

Data Acquisition System for Photovoltaic Maximum Power Point Tracking

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Abstract: - The global solar radiation and temperature are two parameters needed in many studies such as meteorology and the design of photovoltaic (PV) systems which are, by nature, non-linear power sources that need an accurate on-line identification of the optimal operating point for the real time maximum power tracking control. The maximum power, drawn from PV modules, mainly depends on the solar global radiation and temperature.

The solar global radiation and temperature are usually measured by using a pyranometer and a thermometer respectively. Hence, a low-cost battery powered microcontroller based data acquisition system (DAS) has been developed and applied to monitor solar global radiation on tilted surface in PV system. An application of a neural network to prediction of the maximum power drawn from a PV module is also presented in this manuscript. Simulation and experimental results are given to enforce the presented theory.

Key-Words: -Global solar radiation, Temperature, DAS, Neural Network, Maximum power, Microcontroller

1 Introduction

The solar radiation and temperature are two parameters needed in many studies. Major applications of solar energy measurement are found in climatology, hydrology and utilization of solar energy [1]. In climatology, one of the purposes of solar radiation measurement is to study global climate. The earth receives solar radiation and emits far infrared radiation. The difference of both contributions is the so-called radiation budget.

To study the greenhouse effect, the hypothetical heating up of the earth, the measurement of this radiation budget is essential. In hydrology, the radiation budget is an important factor in the process of evaporation of water. In agricultural areas that need irrigation, the water consumption is a function of temperature, wind speed, humidity, type of crop and of solar radiation. There is a relatively simple model in use to describe this function. This model is used to schedule irrigation.

In solar energy studies, radiation needs to be measured for two main reasons. The first is to characterize the solar climate at the location where the solar energy equipment will be installed. Most notably, decisions about the size and the orientation need to be made. The second reason is to monitor solar cell efficiency: The ratio of the amount of energy that is generated to the amount of solar energy that is available.

For the latter purpose, a battery-operated microcontroller-based data acquisition system has been developed to monitor global solar radiation and temperature in photovoltaic (PV) system. The system has been designed around the PIC18F4550 8-bit microcontroller, where the measurement system uses thermopile (black & white) pyranometer and 1-wire bus digital thermometer. The data from sensors have been collected by means on-chip analog to digital converter and stored in serial EEPROM until uploaded to computer for on-line and subsequent analysis to minimize system cost, complexity and downtime [2]. An alternative approach to PV module maximum power prediction is presented in this paper, based on the neural network. The proposed neural network has a simple structure resulting in highly accurate prediction of the maximum power from the PV module.

2 Hardware Design

A low cost 8-bit microcontroller with 13 analog input channels based DAS for long-term collection is shown in the block diagram of the Figure 1. The DAS is connected to computer through USB cable to allow user communication and to download recorded data to the computer for subsequent analysis. The heart of the DAS is the PIC18F4550 microcontroller which is used to control

measurements and data storage sequences [3]. This microcontroller has: 8MHz crystal oscillator used for the clock input allowing 0.5µs instruction cycle, Flash program memory of 32 Kbytes, SRAM capacity of 2048 bytes and 256 bytes for EEPROM data memory. The major on-chip peripheral functions are: Four timers (1x8-bit/3x16-bit), master synchronous serial port (MSSP) with I²C master and slave mode, Universal Serial Bus communications module that is compliant with the USB specification V2.0, a 10 bit/10µs (conversion time) analog to digital converter up to 13 channels where the first input is used to sample signals from pyranometer as shown in Figure 1. The pyranometer produces a voltage between 0 and 10 mV applied to the input of a first order low pass filter (cutoff frequency: 40Hz) for noise suppression. The filtered output is amplified by low cost general purpose instrumentation amplifier INA114AP with an amplification gain of 500 for a maximum output voltage of +5V. This amplifier was chosen because its offset voltage is very low (50µV) offering an excellent accuracy.

The DS18S20 digital thermometer communicates over 1-wire bus that by definition requires only one data line and ground for communication with PIC microcontroller [4][9]. It has an operating temperature range of -55°C to 125°C and is accurate to ±0.5°C over the range of -10°C to 85°C. In addition, the DS1820 can drive power directly from the data line (parasite power) eliminating the need for an external power supply. The DAS system architecture diagram shows that the PIC microcontroller uses an external serial EEPROM memory (24LC256) with a capacity of 32 Kbytes for storing global solar radiation and temperature data. The EEPROM communicates over 2-wire serial interface bus (I²C compatible) with PIC microcontroller. Dedicated I²C communication pins are: serial clock line (SCL, pin 34) and serial data line (SDA, pin 33) on the PIC microcontroller, used to transmit and receive 8-bit data [5]. The SDA and SCK lines are both open drain terminals so 10kΩ pull-up resistors have been used. Port C pins RC4 (data D-, pin 23) and RC5 (data D+, pin 24) are used for USB interface. A 0.22µF capacitor is connected to VUSB pin (pin 18) so the microcontroller can operate the internal USB circuitry. A liquid crystal display (LCD) has been added to inform the user about global solar radiation, temperature, time, date and maximum power. A serial real time clock (DS1307) is used to provide DAS with full binary coded decimal clock/calendar [6]. Address and data are transferred

serially via I²C bi-directional bus. The clock/calendar provides seconds, minutes, hours, day, date, month, and year information. Data and clock signal pins are pulled-up to 5V with external resistor about 10KΩ to ensure proper logic level. In this case, the software I²C routines are used for implementing software I²C communication.

The DAS has its power supply from 12V sealed lead acid battery where a schottky barrier diode D1 is used for protecting the power supply block against damage due to accidental battery or PV module polarity reversal (Figure 2). The cathode pin of the schottky diode is connected to the input of the positive voltage regulator (7809). The negative supply is created from the output of the 7809 by using an oscillator based hex Schmitt trigger inverter (74LS14). The generated square wave, amplified by a bipolar transistor (2N1711) and injected in diode-capacity network, allows obtaining negative supply which is necessary to operate the instrumentation amplifier INA114 in bipolar power supply mode.

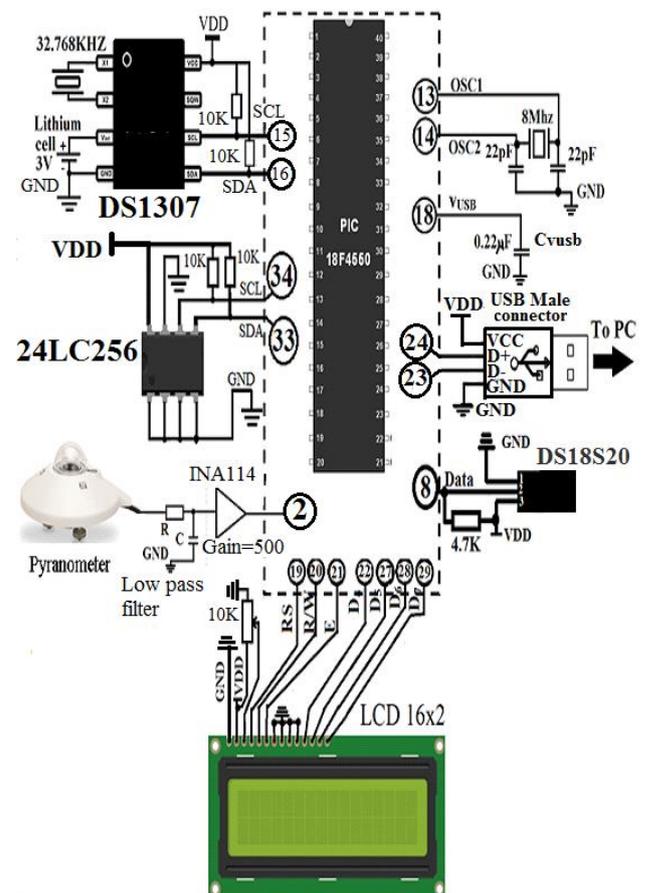


Figure 1. DAS architecture

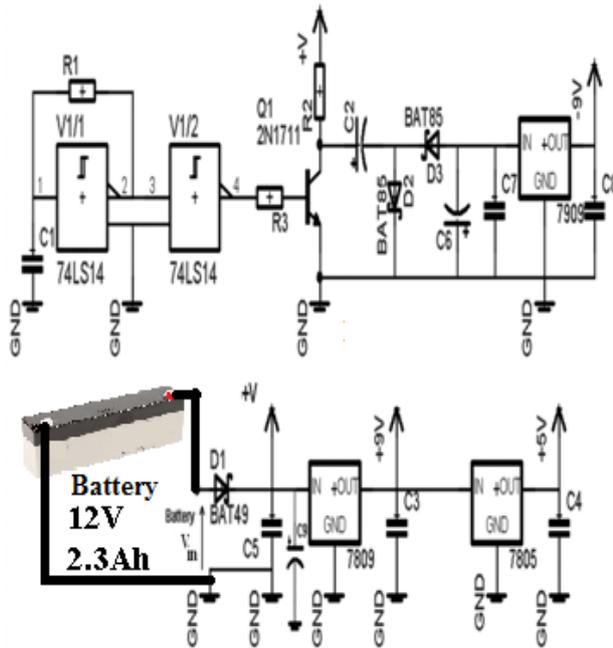


Figure 2. Circuit diagram of the power supply block

3 Software Design

The control program, written in MikroC language, monitors global solar radiation and temperature at 30 seconds intervals. PIC microcontroller converts global solar radiation as an analog input to 10-bit digital data and gets through 1-wire protocol 9-bit from digital thermometer. Solar radiation, temperature, maximum power, date, and time are stored on I²C EEPROM and sent to computer via USB port. Software in visual studio C++ programming environment was developed to facilitate communication between DAS and the computer. Figure 31 shows a simplified flowchart of the process to store the measured and estimated data [7].

4 PV module modeling

The PV module is composed of 36 poly-crystalline silicon solar cells. It is fixed facing to the south with the slope of 35°. Table 1 indicates the specification of the PV module used for the measurements. The circuit model of the PV module is shown in figure 3. The shunt resistance is ignored for the sake of simplicity which is good enough for fairly accurate models. The model was evaluated using MATLAB [8]. A Matlab function is used to evaluate the model associated with the equivalent circuit of the PV module. Inputs of the developed MATLAB function are irradiance, temperature, and PV module

operating voltage and output is PV module operating current. This MATLAB function is used to generate the training patterns for the proposed neural network structure. Thus, the input patterns are the irradiance (from 1 to 1000 W/m² with a step of 1W/m²) and the temperature (from 0 to 65°C with a step of 0.5°C). The target patterns are given by the calculated maximum power from the PV module model.

5 Proposed method

The configuration of the proposed three-layer feed forward neural network is shown in figure 4. This structure is utilized to predict the maximum power drawn from the PV module. The neural network has an input, a hidden, and an output layers. The numbers of nodes are two, five, and one in the input, the hidden, and the output layers respectively. All layers have biases except the first one. Transfer function of hidden layer is ‘tansig’(Hyperbolic Tangent Sigmoid), and ‘purelin’ for output layer. The back propagation network training function is ‘trainlm’ which updates weight and bias values according to Levenberg-Marquardt optimization. ‘trainlm’ is often the fastest back propagation algorithm in the MATLAB toolbox, and is highly recommended as a first-choice supervised algorithm. Training occurs according to training parameters given in figure 5. All computations are performed off-line during the training process. Training stops when performance has been minimized to the goal.

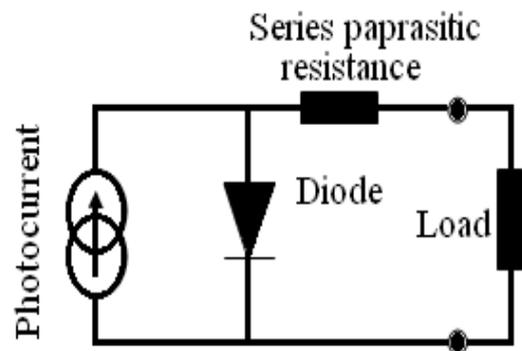


Figure 3. Equivalent circuit of a PV module

Table 1. Specification of LA361K51 PV Module at STC

Maximum power	51W
Short-circuit current	3.25A
Open circuit voltage	21.2V
Optimal voltage	16.9V
Optimal current	3.02A
Series resistance	0.24Ω
Diode quality factor	1.35
Module area	0.438m ²

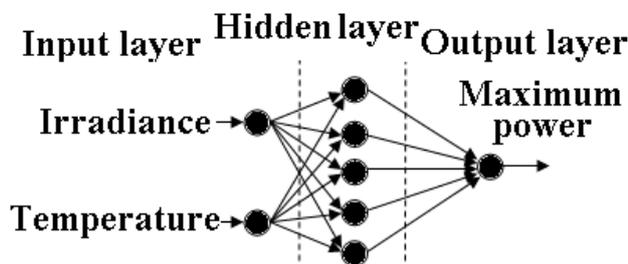


Figure 4. Neural network structure

Figure 6 shows the convergence of error during the training process. Figure 7 shows the correlation between the target and the estimated maximum power. As shown in this figure, a linear correlation exists between these quantities. Therefore, the maximum power can be easily obtained from the neural network output.

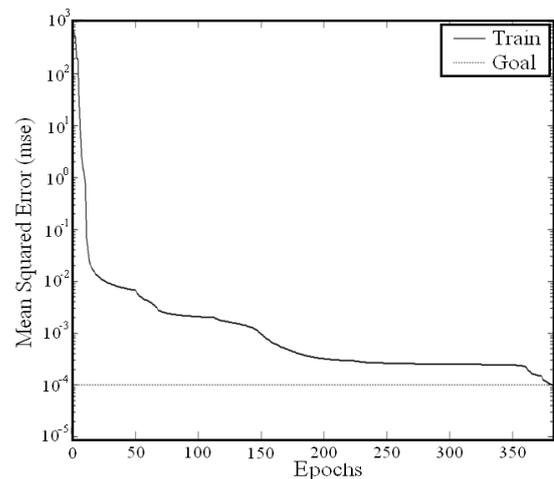


Figure 6. Convergence of Error

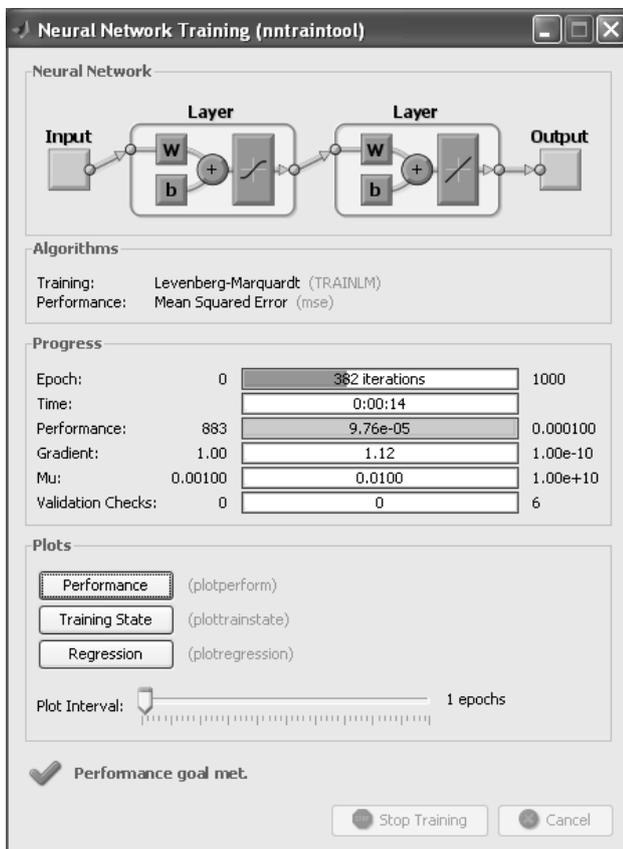


Figure 5. Neural network training window GUI

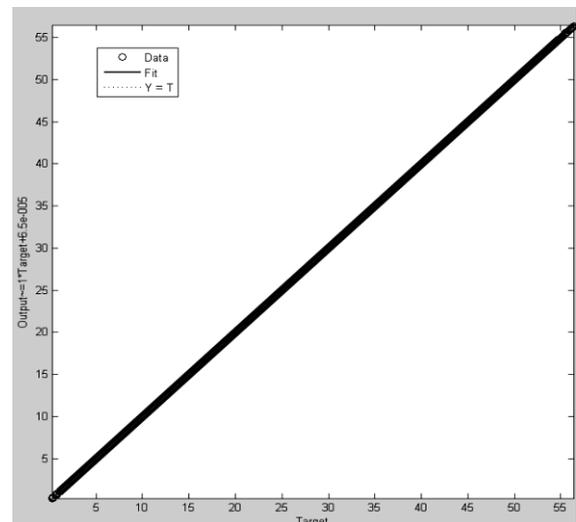


Figure 7. Training output vs. target

6 Results and discussions

The DAS was mounted outdoors with digital thermometer employed to monitor the PV module temperature and pyranometer designed to measure global solar radiation on tilted surface (latitude: 35° N, longitude: 0.7° W, USTO). Readings from the two sensors were taken at 30 seconds intervals. The DAS takes only 1 ms to do 100 analog to digital

conversions which allows a rapid follow of global solar radiation and temperature changes with clear-cloudy transitions as shown in Figures 8 and 9. The global solar radiation curve look like a bell shape with a maximum recorded at mid-day while temperature increases and decreases with solar radiation. Figure 10 shows graphical presentation of data which are stored in DAS EEPROM and sent to computer.

Figure 11 indicates the calculated and estimated maximum power from the same PV module on January 3, 2018. The calculated values are obtained from PVSYST software which is based on a one diode model [10]. This tool can show the model results for any specified operating conditions. The measured patterns (Figures 8 and 9) are not included in the training set. Therefore, the identified maximum power outputs are almost equal to the calculated ones.

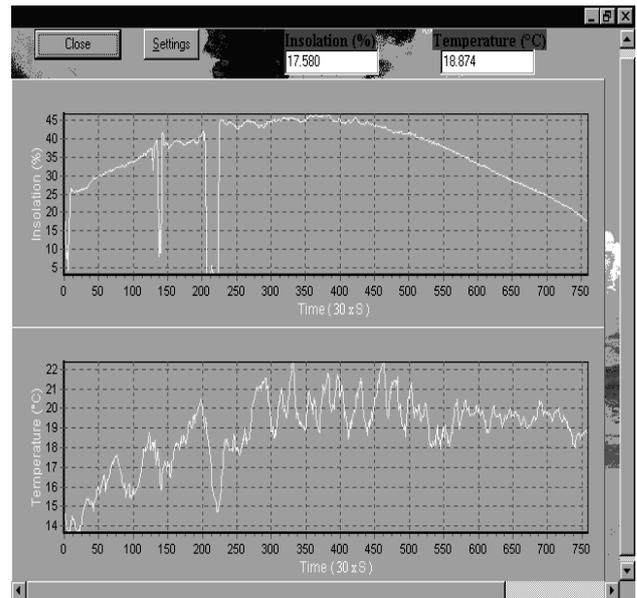


Figure 10. DAS communication interface

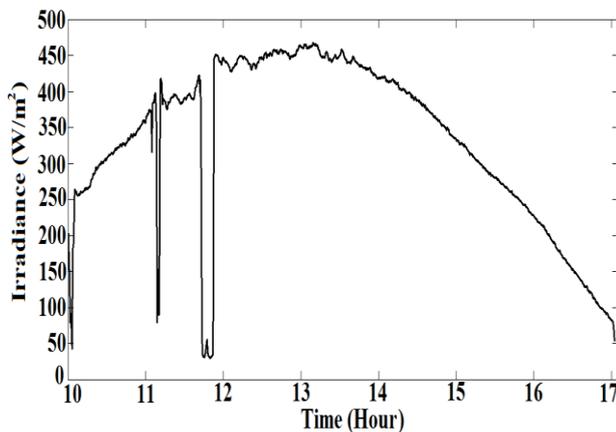


Figure 8. Global solar radiations on tilted surface

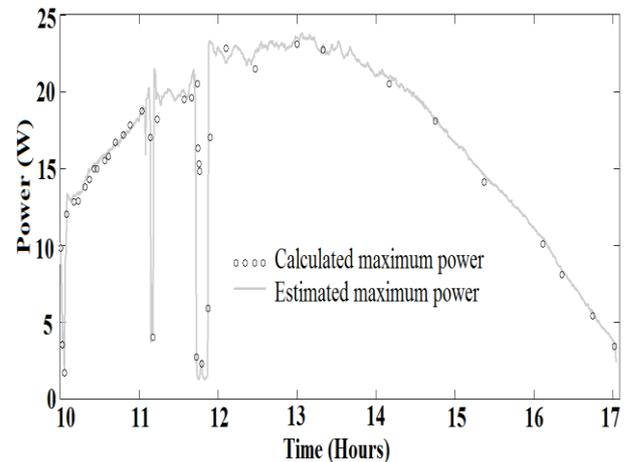


Figure 11. Calculated and estimated power curves

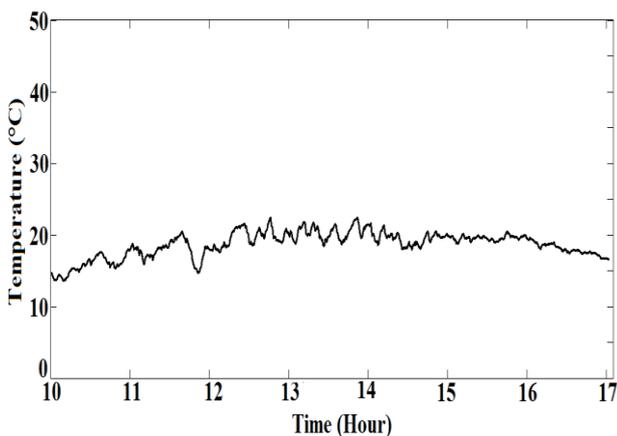


Figure 9. PV Module temperature curve

Figure 12 represents the second set of data for a cloudy day (06-Jan-2018). Proposed neural network is tested with irradiance and temperature data given by figures 13 and 14. Measured data (Figures 12 and 13) are not included in the training patterns for the neural network. As shown in figure 15, the neural network gives the accurate estimation of the maximum power.

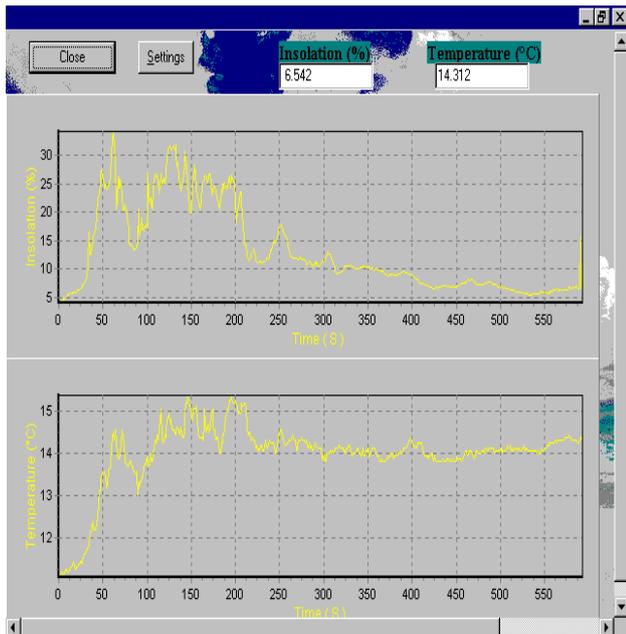


Figure 12. Irradiance and temperature profiles

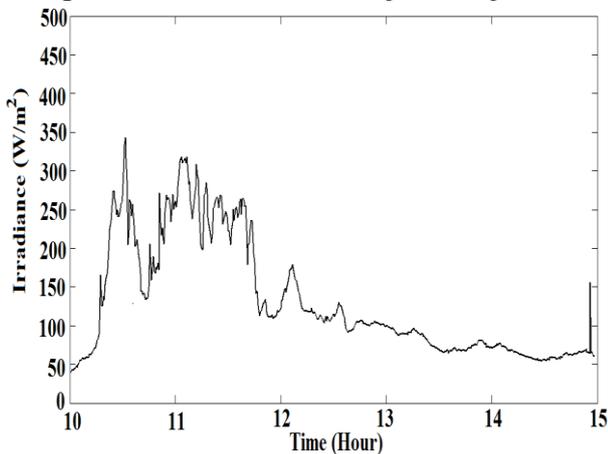


Figure 13. Curve of irradiance data

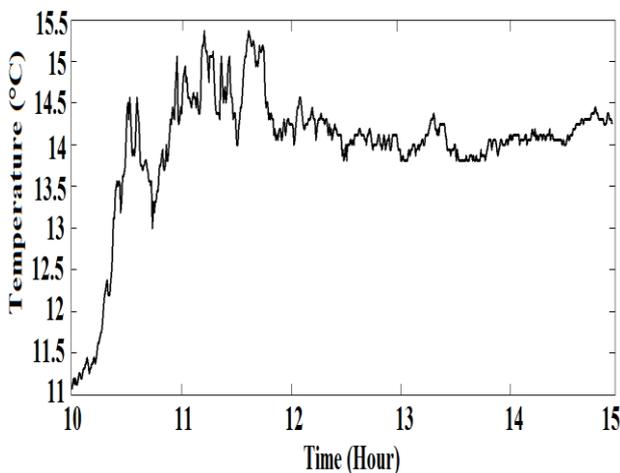


Figure 14. Curve of temperature data

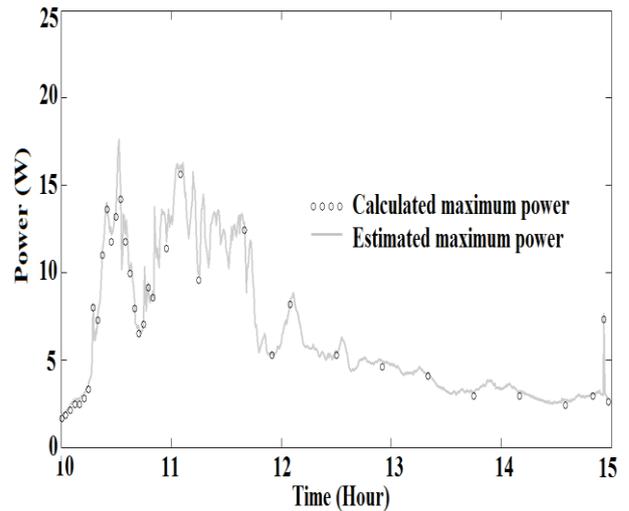


Figure 15. Calculated and estimated power curves

6.1 short-circuit current technique

In this section, a PV module is used for measuring the irradiance based on short-circuit current-irradiance curve. This technique is simple and less expensive than that based on pyranometer. The PV module utilised in this section is Zytech ZT180S which consists of 72 series connected cells [11]. The technical characteristics were gathered from its manufacturer’s data sheet, and are given in Table 2. The PV module short-circuit current is measured with hall-effect based linear current sensor ACS712ELCTR-20A (Figure 32). The latter gives precise current measurement for DC signals. This sensor version is optimized to sensing current up to 20A [12].

Figures 16, 17, 21, 22, 26, and 27 show meteorological data for three days in January, from sunrise to sunset. The meteorological data are obtained from DAS. The relation between the PV module short-circuit current and solar irradiation is shown in figures 18, 23, and 28. Then, the short-circuit current varies linearly with irradiance.

The simulated power is defined as the theoretical maximum power calculated by using Matlab MPPT function and the estimated power represents the power obtained from the output of ANN. As shown in figures 19, 24, and 29, the power curves are superimposed, which means that the ANN can successfully track the MPP even in case of rapidly changing atmospheric conditions. This is confirmed by the tracking error curves in figures 20, 25, and 30 where the error does not exceed more than 2watts in any case.

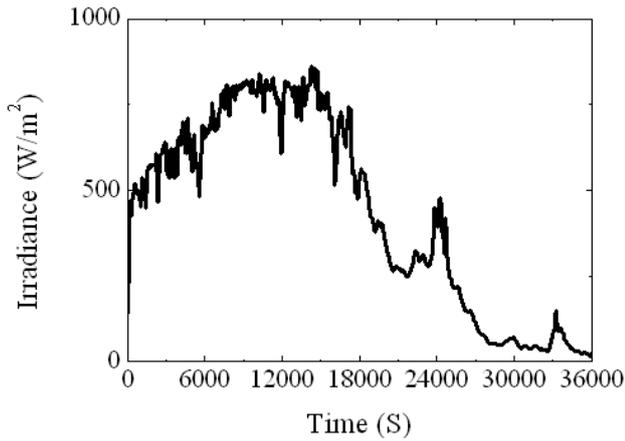


Figure 16. Curve of irradiance data measured on January 15,2019

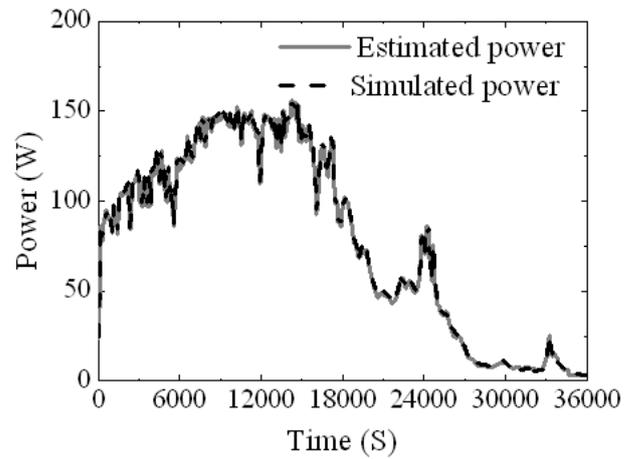


Figure 19. Simulated and estimated power curves

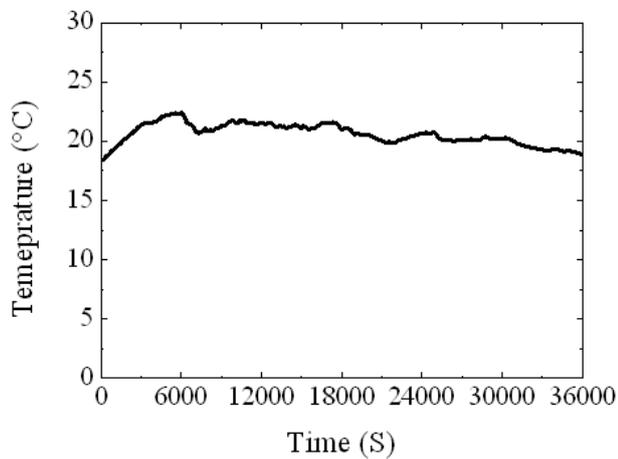


Figure 17. curve of temperature data

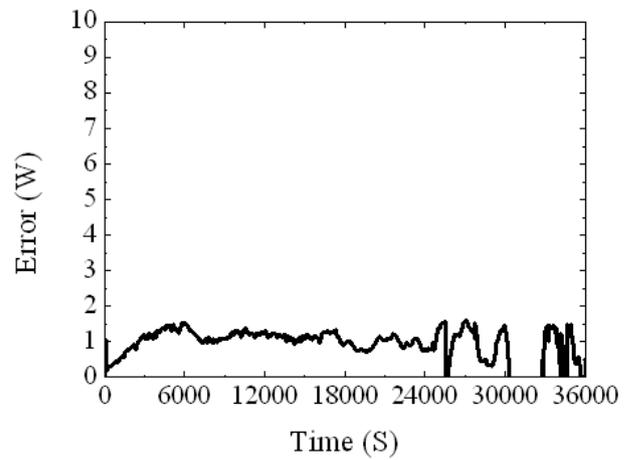


Figure 20. MPP Tracking error curve

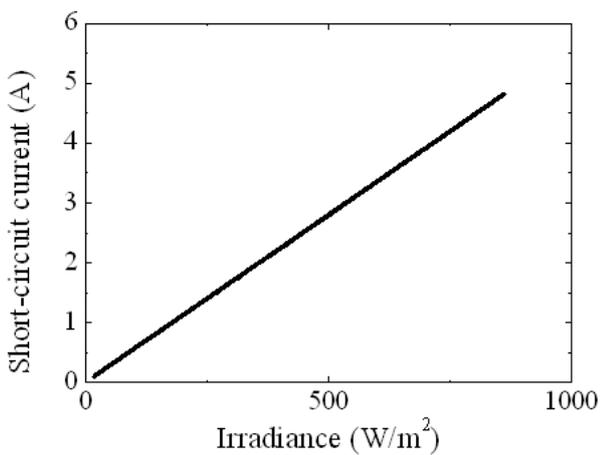


Figure 18. Relation between PV short-circuit current and the corresponding irradiance

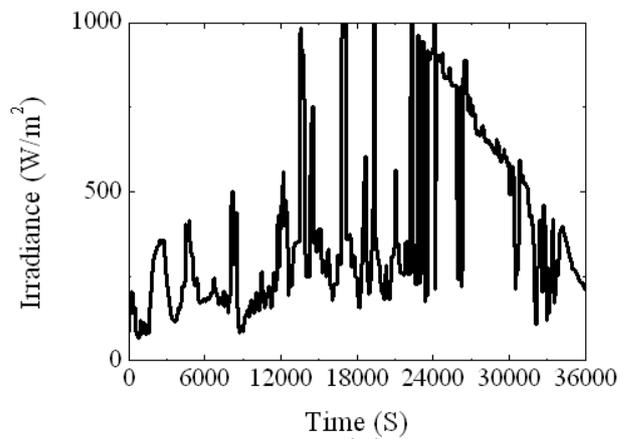


Figure 21. Curve of irradiance data measured on January 16,2019

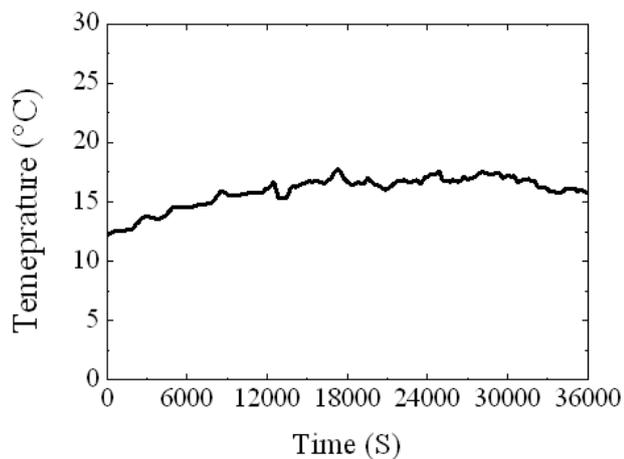


Figure 22. Curve of temperature data

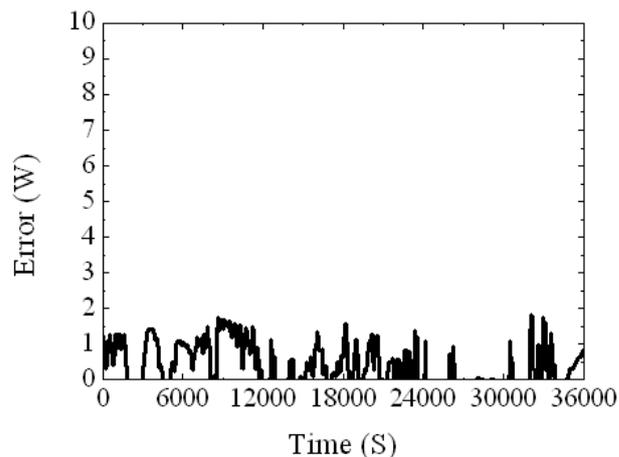


Figure 25. MPP tracking error curve

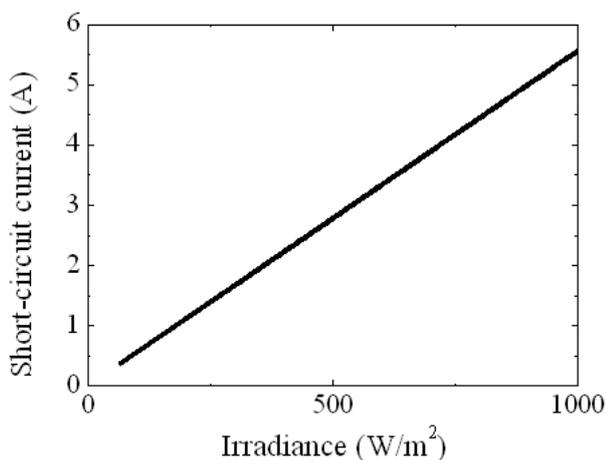


Figure 23. PV module short-circuit current versus irradiance

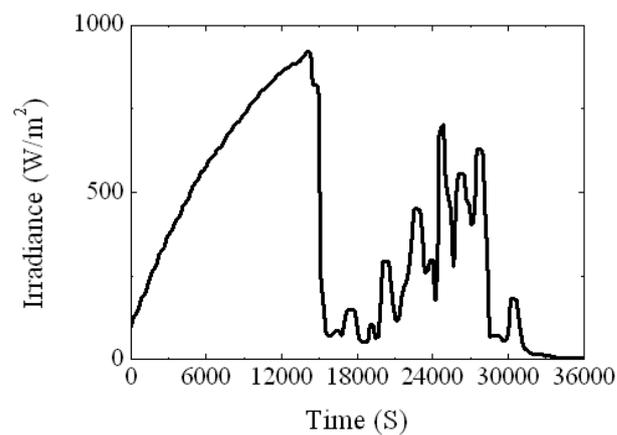


Figure 26. Curve of irradiance data measured on January 21, 2019

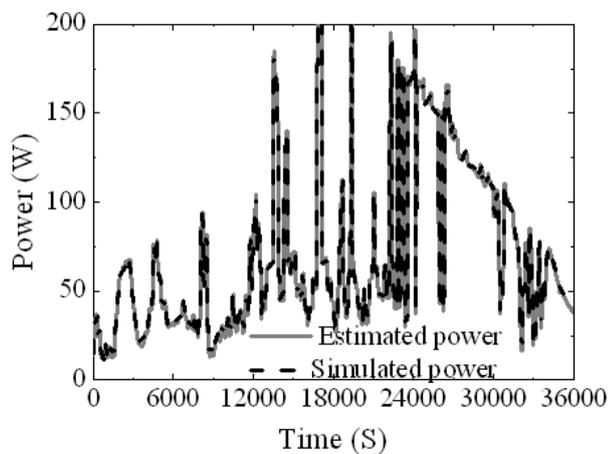


Figure 24. Simulated and estimated power curves

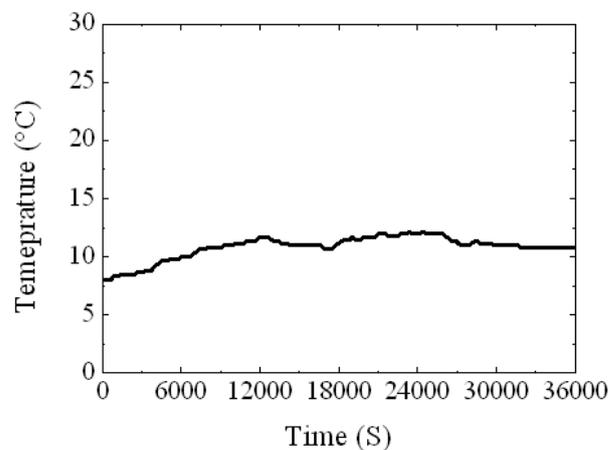


Figure 27. Curve of temperature data

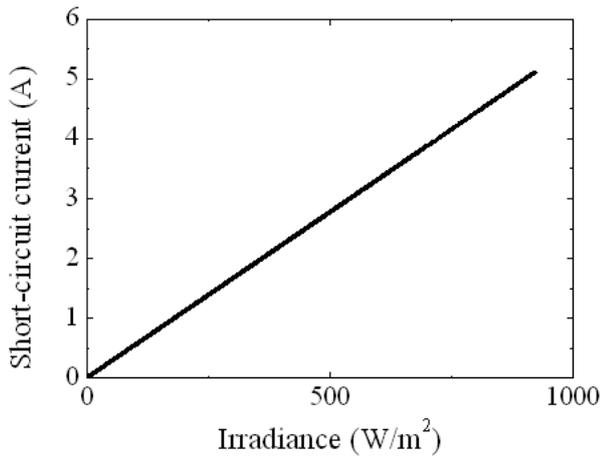


Figure 28. PV module short-circuit current versus irradiance

Table 2. Specification of ZT180S PV Module at STC

Maximum power	180W
Short-circuit current	5.53A
Open circuit voltage	44.71V
Optimal voltage	36.79V
Optimal current	4.89A
Series resistance	0.24Ω
Diode quality factor	1.35
Module area	1.2m ²

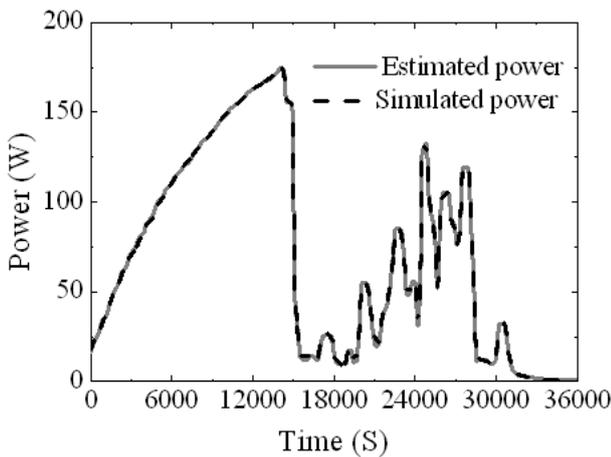


Figure 29. Simulated and estimated power curves

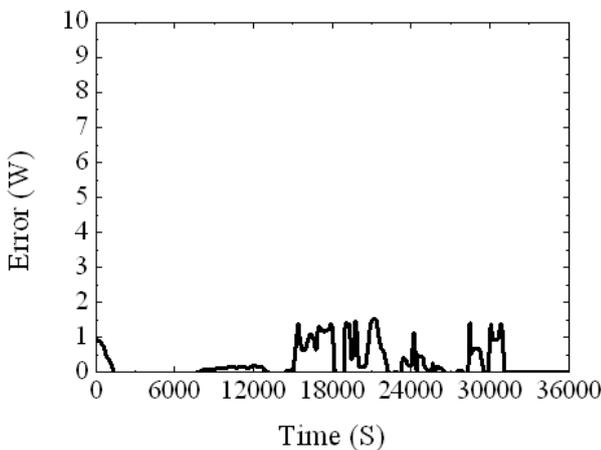


Figure 30. MPP tracking error curve

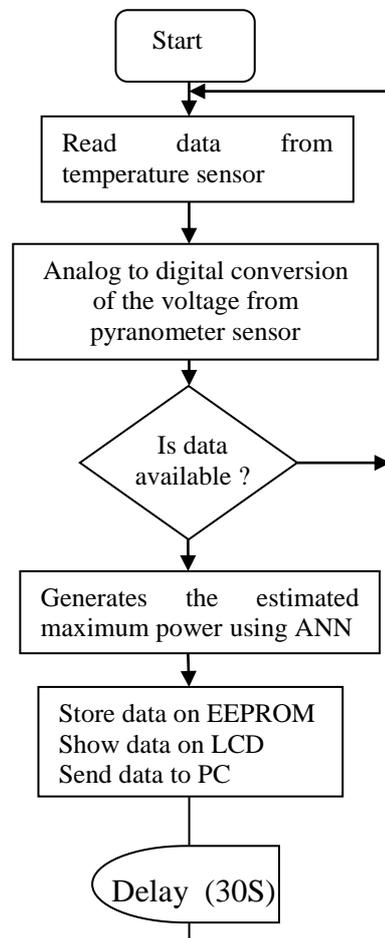


Figure 31. Flowchart of the algorithm to store the measured and estimated data.

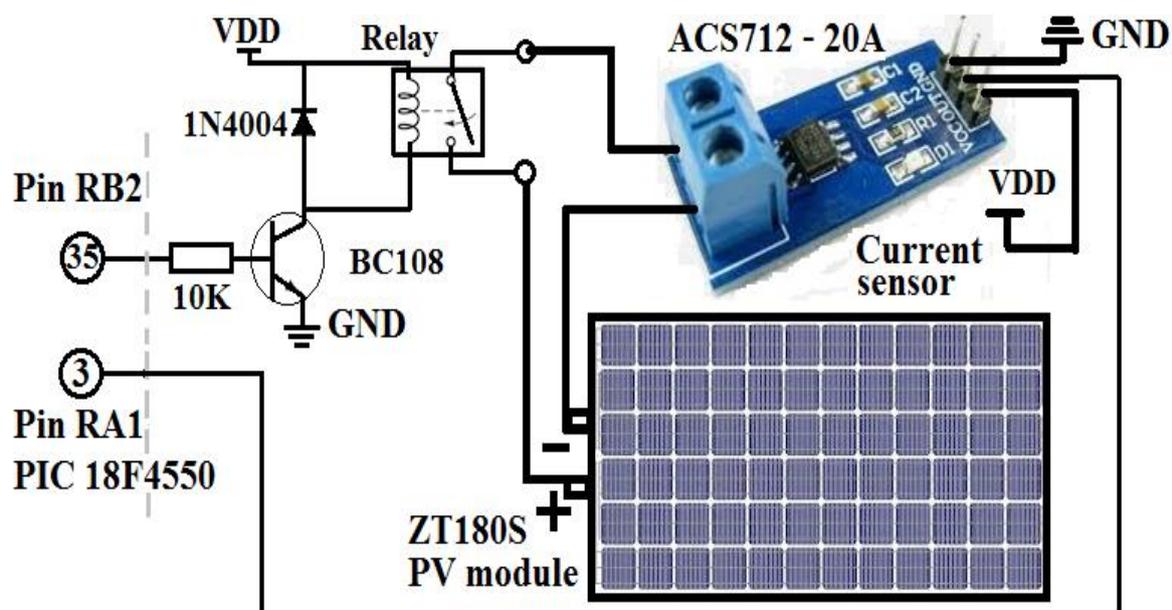


Figure 32. Short-circuit current measurement circuit

7 Conclusion

The design and implementation of microcontroller-based data acquisition system for monitoring global solar radiation and temperature data in PV system is presented. The many salient features of the design include the use of RISC technology, low-cost microcontroller for storing data with the supporting serial communication. An external EEPROM memory is used for recording temperature, global solar radiation and time/date provided by real time clock/calendar connected on the PIC microcontroller I²C pins. The obtained graphics by downloading data on computer help for subsequent analysis. For on-line process, DAS has the capacity to compute the maximum power that a PV array can generate in a PV system and this precious information can be used for maximum power point tracking.

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