Open Source Embedded Data Logger Design for PV System Monitoring

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Abstract—**The monitoring system in photovoltaic power generating system is very important and crucial in some cases for evaluating, troubleshooting and in decision making issue. This paper proposes very simple and low cost an embedded data logger with the high reliability and high precision for monitoring PV power generating system. The data logger meets all of the relevant requirements in terms of accuracy included in the International Electro technical Commission (IEC) standards for PV systems. The implementation process, including design and development of the hardware and software, is explained in detail. The electrical and meteorological sensor outputs are first conditioned according to microcontroller analogue to digital converter input needs using precision electronic amplifier and active filter circuits and then digitized and processed using 32 bit ARM Cortex M4 core microcontroller. Some sample deployment and measurement results are also presented to demonstrate the usefulness of the monitoring system.**

Keywords- embedded system; hardware software co-design; signal conditioning; data acquisition; energy measurement.

I. INTRODUCTION

The usage of photovoltaic system has been more and more popular in last decade as the production cost has decreased and people have become more concerned about the environment-friendly energy to use. Therefore, it is important to understand the energy performance resulting from photovoltaic system. The PV power generating system is often includes one or more photovoltaic array, battery bank, power conditioning unit and electrical loads. During the operation of such system, performance parameters of the system components should be carefully monitored and an appropriate decision must be given on time. In addition reliable functioning of the system, monitoring also is necessary for maximizing the yield of energy production of the PV power generating systems. [1]. Many monitoring systems have been designed in order to collect and process such data, as well as monitor the performance of PV or hybrid power systems under operation, during last three decades [2]. Because of the most PV system are installed in around the remote locations where there is restricted access to performance data, many monitoring system have some kind of a remote monitoring ability [3, 4].

Early monitoring systems include data acquisition board and associated computer software utility. The most popular one of them is LabVIEW™ that gives opportunity to the user create graphical user interface and limited control functions [5-7]. The second generation monitoring systems have been placed on the power condition unit as a utility. On the basic one, user can read only performance parameters on the LCD display which embeds on power condition unit. Enhanced power condition units also consist of communication ports such as RS232, USB, RS485, Wi-Fi or Bluetooth that share performance parameters with other user or networks. Commercially available monitoring systems on the market are quite expensive depending on the monitoring capability and remote accessibility. Designing and building a custom made monitoring system confirm a cost effective solution for a long term benefit [8, 9]. After the year 2000, the sensors and electronic components price has been sharply throw down. Thanks to a new generation of digital systems called microcontrollers, the low cost smart embedded systems can be now designed and assembled easily. These low cost chips are now considering a pivotal axis of the modern control systems, since it is mainly consisting of a small computer embedded on a single chip. Thereafter, many low cost sensor-based microcontroller data acquisition systems have been designed to monitor and store the meteorological and system performance data for the PV power generating systems [10-14].

This work discusses of designing and making a novel low cost data logger for monitoring both PV power system operational parameters and, meteorological data by using the low cost microcontroller. The developed embedded system permits the fast system expansion and has the advantage of flexibility in the case of modifications, while it can be easily extended for controlling the PV power generating system operation. The further sections of this study are structured as follows. In the next section, the parameters of the PV power system are defined according to IEC-61724 Standard. The hardware and firmware development of data logger is described in Section III. Section IV gives and discusses the experimental results and the last section remarks the conclusion of this research.

II. PV POWER SYSTEM PARAMETERS

In general, a photovoltaic system integrates solar modules, batteries and regulators for the case of stand-alone systems, inverters for the case of grid connection, AC and DC wiring, electrical security devices, and protection devices. International standards set the parameters that must be measured and monitored. Specifically, the IEC61724 standard titled "Photovoltaic system performance monitoring – guidelines for measurement data exchange and analysis" describes the general guidelines for the monitoring and analysis of the electrical performance of photovoltaic systems. Fig.1 gives an example of

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applying the IEC61724 standard for a general photovoltaic system and Table 1 presents a summary of these parameters [15]. The IEC61724 standard recommends procedures for the monitoring of energy-related PV system characteristics such as irradiance, array output, storage input and output and power conditioner input and output; and for the exchange and analysis of monitored data. The purpose of these procedures is to assess the overall performance of PV systems configured as standalone or utility grid-connected. Even though this standard opens the door to systems that are hybridized with non-PV power sources such as engine generators and wind turbines, really the inclusion of wind turbines is not fully covered.

So, without the optional parameters, 13 variables must be measured in the general diagram described in Table 1 (2 temperatures, 1 irradiance, 5 voltages, 3 directional currents, and 2 bidirectional currents).

TABLE I. PERFORMANCE PARAMETERS.

Meteorology	
Total irradiance	G_I
Ambient temperature in a radiation shield	T_{am}
Air speed and direction (optional)	S_W
Photovoltaic array	
Output voltage	V_A
Output current	I_A
Output power	P_A
Module temperature	T_m
Tracker tilt angle (optional)	Φ_T
Tracker azimuth angle (optional)	Φ_A
Energy storage	
Operating voltage	V_S
Current to storage	I_{TS}
Current from storage	I_{FS}
Power to storage	P_{TS}
Power from storage	P_{FS}
Load	
Load voltage	V_L
Load current	I_L
Load power	P_L
Utility grid	
Utility voltage	V_U
Current to utility grid	I_{TU}
Current from utility grid	I_{FU}
Power to utility grid	P_{TU}
Power from utility grid	P_{FU}
Back-up sources	
Output voltage	V_{BU}
Output current	I_{BU}
Output power	P_{BU}

The initial device setup and requirements were identified as follows.

- Large dynamic current range 0–15 A with 1 mA resolution and low insertion loss (0.01 ohm max). Voc of 100 V.
- Simple and light in construction so that can be used at roof of the house along with the panel.
- Adjustable scan time, ideally down to 1 second or less so accurate scans can be completed under changeable atmospheric conditions
- Integration of a budget pyranometer, so panel efficiency can be calculated.
- The user can easily adjust the starting up time, the ending time, the number of sensors and the sampling interval by using user interface system.
- The system has its own storage system such as flash memory or SD card; therefore it doesn't require any external computer to store the sensors data.
- The data are stored in a Comma-Separated Values CSV file; therefore the data can be handled and analyzed easily by any mathematical software such as Excel or MATLAB.
- The components of the systems are available in any electronic store with cheap prices and it can be assembled easily by using simple tools.
- The system can be adjusted to measure any sensor as long as the output of the sensor lies between 0 and 5 V DC.

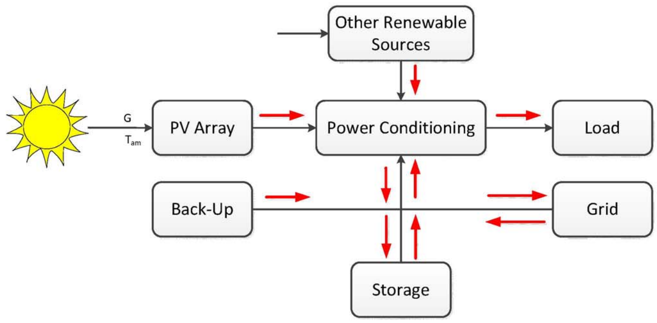

Fig 1- Configuration of PV system that will be tested.

A. Current Measurement

The current parameters may be either direct current (DC) or alternating current (AC). The accuracy of the current sensors, including signal conditioning, must be better than 1% of the reading. The two main methods to measure current consist of using shunts or current transducers. The use of shunts is very simple and does not require power supply. But it needs galvanic isolation otherwise. The preferred method to make this measurement is to use a Hall Effect based DC/AC current probe. However, a good quality current probe is not always available. This design tip describes a low cost alternative that is easy to make with readily available components and works well for monitoring the currents encountered in most motor control and power supply circuits. The major drawback to this sensor is that, unlike commercial current probes, the sensor does not have a clamp on type arrangement so the wire must be cut and the sensor wired in series with the load being monitored. Using multiple sensors provides an inexpensive way to monitor multiple currents at the same time and is much more compact than a typical commercial current probe. The circuit requires only an isolated 5V supply to power the circuitry in the ASC 712 hall-effect current sensor [16].

Two similar current sensors that are ranged as ASC712-10A and ASC712-100A are used for measuring both the DC current coming from the solar panels and the AC current at the output of the filter. They are Hall Effect sensors which brings galvanic isolation between the primary circuit (high power) and the secondary circuit (measurement circuit). The DC current range that is to be measured is [0-100A] whereas the AC current range will be [±10A]. For a measured current of 0A, the output voltage is 2.5V. The output voltage then increase/decrease when the measured current increases/decreases. Since the desired measuring range for the DC current measurement is [0;100A], the output voltage range of the sensor that should be considered is [2.5-3.25V]. For the AC current measurement ([-10;10A] the output voltage range of the sensor that should be considered is therefore [1.75 - 3.25V].

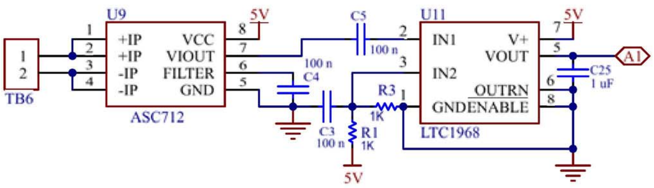

Fig 2- Current measurement circuit.

B. Voltage Measurement

A voltage sensor uses simple voltage divider arrangements to bring the input voltage level to a measurable voltage, as is shown in Fig. 3. The voltage division level is adjusted to get the best resolution for the input voltage level with the help of a few switching resistors. There are four different voltage resolution levels. The maximum measurable voltage is 146 V. The output equation of the circuit in Fig. 2 can be written as equation 1.

$$\frac{V}{V_{PV}} = 1 + \frac{R_1 + R_{dsON}}{R_2} \tag{1}$$

where R1 is the resistance in series with the MOSFET and is the on-state resistance of the MOSFET RdsON. The resistance R2 is connected in series with cell. The different values of resistance are used to measure different cell voltages.

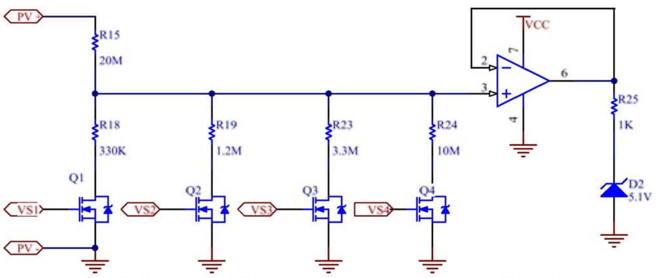

Fig. 3. Voltage divider arrangements to measure PV voltage.

AC voltage sensing will be made at the output of the LCL filter. The ACPL-782T (from Avago Technologies) isolation amplifier will be used in order to bring galvanic isolation between the signal side and the power side of the board. This device has 2 input pins (Vin+ and Vin-) and 2 output pins (Vout+ and Vout-).

The output pins have an offset of 2.5V in addition to their respective input signal multiplied by 8 (internal gain of the amplifier). The datasheet of the ACPL-782T states that for a linear and accurate operation, the signals Vin+ and Vin- must be in the range [-0.2;0.2V]. Therefore Vout+ and Vout- will be in the range

[2.5-(1.6×0.2) ; 2.5+(1.6×0.2)]. We can also simply write that (Vout+ - Vout-) will be in the range [-1.6;1.6V]. AC voltage measurement circuit is shown in fig.4.

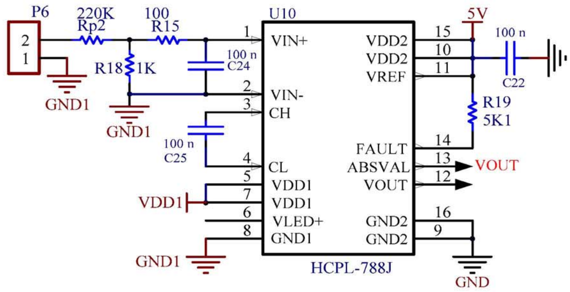

Fig 4- AC Voltage measurement circuit.

C. Temperature Measurement

MAX31855T digital thermocouple interface IC. Measured temperature range is -270C-400C with known thermal characteristics and output resolution of 0.25C. This sensor supports a larger operating range specifically in the negative range than its predecessors, the MAX6674 and MAX6675. Connection diagram of thermocouple interface IC is shown in fig.5.

D. Solar Radiation Measurement

The photodiode, BPW34 as is shown in Fig.6 has been used as the sensor for to measure solar radiation. Although the photodiode is not the ideal choice, but due to cost and other considerations, it is used for the measurement of solar radiation. The photodiode is placed parallel with a 470 resistor which is smaller than the shunt resistance of the photodiode. This arrangement allows the photodiode to act as a linear current generate for the given solar radiation. The output of the photodiode is amplified and fed into the Analogue to Digital Converter of the microcontroller. The maximum measurable solar radiation is 1250 W/m.

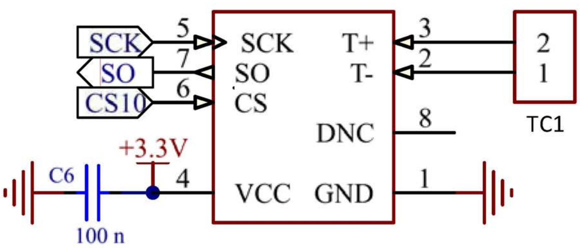

Fig.5. Temperature sensor circuit.

Fig. 6. BPW34 photodiode.

III. Low Cost Data Logger Hardware Design

The low cost data logger hardware and software are explained in this section. A complete block diagram of the system is given in fig.7. The operations of the data logger are managed by the microcontroller. It takes data from sensors using appropriate communication protocols and process the gathered data and send the computer if desired.

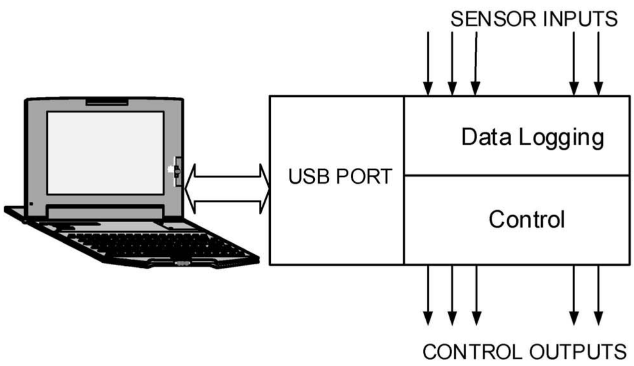

Fig. 7. Detail of the new data logger.

Most microcontroller chips consist of five main parts such as, central processing unit (CPU), to execute the user program, memory unit for user program and the data memory, input/output units, to provide the chip with ability to communicate with outside, some additional peripherals such as timers and Analog-to-Digital converters (ADC), to ease the controlling of complex systems such as robots and smart systems and bus system, to connect all the previous components together [17]. In this study the ARM® Cortex™-M4 based is used. This microcontroller that is called Tiva C Series has integrated USB 2.0 On-the-Go/Host/Device interface, CAN, analog, and low-power capabilities [18]. The evaluation kit features the TM4C123GH6PGE microcontroller in a 144-LQFP package, a 96×64 color OLED display, USB OTG connector, a micro SD card slot, a coin cell battery for use with the Tiva C Series low-power Hibernate mode, a temperature sensor, and easy access to all of the available device signals inputs and outputs.

The system consists of four main parts; the master control board, the microcontroller board, the power supply unit and the sensors terminals unit. The Master control board is responsible for controlling and monitoring the data acquisition system by using 4 press buttons and an LCD screen. The microcontroller board is responsible of measuring the sensors voltages and storing their values in the SD card. The power supply circuit is designated to provide the appropriate voltages to the whole system. Finally, the sensors terminal unit is designed to ease the connection between the sensors and the microcontroller board as shown in the same figure.

IV. Results and Discussion

As an example application, parking lightning is selected whereas system performance data and environmental operating conditions are measured and stored using the graphical control environment. Sample day measured PV system parameters such as PV system output voltage, current, battery voltage and solar radiation are shown in fig.8 through fig.11 respectively. Using stored variables, inverter and charge regulator efficiencies were calculated as 90% and 98% and overall system's electrical efficiency is calculated as 72%.

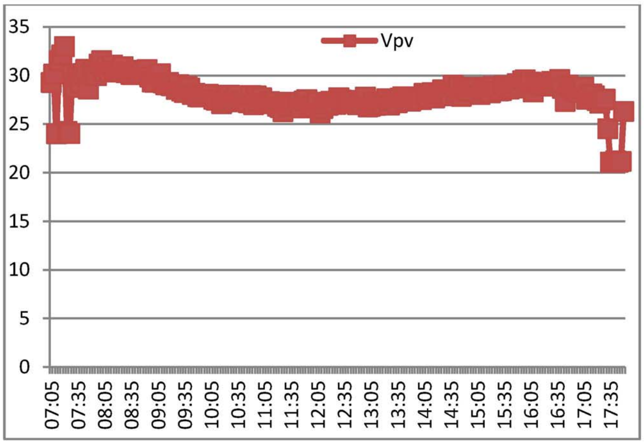

Fig.8. Daily PV panel voltage change (V_{PV}).

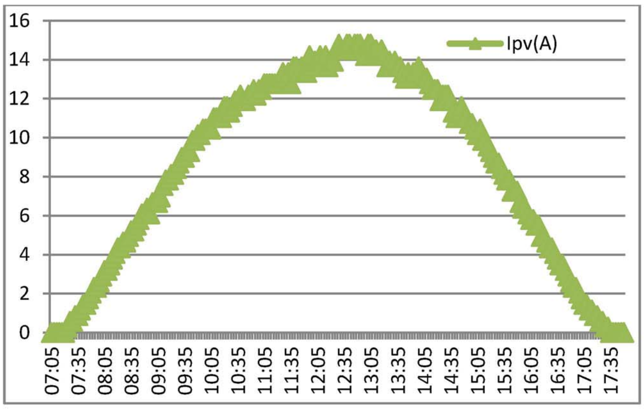

Fig.9. Daily PV panel current change (I_{PV}).

Proposed data logger may be used to track technical and financial performance of PV systems, real-time performance data for each individual module and for the whole system. Using aggregated data, comparative analysis diagnostics and a guided root-cause fault analysis can be made. It enables generation of comprehensive reports on site's energy production, immediate fault detection and troubleshooting, efficient maintenance management, and site profitability analysis.

All these features enable integrators, installers, maintenance staff, and system owners to improve the site performance, assure the yield of the system, maximize solar power harvesting and reduce maintenance costs by increasing system up-time and resolving faults more effectively.

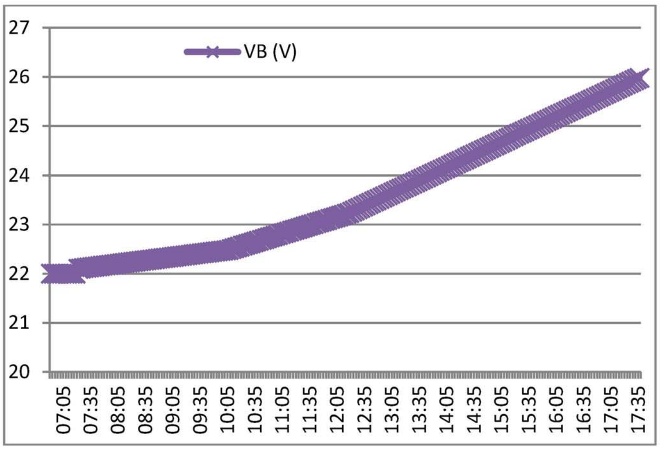

Fig.10. Daily Battery voltage change (V_B).

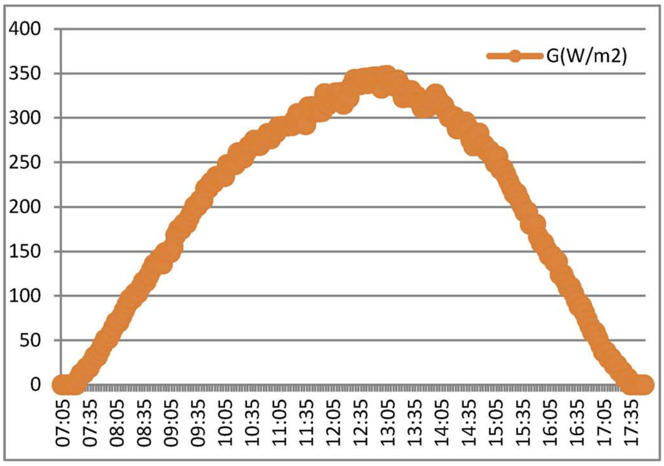

Fig.11. Daily solar radiation change (G W/m2).

V. CONCLUSION

Sensor-based microcontroller data logger system for real time monitoring of the PV system has been successfully developed. The developed system records directly the data on a XLS file, though it has the ability to use a USB port. System performance data and environmental operating conditions are fully monitored and recorded for further analysis. The experimental results show that the proposed monitoring system is very robust. The system is very reliable, precise, cheap and more flexible for use in small to large scale photovoltaic power generating system monitoring.

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