Abstract
To quantify the potential for performance improvement of a standalone photovoltaic (PV) system, a test facility has been installed. This paper describes this development of a prototype standalone PV system. Essentially this entire system involves the integration of a Personal computer (PC), Data Acquisition (DAQ), a battery array and a solar array simulator (SAS) to create a standalone PV system and to test and simulate the system. This new system boasts of high accuracy measurements coupled with the commercial viability of low cost. The basic idea of this facility is that the SAS simulates solar power which is utilized to charge batteries. The information obtained by monitoring parameters, such as average battery’s temperature, voltage and current is fed to the PC via the DAQ for analysis. This customized control interface has been developed by utilizing LabVIEW software, which forms the programming backbone of inter-instrument communication via IEEE-GPIB bus. The software created for this system is highly generic and can be used for other instances where different hardware is used. This paper also discussed further research plan, in utilizing this standalone PV system to perform load analysis and batteries charging or discharging with the inputs to the SAS with actual meteorological data obtained from the Malaysian meteorological department.

1. Introduction
The rapid evolution of renewable energies for sustainable development during the last two decades has resulted in the installation of significant amount of renewable power systems, e.g. photovoltaic, wind, wave powers etc. all over the globe. As natural resources, such as fossil fuels are depleted promptly due to the huge demand of power, alternatives such as renewable energies are desperately needed to avoid economic breakdown and subsequently poorer standards of life around the globe. With more solar array systems in the world, a free and unlimited resource is tapped for practical usage, which could be used in many applications saving limited and expensive ones such as natural gas and oil. In retrospect, the development of a standalone PV system is critical in analysis and mass production of solar array systems.

A typical PV system [1-2] normally entails a battery array management and monitoring system as well, and this also provides the framework for an accurate and commercially viable battery testing unit. Practical applications can be improved with the addition of a powerful and reliable battery monitoring system.

In this aspect, the control of the entire PV system via PC may be a cheap and viable solution. In this work, the utilization of the PC completes all measurements, calculations and analysis. Firstly the user simulates a preset sequence of “solar power” to be generated by the SAS via the PC; the output of the SAS is subsequently fed to the battery array. The DAQ monitors the battery data directly at regular intervals, which is also pre-set by the user. Using a computer directly instead of a microcontrollers allows for a more controllable and flexible operation of the system [3]. This paper is mainly structured into four major parts, with sections 2 and 3 discussing about the DAQ system, section 4 describes about the hardware setup, sections 5 and 6 describing about the operational modes of the SAS. The discussion and future research plan are described in the last section.

2. Data Acquisition
The DAQ can measure a wide variety of readings, at the very least: voltage, current and temperature. These three units are essential for the purposes of a standalone PV system [4]. Temperature of the battery is taken as a secondary method of fault and overcharge detection in case of failure or error in voltage and current measurement. In this system, the DAQ is connected via IEEE GPIB bus interface to the USB port of the PC. This provides for low noise and interference immunity as well as a fast means of data transfer. GPIB is used instead of the older RS-232 due to the higher transfer rate (8Mbytes) and the fact that most industrial applications in testing and analysis are currently in favor of the GPIB standard.

In conjunction with the DAQ unit, it is the battery array. The DAQ is directly connected to the battery array via standard laboratory wiring for voltage and current, and a J-type thermocouple for temperature readings. The J-type thermocouple is used due to its practical operating temperature range being that of 0 to 750°C with an error not exceeding 0.75%. Voltage readings can be taken in as alternating current (AC) or direct current (DC) with an accuracy of 0.004%, while current readings can also be taken as AC or DC with an accuracy of 0.06%.

The battery array consists of a pair of deep cycle NP38-12 lead acid batteries, which have a rated output of 12V at capacity of 38Ah. These specifications were found to be suitable for the SAS used, which will be discussed subsequently.
For the operation of the DAQ, the user needs to specify the means, whereby the instrument communicates with the PC via the GPIB. Instrument communication, in this case, also supports LPT (the RS-232) and the ASRL formats. In theory, any standard, which is accepted by the VISA function in LabVIEW, is perfectly usable. Once the user specifies parameters specific to the measurement wanted, the data acquisition can commence.

3. Development of LabVIEW Based Control for the DAQ

3.1 Data Acquisition:

The three important measurements, which are critical to the analysis and operation of a standalone PV system, are voltage, temperature and current of the battery storage units. In the SAS unit, the user has to specify certain parameters as preset values so that the system knows what to do. Certainly, there are preset default values, which are present for this system but to cater for versatility, the user has the option to change those parameters.

For all three measurements, the user should provide the type of communication module used between the DAQ and the computer, the default method being GPIB. The DAQ channel utilized for measurement has to be specified so the system knows which channel to monitor, where each channel corresponds to the physical wires connecting the DAQ to the BAU. There are up to 22 channels for this system, where only two of them are able to measure current due to hardware restrictions, namely channel 21 and channel 22. The hardware DAQ model used is the Agilent 34970A [5]. This will be highlighted in section 4.

After receiving data from the DAQ, LabVIEW does a fast check to see if the decoded data can be considered valid measurements (no error) and whether they are within limits of the preset value hard coded into the program. In the case, a value precedes or exceeds the limits, LabVIEW will send a coded instruction to the DAQ to sound the alarm (For example, this happens in the case of battery overcharge or nearly empty).

Graphical User Interface (GUI):

The software for system operation of the DAQ was created with ease of use in mind. The user is prompted to enter the necessary details. Figure 1 shows the front panel for voltage acquisition, the user has to enter the communication method (under VISA resource name), channel to be scanned (under scan list), AC or DC measurement (toggle switch under AC/DC) and a rough range of voltages to measure.

Figure 2 shows the front panel for temperature acquisition. As in the voltage acquisition virtual instrument (VI), the user has to enter the mandatory VISA resource name and channel to be scanned. However for this measurement, the user has the option to choose the type of thermocouple to be used, the default being J-type. A typical LabVIEW Virtual instruments (VI) is shown in figure 3.
A sample flowchart for voltage measurement is shown in figure 4, depicting a general idea of what happens during data acquisition:

![Flowchart for temperature acquisition](image)

**Data Storage:**

Data acquired from measurements are automatically stored into a preset text file, which can be modified by the user. The data collected can be utilized for post-processing purposes, although real-time data processing and analysis is possible. The user has the option of overwriting the data already in the file, or appending the fresh data to the data previously collected.

### Figure 4: Flowchart for temperature acquisition

#### 4. Standalone PV set-up

Figure 5 shows the set-up that has been used in the investigation of the standalone PV system. As shown, the following instruments are required:

i. Personal Computer
ii. Solar Array Simulator (Agilent E4350B) (Max power: 480 Watts)
iii. Data Acquisition Unit (Agilent 34970A)
iv. Resistor pack as load

**Figure 5: Experimental Set Up**

5. **SAS**

The SAS is actually a DC power supply that simulates the output characteristics of a solar array panel. It is used to simulate different current-voltage (I-V) curves of different arrays under various conditions. Some of the conditions are irradiance, temperature and loads. The SAS has three different operating modes as follows [6]:

i. Fixed Mode
ii. Simulator Mode
iii. Table mode

Followings are brief descriptions of the three different modes of operations.

1. **Fixed Mode**

This mode is the default mode, which is set when the unit is first powered on. The I-V characteristics for this mode is rectangular in shape as shown in figure 6, which actually follows a DC power supply. This mode also allows users to program the unit from the front panel and brings the convenience when there is a need to do certain testing, which does not need the I-V curves.

**Figure 6: Fixed Mode Characteristics**
ii. Simulator Mode

The SAS’s internal algorithms are used to simulate the I-V curve. The curve can be generated by keying in the following four input parameters:

a. Open circuit voltage (Voc)
b. Short circuit current (Isc)
c. Current at the maximum power point on the curve (Imp)
d. Voltage at the maximum power point on the curve (Pmp)

Figure 7 shows the I-V characteristics curve generated by the simulator mode [6]:

Figure 7: Simulator Mode Characteristics

iii. Table Mode

This mode is the fastest mode compare to the earlier two modes mentioned. The operation on this mode will provide an accurate I-V simulation of the SAS simulator. Another added advantage of using this mode is that it provides 60 tables with a total of 33,500 I-V points of storage and a maximum of 4,000 I-V points per table. The tables are easily retrievable from its stored location. About 30 lookup tables amounting to a total of 3,500 points are stored in a non-volatile memory. These data will be retained when the power is switched off. This mode allows using the current and voltage offsets to the selected table to simulate a change in the operating conditions of the solar array [6]. Figure 8 depicts the table mode output characteristics:

Figure 8: Table Mode Characteristics

6. Development of LabVIEW Based Control for the SAS

LabVIEW is used to control and monitor the performance of stand-alone PV system. In the LabVIEW software, there are huge varieties of libraries. Some of the library functions that are useful are data acquisitions, data analysis, waveform generation, arrays, looping function for continuous operation, data storage, and reading data files from external source. Each LabVIEW created is called a “Virtual Instrument (VI)”. These VIs comprises of two segments, one segment is for user interface called “Front Panel”, the other is the back end segment called “Block Diagram” which houses all the program code for execution in the form of blocks and connection paths for data flow [4]. The LabVIEW software is executed on PC and the control signals are sent over to the SAS via IEEE-GPIB interface bus.

Data collection and processing:

Data transmission between the PC and the SAS is carried out via a General Purpose Interface Bus (GPIB) which allows parallel communication. This device uses the Universal Synchronous Bus (USB) port of the PC. When the GPIB is plugged into the PC’s USB port, an electrical handshake will take place internally and the “Ready” signal, which is indicated by a LED is seen. After the program code was sent to the SAS, the GPIB unit will show an “Active” signal indicating that the program has been successfully downloaded to the SAS and waiting for execution.

The SAS unit’s address, which is a default value set by the manufacturer of the unit itself, needs to be keyed in the block program prior to execution of the code. When the program is executed, the data generated by the SAS will be on real time basis, this valid data chain will be channeled back to the PC from the SAS. The LabVIEW software decodes this received data, and if it is recognized as measured values, then it will be stored in a buffer and also displayed as a graph on the Front Panel.

The simulator and table modes are employed to simulate the standalone PV system. These two modes are successfully created and executed. A flow chart is shown in figure 9, it depicts how the program will be executed by stages and the respective data flow path:

User interface and results:

Figure 10 depicts how the block program code looks like for the SAS control system. Figure 11 and 12 indicate two screen shots of the graphical user interface (GUI) called “Front Panel” together with the results obtained from the simulation [4]. Figure 11 shows the screen shot of the simulator mode GUI and its respective result in the graph form. Figure 12 shows the table mode GUI and its respective result. The important points to note for the table mode is that its output graph displays two different
plotting, the first plot is the curve generated from the user-defined table of current and voltage pair array, the second plot, which overlaps the first curve, is the curve generated by varying the load. These output graphs validated that the implementation of the simulator and table mode operation were successful.

Figure 9: Program Flow Chart for SAS Control

Figure 10: Block Diagram for SAS control

Figure 11: Simulator Mode Operation

Figure 12: Table Mode Operation

7. Discussions

The integration of the SAS and the DAQ system together using LabVIEW to create the standalone PV system has been successful. The data from the DAQ, which measures the battery average temperatures, will be feedback into the SAS. The SAS will process this data and carry out the respective task such as either to continue charging the battery or to stop charging battery. Having the different I-V curves for the 12 hour operation or longer will enable the user to study how a particular PV array behaves or is affected, based on the load requirement or even the sun radiation at certain area.
8. Conclusions

In this paper, the real time control strategies were successfully employed to integrate the data acquisition unit, the solar array simulator, battery and load into the standalone PV system. The LabVIEW is used as the software to create a GUI for the data acquisition unit and solar array simulator. The preliminary testing results show the simulator mode operation based on the parameters of an existing solar array panel and the table mode operation based on a random data have been implemented. These two modes can be used to generate the IV curves which simulate the characteristics of the solar array. Furthermore, the system can monitor and measure the system parameters, such as voltage, current and temperature. However, further development of the system is still needed to enhance the system functions.

9. Further Development

Further studies on how the standalone PV system responds to the changes like load requirement, battery state of charge, battery and PV array cell temperature and sun irradiance. Therefore as part of the further development phase, the plan is to use the data collected from the meteorological department Malaysia with regards to sun radiation data and the following I-V characteristic equations [1], to generate the different I-V curves for long term operation. To generate these I-V curves, two important parameters are needed to be calculated, which is the short circuit current (Isc) and the open circuit voltage (Voc).

\[
I = I_i - I_0 \left( e^{\frac{qV}{kT}} - 1 \right) \quad \text{Equation (1)}
\]

where by the \( I_i \) is the component of the cell current due to photons

\[
q = 1.6 \times 10^{-19} \text{ coulomb} \\
k = 1.38 \times 10^{-23} \text{ Joules/K} \\
T = \text{ cell temperature in K}
\]

The above equation needs to be used to find the short circuit current (Isc) of any PV cell, by setting the V = 0 in the equation and this will lead to \( I_{sc} = I_i \). Based on the principal that the cell current is proportional to the cell irradiance, therefore under a test condition, \( G = 1 \) kW/m² at AM 1.5, then the cell current at other irradiance level is given by equation [1]:

\[
I_i(G) = \frac{G}{G_0} I_i(G_0) \quad \text{Equation (2)}
\]

For the open circuit voltage (Voc) computation equation 3 need to be used and also with setting the cell current to zero [1]:

\[
V_{oc} = kT \frac{Q}{q} \ln \frac{I_i + I_0}{I_0} = \frac{kT}{q} \ln \frac{I_i}{I_0} \quad \text{Equation (3)}
\]

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11. References


