LabVIEW Based Monitoring System Applied for PV Power Station

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Abstract: -The monitoring system in photovoltaic (PV) power plants is very important and urgent in some cases for analyzing, troubleshooting and in decision making issues. This paper proposes very simple, low cost, high reliability, and high precision PV monitoring system. The proposed system is composed of a laptop connected to very cheap microcontroller board via serial cable. All the sensors and actuators are emulated in a prototype board that interfaced to the microcontroller system. A graphical user interface (GUI) program is developed in LabVIEW to monitor all the collected data in the laptop monitor and controls the system actuators via the microcontroller. An assembly program is written on the microcontroller board to scan and acquire all required data from sensors, transfer it to laptop for monitoring and then storing it for PV system documentation. The experimental results show that the proposed monitoring system is very robust and the control signals are very accurate. The system is very reliable, precise, cheap and more flexible for use in large scale photovoltaic power plant monitoring.

Key words; solar cell model, monitoring system, LabVIEW, PV power station, sensors and actuators

1. Introduction

In large scale PV power station, a monitoring and control system is necessary to monitor and control the system operation. The PV power station is often consists of photovoltaic array strings, storage batteries bank, power conditioning unit and electrical loads appliances. In the operation of such station especially with large size (kilowatt or megawatt scales), the system performance should be carefully monitored and a proper decision must be taken in time. The monitoring system for PV power station is very important to analyze, examine and decision making issues [1-4]. For example, if one cell or branch of cells in one module is shadowed, broken, or have a problem, a hot-spot phenomena will be occurred and the PV cell or module may be damaged. It also reduces the overall system efficiency. So that a warning alarm should be draw the operator attention to make a decision to remove or repair that fault. The role of monitoring system is to discover such drawbacks and inform the operator by the type and location of the failure to take decision or act a fault tolerant system if the monitored hardware is supported. In this paper, a proposed monitoring and control system is designed and implemented for such PV power stations based on LabVIEW software and microcontroller interfacing. In this work, integrating several types of instruments make the system very popular and may be used in system monitoring, control, or data logger issues. These instruments such as current and voltage sensors, state of charge (SOC) sensor for the battery bank, pyranometer, and temperature sensor combined in single system capable of acquiring measurements from all data sources placed on-line. In the proposed system, the advantages of NI software in combined with the robust, reliable and more cost effective microcontroller to present a more cheap system for PV power stations applications. The system also maintains an extensive database of minute-by-minute data for subsequent retrieval and analysis, and regularly updates hourly, daily, and monthly summary performance graphs.

2. Proposed PV System Description

The proposed PV system is composed of eight PV strings, battery bank, battery operation control unit and an electrical load appliance. A multiple sensors and actuators are placed in different locations in the system to monitor and control the system operation as shown in Figure 1.

3. Proposed Control and Monitoring System Description

As shown in Fig.1 and Fig.2, the monitoring system contains sensors and actuators to monitor and control of the system operation. All the sensors are attached to the analog to digital converter (ADC) of the microcontroller unit via analog multiplexer. The collected data has two functions; monitoring and control. The output control signals outs from the microcontroller and go to the actuator to operate (ON or OFF) in order to control the system operation. The various sensors in the system are:

A: Current Sensors for;

- PV strings (IS_1 to IS_8),
- summation of the PV strings currents (I_{PV}),
- battery bank current (IB), and
- Load current (IL).

B: System voltage sensors for;

- PV output voltage (VSA), and
- Load terminal voltage (VL).

C: Pyranometer (Sun insolation sensor); (Insol).

D: Cell surface temperature sensor (Temp).

Actuators as shown in Fig.1 are placed in distributed places to control the system operation as:

- Contactor in each string output terminal (S1 to S8) to control the current flow from that branch (ON-OFF).
- Contactor at the PV system output terminal (SP).
- Contactor at the battery bank (SB) output terminal to control the flow of the battery current (charging, discharging, or OFF state).
- Contactor at the load input terminal (SL).

All the sensors are connected to analog multiplexer and then to the ADC of the microcontroller. The microcontroller collects the data and transmits it to the PC via serial interfacing cable.

The LabVIEW program in the PC is built to receive the data from the microcontroller unit and manipulate it to display on the computer monitor and to control the system operation.

4. Proposed System Modeling

4.1. Modeling of PV Array

The PV array model that is widely used is the one-diode model and is referred in subsystems with a specific number of cells in series and/or parallel. The relationship between current and voltage for one cell is given by [2]:

$$I = I_{SC} - I_O \left\{ e^{\left(\frac{V + IR_S}{\alpha}\right)} - 1 \right\} - \frac{V + I\,R_S}{R_{sh}} \qquad \text{Eq. 1}$$

Where:

Isc is the short-circuit value of light-generated current

Io is the dark saturation current

$$\alpha = kT / q$$

q is the charge of an electron (coul)

k is the Boltzman constant (j/K)

T is the cell temperature (K)

I, V, are cell current (A), voltage (V),

Rs, Rsh series and shunt resistance (Ohms).

Solar array are constructed from a series and parallel combination of solar cells. The solar array model is simulated at different insolation levels and STC as [5]. The results of simulation are presented in Figure 3

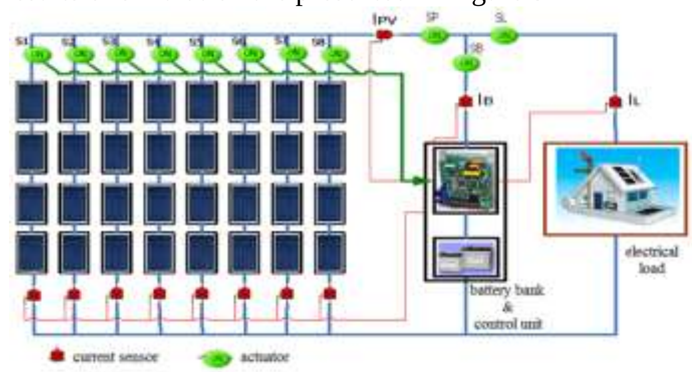


Figure 1, Proposed PV system connection.

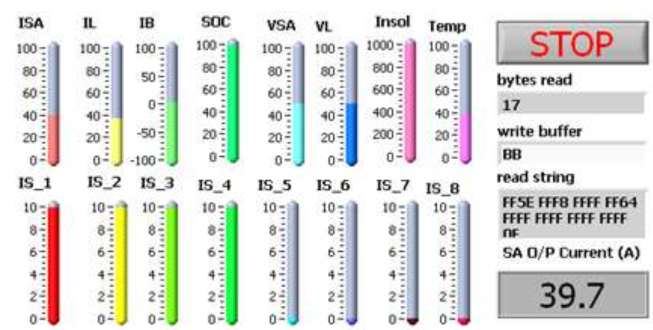


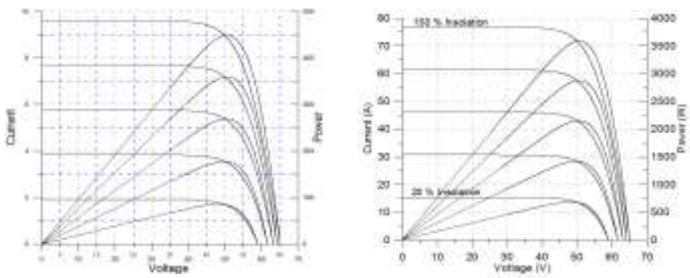
Figure 2, Proposed PV monitoring system

4.2. Modeling of Storage Battery

Another important element of solar array photovoltaic system (SAPV) is the battery. The battery is necessary in such a system because of the fluctuating nature of the output delivered by the PV arrays. Thus, during the hours of sunshine, the PV system feeds directly the load and the excess electrical energy is stored in the battery. During the night, or during a period with low solar irradiation, energy is supplied to the load from the battery [6].

The battery storage may be modeled in different ways. Due to the fact that a battery is an electrochemical device with rather complex behavior it is not easy to represent precisely. Two different types of model suited to lead acid batteries may be considered depending on the accuracy and properties [4]:

i) Energy transfer model, ii) Simulation model



(a) (b)

Figure 3, I-V and P-V curves at different insolation level for (a) one solar array string, and (b) the global system.

Both models are used in this paper. The internal resistance of a battery stack is determined experimentally in three cases of the battery SOC; minimum SOC, medium SOC and maximum SOC in Ref. [3]. The results of experimental test are summarized in Table 1.

Table 1, battery stack parameters at different SOC's

Item	SOCmin	SOCmed	SOCmax
E_S(V)	48.44	50.32	52.00
V_S(V)	47.28(disch)	48.28(disch)	52.68 (ch)
I_{ch}(A)	6.23	6.27	1.35
R_b(Ω)	0.186	0.3252	0.504

The different loading currents of the PV array and the storage battery at different operating conditions are used to estimate the system operation performance [3, 7]. Lead Acid batteries dynamic model is presented in many references [8-11]. At the end of charging/discharging cycle, the battery SOC can be calculated using following equation,

$$SOC = SOC_{max} - \left(\frac{[I_D * T_D - (I_C * T_C) * \eta_C]}{C_{BAT}}\right) \quad \text{Eq. 2}$$

Where:

- ID is the battery discharge current in Amperes,
- TD is the discharge interval in hours,
- IC is the battery charge current in Amperes,
- TC is the charge interval in hours, and
- C BAT is the battery capacity in Ah.
- ηc is charging efficiency is assumed as 80%

The battery voltage model is given by the following equation:

$$E = E_s - K\left(\frac{Q}{Q - I_b . t}\right) I_b - N . I_b \quad \text{Eq. 3}$$

Where:

- E is the battery voltage,
- Es is a constant potential,
- K is the coefficient of polarization per unit of current density,
- Q is the amount of active material available per unit of electrode area,
- Ib is the apparent current density, assumed constant during the discharge,
- t is the time elapsed since the start of discharge, and
- N is the internal resistance per unit area.

5. System Implementation

5.1. Hardware Implementation

The microcontroller board is interfaced to the laptop computer via serial interface. The sensors and actuators are emulated using a prototype board. All the interfacing circuit is built in that board to emulate the system operation. Figure 4 shows the microcontroller board, the interfacing and the emulating circuit. The LED's show the switched ON and OFF solar arrays. Interfacing cables with computer and power supply are also illustrated.

5.1.1. The microcontroller board

The ATMRGA16 microcontroller has the following features:

- High-performance, Low-power AVR 8-bit Microcontroller
- Advanced RISC Architecture
- High Endurance Non-volatile Memory segments
- 32 Programmable I/O Lines
- 0 - 16 MHz for ATmega16
- Two 8-bit Timer/Counters and One 16-bit Timer/Counter.
- Real Time Counter with Separate Oscillator
- Four PWM Channels
- 8-channel, 10-bit ADC
- Byte-oriented Two-wire Serial Interface
- Programmable Serial USART
- Master/Slave SPI Serial Interface
- On-chip Analog Comparator
- External and Internal Interrupt Sources
- Low Power Consumption.

All these features make the microcontroller board very suitable, cheep and high performance solution for the monitoring system.

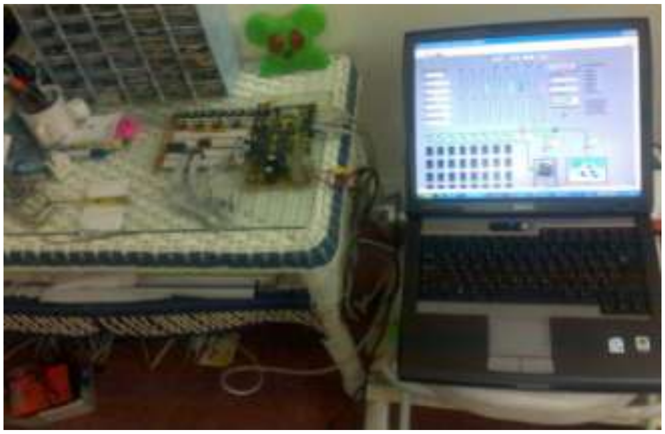


Figure 4, Emulator board and Computer Interfacing.

5.2. Software Implementation

There are two software algorithms are built in this work; one for the laptop that is the LabVIEW graphical user interfacing (GUI). The second is the microcontroller interfacing and data logger program. The integration of the two algorithms gives the system more robustness and flexibility than one algorithm. The microcontroller program is written with assembly language, whereas the laptop program is written by LabVIEW software package.

5.2.1. System logical control flow chart

Figure 5 shows the flowchart of the control algorithm of the system. The system starts with reading the operating sensors and actuator states, and then checks the battery current (charging or discharging).

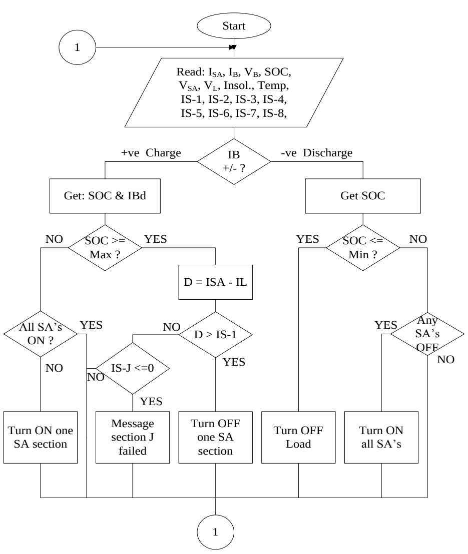


Figure 5, Logical block diagram.

5.2.2. Microcontroller algorithm flowchart

The microcontroller's job in the system is a data logger device and a control circuit. The microcontroller is an 8-bit cheap device and works with a very extensive way to collect system data, transfer these data to the computer, and to receive the operation commands from the computer and execute it. It is attached to the analog sensors via analog multiplexer and collects the sensors data periodically. The flowchart of the microcontroller is shown in Fig.6. The algorithm starts with microcontroller peripheral initialization, then it begins scanning of the various sensors reading and storing in its RAM and transmits this data to the computer via the serial interfacing.

6. Monitoring system block diagram

Figure 6 shows the monitoring system block diagram. In the top section of the block diagram, the serial interface and the analog sensors of the PV station different variables mentioned above are realized. In the middle of block diagram, the mathematical and logical operations are implemented in the LabVIEW math-script module; the digital interface also is presented. While in the bottom of the block diagram, the current sensors of the individual PV array strings are realized.

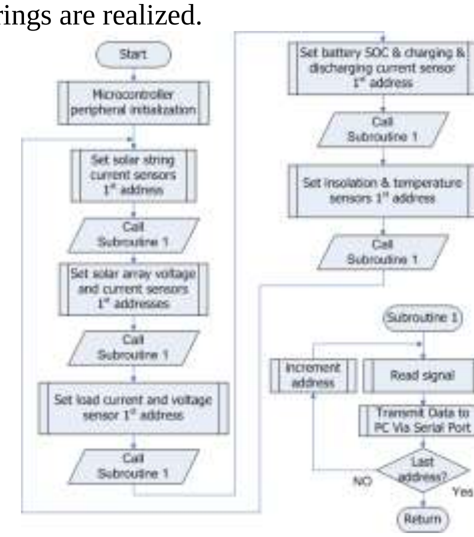


Figure 6, Microcontroller program for data acquisition and packing flowchart.

The logical and control routines are implemented in the math script module as shown in Figure 7. All the data are collected by the microcontroller unit and transferred to the laptop via a serial cable. In the laptop LabVIEW program, processing is occurred on those data for monitoring and data saving for system documentation. Also if there is a problem, an action is taken to remove or repair that problem. The interface board is designed and implemented using ATMEL microcontroller ATMega16 board. An analog multiplexer is added to handle the multiple analog signals. A digital indicator is added to show which PV string is connected and which is disconnected; this indicator is transmitted to the laptop and presented in the front panel with the other indicators for easy monitoring of the system performances in one show.

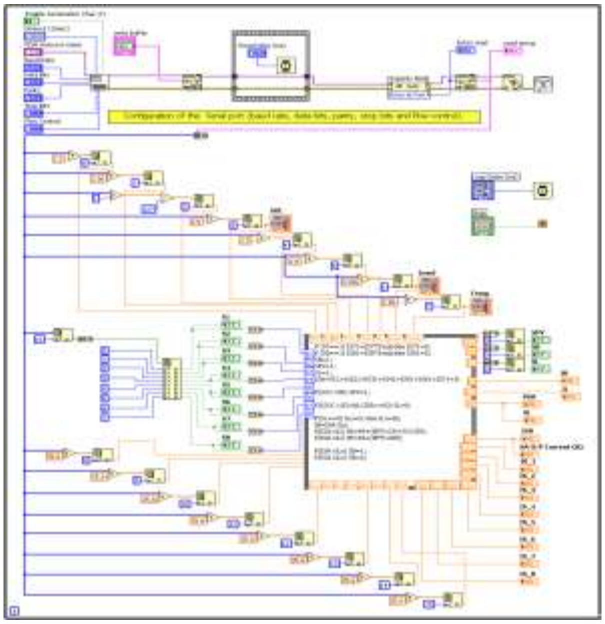


Figure 7, Monitoring System for PV Power Station Block Diagram.

7. System Operation and Experimental Results

The proposed system is experimentally tested in very large number of modes and states. All modes of operation gave the expected response from it. Selected states of operations can be summarized in the following modes:

Mode 1: Sunny periods and battery is excellent:

In the sunny periods, the PV output power is adequate to power the load and charging the battery. If the battery is fully charged as indicated from SOC sensor reading, the battery is disconnected from the system (SB is OFF and IB=0). If the SA power is higher than the load requirement, some of PV strings must be OFF.

Figure 8 represents mode 1. The battery SOC is close to 100%, some of the SA strings are switched OFF and the summation of current is 39.7A while the load current is 36.7A. The battery is charging with minimum controlled current in this case because it is close to being fully charged.

Mode 2*: *Sunny periods and medium battery SOC:

Figure 9 represents the second mode of operation. Insolation level is very high, the battery SOC is about 50%, and all the SA strings are ON. The summation of SA current is 76.9A shared between powering the load and charging the battery.

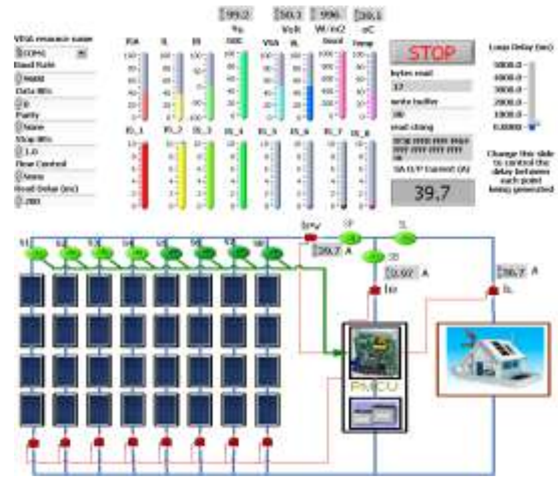


Figure 8, Mode 1: Sunny period (ISA is excellent), SA powering the load, charging the batteries, and some of SA strings are OFF.

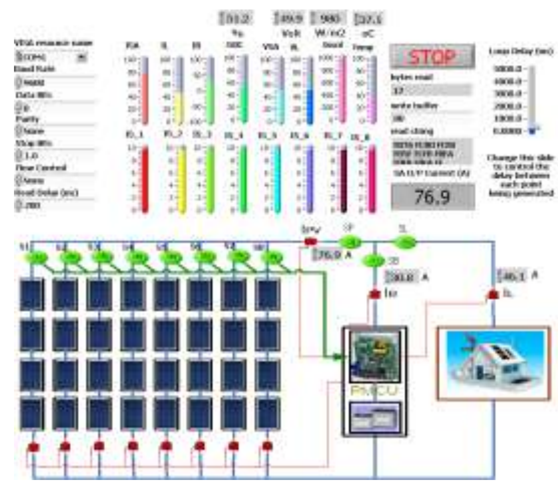


Figure 9, Mode 2:, Sunny periods and battery SOC is medium, ISA is very good, load is powered from SA and Battery is charging, all SA sections are ON.

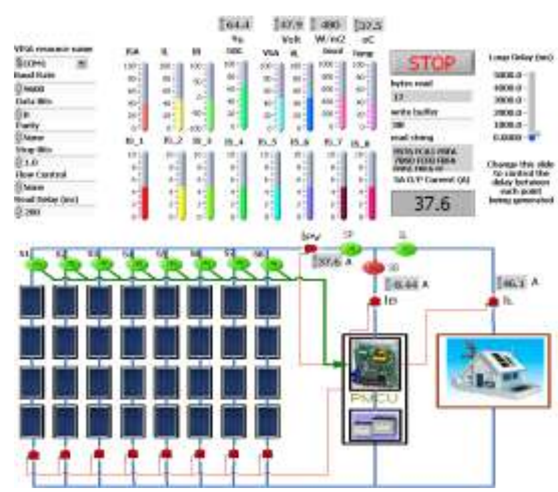


Figure 10, Mode 3: Low insolation level and battery SOC is good, ISA<IL, load is powered from SA and battery, battery in discharge mode and all SA sections are ON.

Mode 3: Low Insolation level and medium battery SOC:

In the low insolation periods while the SA energy is not adequate for powering the load and the battery SOC is good, all the PV strings are ON and the storage battery shares the PV strings in load powering. Figure 10 represents the third mode of operation. The battery SOC is medium (>60%), all the SA strings are ON and the output current is not enough to power the load, the battery shares the SA's to power the load, battery operated in discharge mode.

Mode 4: Eclipse mode and very good battery SOC:

In the eclipse mode during the night, the battery becomes the main source of energy to power the loads. The system controller monitors SOC of the battery and takes the proper action to disconnect the load if the battery SOC goes below the permitted values. Figure 11 represents this dark mode of operation. The battery SOC is about 75% and the SA current is zero, the battery powers the load alone and the controller monitors the battery SOC.

Mode 5: Eclipse mode and empty battery:

The second critical dark mode of operation happens if the battery SOC is < 20%, theload is disconnected from system bus to protect the battery from deep discharge.

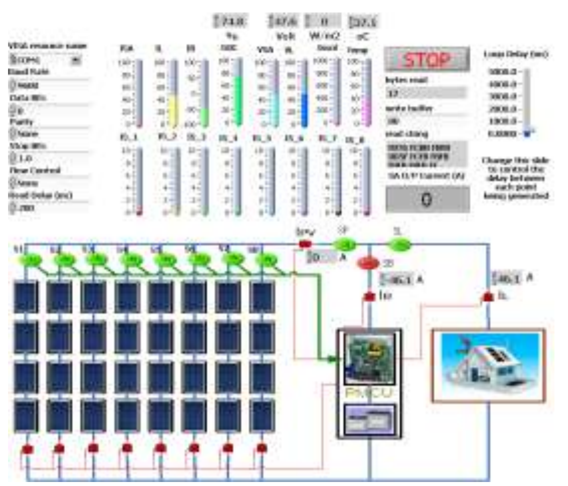


Figure 11, Mode 4: Eclipse mode, and the battery is very good, load is powered from battery, battery in discharge mode.

8. Conclusions

The main goal of this paper is to increase decision effectiveness in PV power stations through the design and implementation of a new real-time system for measuring variables, monitoring, and making a decision for the photovoltaic power system. The proposed system is designed, emulated, implemented, and experimentally tested. The friendly GUI enables user to define and rearrange the monitored variables to suit his needs and sense. The experimental results show that the logical operation of the proposed system is straightforward and the results are obvious, and clear. All thinkable modes of operation are applied to the system and its response was excellent and it was as expected. The software can be expanded to match larger PV plants with the same implemented hardware. So that, the proposed system is reliable, simple, cheap, and has excellent performance.

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