Battery monitoring for stand-alone photovoltaic system

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Abstract: This project deals with the design of a system to monitor the performance of Photovoltaic (PV) battery for Stand-alone system. This monitoring system is developed by using a Peripheral Interface Controller (PIC) a microcontroller as a control unit. The data measurement will be sent to a personal computer (PC) by Universal Asynchronous Receiver/Transmitter (UART) device and save in database file that can be visualized in table by Microsoft Excel software. The battery monitoring will measure and displayed on the LCD (Liquid Crystal Display) the several parameters of the PV system such as voltage, current, solar irradiance, ambient and cell temperature of the Stand-alone PV system. The State of Charge (SOC), Depth of Discharge (DOD) and ampere-hour (AH) of the battery have been analysed to prove the battery performance of the Stand-alone PV system.

1. Introduction

The increasing demand of resources specifically on energy sector is the most obvious implication of the growth of global population. Solar energy is one of the potential forms of renewable energy to partially replace the fossil fuel. One of the methods to harness the solar energy is by using Photovoltaic (PV) cells. Photovoltaic is becoming essential renewable sources as it is a clean source of energy. PV cells absorb and change sunlight continuously into electricity without any noise and pollution [1]. Nowadays, the use of solar energy in the public sector, particularly in the lighting system has actually been expanded.

The photovoltaic systems can be classified in two types which are Grid connected (On-grid) and a standalone (Off-grid) system. These systems are classified according to their functional and operational requirements, and their component configurations[1]. Figure 1, shows the diagram of SAPV system with battery storage powering DC and AC Loads. SAPV is a system designed to operate independently without grid utility[2] and built to supply power directly to AC and/or DC loads. It is usually used to provide electricity for rural areas.

Generally, in SAPV system, batteries are work as energy storage for excess energy by PV array during the day. It supplies power to the load when needed especially during the night time and period’s low of solar irradiance during the day. In addition, batteries are used for several other functions such as to ensure that the PV array operate near to its maximum power point[1, 3] to provide higher surge currents to the electrical load and inverter and to ensure the power electrical loads at stable voltages[1, 3, 4]. A basic battery charge controller is to perform the necessary function to prevent the batteries from damaged due to over-charging and to cut-off the current from PV array when the battery voltage reaches a certain minimum level which can reduce battery performance or lifespan[3, 5].
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In Stand Alone system applications, the function of battery is used as energy storage element that store excess energy from PV array during day time. During night time, rainy period and cloudy period, the batteries supply the required energy to the loads. The energy that has been discharged from the battery bank is replaced by charging the battery when the solar energy is sufficient from the PV array during day time.

The state of charge (SOC) indicates the level of battery charge in terms of percentage referring to its capacity. The battery is fully charged when the SOC level is 100%. Each battery has its specific minimum SOC allowed to operate and it is usually recommended by the battery manufactures. The battery’s safe operating SOC is between 40% and 100%.

The depth of discharge (DOD) indicates the percentage of rated battery capacity has been discharged. The relationship between SOC, DOD and battery capacity can be illustrated in Figure 2. The maximum depth of discharge (DOD\textsubscript{max}) is the percentage of the maximum permissible depth of discharge. Generally, it is stated by battery manufacturer and commonly the value of DOD\textsubscript{max} is between 60% and 80%. Frequent discharge to DOD\textsubscript{max} can caused the cycle life dramatically reduce.

### 2. System Architecture and Working Principle

The proposed architecture of monitoring system development for PV battery using microcontroller PIC 16F873 are divided into two parts hardware and software. The concept of this project is to develop microcontroller and to develop battery monitoring system for stand-alone PV system. The proposed system is able to save the several parameters of the PV system within time range. In the circuit, it consists of current sensor, voltage sensor, temperature sensor, irradiance sensor and LCD (Liquid Crystal Display). PIC16F873 microcontroller that is compatible with MPLAB IDE is used. This feature was selected as MPLAB IDE based microcontroller to provide the programmer with the easiest possible solution for developing applications for embedded systems, without compromising performance or control[7]. Block diagram of monitoring system device is shown in Figure 3.
Hardware Development
The battery monitoring system circuits have been integrated on the Printable Circuit Board (PCB) and tested with the Stand-alone PV system. Figure 4 illustrates the PCB layout for the battery monitoring system.

Software Development
The final stage of the system is a software implementation. For this project, two types of software have been used which are MPLAB IDE and Microsoft Visual Basic. The MPLAB IDE used to read data (output from the several sensors) and display on LCD. The Microsoft Visual Basic used to developed most user-friendly utilized in terms of a graphical user interface (GUI) as an interactive tool. Figure 5 shows the main program flowchart. Once power button switches ON, the monitoring system will initialize the input and output port. This device will start with LCD display “Battery Monitoring System”. The ADC in PIC microcontroller already functions and operates to monitoring the data. The data are displayed on the LCD and GUI simultaneously for 5 minutes interval, then the data will be saved in personal computer in Excel format. So, this will make user friendly feature for the further analysis of the system. Figure 6 shows the GUI for battery monitoring system using Microsoft Visual Basic.
3. Experimental Results

In the first stage, it has been discussed the different between multimeter reading and the monitoring system device. Device sub systems was measured using standard laboratory instruments. Experimental result in Figure 7 shows there is small voltage different between multimeter reading and hardware device with 0.9 V. On the other hand, Figure 8 shows current measurement result, both are exhibit the same value of current.
Remote monitoring purposely used to monitor the performance of the system. The monitoring system used to gather all the real-time data recorded by multiple sensors such as irradiance, ambient temperature, module temperature, voltage and current, then sent to PC for the purpose of data storage. Figure 9 shows the overall setup during the experiment.

All the real time data were being monitored by battery monitoring system for the performance monitoring purposes. The real-time statistics recorded to create one data point on average for every 6 minutes. Figure 10 interprets the recorded raw data files in Microsoft Excel as follows;

4. System Performance

The real time data have been analysed. Figure 11, shows the relationship between voltage, current and ampere hour versus time in charging and discharging process from 0930 to 1745. At 0930 the battery voltage is around 12.43V and during that time the load will be turn on. The positive current meant current drawn from the battery to the load and the voltage will slightly decrease. This process known as battery discharged. The battery cannot supply energy to the load in a long period time because the capacity of battery is small. In this part, 20Ah battery has been used. When the load automatically off, this indicate that the Low voltage load disconnect (LVLD) by charge controller and during that time battery start to charge. During battery charging process, the current indicates negative values by this time the PV module always connect to system and it will transfer the energy from sun and convert to the electricity and stored in the battery. In this condition, the voltage of battery will be increased slowly until the battery gets fully charge and the load will automatically turn on. This process, charged and discharge will continue until the system is turn off. From the data obtained during charged and discharged condition, the cumulative graph of ampere hour has to be produced shown in
Figure 10: Measured Parameters in Microsoft Excel file

Figure 11: Performance of battery parameters during charge and discharge battery.

Figure 12: The Ambient and Cell temperature for a day
Figure 1 shows that the relationship between Ampere hour and current proportional each other but inversely proportional to voltage. The increasing of the Ampere hour indicates that the current drawn from the battery and supply to the load and the constant condition point to the low of current and solar irradiance during that time. Weather condition will affect to the performance of battery. This is because performance of battery is depending to the solar irradiance. At the end of the day, the ampere hour end at positive value. This indicate that the capacity of battery is well perform with load and suitable to the system.

Figure 2 shows that the relationship between ambient temperature, cell temperature and solar irradiance. From the graph, the increasing of solar irradiance will affect cell temperature and ambient temperature as well. Ambient temperature is directly proportional to cell temperature and solar irradiance.

Figure 3 shows that the solar irradiance will affect the State of Charge Battery. The high of solar irradiance will produce more current during battery charging.

Figure 4 shows that the SOC of two 12 Volt, 20 Ah batteries are connected in parallel and became 12Volt, 40Ah. The capacity of batteries is larger than the capacity battery used to determine the Ampere hour of battery. To shows the relationship between Solar Irradiance and current, the solar irradiance must be normalized at 1000W/m$^2$.

At the point 20% of SOC the batteries start charging with 28 A. The current will decrease with the increasing of SOC until the batteries fully charged. When the batteries approaching fully charge, the amount of current is small entering the batteries even the Solar Irradiance is high on that time. The charger controller will indicate the stage of charge batteries by blinking the LED on that stage. Table 1 below show the relationship that the state of charge and depth of discharge of the batteries during the experiment.
Figure 14: The State of Charge Battery (SOC) during a day

Table 1: The SOC and DOD of battery

| 12 Volt Battery Voltage, (V) | State of Charge (SOC) % | Depth of Discharge (DOD) % |
|-------------------------------|--------------------------|---------------------------|
| 12.67                         | 100                      | 0                         |
| 12.21                         | 70                       | 30                        |
| 12.08                         | 50                       | 50                        |
| 11.56                         | 20                       | 80                        |

5. Conclusion

The development of Battery Monitoring System has been discussed in this paper. By using this monitoring system, the performance of the battery can be analysed. The three characteristics of batteries which are State of charge, depth of discharged and Ampere hour performance has been discussed. All the characteristics show the battery in good condition. In the future, this project can be improved to make it an IoT based monitoring system.

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