Real Time Monitoring and Analysis of Tropical Impact on PV Performance Based on LabVIEW Architecture

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***Abstract*—This paper presents a systematic, real-time and synchronized monitoring system for a 6-parameter tropical environmental elements and the energy performance of 3 types of Photovoltaic (PV) generator systems with the total generation capacity of 10kW. Based on recent studies, PV technology and application is economically viable to be adopted in tropical countries like Malaysia where it receives more than 6 hours of direct sunlight each day throughout the year. The task aims to feasibly integrate all 6 climatic parameters of Radiation, Temperature, Wind, Humidity, Light Intensity, and Rain using graphical LabVIEW software and cRIO as means of Data Acquisition and Real Time Monitoring (DART) system. This approach creates a unique platform interface for Solar PV Monitoring Station (SPMS) to capture measurement from multiple sources and analyze visually in real-time and synchronize mode which is the crucial aspect for rapid fluctuating data flow. This information will be the source of reference in designing a complete PV generator system cited in the tropics. The detail hardware integration, data flow process and SPMS system are further discussed.**

***Index Terms*—PV performance, tropical environment, real-time monitoring, LabVIEW**

I. Introduction

Renewable Green energy sources have been the chosen approach by various developing countries in the world as an inevitable necessity to reduce Green House Gas (GHG) emissions and dependence on fossil fuel based energy generation.

Since the main source of energy for electricity generation in Malaysia comes from fossil fuels, the ever increasing electricity demand will definitely put a constraint on the fossil fuel supply and contributes to the adverse effect on the environment. Due to this, the Government of Malaysia is working towards attaining energy independence and promoting efficient utilization of supply and utilization of renewable energy resources. One of the main sources of renewable energy that is highly promoted in the tropical climate like in Malaysia is the solar photovoltaic energy. PV technology harvests the abundance and free sunlight source to produce electricity via photonic effect. There have been some projects developed in Malaysia based on PV systems and mostly they are in remote areas and are off grid. One of the questions in the initial design stage of the PV systems is how much power that the PV systems can generate and the generated figure usually reflects the entire PV system configuration without guarantee.

Based on recent studies in [1], [2], [3], [4], [5], PV technology and application suits economically to be adopted in tropical countries like Malaysia where it receives more than 6 hours of direct sunlight each day throughout the year. This statement is further supported by the active and strategic approach in culturing the green technology application with various schemes and funds by the government.

The recent trend of adapting Renewable Energy Resources (RES) for energy supply is to equip the overall system flow with a high technology and precision Data Acquisition and Real-Time Monitoring (DART) system. Giannone *et al.* [6] highlight the issues of choosing the suitable monitoring and DAQ system which lies on how long to acquire multiple data sources in the context of real time number crunching. Crunching condition refers to acquiring multiple data from various sources at the sequence of time but with different sizing, type and other sensor-specific output format. From this condition, Forero *et al.* [7] suggest further enhancement of control and optimization using DART for system performance, reliability and efficiency as the main criteria of selection suitable monitoring system especially in solar PV applications.

LabVIEW system software promotes the tools needed to create and deploy measurement and control system via unprecedented hardware integration which ease the acceleration of productivity and continuous innovation. This approach deflects the traditional method of using data logger or microcontroller circuit to acquire signal from sensor and transmit them to PC via common serial RS232 port. The LabVIEW environment gives comprehensive system design approach, unique graphical programming language; built-in engineering-specific libraries of software functions and hardware interfaces, data analysis and visualization and other intuitive features of simplify control and reusable coding. By using

Manuscript received June 5, 2013; revised August 29 14, 2013

doi: 10.12720/joace.2.2.138-142

LabVIEW program, Anwari *et al.* [8] developed a system to simulate and monitor the 2-parameter environmental data, photovoltaic array voltage and ampere drawn from the small scale PV system. A recent work on mobile stand alone photovoltaic generator developed by Bientz *et al.* [9] by means of the LabVIEW programming environment has the specialty of easily relocated in remote areas to evaluate the feasibility and efficiency of photovoltaic energy applications. Another application of LabVIEW in renewable energy (RE) development lies in the development of wireless data acquisition system (WDAS) for weather station monitoring by Benghanem [10] where the proposed architecture permits the rapid system development and has the advantage of flexibility and it can be easily extended for future research and advancement.

By means of DART application, Wei *et al.* [11] designs a hardware of multi-core test bed using Intel Core Duo T2500 processor with dynamic voltage scaling (DVS) capability and runs the Linux Fedora 8 operating system to validate and benchmark various rate monotonic scheduling (RMS)-based task allocation and scheduling schemes in energy consumption. Another approach by Wang *et al.* [12] adapted DART system to enhance the coefficient of performance of solar absorption refrigerator and analyze the system performance via combination technique of visual instrument and the characteristic of solar absorption refrigerator. Effective data acquisition system are essential for capturing real-time data for the elements of temperature, water flow rate and pressure as well as data transmission, processing, and display, in addition to provide users with historic data inquire. Stewart and Purucker [13] highlights visualization with spatial data analysis and assessment algorithms as the key component of modern site assessments and proposed Spatial Analysis and Decision Assistance (SADA) program that incorporates spatial assessment tools for effective environmental remediation.

Fast programmable devices such as FPGAs can be used either for data processing and data transfer but the method presents speed limitation at some specific tasks, leading to an unavoidable data lost due to pulse pile up discrimination when integrating with customary sensor or demanding algorithms are applied. Fernandez *et al.* [14] developed a new data acquisition (DAQ) system to fulfil the requirements of the gamma-ray spectrometer (GRS) JET–EP2 (joint European Torus enhancement project 2), providing high-resolution spectroscopy at very high-count rate (up to few MHz). The system is based on the Advanced Telecommunications Computing Architecture™ (ATCA™) and includes a transient record (TR) module with 8 channels of 14 bits resolution at 400 MSamples/s (MSPS) sampling rate, 4 GB of local memory, and 2 field programmable gate array (FPGA) able to perform real time algorithms for data reduction and digital pulse processing.

Adapting cRIO as the housing modular and LabVIEW programming as means of DART system creates prototype faster with graphical programming, reduce time to build functional embedded system using graphical approach and ability to reuse powerful programming language codes seamlessly in the overall monitoring system. The housing system consists of the following features [15]:

i) an embedded controller for communication and processing,
ii) a reconfigurable chassis housing the user-programmable FPGA or Windows platform,
iii) hot-swappable I/O modules, and
iv) graphical LabVIEW software for rapid real-time

Undertaking good science under increasing resource constraints creates the terminology of knowledge encapsulation where modelling, tools and technologies from computer science and software engineering are being transferred to applied environmental science fields to meet the increasing requirements for multi-scale and multi-objective assessment and decision making that considers economic and social systems, as well as the ecosystem [16]. As world market on PV pricing drops significantly over the past five years, most DART system either stays with existing market price or increase with the adaptation of new high technology processor and other advance peripherals to cater the need for statistically evaluating the environmental variables.

The sudden drop in I-V curve reflects the decrease in energy generation for certain time duration and most researchers claimed this condition is due to shading of sun radiation towards PV surface. This research intends to explore further by considering other influential factors such as ambient temperature, light intensity, wind cooling effect and humidity that would contribute to the sudden drop in PV energy generation. These factors are especially important to the conditions in tropical weather locations. The programming feature aims to feasibly integrate all 6 climatic parameters of Radiation, Temperature, Wind, Humidity, Light Intensity, and Rain using graphical LabVIEW software and Compact Reconfigurable Input/output (cRIO) as means of Data Acquisition and Real Time Monitoring (DART) system. The approach creates a unique platform interface to capture measurement from multiple sources and analyze visually in real-time and synchronize mode which is the crucial aspect for rapid fluctuating data flow. This information will be the source of reference in designing a complete PV generator system citing in the tropics.

II. Methodology

The UPM PV Pilot Plant starts operation in September 2011 comprises of 3 types of PV generator system namely Fixed Flat (FF) PV, Tracking Flat (TF) PV and Concentrating (CPV) Generator system rated at 1kW each. All the ten units of PV generator are connected to 3 units of Aurora Inverter system with the capacity of 2 x 3.6 kW and 6.0 kW for the purpose of Grid-tied operation. This paper focuses on the Solar PV Monitoring Station (SPMS) via Data Acquision and Real-Time Monitoring (DART) system as shown in Fig. 1. As illustrated, various sensors with various signals have been placed near to the PV plant to measure 3 segments of data i.e. 6-parameter environmental condition (using weather station features), Inverter Data, and 5 thermocouple sensors for temperature effect.

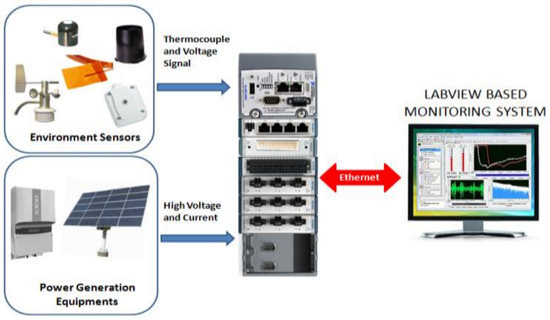

Figure 1. Overall system setup for Solar PV Monitoring Station (SPMS)

Three modules of Analog Input, Serial Interface and Thermocouple are slot-in the cRIO Platform as shown Fig. 2, Fig. 3 and Fig. 4 as a setup for PV environmental impact integration assessment.

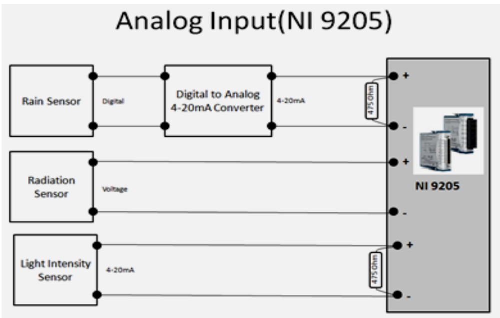

Figure 2. Interfacing for analog input module to three climatic sensor

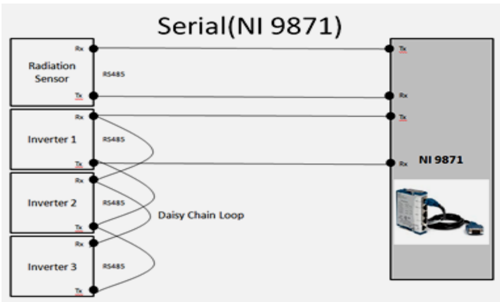

Figure 3. Interfacing for serial port of cRIO platform to 3 units of inverter and radiation sensor of RS485 output

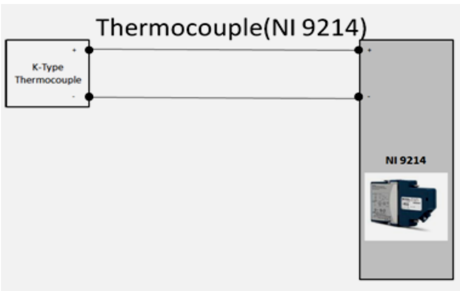

Figure 4. Interfacing for thermocouple module to K-Type sensor

Due to the modularity of cRIO, signals such as RS-485 serial, current (4-20mA) and high voltage can be easily integrated into a single platform for data logging and streaming purposes. Additionally the power generated from the PV panels and the surface temperature of the PV also has be captured and synchronized with the environment data. The cRIO has been programmed to automatically measures and log data on a real time-based event, normally from 7am till 7pm every single day. The system is designed to be able to operate on a stand-alone mode, and shall be able to stream data every time a PC is connected to the cRIO.

III. RESULTS AND DISCUSSION

A host program developed with LabVIEW software has been designed to monitor the data in real-time and also to analyze the data in offline mode. The analysis of (individually independent) graph helps to compare graphically more than 2 parameters from each of the three peripherals listed above. The lower side graph shows the overall correlation of the selected parameter to ease the process of analyzing results especially for fluctuating parameters in short time period.

Three main features of thermocouple data (10 segments), environmental data (6 segments) and PV generation data (22 parameters x 3 Inverter inputs) are captured in real-time mode.

TABLE I. SAMPLE DAILY DATA RECORDED COMPRISING SIX ENVIRONMENTAL PARAMETERS INSTALLED AT SITE

Time	Wind (m/s)	Temp (^{0}C)	Humidity (RH)	Rain (m^3)	Irradiance (W/m^2)	Light Intensity (Lumen)
7.06	0.3	23.4	96	0	0.94	0
7.36	1.1	23.5	96	0	56.42	3750
8.06	0.8	24.4	94	0	87.20	11250
8.36	1.1	25.5	89	0	171.32	18750
9.06	1.1	26.8	86	0	263.57	26250
9.36	1.1	27.9	81	0	347.45	45000
10.06	1.6	29.5	73	0	450.38	63750
10.36	1.6	30.6	70	0	518.25	63750
11.06	0.8	31.3	67	0	522.52	63750
11.36	1.6	31.4	63	0	707.44	63750
12.06	1.3	32.2	62	0	792.63	63750
12.36	2.9	31.4	59	0	306.67	45000
13.06	1.6	32.8	57	0	776.87	63750
13.36	1.3	30.9	63	0	177.07	26250
14.06	1.9	30.4	67	0	139.89	22500
14.36	5.6	27.9	76	0	1.19	0
15.06	2.4	23.1	96	0	6.19	3750
15.36	1.3	22.6	97	0	2.25	3750
16.06	1.6	23.3	97	0	36.89	7500
16.36	2.1	23.8	97	0	47.89	7500
17.06	1.1	23.8	98	0	67.99	11250
17.36	1.1	24	97	0	90.24	11250
18.06	1.1	24.3	96	0	112.73	15000
18.36	1.1	24.4	96	0	37.053	3750

The data in Table I show relationship of six environmental factors monitored for PV research and applications. Based on daily average for sample day of 27th of June 2012, the climatic parameters are valued at wind speed of 1.7 m/s, ambient temperature at 27.1 ^{0}C, Humidity of 81.8 RH, Irradiance of 238.4 W/m^2 and light intensity of 27,509 lumens. The maximum recorded radiation level is at 12.26 noon with 851 W/m^2. From the system setup and data monitoring process flow, each data from 6-parameter sensor can be individual analyzed and viewed in real-time for recording in database (.tdms format) as illustrated in Fig. 6 and Fig. 7. The time sequence or sampling rate can easily be reconfigure in the SMPV system based on analysis requirement and the duration is set from 7.00am to 7.00pm to ease the analytical process.

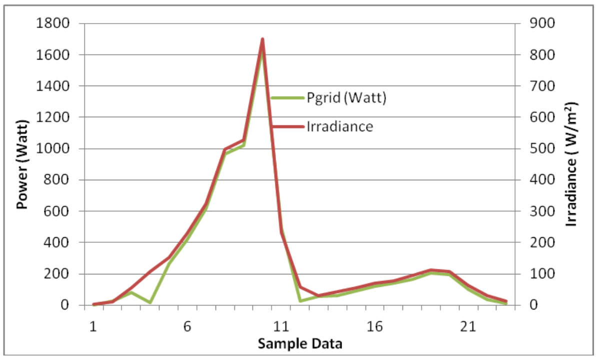

Figure 5. Correlation between irradiance and power generated from PV array

The direct correlations of Irradiance (in W/m^2) and Power (grid-tied in Watt) can be shown in Fig. 5 with recorded maximum power of 1,646 Watt directly generated from 851 W/m^2 of sun radiation. The total daily energy generation from the PV pilot plant for the sample day of 27th June 2012 is 13.2 kWh.

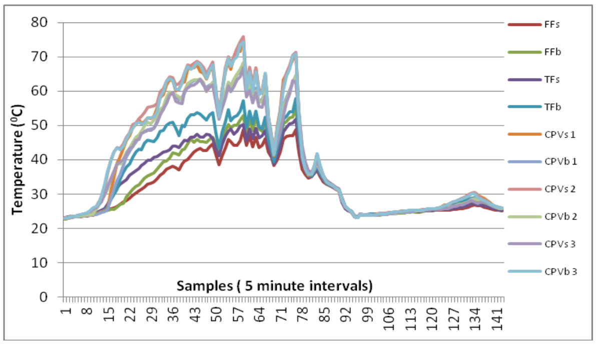

Figure 6. Plotted graph of daily temperature reading from 10 thermocouple sensor

The temperature elements of each individual PV generators are monitored based on the surface and bottom side readings as illustrated in Fig. 6 where 142 daily sample data are used. The maximum temperature for the CPV generator projects the value as high as 76 ^{0}C on the surface side and 74.5 ^{0}C on the bottom side. The TF generator and the FF generator produce the highest temperature on the bottom side with the values of 57.8 ^{0}C and 55 ^{0}C respectively.

Based on the average daily data analysis, the relationship of surface temperature (T_s) and the bottom temperature (T_b) can be described in Table II.

TABLE II. RELATIONSHIP BETWEEN TEMPERATURE EFFECT TOWARDS 3 TYPES OF PV GENERATOR SYSTEM

	Temperature Effect	Comments
Fixed Flat PV Generator	ΔT = 9.34 ^{0}C Surface temperature (Ts) is lower by the AE value of 5.63% compared to the bottom temperature (Tb)	Most researcher adapts the bottom-side values as the cell/ module temperature for crystalline PV due to the higher temperature value
Tracking Flat PV Generator	ΔT = 11.64 ^{0}C Surface temperature (Ts) is lower by the AE value of 5.4% compared to the bottom temperature (Tb)	The same concept as above. The tracking mechanism which receives peak radiation level most of the time results in higher bottom temperature values compared to FF generator
CPV Generator	ΔT = 17.34 ^{0}C Surface temperature (Ts) is higher by the AE value of 5.8% compared to the bottom-side temperature (Tb)	The uniqueness of adapting two elements of tracking mechanism and mirror concentrator creates much higher value on the surface side of the PV Module which contradicts the normal concept of Tc

** AE = Absolute Error*

For all the three types of PV generator, the surface and bottom temperature fluctuates between the range of 30 ^{0}C to 60 ^{0}C which is an important value to determine cell or module temperature.

For CPV generator, the surface temperature is much higher than the bottom value due to the mirror concentrating effect of heat convection. The surrounding or ambient temperature fluctuates between the range of 25 ^{0}C to 33 ^{0}C which reflects the Nominal Operating Cell Temperature (NOCT) in MS/IEC Standards with an average daily values of 29.56 ^{0}C.

IV. CONCLUSION

There are various research areas that need to be explored on solar PV application as it is the question mark to everyone involved in the solar PV business whether the technology can be the best energy source for Malaysia condition. This study presents a unique platform interface for Solar PV Monitoring Station (SPMS) to capture measurement from multiple sources and analyze visually in real-time and synchronize mode which is the crucial aspect for rapid fluctuating data flow. The adaptation of cRIO as platform interface is proven to be the most suitable technique due to its ruggedness and its modularity with wide range of modules and sensors can easily be integrated. Data synchronization is the most crucial part in this research and some field analysis on temperature effect are brought forward as means of reference and potential guidelines for other researchers and practitioners in designing a complete PV generator system cited in the tropics.

ACKNOWLEDGMENT

The author would like to thank Sichuan Zhonghan Solar Power Co. Ltd for the generous support on setting up the PV Pilot Plant, assisting in data monitoring and analysis and sharing of technologies throughout the research process. Furthermore, we delegate our thanks to the Research Management Centre (RMC), Universiti Putra Malaysia for the approval of research funding under the Project Matching Grant (Vote no: 9300400) and Ministry of Higher Education, Malaysia for the approval of Fundamental Research Grant Scheme (FRGS Vote no : 5524167).

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