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# Design & Implementation of a Low Cost Data Logger for Solar Home System

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**ABSTRACT**

**The demand of electric power is increasing gradually with the advancement of modern technology & engineering. Because the demand of electricity in urban areas or in industrial zones is large in amount & also more important than the rural areas, there exists a shortage of electric power supply facilities for rural households or remote location from the cities. In this case, Solar Energy is a promising solution to meet the demand for electricity services of rural areas in developing countries like Bangladesh. The effectiveness & stability of small PV systems for rural development is needed to be monitored for successful installment of Solar Panel. In order to analyze the system & modify it for cost reduction a data capturing unit should be constructed that can store the voltages & currents at three different terminals. A microcontroller operated Smart Data Logger can perform this work with high accuracy & precision maintaining the system cost much less than the conventional system. This paper deals with the design and implementation of a low cost data logger for solar home system. An experimental set up is designed and implemented and the paper illustrates the working principle, data observation and analysis, limitations, and future aspects of a low cost data logger for solar home system.**

***Keywords*--** Solar System, SHS, PV Panel

## I. INTRODUCTION

The most suitable one amongst many forms of energy, electricity is the driving force behind all types of human activities, developments and researches in other areas of technologies. Briefly, it is the electricity that gives birth to other technologies. Though lack of power security is still a main challenge not only in Bangladesh but also all over the world [1]. If statistics is studied, it is found that only 62% of the population has access to electricity in our country [2]. As stated by Bangladesh Power Development Board, the installed power generation capacity is about 16982 MW, derated power generation capacity is 16344 MW [3]. Furthermore, emission from this fossil fuel is another concern to the ecologists throughout the world. Though, electricity generation capacity in Bangladesh has been increased appreciably during the past few years, the country has enormous crisis due to the increasing demand in almost all and every sector. Bangladesh still suffers from major scarcity of electricity production to satisfy the daily demand. Based upon this study the peak demand would be around 10,283 MW in FY2015, 17,304 MW in FY2020 and 25,199 MW in 2025. [4] Though it is quite difficult to achieve the goal without other energy sources except fossil fuel. Consequently, emphasis have been given to generate electricity from many renewable sources and to diminish environmental pollutions.

Amongst the accessible renewable energy sources in Bangladesh solar, biomass & wind are the prominent candidate. The typical solar irradiance in Bangladesh varies from 3 to 6.5 kWh/m$^2$. In Dhaka, the average solar irradiance accessible is 4.82 kWh/m$^2$/day. The combination of sufficient sunshine and the requirement of more energy makes Bangladesh an ideal location for off-grid solar photovoltaic systems [5].Effortlessness uninterrupted & emission free electricity are the main reasons for its huge acceptance. So far in Bangladesh, about 2 million SHSs/SHLSs with solar water pump and solar central unit of total capacity 81MW has been distributed [6]. Though, absences of information & financial restrictions are the main barrier for economic sustainability of SHSs in rural areas of Bangladesh. Many researchers have dedicated themselves for finding an economic solution to fight against the diminution of natural resources responsible for electricity production in Bangladesh through another renewable energy sources like solar photo voltaic energy, wind energy, biomass etc. Solar energy is the new source of energy used in most of the advanced countries. The solar system technology has started to gain attractiveness in developing countries too. On approximation the government and many other companies give the advantage of solar energy to 3.5 million houses by installing solar panels with an amount of about 135 MW. For this, solar electricity reaches to more than 13 million receivers, which is around 10% of the

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entire demography of Bangladesh. Bangladesh SHS (Solar Home System) is recognized as the fastest progressing solar power distribution programs in the world by the international society. An Infrastructure development company limited (IDCOL), Grameen Shakti, a government had monetary organization was put through utmost of the capacity connections which is from solar home systems. At a mean establishment, growth rate of 58% more than 65,000 SHSs are connecting in each month now. 3 million systems have previously been installed with support from development partners. Due to the success of the programme, Bangladesh received an additional $78.4 million from the World Bank as soft loan [7]. Rural electrification through solar PV technology is standard in Bangladesh. The idea of solar home systems (SHSs) started in 1996-97, but the rate of acceptance was very low then because of the high initial cost. This however changed, with significantly rise in uptake recorded from 2004 to 2010 because of the soft credits that inspired uptake, decrease in module prices and the promising policy by the Bangladesh government [8]. By the end of January 2013, about 1.4 million SHSs had already been installed in the rural areas of Bangladesh [9].

**Table 1: SHS installation data in Bangladesh [9]**

| Partner Organization | Number of SHSs Installed |
|---|---|
| Grameen Shakti | 795,957 |
| RSF | 216,434 |
| BARC | 77,019 |
| Srizony Bangladesh | 58,927 |
| Hilful Fazlul Samaj Kallayan sangstha | 37,078 |
| UBOMUS | 25,234 |
| BRIDGE | 20,449 |
| Integrated Development Foundation | 14,238 |
| TMSS | 13,059 |
| PDBF | 10,672 |
| SEF | 21,720 |
| AVA | 12,817 |
| DESHA | 10,931 |
| BGEF | 16,995 |
| RDF | 20,027 |
| Others | 77,883 |
| Total | 1,429,440 |

**Table 2: Division Wise Connection of SHSs [8]**

| Division | Number of SHSs Installed |
|---|---|
| Barishal | 265,320 |
| Chittagong | 278,730 |
| Dhaka | 374,587 |
| Khulna | 158,409 |
| Rajshahi | 200,480 |
| Sylhet | 151,914 |
| Total | 1,429,440 |

Solar panel is still a new idea in Bangladesh. SHS users as a result face diverse problems due to their lack of technical knowledge. Because of poor maintenance they do not get adequate output from their connections. Furthermore different new companies are arising and to sustain and make profit in this competitive market, they often operate on such policies that diminish the acceptance of SHS to users. For this reason, the restrictions of SHS are categorized basically in the following two parts which are discussed below:

***A. User-based Restrictions***

**1)** Tilt Angel: Tilt angle of PV panel is most significant issue for effective power production. If the proper tilt angle is not maintained in maximum houses due to their absence of knowledge on SHS and unconsciousness as a result they cannot able to get effective output from PV panel [10].

**2)** Shading and Hotspot problem: Shading is one of main restrictions of SHS that results hotspot problems [11].

**3)** Panel Cleaning: Solar panel efficiency decreases day by day because of unconsciousness about panel cleaning [3].

**4)** Peoples cannot get efficient output from PV panel because of careless about taking necessary training on PV panel [12].

***B. Service Providers-related Restrictions***

**1)** High interest rate: SHS is sold at high interest repayments.

**2)** Poor number of counseling: A SHS service Provider Company has a lot of workers who do servicing but they do not deliver sufficient trainings to users about the maintenance of SHS.

**3)** Undeveloped and unregistered organizations: Different new companies are rising every day. To gain popularity in this competitive market they offer SHS connection at a comparatively low price. For this they deliver low quality equipment which is more disposed to to facing problems. Furthermore their service is of low quality and they do not maintain any notable program to train users about the proper maintenance of SHS. All these things make confusion in users and they are discouraged to increase connection in future [13].

**4)** Small response in remote areas: In highly distant areas there are less SHS users compared to less remote areas that is their income is low from highly remote areas.

## II. LOW COST DATA LOGGER FOR SOLAR HOME SYSTEM

For future analysis & processing, Solar Home System needs real time data storage element. It allows the system to monitor the stability & accuracy of the system. With the evolution of information technology & Electronics it can be possible to store various real time data found from the system to a micro SD card without any time lag. Most of the modern system demands data to be saved for further analysis. Data is no longer to be transmitted to a remote server for all the time. Real time transmission of Data needs more power, cost & Hardware

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Software interfacing circuitry. If data for several days is saved locally, then it can be used next to estimate system's current operating state. Where a conventional Data Logger or real time monitoring unit costs more with advanced transmission process, a Smart data recorder interfaced with Solar Home System can do all the same monitoring and data storing with less cost. a system is developed to sense these data and send to a micro SD card where a text file is created automatically for data storage. The process of system design & verification is very economical i.e. overall cost is kept as less as possible. Household applications of solar PV in developing countries are limited to the following three system.

- Small PV system consisting of one or more solar PV modules with a total peak power of 200W or less & a battery. These are used for powering household appliances such as lights, radio, television & fans.
- Solar lanterns consist of a PV-module & a portable light with battery.
- PV battery charging stations have an array of PV modules, which are used to charge batteries for individual households. These can be used for powering home systems & portable lanterns.

The Smart Data logger can be used for any of three above systems in order to estimate the operating condition.

## III. SYSTEM DESIGN &SETUP

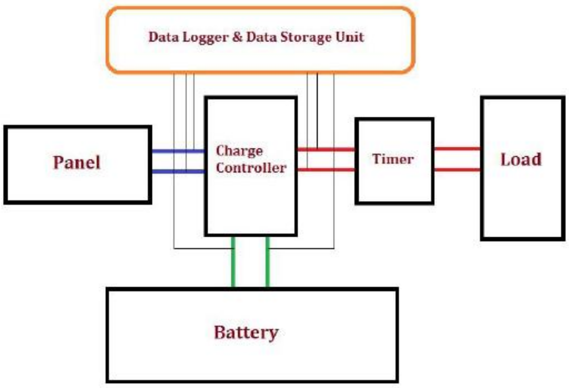


**Fig- 1 Complete diagram of the system**

### *3.1: Components of theSystem*

The overall system is composed of some basic elements

- Solar Panel
- Solar Charge Controller
- Battery
- System Load
- Microcontroller (Arduino Mega)
- Analog Voltage & Current sensors
- Real Time Clock
- SD Card Module
- TFT monitor
- Buck Regulator

The first four components are main system elements & the last ones are the elements of control & data storage unit.

### *3.2: The Implemented HardwareCircuitry*

For the purpose of data storing & analysis a hardware circuit was implemented with the basic elements mentioned above. Then it was interfaced with software for the real time operation.

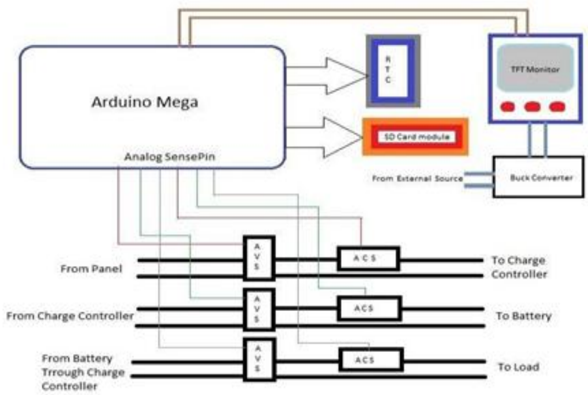


**Fig-2 Block Diagram of Hardware Circuit**

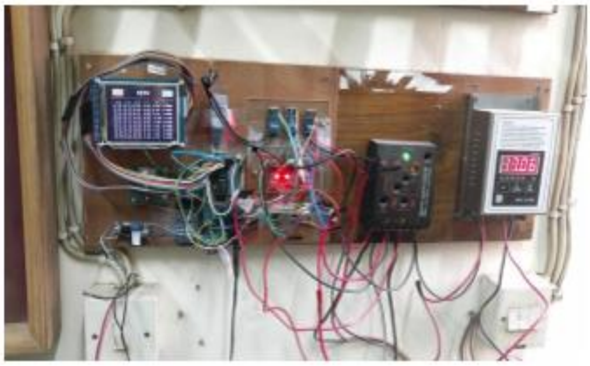

**Fig-3 Implemented Hardware Circuit**

### *3.3 The Working Principle of the Hardware Circuit*

3 Analog Voltage sensors & 3 Analog current sensors were used here to read the corresponding voltages & currents (Load, Battery & Panel). These readings were then sensed by the analog input pin of Arduino Mega. Arduino itself has a compiler which allows a user to interface Software program with Hardware circuit. A code was uploaded in Arduino board for perfect functioning & synchronization of basic circuits & the commands that the user wants the circuit to be followed. The real time clock tracks the time & synchronizes the time with the data found from the sensors. After that, a text file was generated automatically in the micro SD card already inserted into the module & data is written with the time of reading into the text file named 'DATALOG.txt'. The 1minute of logging delay was selected for reading the data. The TFT monitor could display the real time data on its' screen. The load switching time & the interval of data logging could be selected easily by using the button Pad installed just below

 

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the screen. Since a timer for load switching was installed, load switching control from microcontroller is avoided. A buck converter was used to supply power to the TFT screen & the analog sensor to reduce the load on microcontroller. The Arduino board has also its' 9V external power supply. After having sufficient data, The Arduino could be switched off & SD card could be removed from the module. Then using a USB card reader this text file was transferred to a PC. The data stored in the memory card could be plotted using MATLAB to analyze the system condition with respect to various time of a day. Through this process we can analyze & study the performance of the system & weather condition among several days.

The system discussed so far was initial setup in detail. This is quite costly due to the TFT monitor & also large is size. So, for economic purpose & limited space a compact form of the Hardware circuit was designed that exclude the TFT monitor, button Pad & buck converter. After eliminating these elements, we have only Arduino Mega, analog sensors, SD card module & RTC in our Hardware element.

The compact system works just similar to the initial set up but the real time monitoring of the data couldn't be possible in this case without observing the serial monitor of Arduino Compiler. Through the serial monitor or serial plotter, the real time data was easily observed but it required the Arduino to be connected to the PC with USB cable so that it could transfer the data to the serial monitor or serial plotter.

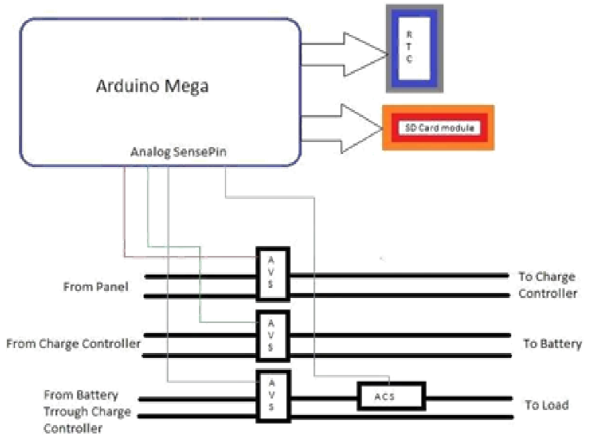


**Fig-4 Block Diagram of Compact Hardware Circuit**

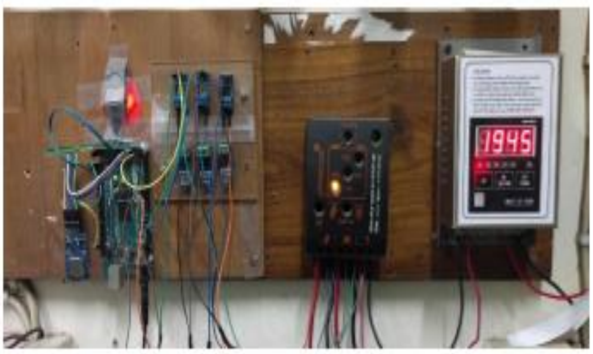


**Fig-5 Implemented Compact Hardware Circuit**

***3.4 Solving a Major Problem during Design***

During the reduction of cost & size a problem was noticed that the charge controller & timer for load switching had common positive ground. But all other electronics & microcontroller that was used had common negative ground.

During summer the weather was sunny & the battery was fully charged by the panel current within the daylight. The battery voltage was maintained a constant value of 12.6V after being fully charged. But if the weather was cloudy or foggy then, battery might not be charged up completely within the daylight period & the current to flow to the load was prevented by the charge controller & stopped discharging of battery by switching the timer off & goes to the 'Load Out' state. At this time the load voltage falls to zero by the charge controller.

If external hardware circuit with common negative ground was connected to the system having common positive ground in the 'Load Out' state, then a large current flows through the ground of the hardware circuit causing a serious damage of the interconnection wires & the microcontroller.

In normal state, the negative terminals of load & battery were shorted by charge controller & found the battery voltage across the load. In this case, the power to the timer was supplied by the battery. But when load was cut off by the charge controller, the timer was switched off & the total battery voltage drops across the interconnecting wire that connects the two negative terminals having different potential. As a result, a large amount of power was dissipated by the wires continuously & they get damaged potentially.

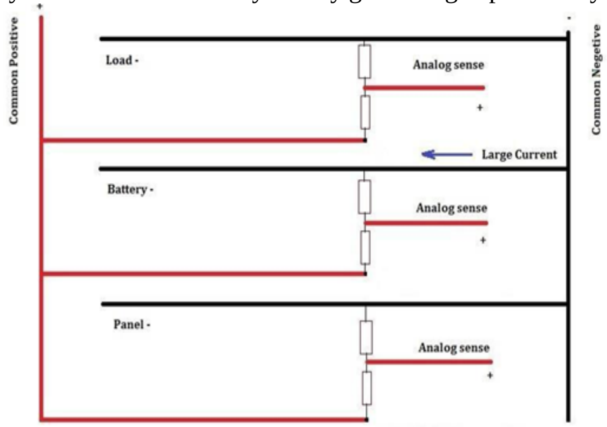


**Fig-6 Problem arises from interconnection between common positive and common negative**

During the data collection using initial large hardware circuit don't have to face any problems like the 'Load Out' state. So the data found from the initial hardware circuit was correct. But as change the circuit during the winter, we faced this problem & we found wrong data. So we had to find a possible solution to make our circuitry valid for reading correct data without any damage of the system.

In this case we had developed a way to get rid of this problem & implement it successfully. We had isolated the

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hardware circuit completely from the main system & convert it to a common positive circuit.

The negative voltage was read by the analog voltage sensor (since the positive terminals of the voltages are common & shorted) & then apply a DC offset (constant 5 volt) to restore back the positive voltage. The DC offsets for 3 analog voltage sensors were also creates complete isolation since we had used rectifier circuit for DC offset where the isolation was created by step down transformer. For the hardware implementation, the charger of TPLINK router in which a built in constant 5V rectifier was installed.

Output voltage through Hall Effect was produced by the analog current sensor. Electromagnetic isolation was automatically produced through Hall Effect.

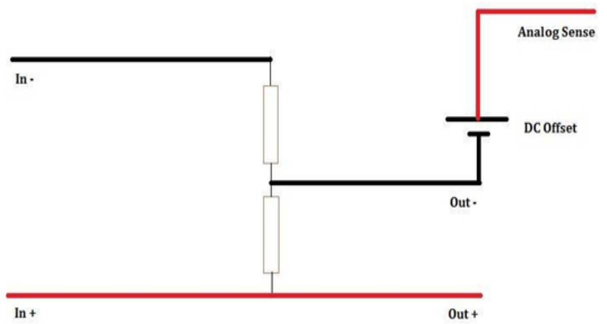


**Fig-7 Common Positive Isolation**

Since, the load current was the most significant among 3 currents, load currents was read using a single current sensor in compact circuit. The other 2 currents measurement was not included for simplicity of the hardware circuit.

***3.5 Software Interfacing withHardware***

In order to operate the system perfectly the software program was interfaced with the hardware circuitry. The microcontroller (Arduino Mega) had its' own interfacing compiler that allows the user to compile a code & upload to the microcontroller board. The Arduino programming language was basically JAVA based. It was very user friendly to use & very easy to compile. According to hardware circuit, some handsome algorithm was needed to make the software program. The algorithm quite simple to understand & ensures a very fastresponse.

***3.5.1 Sensor Calibration***

The analog voltage & current sensors must be calibrated to find the real data. This calibration was done by the software. Firstly data having '0' value was read & then another data with known value. For example, 0V & 5V was read with voltage sensor. Since Arduino was a 10 bit microcontroller & the maximum readable value with the analog pins is 5V, we had the calibration factor 5/1023 for maximum value. Now if the output of the analog pin corresponding to a voltage value was 774, the voltage value was (774×5)/1023= 3.7829V. Similarly Current sensors were calibrated measuring a known value of the current. An output voltage was produced by the current sensor proportional to the input current, so the procedure was just the same as mentioned above. The calibration factor may vary from time to time due to environmental effect, aging or noise. A slight change could be neglected & corrected by software program but an unexpected change was not desirable because this might happen only if the calculation procedure was wrong or the sensor was totallydamaged. In order to get a stable calibration factor, successive calibration was needed. Calibrating the sensor for several times & averaging them to get the final calibration factor was a good practice.

## IV. DATA OBSERVATION & ANALYSIS

The system was limited only to the structure & input section of the design. The output or response of our system must be checked & analyzed perfectly to ensure the system reliability, stability & effectiveness. The data found from the system was plotted & the curve was studied to check the fact that whether the system is working perfectly or not. If there exist any undesirable response, the system must be redesigned to eliminate that response & restore back the original response. In this section, the data of several days and was analyzed & was checked against the theoretical analysis. Some data of sunny weather was analyzed & then the data of foggy & cloudy weather was analyzed. The data of both case with the ideal data according to the period of the day was compared. The both case was compared mutually. Finally an undesirable condition like 'Load Out' state was analyzed & was conclude an acceptable explanation about all the cases.

***4.1 Data Analysis of sunny weather***

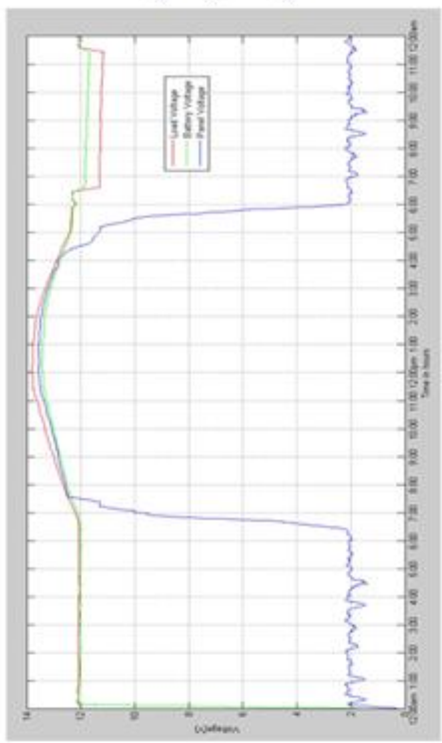

**Fig-8 Load, Battery & Panel Voltages of a Typical Sunny Day**

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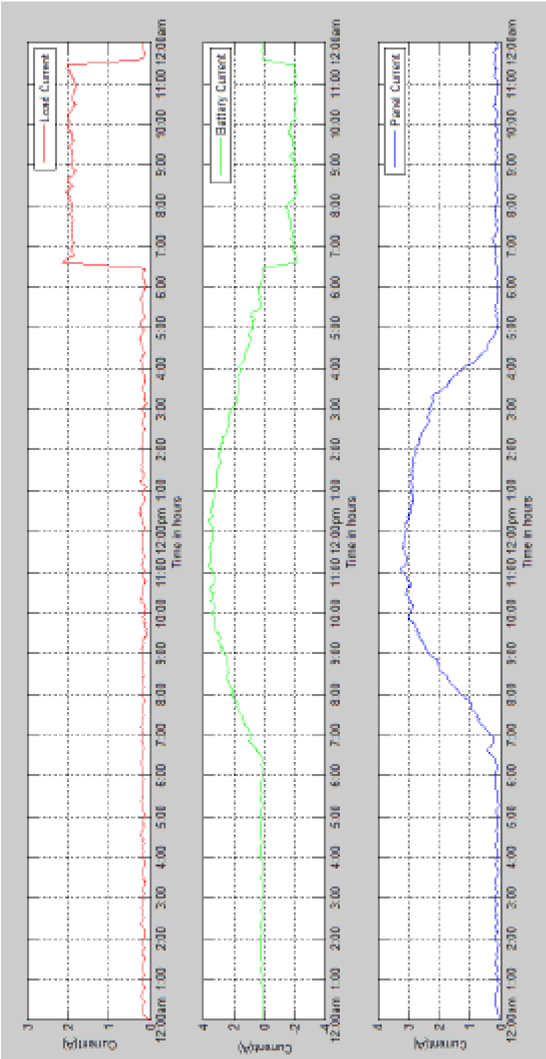


**Fig-9 Load, Battery & Panel Currents of a Typical Sunny Day**

The observations are listed below:

- ➢ The battery voltage remains almost constant over the time.
- ➢ During charging, battery voltage increases gradually within a very small range & it tracks the panel voltage in this period. If it is charged up fully, then the system maintains its' normal state. Battery voltage remains constant although the panel voltage falls in the evening.
- ➢ The panel voltage again raises up to 12.6V in the next day when the brightness of the sun starts increasing.
- ➢ In case of a typical day of summer the daylight sustains up to 6pm. So panel voltage falls after 6 pm. Since the sun brightens at about 7 am, panel voltage raises to the typical value of 12V at this time.
- ➢ After the load is switched on at 6:25pm, the battery voltage falls to a slight extent due to loading effect, & load voltage tracks the battery voltage.
- ➢ When load is switched off at 11:25pm, the battery voltage is again restored back to its' constant 12.6 V level. If we analyze the curves of currents.
- ➢ During the charging period the panel current increases gradually with the irradiance & battery currents follows the panel current.
- ➢ In this case, current flows from panel to battery which is considered to be positive.
- ➢ At zero irradiance in the evening, the panel current falls to zero & battery current also becomes zero.
- ➢ When load is switched on, the load current starts flowing through the load & battery current follows the load current.
- ➢ In this case, battery current is negative since it flows in the reverse direction from battery to load.
- ➢ Before switching on the load, the load current is zero.

The data found from the system was consistent & it matches with the theoretical ideal value.

The data of 3 weeks with sunny weather was analyzed. The voltages & currents were just similar to that of our previous discussion.. The data of 1 week was plotted in a single figure. The voltages were shown in a single plot whereas the currents are sub-plotted for proper analysis. The periodic variation of data & periodic shape of the curves ensures the stability & desired performance of the system.

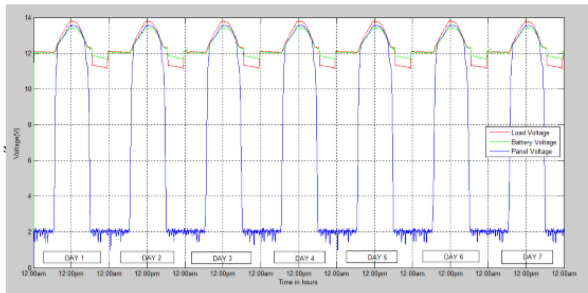


**Fig-10 Load, Battery & Panel Voltages of the First week**

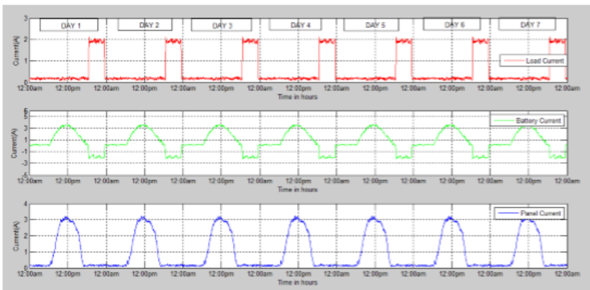


**Fig-11 Load, Battery & Panel Currents of the First week**

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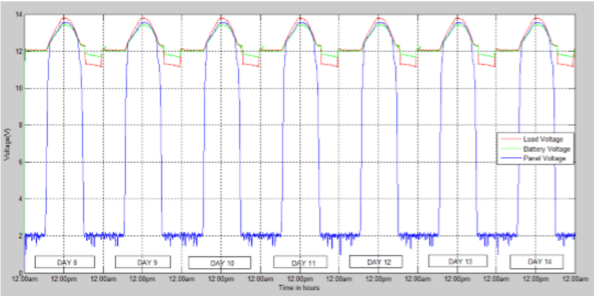

**Fig-12 Load, Battery & Panel Voltages of the 2nd week**

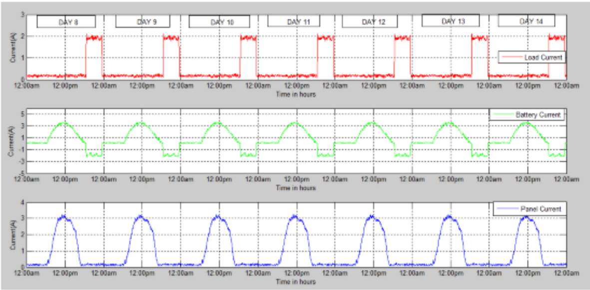

**Fig-13 Load, Battery & Panel Currents of the Second week**

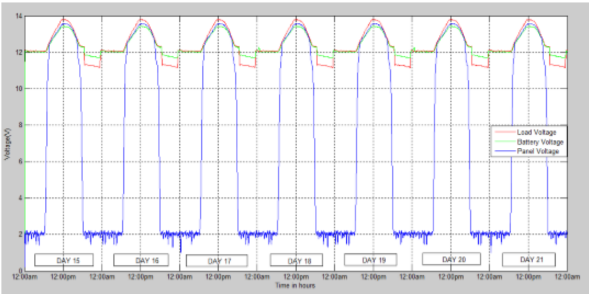

**Fig-14 Load, Battery & Panel Voltages of the Third week**

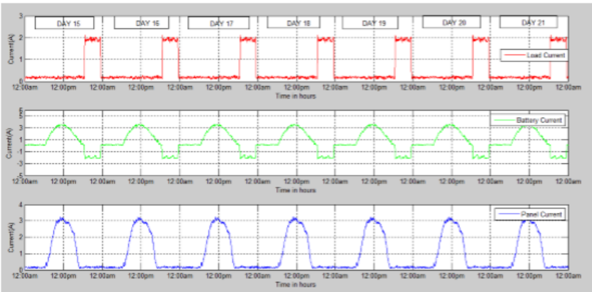

**Fig-15 Load, Battery & Panel Currents of the Third week**

*4.2Data analysis of foggy and cloudy weather*

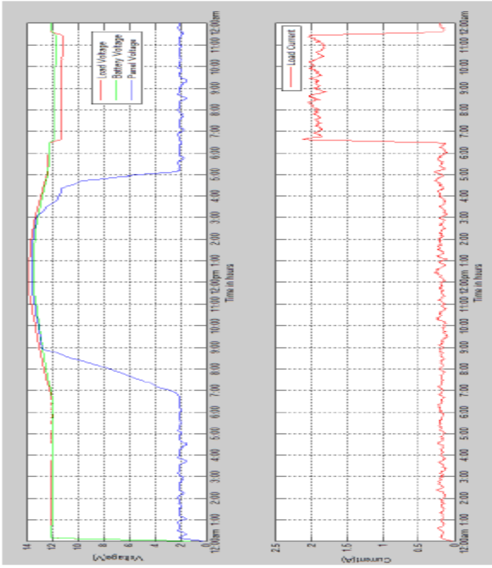

**Fig-16 Load, Battery, Panel Voltages & Load Current of a Typical Winter Day**

For a typical winter day, the curves found from the data was different from the previous case to some extent due to the variation of daylight period. Only the Load current is measured which is most significant & other two currents were eliminated for simplicity. The voltages & load current is plotted in a figure for analysis purpose.
The observations are listed below:

- In the early morning, due to foggy or cloudy weather, the sun becomes visible at around 8am.
- The brightness of the sun increases after 9am approximately & the panel voltage settles down to the typical ideal value.
- Battery voltage follows the panel voltage in the charging period.
- The daylight starts decreasing at around 4:30 pm and completely falls at 5:30 pm.
- As a result the panel voltage also falls to zero ideally & battery voltage remains constant.
- When the load was turned on, the battery voltage falls to a slight extent & load voltages tracks the battery voltage.
- The load current becomes stable to a value of 1.82 ampere. After turning off the load, the load currents falls to zero & battery voltage again goes back to its stable value.
- During a typical winter day, the panel is illuminated by the sun for a shorter period of time in comparison with a typical summer day.
- The brightness of the sun is also less than that of the previous case.
- Again the weather may be cloudy that interrupts the sunlight at any time of the day. So the battery cannot be charged up completely in this case & due to this undercharging the battery voltage may falls below the typical level 12.6V.

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- ➢ If the battery voltage is less than the voltage of the completely charged state, the charge controller cuts the load from the battery & load voltage falls to zero.
- ➢ In the 'Load Out' state the load is switched off to prevent low voltage discharging of the battery.
- ➢ So the timer is switched off & the load is not be activated for that particular day.
- ➢ In this case zero load voltage & zero load current were found.
- ➢ If battery was charged up completely during the daylight period of the next day, then the load voltage again rises up to the battery voltage since the charge controller again activated the load by connecting it to the battery.
- ➢ The timer is also powered up by the charge controller & after the load switching at evening, the load current starts flowing since there exist a voltage across the load at this moment.

At this stage, the voltages & load current were observed of a single week of a typical winter day. The voltages & load current of two consecutive days were observed while the system encounters the 'Load Out' state.

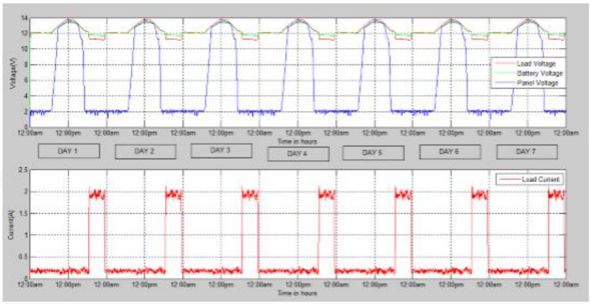


**Fig-17 Load, Battery, Panel Voltages & Load Current of the Fourth Week**

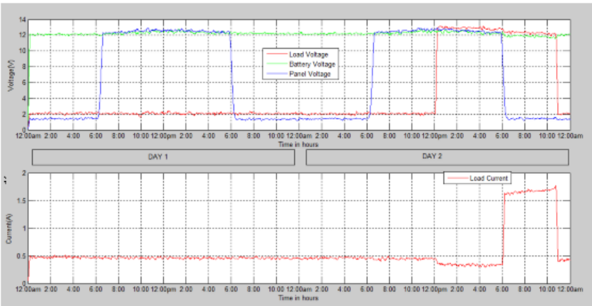


**Fig-18 Load, Battery, Panel Voltages & Load Current of Two Consecutive Days with 'Load Out' State.**

## V. LIMITATIONS

- The main system has common positive ground whereas the microcontroller circuit has common negative ground. So without isolation, the system may damage if any undesirable incident occurs.
- The isolation needed for preventing the ground terminals with different potentials from being short circuited, makes the circuit quite bulky & costly. Since the microcontroller has limited number of output pins, the panel current & battery current is removed to avoid complexity.
- DC offset voltages with isolation is selected to have a constant value of 5V (since the maximum readable value through the microcontroller is 5V). This voltages may vary within a range to some extent & it may affect the data written into the SD card.
- Without filtering, smooth plot with accurate data cannot be obtained since the voltage sensors & current sensors are affected by internal or external noise.
- Since current sensor works according to the principle of Hall Effect, electromagnetic noises easily corrupt the readings & degrade the accuracy of the sensors. So careful calibration is needed to read the valid data using current sensor.

## VI. FUTURE ASPECT

Remote monitoring of the data is possible if the data can be transmitted through WIFI or Bluetooth. The range of Bluetooth module is limited. So we have a plan to use WIFI module to send the data to the internet so that a user can have easy access to the data from a remote location. The three individual isolation & DC offset can be reduced to a single offset with separate isolation by modifying the connection of the common positive isolation circuit. Maximum electric appliances are AC loads. The AC load can be operate by using inverter. Since the load voltage & load current is AC in this case, an AC data logger can be used to measure the load voltage & load current. Using a step down potential transformer (PT) & current transformer (CT) we modified the DC data logger & convert it to an AC one.

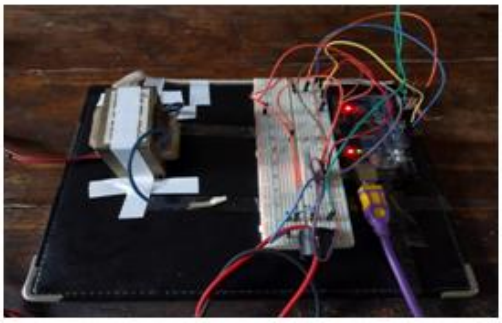

**Fig-19 An AC Data Logger**

This AC data logger uses potential transformer to measure AC voltage. In order to make the voltage readable for microcontroller, the transformer steps down the input voltage & then uses voltage divider. A DC offset is applied to read the negative half cycle of the AC voltage using the VCC pin of the microcontroller.

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The current transformer produces a voltage across its' output terminal which is proportional to the input current. This voltage is taken from a resistor connected across the output terminal. The same DC offset is applied to read the negative half cycle of the AC current. Proper Calibration of the system gives us the real time values of voltage across & current through an AC load. Then the values can be plotted to observe the sinusoidal behavior of the currents & voltages. This data can also be used to measure real power dissipated by the load, frequency of the inverter & power factor of the load.

## VII. CONCLUSION

After observing & analyzing the response of the system, we can conclude that the implemented system works perfectly with high precision. The system is also reliable since all the hardware element is protected by isolation using step down transformer. Cost of the overall compact system is very little since we do not use any expensive component in our design. The raw data found from the sensors is corrupted by white noise. So it can be easily eliminated by using filter. Since analog filter design increases the cost, we applied the filtering process using MATLAB software.

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