Wired and Wireless Remote Control of PV System

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Abstract: This paper describes a recent work developed for the real-time diagnostic monitoring system of photovoltaic (PV) power plant. It aims to create a stand-alone photovoltaic generator that can be easily relocated in remote areas to evaluate the feasibility of photovoltaic energy applications. For research and development purposes, the main goal of this work is to develop a cost effective and modern technique for monitoring and control the variable of the PV system. A set of sensors were installed to monitor the electric current and voltage of the energy generated, the energy stored and the energy used by the loads that may be connected to the system. Other parameters like solar radiations and temperatures of the photovoltaic module were monitored. In order to reduce off-site analysis effort, reports on PV plant performance are generated on request for user defined time period. User interface provides information on PV plant operation, displayed as digital values, slide bars and graphs. A proposed wireless system configuration is presented also in this paper using NI WSN 3202 nods and WSN-9791 module and NI WAP3711 Industrial Access Point. The novelty of the system is that it can publish data over the Internet using LabVIEW Web Server capabilities and deliver the operation performance data for the end user location. Finally, a measurement and communication hardware was installed to interface the system developed with a conventional computer. A PC -microcontroller interface based software and hardware is implemented as a wired monitor and control of PV system. In this way, the performance of the overall system in real rural conditions could be evaluated efficiently. Visual software that reads, visualizes and saves the data generated by the system was also developed by means of the LabVIEW programming environment.

Keywords: Solar cell model, monitoring system, LabVIEW, PV system, sensors and actuators, wireless, remote control.

I. 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. Therefore a warning alarm should draw the operator attention to take a decision in order 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.

II. WIRELESS AND WIRELESS MONITORING SYSTEMS SURVEY

Biosar Energy SA, has reported in [5] that, the Integrated Facility Management System for Photovoltaic Plants (IFMSPV) constitutes a modern, integrated, technologically advanced and simultaneously cost efficient solution for the monitoring, control and more generally the management of photovoltaic plants. The system continuously monitors and controls the equipment of Photovoltaic Plant (PV) aiming at the recognition of operation failures, alarm detection, security and access control, collection and recording of statistical data and provision of integrated reports.

The offering is based on concepts, system architecture, software and hardware, provided by inAccess Networks

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S.A. and already proven in the field for Telco customers that use it in country wide installations and according to the applicable European and International standards and practices. The network System Architecture is illustrated in the following diagram.
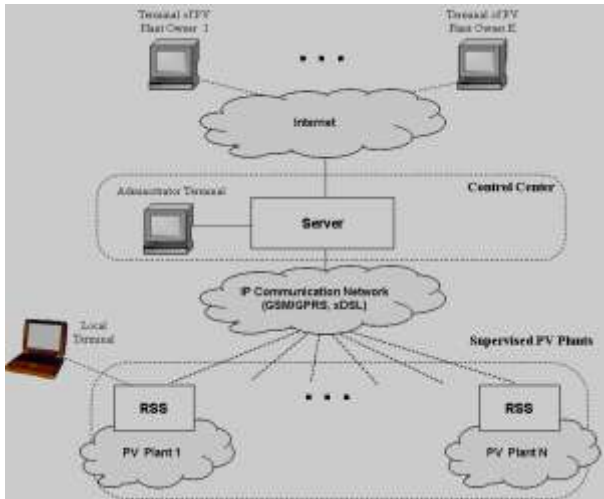

Fig 1, IFMSPV System Architecture [5]

The control center is operated under the supervision of a specialized team, which can also provide for the maintenance of PV infrastructure. Hence, the owner of the PV plant is released from the obligation of everyday monitoring of the plant as well as from the obligation of immediate intervention in case of a problem, such as an E/M equipment failure or the intrusion of undesirable individuals in the area of the plant. The system also supports the connection of the PV Plants owners with the control center through the internet and a related portal. So, the owner has access to his/her PV plant for monitoring and retrieval of related information.

Besides, a temporary connection of a local terminal with the control subsystem is possible for maintenance and recognition of failures [5].

FAZLUR RAHMAN has reported in [6], a LabVIEW based mobile health monitoring system for physiological studies and for assisting patient-centric health care management is developed. The system consists of several one sensor connected to the laptop computer through the

DAQ Card and one sensor are connected directly to the RS232 port of the laptop computer. The data is logged onto the laptop and also transmitted to a server through a wireless local area network [6]. The system block diagram is shown in the following Fig.
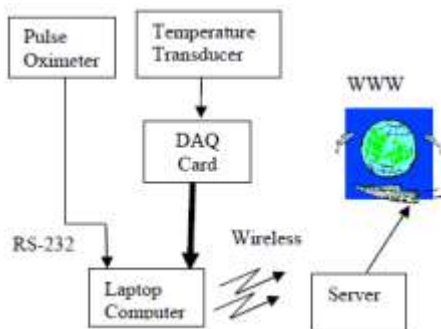

Fig 2, mobile health monitoring system block diagram.

M. F. M. Zain has developed in [7] and R. Soler-Bientz in [8] that, a Wireless Intelligent Sensor and Actuator Network. WISAN has been developed as a reliable tool for vibration based monitoring of structures. The devices in the network are built around the ultra-low power MSP430 microcontroller MSP430F1611 from Texas Instruments and radio transceiver from Chipcon. WISAN is fully compatible with IEEE 802.15.4 and can be utilized worldwide in 2.4 GHz ISM frequency band and coexist with Wi-Fi and other devices. Also, A TCP based server and LabVIEW based client has been developed to control different clusters using single application software.

R. BACHNAK has reported in [9], the control system is built around a powerful controller by National Instruments (NI). The software was developed using the LabVIEW Real Time (RT) development environment. A wireless transmission system is composed of two 900MHz, spread spectrum radio modems manufactured by Freewave. These transceivers use the RS-232 to interface with the cFP-2020 controller as well as the user's computer.

Siva Kumar A/L Subramanlam et. al, have proposed in [10] a wired production performance monitoring system. A PLC is used as system controller in this application. With the help of this monitoring system the management will be able to monitor both the workers and machine performance. This performance will directly reflect towards the production output.

S. GAGLIANO et. al, have reported in [11] that, in the Operation of PV system: to be sure that a PV plant is working well, monitoring the primary energy, that is the solar radiation is needed.

Cheng-Chien Kuo, et. al, have reported in [12] that, the development of wireless communications has been improving and enhancing the remote monitoring technology. It is an important link of the remote monitoring technology to transmit data or control commands accurately and quickly between the monitoring end and the controlled end.

III. PV SYSTEM DESCRIPTION

The proposed PV system shown in Fig 3 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.
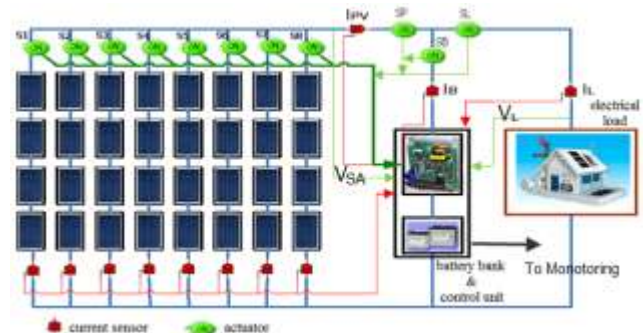

Fig 3, Proposed PV system connection.

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A LabVIEW SW is applied in our system. In the advantages of LabVIEW, Recayi Pecen et. al, have reported in [13] that, Laboratory Virtual Instrument Engineering Workbench (LabVIEW™) is a powerful and flexible instrumentation and analysis software application tool which was developed in 1986 by the National Instruments. LabVIEW™ has become a vital tool in today's emerging technologies and widely adopted throughout academia, industry, and government laboratories as the standard for data acquisition, instrument control and analysis software. The front panel of the monitoring system is shown in Fig 4.
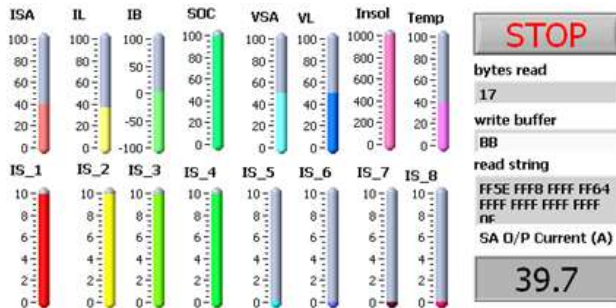

Fig 4, Proposed PV Monitoring System.

IV. PROPOSED SYSTEM MODELING

A. 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]:

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

Where:
- I_{sc} is the short-circuit value of light-generated current
- I_o 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),
- R_s, R_{sh} 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 [14]. The results of simulation are presented in Fig 5.

B. 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 [15].

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]:
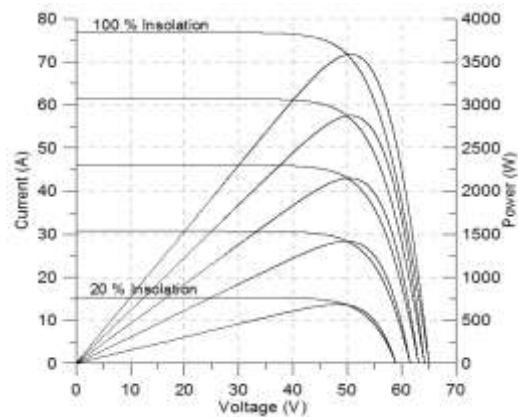 i) Energy transfer model,
  ii) Simulation model

Fig 5, I-V and P-V curves at different insolation level for the global system, all currents with "A", voltages with "V" and power with "W".

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, 16]. Lead Acid batteries dynamic model is presented in many references [17-20].

At the end of charging/discharging cycle, the battery SOC can be calculated using following equation,

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

Where:
- I_D is the battery discharge current in Amperes,
- T_D is the discharge interval in hours,
- I_C is the battery charge current in Amperes,
- T_C is the charge interval in hours, and
- C_{BAT} is the battery capacity in Ah.
- η_C is charging efficiency is assumed as 80%.

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The battery voltage model is given by the following equation:

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

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.

V. PV SYSTEM CONTROL SIGNALS DESCRIPTION

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 3* 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).

VI. MONITORING AND CONTROL SYSTEM

The proposed monitoring and control system is introduced in two techniques; wired and wireless monitoring systems.

A.   *Wired Monitoring and Control System Description*

Like [21], our proposed is constructed. The Wired Monitoring and Control System are suitable for systems that are controlled on site by the operator himself. The proposed system is a modular construction. This means you can choose exactly the components you need. Only a few professional tools are needed for this monitoring system: analog and digital sensors, microcontroller as Data logger, one serial cable and a computer equipped with LabVIEW software. Visualization, system administration and further processing of the data could be executed from user PC. The necessary hardware is constructed to be user-friendly with the plug & play system.

As shown in Fig 3 and Fig 4, the monitoring system contains sensors and actuators to monitor and control of the system operation. All the sensors are attached (hardwired) 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 [22]. 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.

B.   *Wireless Monitoring and Control of PV System*

Wireless technology provides promising possibilities and benefits, reduced cost of cabling; measurements previously prohibited by physical location; distributed measurements; and intelligent, self-healing networks. Wireless is poised to play a significant role in shaping the capabilities of future measurement systems [23]. The description of wireless system is quite similar to wired one except that all signals are transmitted by radio and access point's modules and gate way server are used instead of hard wired cables between the control units and sensors and actuators.

VII.   WIRED SYSTEM IMPLEMENTATION

A.   *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. Fig 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.

B.   *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

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- 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.

Fig 6, Emulator board and Computer Interfacing card.

C. Software Implementation

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

D. System logical control flow chart

Fig 7 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).
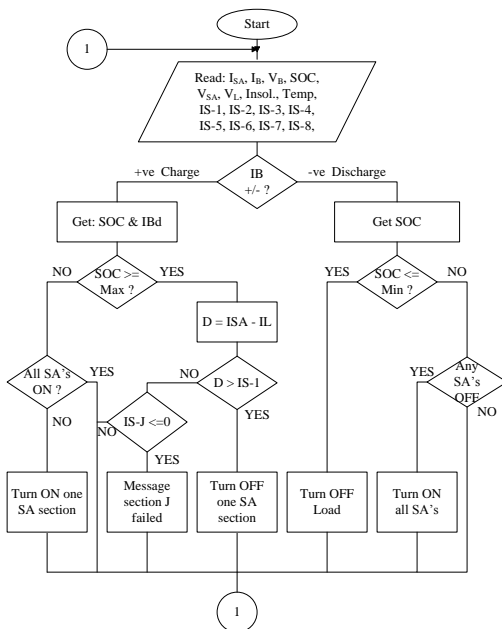

Fig 7, Logical block diagram.

E. 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 8.
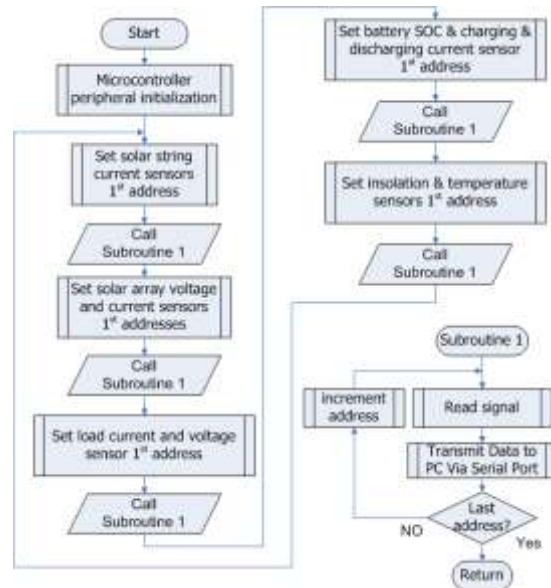

Fig 8, Microcontroller program for data acquisition and packing flowchart.

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.

F. Monitoring system block diagram

Fig 9 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. The logical and control routines are implemented in the math script module as shown in Fig 9. 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.
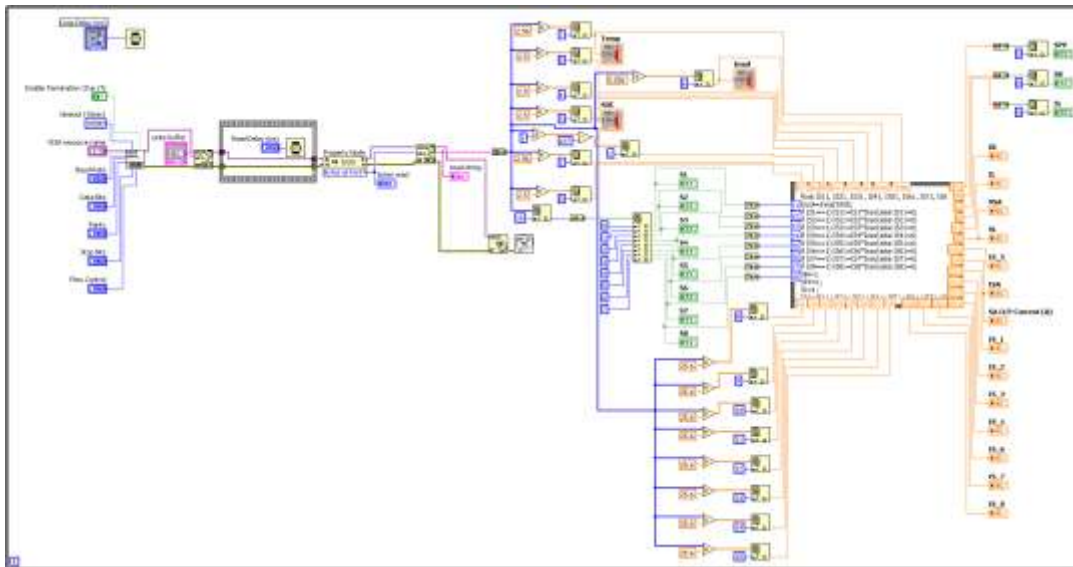
Fig 9, Wired Monitoring System of PV Power Station Block Diagram.

VIII. WIRELESS SYSTEM IMPLEMENTATION

There are two major options for implementations of wireless system monitoring and control. Fig 10 shows the two major options.

- Option one was to use NI Wireless Sensor Network to feed the Ni LabVIEW for Windows through our a developed Atmel microcontroller board which acts as data acquisition and system controller, While

- Option two was to use NI Wireless Sensor Network to feed the Ni LabVIEW for Windows through NI LabVIEW compact reconfigurable input output (cRIO) Real-Time controller.
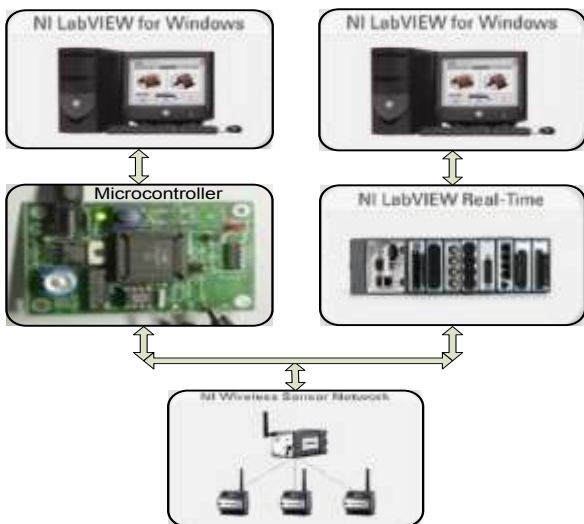

Fig 10, Real time and windows based options [24]

A. Option one; wireless with microcontroller

In this option, the system sensors collect the physical parameters, variables, signals and send them to microcontroller board which convert the analog signals to digital form, then make the necessary mathematical and logical processes, and send the signals to the front panel with LabVIEW software monitor.

B. Option two; wireless with cRIO Real-time Controller

In this option, we explore the use of an easy to develop technique which is known in the industrial field by Programmable Automation Controllers (PAC). The PAC has the ruggedness of a PLC combined with processing power of a PC. The term Programmable Automation Controller (PAC) has been used for over eight years with a few companies claiming to have invented the term.

IX. IMPLEMENTATION OF WIRELESS WITH MICROCONTROLLER MONITORING SYSTEM

Like [25], the proposed hardware is design based on distributed Measurement Nodes and gateway system for wireless sensor network. The NI WSN-3202 analog input nodes will be applied; it is equipped with four analog voltage inputs and four digital I/O. The PV station monitoring sensors outputs will be connected to the analog and digital input of the NI WSN-3202 modules. Four modules will be used to cover the monitored signals from the PV power station. The PV power station has 16 analog signals and 11 actuators. Fig 11 shows a NI WSN-3202 module.

Fig 11, NI WSN-3202 Measurement Node

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A. *Specification of the NI WSN-3202*

- Four analog input channels
- Programmable input ranges: ±0.5, ±2, ±5, ±10 V
- Sensor power output channel provides up to 20 mA at 12 V
- Four digital I/O channels configurable for input, sinking output, or sourcing output
- Industrial ratings: -40 to 70 °C operating temperature, 50 g shock, 5 g vibration,
- Up to 3-year battery life.

The Typical integration of WSN 3202 and NI WSN-9791 modules with monitoring system are shown in Fig 12.
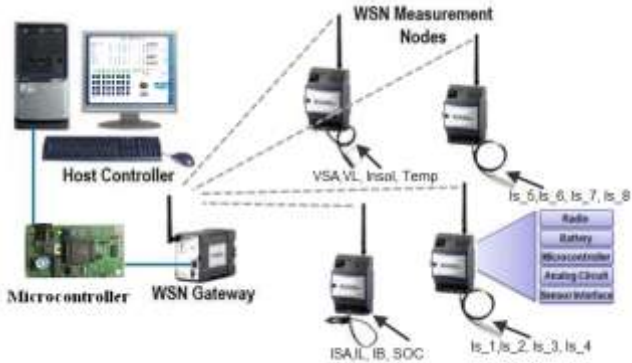

Fig 12, Typical integration of WSN 3202 and NI WSN-9791 modules with monitoring system [26].

General-purpose operating systems are optimized to run a variety of applications simultaneously, ensuring that all applications receive some processing time. These operating systems must also respond to interrupts from peripherals such as the mouse and keyboard. The user has limited control regarding how these tasks are handled by the processor. As a result, high-priority tasks can be preempted by lower priority tasks, making it impossible to guarantee a response time for your critical applications. In contrast, real-time operating systems give users the ability to prioritize tasks so that the most critical task can always take control of the processor when needed. This property enables you to program an application with predictable results. With the NI WSN-9791 Ethernet gateway, communication between the LabVIEW PC base station and the wireless sensor nodes could be facilitated. Gateway should be in the control room while radio between Gateway and sensors nodes could be communicated. The data stream from PC LabVIEW based monitoring system in real time could be packed and prepared to uploaded web data repository, which provides a user-friendly Web interface to download, browse, share, and organize data. In addition, this repository provides a Web service application layer used to develop customized Web pages for presenting PV power station information to computer users.

X. IMPLEMENTATION OF WIRELESS WITH cRIO SYSTEM MONITORING SYSTEM

The proposed second option consists of main NI cRIO 9012 module; Fig 13 with chassis 9111; Fig 14 which used to assemble the data acquisition cards for both analog and digital signals. The active element in wireless system is the access point NI WAP 3711; Fig 15 [27-31].

A. *NI cRIO-9012 Specification*

Fig 13, image of NI cRIO-9012

- Real-Time Controller with 64 MB DRAM, 128 MB Storage
- Embedded controller runs LabVIEW Real-Time for deterministic control, data logging, and analysis
- 400 MHz processor, 128 MB nonvolatile storage, 64 MB DRAM memory
- 10/100BASE-T Ethernet port with embedded Web and file servers with remote-panel user interface
- Full-speed USB host port for connection to USB flash and memory devices
- RS232 serial port for connection to peripherals; dual 9 to 35 VDC supply inputs
- -40 to 70 °C operating temperature range .5

B. *NI cRIO 9112 Specification*

Fig 14, NI cRIO 9112

- 8-Slot, Virtex-5 LX30 CompactRIO Reconfigurable Chassis
- 8-slot reconfigurable embedded chassis that accepts any CompactRIO I/O module
- Xilinx Virtex-5 reconfigurable I/O (RIO) FPGA core for ultimate processing power
- Ability to automatically synthesize custom control and signal processing circuitry using LabVIEW
- DIN-rail mounting options
- -40 to 70 °C operating range

C. NI WAP 3711 specification

Fig 15, NI WAP 3711

- IEEE 802.11g/b wireless access point, client, and bridge
- Web-based management software included
- 64- and 128-bit wired equivalent privacy (WEP) security
- Redundant dual 24 VDC power inputs
- Metal enclosure, IP30 rated; Class I, Division 2 hazardous locations
- DIN-rail mounting support.

The implemented system are shown in Fig 16. The NI WAP-3711 was used like any normal access point. It was configured to communicated between data received by the cRIO and the PC or laptop wireless.

Fig 16, implemented system with wireless access points devices

The software was developed by the LabVIEW. No necessary commands were programmed for the NI-WAP3711 in the LabVIEW, we mean nothing will appear neither in the Block diagram nor the front panel of the LabVIEW program belongs to the WAP-3711 since it is simply an industrial access point used to communicate data wirelessly. The only place NI-Access Point (NI-AP) will appear only when we asked our laptop to communicate wirelessly with it. Meanwhile we connected the CRIO 9012 with a crossover cable to the NI-WAP. As shown in figure Fig 17. The Laptop was configured to communicate wirelessly with NI-WAP 3711 and hence the cRIO 9012 was getting its commands remotely from the Laptop viaNI-AP. We here confirm that except for giving NI-WAP a

certain IP address and configuring the cRIO 9012 to communicate the data through this IP address. In the same time telling the Laptop to communicate wirelessly with the system.

Fig 17, The Blue crossover cable is used to connect between the cRIO 9012 and the NI-WAP 3711.

XI. SYSTEM OPERATION AND EXPERIMENTAL RESULTS

The proposed system is experimentally tested in different modes operation and states. All modes of operation gave the expected response from it. Selected states of operations are summarized in the following modes:

A. 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.

Fig 18 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.

B. Mode 2: Sunny periods and medium battery SOC:

Fig 19 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.

C. Mode 3: Low Insolation & 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. Fig 20 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.

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D. Mode 4: Eclipse mode & 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. Fig 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.

E. Mode 5: Eclipse mode and empty battery:

Fig 22 represents the second critical dark mode of operation. The battery SOC is < 20% and load is disconnected from system bus to protect the battery from deep discharge.
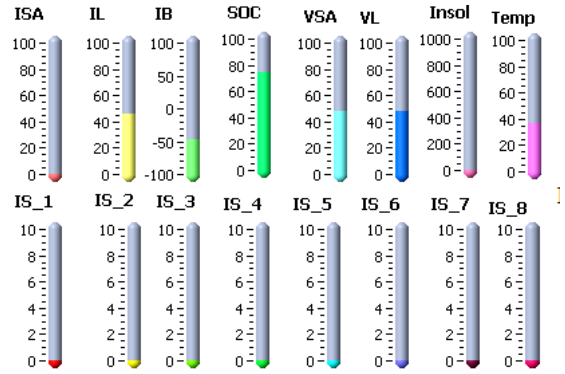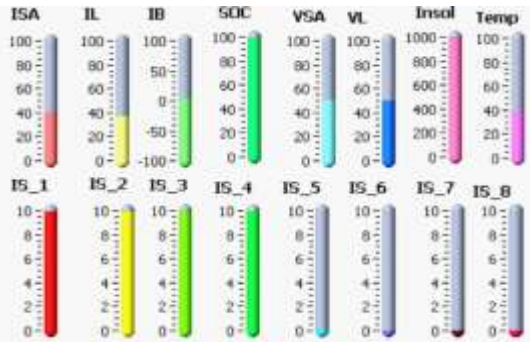

Fig 18, Mode 1: Sunny period (ISA is excellent), SA powering the load, charging the batteries, and some of SA strings are OFF.

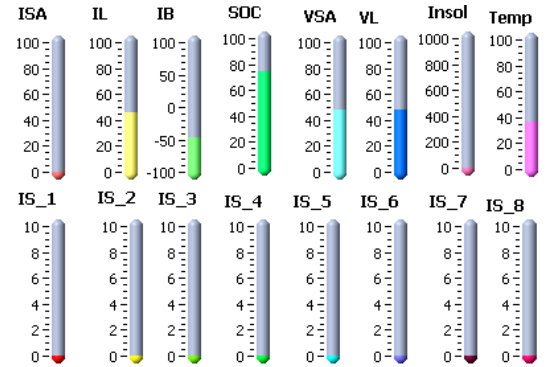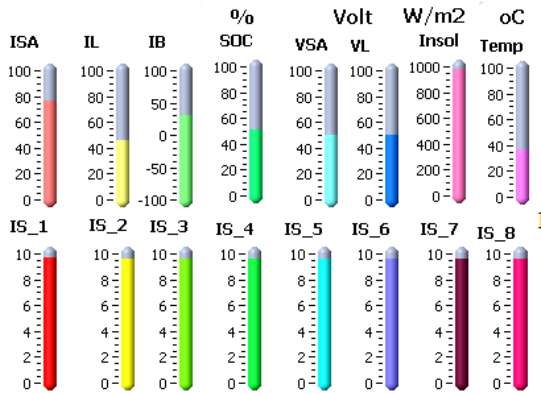Fig 19, Mode 2: Sunny periods and battery SOC is medium, ISA is very good, load is powered from SA and Battery is charging, all SA sections are ON.
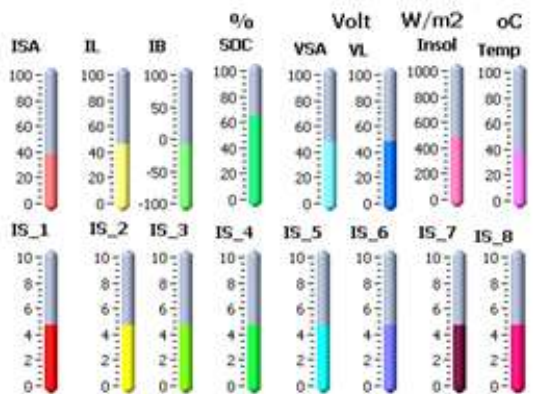

Fig 20, Mode 3: Low insolation level and battery SOC is good, ISA<IL, load is powered from SA and battery, battery in discharge mode and all SA sections are ON.

Fig 21, Mode 4: Eclipse mode, and the battery is very good, load is powered from battery, battery in discharge mode.

Fig 22, Mode 5: Eclipse mode (Insolation is zero), battery SOC <20%, load switched OFF, battery stops discharging.

XII. 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, expandable and has excellent performance.

It is proposed that the wired monitored system to be replaced by a wireless system in order to facilitate a remote monitoring and control. The proposed system composes four NI WSN 3202 sensor nodes and one WSN-9791 gateway module. The PC - LabVIEW based station is proposed instead of NI cRIO-9014 real-time controller that is usually used in such application to reduce the cost, limitation less and wide application just with LabVIEW software and user friendly graphical user interface front panel window.

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