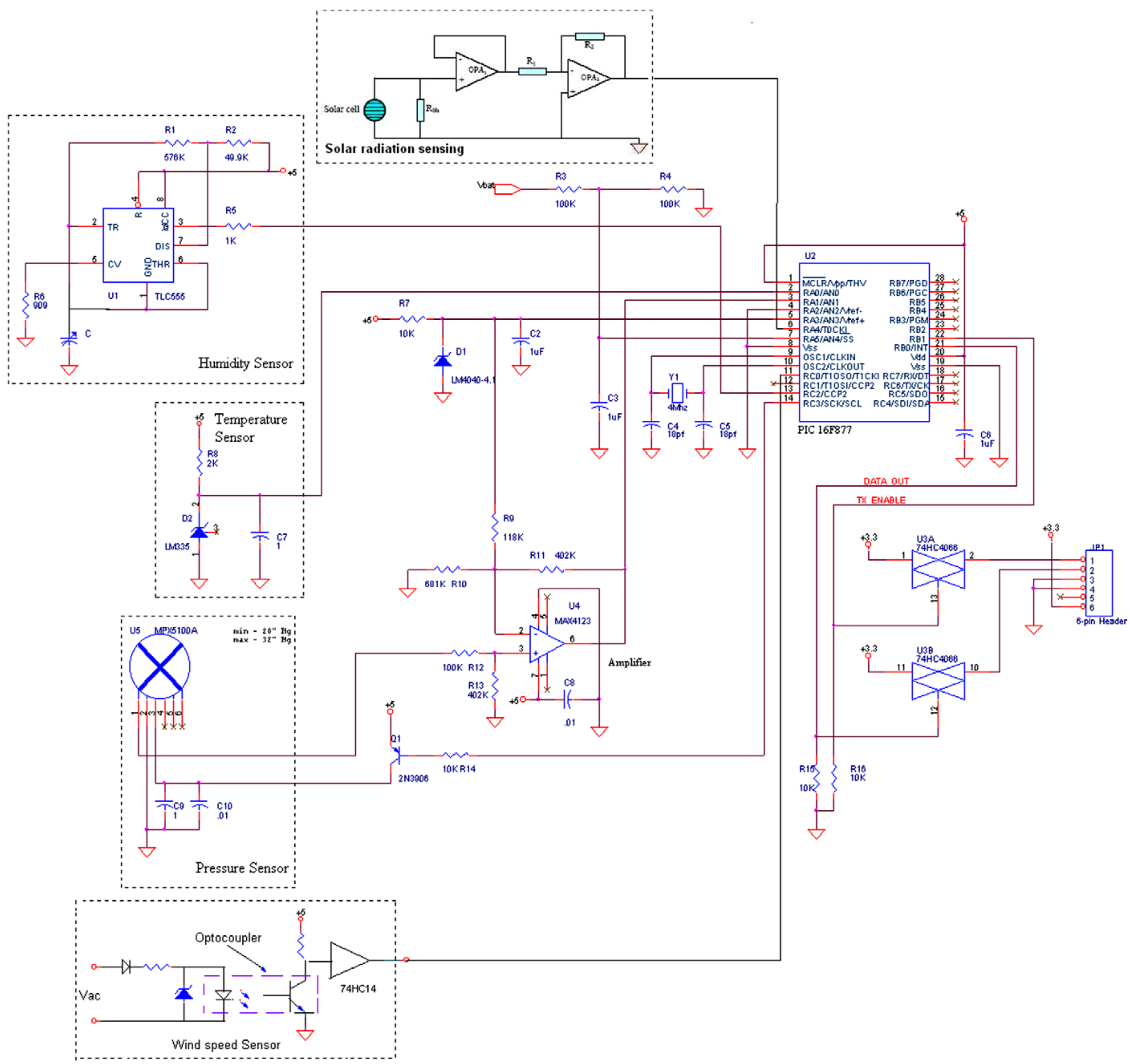

Fig. 2. Sensors and microcontroller areas.

produced by a silicon PN junction is used as a solar radiation transducer.

We have used a mono crystalline silicon solar cell to measure a solar irradiation. The solar cell used presents a large spectral response also important than a usual pyranometer. The use of solar cell as solar radiometer reduces the cost of all system. The solar cell device conditioning is assumed by two operational amplifiers.

The method of measure consists in acquiring the short circuit current I_{SC} which is proportional to the incident solar irradiation. The calibration of the solar cell allows getting the short circuit current according to the incident solar irradiation:

$$I_{SC} = K \cdot H_i \tag{1}$$

where K is the calibration factor and H_i is the incident solar irradiation. The solar cell used in our case gives a calibration factor of 80 mA/kW/m^2.

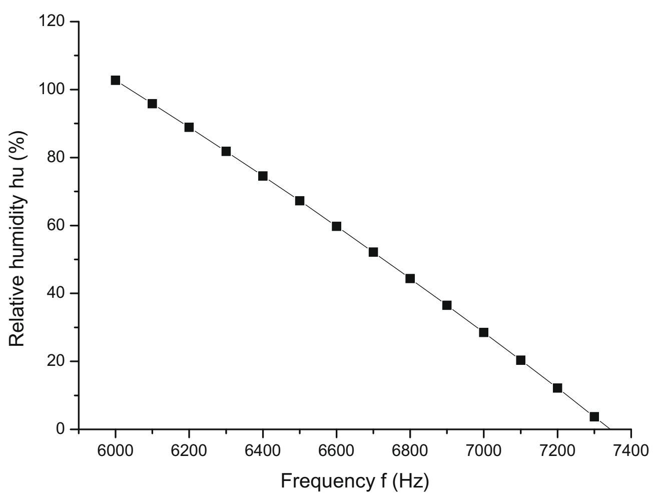

Fig. 3. Relative humidity versus frequency.

The measure of the short circuit current I_{SC} is realized by measuring the voltage across the shunt resistor R_{Sh}. For adaptation, we use the first operational amplifier (OPA1) as follower and in order to get a large scale measurement, we amplify the signal via the resistors R$_1$, R$_2$ and the second operational amplifier (OPA2). We have used the LM 324 series consists of four independent high gain, internally frequency compensated operational amplifiers which were designed specially to operate from a single power supply over a wide range of voltages.

2.1.2. Humidity sensing

For humidity sensing, we opted for the Humirel HS1101 capacitive sensor. This device, when combined with a CMOS 555 timer operating as an astable multivibrator, produces a signal with a humidity dependent frequency. To minimize temperature effects, it is important to use the Texas Instruments TLC555 device in this design. Also note that care must be taken at the node of the HS1101 and the 555 timer. Stray capacitance values will lead to erroneous and unpredictable measurements. The relationship between the output frequency of the 555 timer and the relative humidity can be seen in Fig. 3.

A first order equation that relates relative humidity h_u to frequency f is:

$$h_u = 565.1 - 0.0767 * f \tag{2}$$

A second order equation can be used for improved accuracy, so:

$$h_u = -6.4790.10^{-6} * f^2 + 1.0047 \times 10^{-2} * f + 2.7567 * 10^2 \tag{3}$$

2.1.3. Temperature sensing

Temperature sensing is very straight-forward with the LM335. The output of this device is equal to the absolute temperature in degrees Kelvin divided by 100, so:

$$V_{out} = \text{Temperature } (^\circ\text{K})/100$$

To determine the temperature in °C, we use the equation:

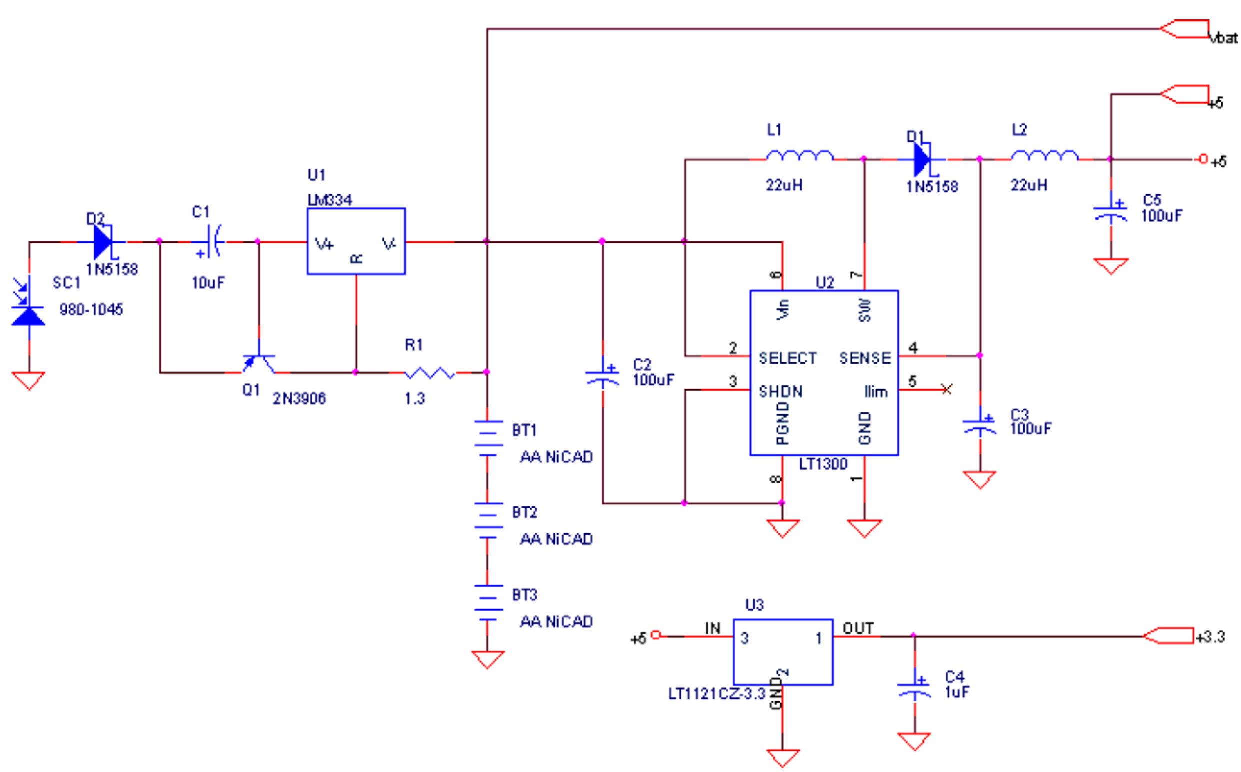

Fig. 4. Power supply for remote station.

$$°C = 100 * V_{out} - 273 \quad (4)$$

To determine the temperature in degrees Fahrenheit, we use the equation:

$$(5)°F = 1.8 *° C + 32.2 = 1.8 * (100 * V_{out} - 273) + 32.2$$

Then:

$$°F = 180 * V_{out} - 459.2 \quad (5)$$

At room temperature, this device outputs about 3 V.

2.1.4. Pressure sensing

Pressure sensing is provided by a Motorola MPX5100A, which operates from 0 to 16 PSI. However, we are interested in only a very small part of that range. Barometric pressure readings fall between 28 and 32 in. of mercury. This translates to 13.75–15.72 PSI. To increase the dynamic range of the output, we added an amplifier circuit (U4), which subtracts about 3.7 V from the sensor output and then multiplies the difference by 4. Since the MPX5100 can require as much as 10 mA, Q1 was added to provide microcontroller-controlled switching.

2.1.5. The wind speed and direction sensing

The wind speed and direction are measured with the Vector Instruments A100R type anemometer and the W200P type wind vane, respectively. The wind speed is measured using the circuit based on the optocoupler and the counter. The sinusoidal voltage between two phases of the wind sensor is transformed into a TTL level digital signal with frequency proportional to the wind speed.

Table 1
Components values used for RF section.

Reference	Transmitter value	Receiver value
C1, C4	100 pF	100 pF
C2	10 μF	10 μF
C3	Not used	.015 μF
JP1	Used	Not used
JP2	Not used	Used
JP3	Not used	Used
JP4	Not used	Used
J1	BNC	BNC
J2	6-pin header	6-pin header
L1	56 nH	56 nH
L2	220 nH	220 nH
L3	BEAD	BEAD
R1	Not used	270 K
R2	Not used	330 K
R3	Not used	27 K 1%
R4	Not used	100 K 1%
R5	Not Used	30 K
R6	47 K	47 K
R7	8.2 K	Not used
R8	10 K	Not used
U1	TX5002	RX5002

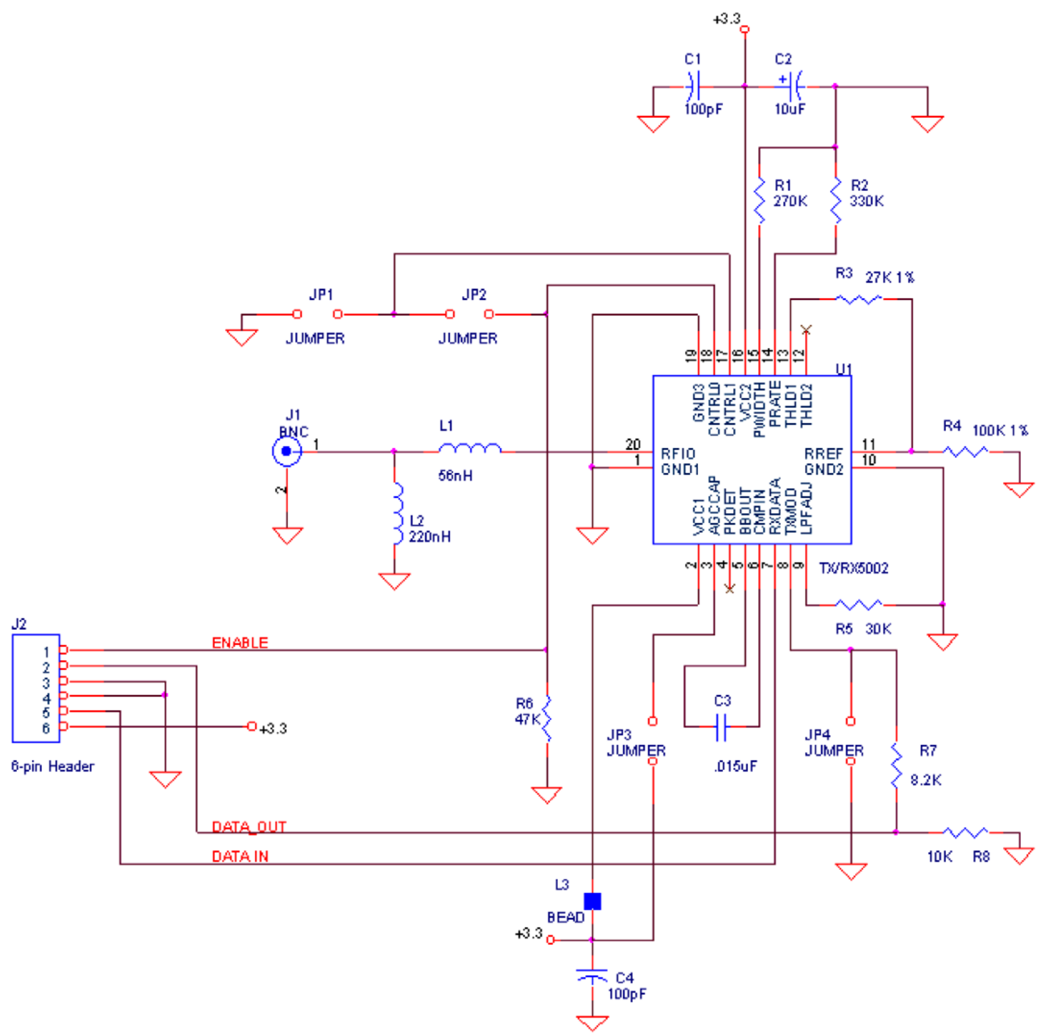

Fig. 5. The RF section using the TX5002 and RX5002 chips from RF Monolithic.

We have chosen the Microchip PIC16F877 because it had the right mix of program and data memory. The PIC16F877 Microcontroller includes 8 Kb of internal flash Program memory, together with a large RAM area and an internal EEPROM and three timers (one 16-bit Timer with two 8-bit Timers). An 8-channel 10-bit A/D converter is also included within the microcontroller, making

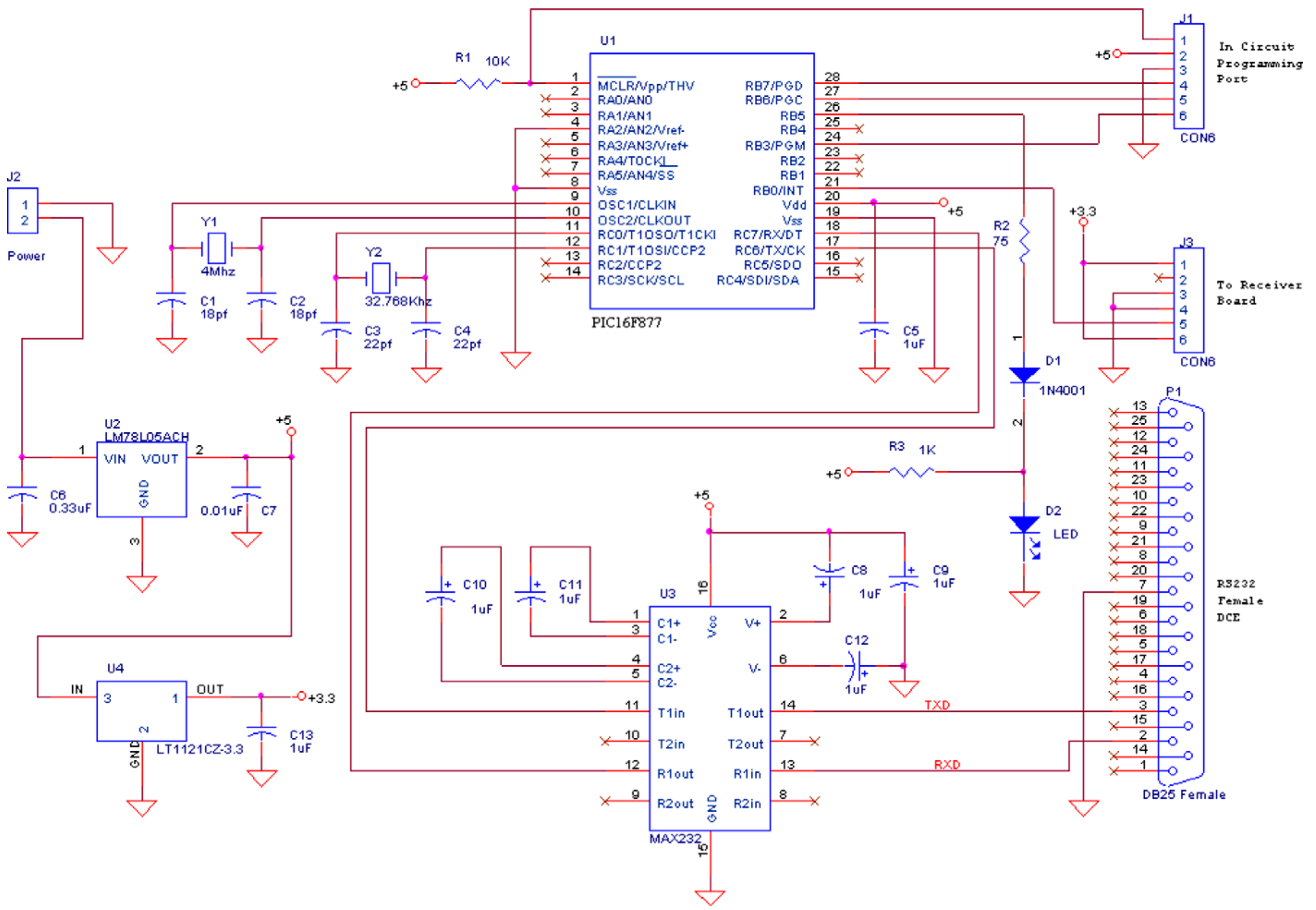

Fig. 6. Base station electronic circuit using the microcontroller PIC16F877.

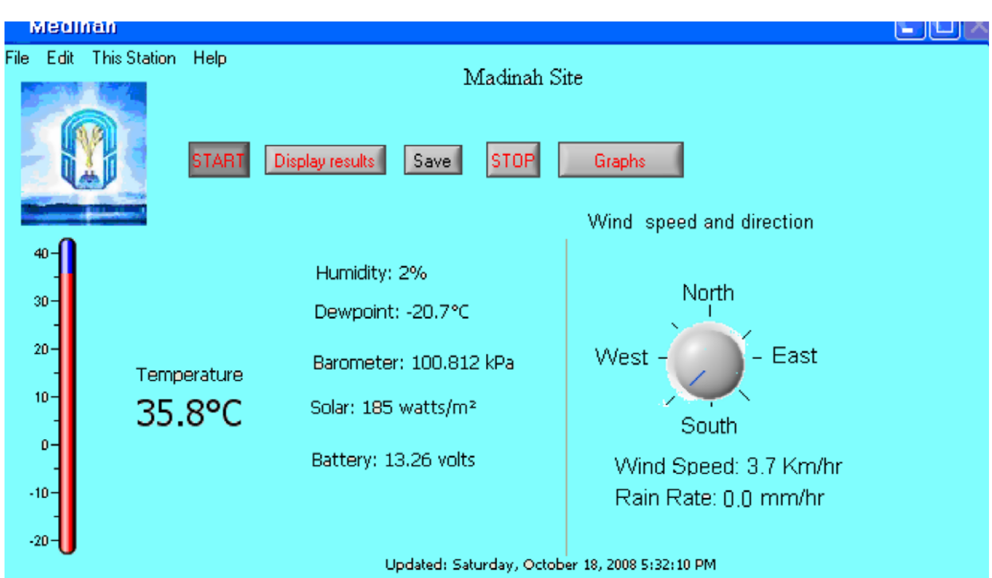

Fig. 7. Weather monitor window.

it ideal for real-time systems, and monitoring applications. All port connectors are brought out to standard headers for easy connect and disconnect.

Timer 2 is used to measure the period of the humidity signal. The A/D is used to measure the temperature and pressure sensors as well as to monitor the battery voltage. To maximize accuracy we have used an external 4.096 volt 0.1% reference from National Semiconductor. With the 10-bit A/D, this provides a resolution of 4 mV per count. The interface to the RF link consists of an enable line and a data output. Since the transmitter circuit operates at 3.3 V, we have used analog switches to translate from the five-volt outputs of the microcontroller.

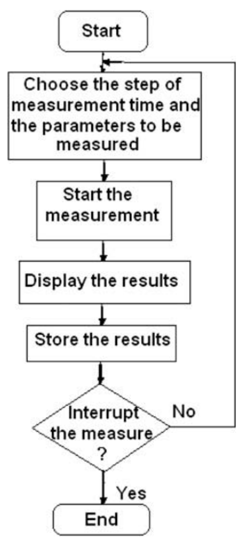

Fig. 8. The LabVIEW measurement program flowchart.

The power supply for the Remote Station is shown in Fig. 4. When the sun is shining on the solar panel, enough power is generated to drive the 50 mA current source formed by Q1, U1, and R1. This current acts as a trickle charger for three AA NiCAD batteries. The batteries power U2 – a switch mode regulator that provides the 5 V for the microcontroller and sensors. This is followed by U3, which is a linear regulator that provides the 3.3 V for the RF circuitry. L2 and C5 were added to reduce the switching noise from U3. D2 is used to isolate the solar panel from the rest of the circuit when it is dark.

The RF section of this design, shown in Fig. 5, was built around the TX5002 and RX5002 chips from RF Monolithic. Due to the footprint of these devices, it was necessary to design a small printed circuit board. Fortunately, the chips have a pin-out that allowed a single board to be used for both the transmitter and the receiver.

The antenna is connected via a BNC jack on the left side. However, a length of coax can be connected to this pad in order to use a panel-mount connector. To maximize range, $\lambda/4$ stub antennas over $\lambda/2$ ground planes were used for both the transmitter and receiver.

The same board is used for both the transmitter and the receiver. The function of the board is controlled by which parts are used. Table 1 summarizes which components are used for each board.

2.2. Base station design

The Base station (Fig. 6) is also built around the PIC16F877 microcontroller. For this application, we have used the second on board oscillator to generate a real time clock and configured the Master Synchronous Serial Port (MSSP) as an Universal Asynchronous Receiver Transmitter (UART) for asynchronous communication with the host PC.

RS232 buffering and level translation is accomplished through the MAX232. A standard DB25 connector is used to connect to the PC. J3 provides connectivity to the RF Receiver board which was assembled with the appropriate components. No voltage conversion is required between the Data In pin of the RF Receiver and

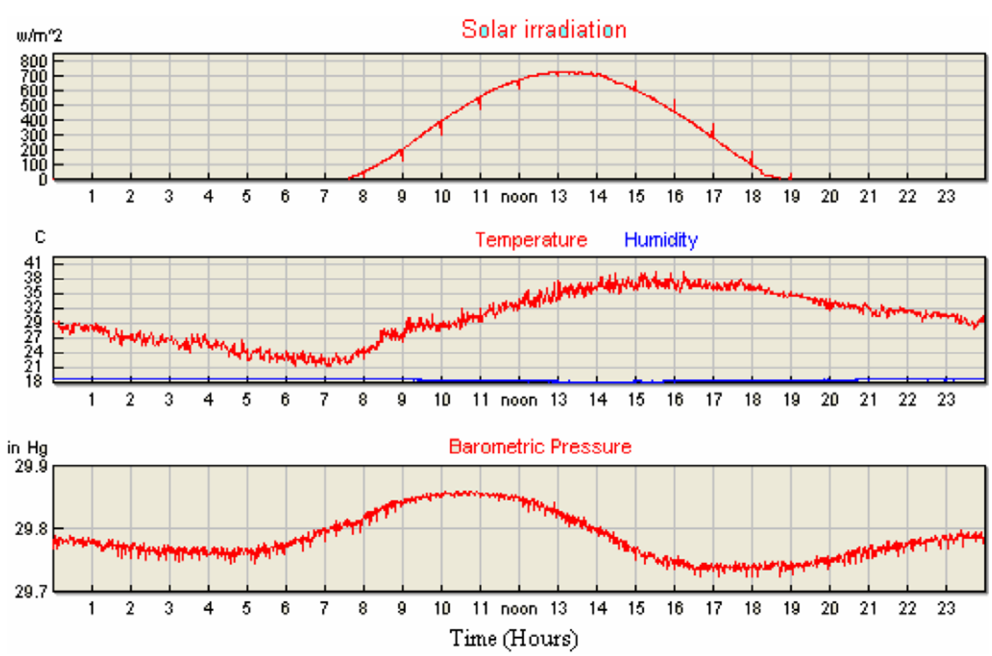

Fig. 9. Atmospheric condition measurements for a specific day.

the microcontroller since the minimum Input High voltage for the PIC is 2.0 V.

Power is provided via a 9VDC wall mount power supply driving a 78L05 regulator for 5 V and an LT1121 for 3.3 V. A single green LED is used to provide a power indicator. When the microcontroller detects the reception of a valid data packet, additional current is injected into the LED causing it to pulse.

3. Application program

To take full advantage of the Remote Weather Monitor, we wrote a simple program in LabVIEW to collect the data from the base station, perform the calibration corrections and data conversions, and display it on the screen. Buttons are provided to start, display the basic data and to plot the data in real time. Fig. 7 shows a screen shot of the monitor window. The monitoring system and microcontroller code are presented in Appendix A.

The primary objective of this project was to design and implement a weather data acquisition system that monitors and collects weather data automatically from a remote weather station and uploads the data to the server. The other desired design objectives were persistent data storage capability, end-to-end data reliability, a flexible and easily extensible framework, and a robust architecture. The present implementation meets all of these functional and design objectives.

The data acquisition card is controlled by a properly developed interface, using the LabVIEW software, running on the PC. It consists of two parts: (a) a graphical environment with components such as displays, buttons and charts in order to provide a convenient-to-use environment for the system operator, and (b) the program code, which is in block-diagram format and consists of built-in virtual instruments (VIs), performing functions such as analog channel sampling, mathematical operations, file management etc. The LabVIEW software runs under the Windows 95/98/NT/2000/XP operating system and it requires a Pentium processor, a minimum RAM of 32 MB and 60 MB of disk storage space.

The block diagram of the developed LabVIEW program is illustrated in Fig. 8. Initially, all analog signals are sequentially sampled and the input voltage data are calibrated to correspond to physical units. The calibration equations have the general form:

$$y_i = a_i \cdot x_i + b_i \tag{6}$$

where y_i is the ith sensor output in physical units, x_i is the ith sample and a_i, b_i are calibration constants.

The frequency of the anemometer digital output signal is used for calculation of the wind speed, forming the corresponding LabVIEW built-in VI. The relation for the conversion of frequency to wind speed is the following:

$$V_{SP} = \frac{N_a}{D} = \frac{60 \cdot f_m}{D} \tag{7}$$

where V_{SP} is the calculated speed (m/s), N_a are the anemometer revolutions per minute (rpm), D is a conversion constant given by the anemometer manufacturer and equal to 47.7 rpm/m/s and f_m is the measured frequency (Hz).

4. Experimental results

The measurements of all sensors, collected in a specific day, are illustrated in Figs. 9 and 10. The data base obtained from January 2007 until January 2009 with one min step time, allow us to get a better view of the solar energy potential in Madinah site. So, we have deduced the sunshine duration SS_0 which is the duration time when the energy received on horizontal surface is above 120 W/m^2. Fig. 11a illustrates the evolution of daily irradiation for the year 2008. It also shows the values of H_0, which represents the extraterrestrial radiation. Fig. 11b shows the evolution of daily sunshine duration for the year 2008. This figure shows clearly that there is seasonal trend with super imposed fluctuation day to day of the daily values of solar radiation data, corresponding curves of clearness indexes ($K_t = H_G/H_0$) values and sunshine duration fraction ($SS = S/S_0$) are presented in Fig. 11c. The distribution of clearness index K_t is around the yearly average clearness index 0.73. This shows that the global irradiation at Madinah site is higher and many applications of solar energy will be done with good results.

The objectives of our wireless data acquisition system is not only to collect meteorological data, but also to be used for controlling the renewable energy systems. For this, we have set up an experimental photovoltaic system in remote area. Then, we have

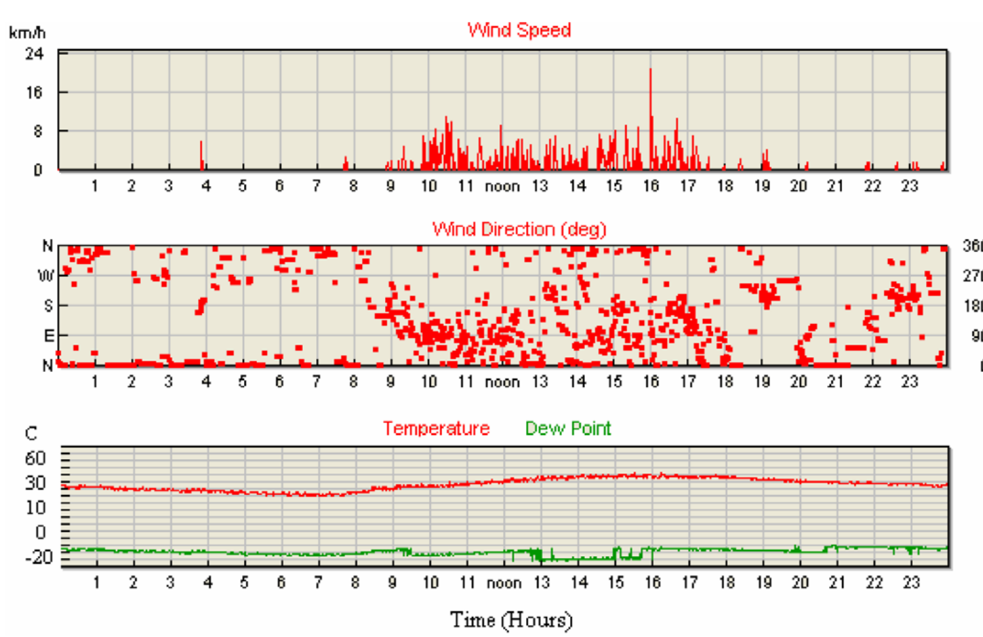

Fig. 10. Wind speed, wind direction, temperature, and Dew Point measurements for a specific day.

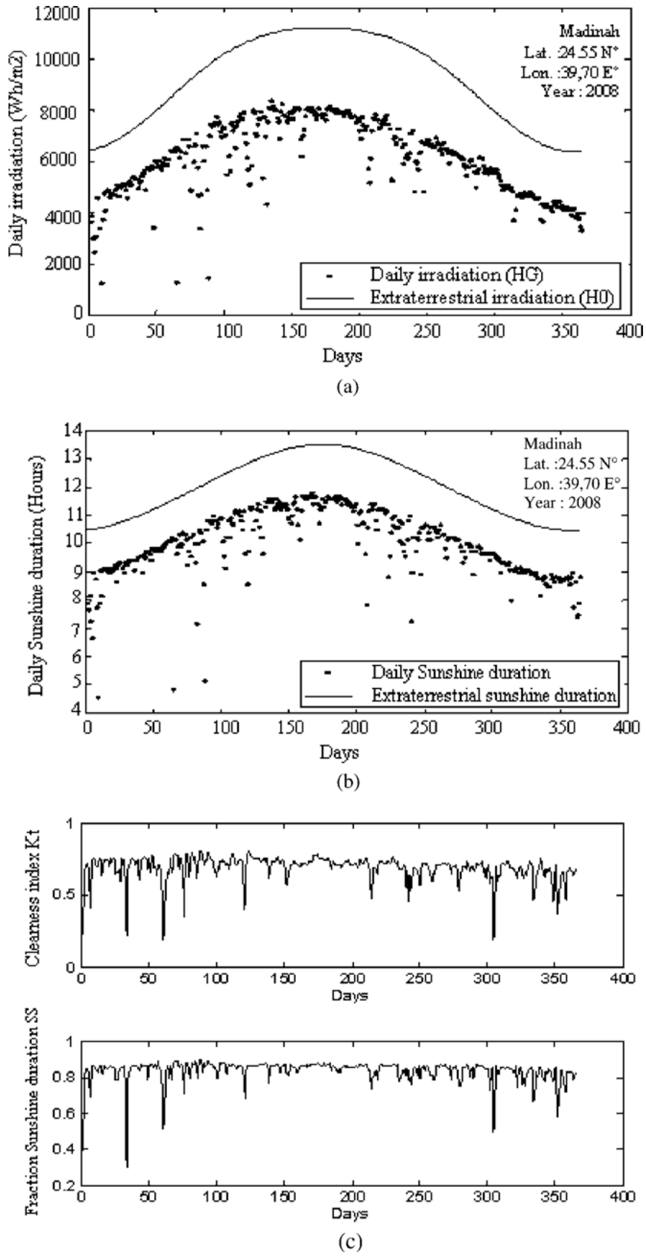

Fig. 11. Daily evolution of (a) global solar radiation, extraterrestrial global irradiation, (b) sunshine duration, extraterrestrial sunshine duration, (c) clearness index and fraction sunshine (Site: Madinah, year: 2008).

measured the voltage and current issued from the PV system using the WDAS system proposed (Fig. 12). The control of the PV system installed is in real time which allow us to evaluate its performance.

5. Conclusion

The original aim of this paper was to develop the application as a technology demonstrator and proof of concept for deployment in remote data acquisition system applications such as for the PV industry.

The wireless data acquisition system are used in renewable energies sources systems in order not only to measure the meteorological parameters, but also to collect data regarding the system performance for evaluation purposes.

In this paper, we have focused on the development of a wireless data acquisition system (WDAS) by using Microcontroller PIC 16F877. The proposed WDAS is based on precision electronic circuit and a graphical environment using the LabVIEW software, for processing, displaying and storing the collected data.

The proposed architecture has the advantages of rapid development, flexibility, quick installation, modularity, expendability and reduced amount of data processing. The WDAS proposed can be used for others remote sensor applications to transfer measurement information and configuration commands.

Appendix A. Monitoring system and microcontroller code

A.1. Remote station

The code for the remote station is very simple and can be explained easily with pseudo code:

```
Loop
    Sleep for 1 min
    Turn on Pressure Sensor
    Perform A/D conversion on Temperature Sensor
        Average four readings
        Add Hamming codes to data
    Measure pulse width of humidity sensor circuit
        Measure period of 555 oscillator/16
        Compress data to fit into 10 bits
        Add Hamming codes to data
    Perform A/D conversion on battery
        Average four readings
        Add Hamming codes to data
    Delay additional 20 ms for Pressure Sensor Stabilization
    Perform A/D conversion on Pressure Sensor
        Average four readings
        Add Hamming codes to data
    Turn Off Pressure sensor
    Transmit Data
        Turn on transmitter and wait two bit times for settling
        Send Preamble of eight 1's and eight 0's
        Send 14 bits of temperature data
        Send 14 bits of pressure data
        Send 14 bits of humidity data
        Send 14 bits of battery data
        Turn off transmitter
Repeat Loop
```

A.2. Base station

The firmware in the base station performs the following functions:

- Detect and decode data from the RF Receiver.
- Perform error correction on the received data.
- Encode the received data into ASCII format.
- Transmit the ASCII data to the RS232 port.
- Perform hourly data logging on RCVD data for a total of 24 h of data.
- Detect and respond to RS232 requests for latest and historical data.

The base station firmware relies on interrupts to detect and collect incoming data as well as to maintain the 1 h clock for data logging. Once these events occur, flags are set that inform the main loop that either new data is available or that it is time to store a reading in memory.

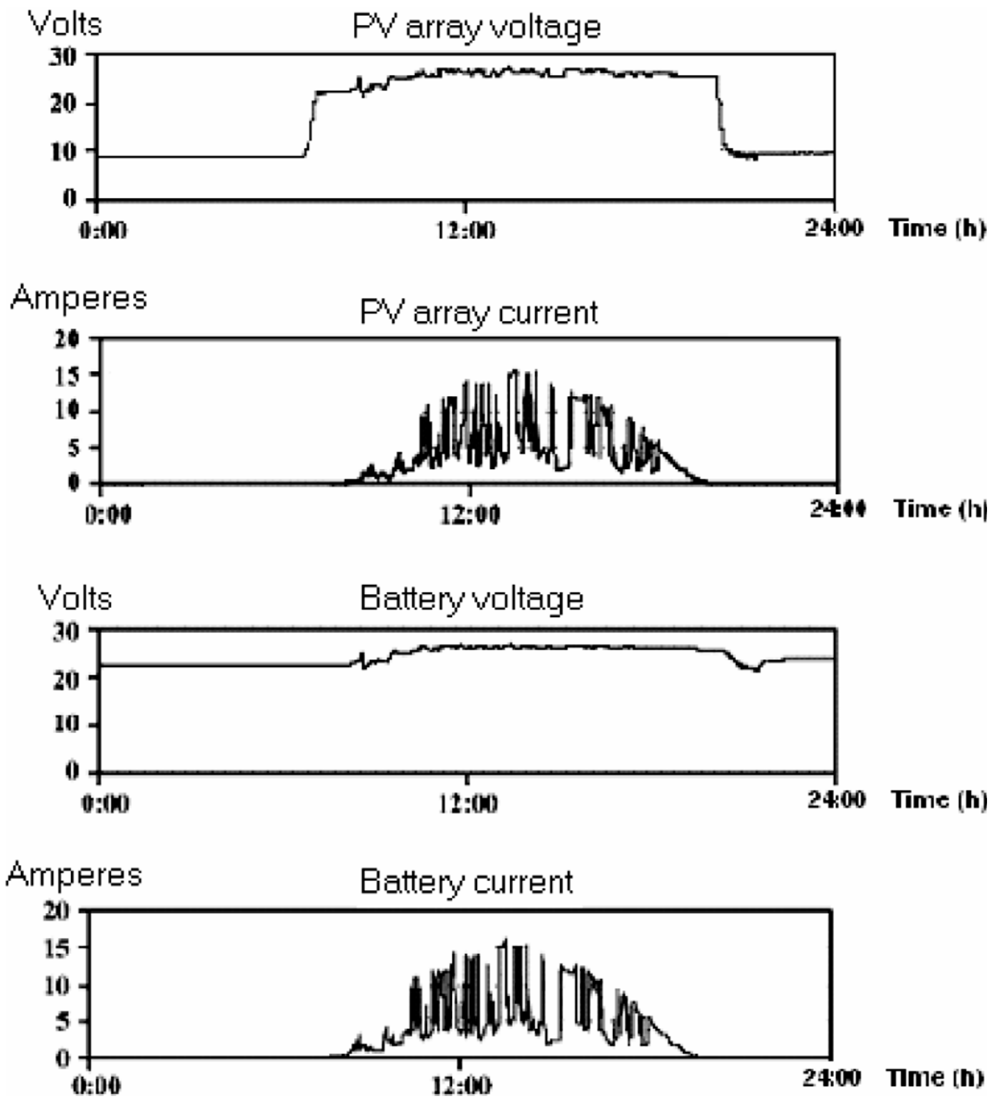

Fig. 12. PV and battery voltage and current measurements for a specific day.

The main loop monitors the flags set by the interrupt service routine. If the Received Data flag is set, the RS232 transmitter routine is called. If the log data flag is set, the last received data block is buffered. In addition, the main loop monitors the RS232 receiver. If the character "L" is received, the last reading is transmitted to the serial port. If the character "H" is received, the last 24 h of logged data are sent to the serial port.

The serial data is transmitted at 9600 bauds using an 8N1 format. The ASCII encoded measurement data stream looks like:

$T:\mathrm{ttt}, P:\mathrm{ppp}, H:\mathrm{hhh}, B:\mathrm{bbb}$

In the above, T is temperature, P is pressure, H is humidity, and B is battery voltage. "ttt", "ppp", "hhh", and "bbb" are the 10 bits readings in hexadecimal format. This data has been error corrected but not calibrated. It is the function of the application software to convert the 10 bit hex values and perform the calibration corrections.

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