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Design and Development of a Smart Charge Controller with Load Power Controlling System

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Abstract— The solar charge controller is a crucial device for a standalone system which prevents the battery from overcharging and discharging. But in a real-world application, the sudden disconnect of the charge controller in low battery condition from the load may cause problems. That is why a smart charge controller with a load power controlling system is a prime need. To mitigate this issue, our research design and develop an intelligent charge controller with load power controlling. A charge controller prototype based on Arduino is developed, which uses pulse width modulation for load control. For high power rating, the proposed system uses optocoupler to isolate high power circuit from the low power circuit. The prototype is tested in a real environment with different PV Panel conditions such as 10W, 50W, and 55W, respectively. The maximum current rating for the charge controller was recorded at 2.97A. The prototype uses different duty cycle signals which control different load settings. Moreover, this prototype also successfully implements the desired charge controller setpoints. The only drawback of this designed system would be an incompatibility to the loads that always need a 100% consistent power.

Index Terms— Solar Charge Controller. Maximum Power Point Tracker, Low Voltage Load Disconnect (LVD) SetPoint, Pulse Width Modulation (PWM) Charge Controller, Microcontroller, Thin Film

1 Introduction

Electricity plays a critical role in developing the economy and the standard of living of a country. However, generation and supply of electrical power in the country is lagging much behind the growing demand prohibiting sustainable growth of the economy. Bangladesh largely depends on natural gas and hydropower stations to generate a significant portion of power. But our demand rises day by day, and the power crisis becomes a considerable problem for our country nowadays. Though many power generation units have been added to the national grid to solve the power crisis issue, it is not enough. [1] High demand and increasing need for power have created a challenge for the power stations to meet the demand. In Bangladesh, a large portion of the total population still does not have access to electricity. Nowadays, fuels account for 99% of the energy consumed in rural households. Only about 60% of total populations in Bangladesh have access to power, and it would take around 15 years to provide electricity to all. To solve this energy crisis, we can use a different form of renewable energy to generate power. Renewable energy comes from different types of natural resources, mainly from sunlight, wind, rain, tides, and geothermal heat, biodiesel, biofuel, etc. Many Government and non-government organizations are working with different types of renewable energy sources to provide electricity to the common masses. To fulfill our electricity demand, solar energy through the solar home system (SHS) has become popular in Bangladesh due to its low price and loan system provided by different organizations. The implementation of SHS programs was carried through two different delivery models. The first model is implemented by the Rural Electrification Board (REB), the state-owned utility responsible for grid-electrification in rural areas. The second approach is through a private implementing agency, the Infrastructure Development Company Limited (IDCOL), which sold the systems to households using a micro-finance scheme implemented by various private agencies, such as Grameen Shakti. [2] In particular, Grameen Shakti has played an essential role in the dissemination of SHS in rural Bangladesh, and its credit program has reached many low-income households. Nowadays, people of the country have taken solar energy as the alternate of grid electricity. However, SHS users may face some problems due to the new technology, lack of knowledge, and lack of consciousness.

Therefore, it is essential to assess SHS users for a bright future of solar PV panels as a source of efficient electricity generation in Bangladesh. In this paper, we discuss the present electricity scenario from solar PV panel, different issues of solar home system users, user satisfaction level, constraints of SHS, and overall impacts on the user of SHS in Bangladesh. This thesis demonstrates a microcontroller-based charge controller with autonomy and loads power control features. This system would be beneficial for people in rural areas who lack knowledge about PV systems.

2.1 Motivation

Most of the charge controllers on the market are not autonomous. A few charge controllers have PWM technology, and some have MPPT. However, they are not as smart as much as required. Why are they not bright, according to us? Usually, the charge controller has set points of low voltage load disconnect, PV array reconnects, and load reconnects. When the battery voltage is low, the controller disconnects the load. They have no intelligence for controlling load power; hence the autonomy cannot be elaborate. If the charge controller has information that it can manage the duty cycle of the load, then it will be a smart feature. Regular controller vs. our proposed controller illustrates that duty cycle controlling will enhance the autonomy. Especially for village people, such type of charge controller will be hugely beneficial to them. During the rainy season most of the month, the sky remains cloudy. They need light or power for survival. In such a case, a smart charge controller will help to get a maximum time load running facility than a regular charge controller. The importance of the charge controller and the battery cannot be neglected when designing a solar home system. Local people of the remote area have a lack of knowledge of the importance of battery and charge controller, so that is the system getting disable within a short period. If they have proper operation, it will be economical for them. [3]

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2.2 AIMS OF THE RESEARCH

The objective of the design and development of the charge controller to provide economically beneficial to the people. The efficient and smart charge controller, which has many features the price is high and not affordable to everyone. We aim to design everyone can buy an economical, efficient controller. Furthermore, it will extend battery life for the duty cycle control. A standard controller cannot manipulate the load duty cycle, and battery plates gradually get erosions. For that, we have to buy a new battery in that case. On the whole system, the price of the battery is excellent than other components. If we can enhance the life of the cell, it will be a great benefit to the users. In this way, a smart load power controller can be economical to use alongside the facility of autonomy. Although the SHSs are gaining its popularity hastily, however, SHSs market in Bangladesh is affected by several risks and weakness. Research identifies the numerous dangers and weaknesses affecting the SHSs market (Urmee & Harries 2011). [4]

Nonperforming payment, an increase in equipment cost, transport cost, natural disaster, etc. are the risk include in the Bangladesh market for SHS. The weak points are getting a load from any institute, inferior quality parts of the solar system, lacking policy and support from the government, lack of managerial training, etc.

2.3 Literature Review

Many researchers have developed a cost-effective Solar charge controller with different microcontrollers, Arduino, and PIC microcontroller with some specific area of concern. In research, the researcher focuses on developing PIC microcontroller-based charge control with basic set-points. They also considered the temperature sensor of the primary charge controller, but their power rating is minimal. They propose to use a PIC microcontroller with a higher power rating for further research. [2]

Another PIC microcontroller based Solar Charge controller is developed in another research. [6] They have gone for a better power rating with smart uses of the optocoupler. They also accommodate LCD, but they failed to develop load centric low voltage disconnect features where in their system, the load disconnects pretty early. In a Conference Paper, the researcher's emphasis on cost-effective design solutions. [7] However, in this paper, they also use a 32-bit microcontroller in which they develop a state of charge in different battery scenarios. They focus on the battery state of charge, and their power rating is minimal, only 1.2 KW.

In this research paper, they developed the smart charge controller with an emphasis on the smart grid. This excellent research paper proposes different load connections with proper data modeling and both way communication with the meter. [8] According to a critical and resourceful conference paper, the researchers proposed a system to present a unique cost-effective and highly efficient microcontroller based MPPT system for the solar photovoltaic system to make sure the maximum power point operation at all different changing environmental condition. [9] The P&O MPPT algorithm is used to control the maximum transfer power from a PV panel. This algorithm is executed by MPPT Controller using LM324.

Even with a proper charge controller, the expectation of having to pay 30-50% more upfront for additional solar panels enhances the MPPT controller very lucrative, which is presented in this journal paper [10]. The researcher employs the buck converter since it provides a linear voltage transfer function when working in Continuous Conduction Mode (CCM). This makes things simplifies things a lot, and the MPPT controller can be implemented by operating directly on the converter duty cycle.

The other topologies have a nonlinear voltage transfer function, and working directly on the duty cycle will yield unpredictable results, especially at high duty cycles. In this case, the algorithm modifies the solar panel operating voltage by using a proportional-integral (PI) control loop, which steers the energy to the desired value. This paper provides details on the solar charge control device at the best PowerPoint. [11] The results include the change of the duty cycle with the change in load and thus mean the variation of the buck converter output voltage and current controlled by the MPPT algorithm.

3. Research Methodology

In this research, we have completed the following methodologies to complete the study. The steps are as follows:

1) Literature review
2) Prototype design
3) Data Collection
4) Data Analysis
5) Charge controller design

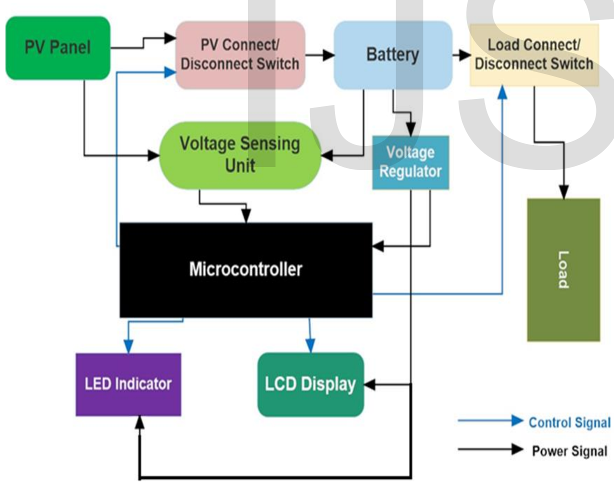

Fig-1: Block Diagram of the Proposed Charge Controller

4. Block DIAGRAMS of the Proposed Charge controller

Fig-1 is the block diagram of the proposed system. The system consists of a day/ night sensor, two voltage sensing units, two switching devices to connect/ disconnect the load and PV panels, an alphanumeric LCD, and LED indicators. To sense the battery voltage, a voltage divider circuit is used. [12] The course is designed this way to detect the maximum battery voltage 16 Volts. The output voltage V1 (range 0-5 V) of this circuit is fed to the microcontroller ADC1 or pin A0.

The switching section consists of power transistors (IRF 540N). The microcontroller controls the electronics. When the gate of the transistor (IRF540N) is high (5V), then they work like a short-circuited switch, when the gate voltage is low, the work as an open circuit switch.

Fig-2: Charge Controller in operation

Fig -3: Output Display

Display Section consists of a 16x2 Character LCD. This LCD can display two lines and 16 characters in each line. The LCD works on 4.7-5V, which is powered from the 7805-voltage regulator output. A resistor is added to the VE pin to adjust the contrast of the LCD.

The limitation of such a display is it cannot display too many characters. For example, if battery and PV voltage is displayed on the LCD, then "BATT VOLT" and "PV VOLT" texts take up so much character space that no more data can be viewed at a time. To overcome this problem, the custom character icon for the battery and PV panel was created and called into the program. In Fig-3, the LED display in operation is shown, whereas the charge controller is in process at Laboratory.

5. Data and Analysis

6.1 5.1 Set Point Test

Four set points of the charge controller were tested, using two power supplies acting as PV module and battery, respectively. The test was set up according to the arrangement shown below.

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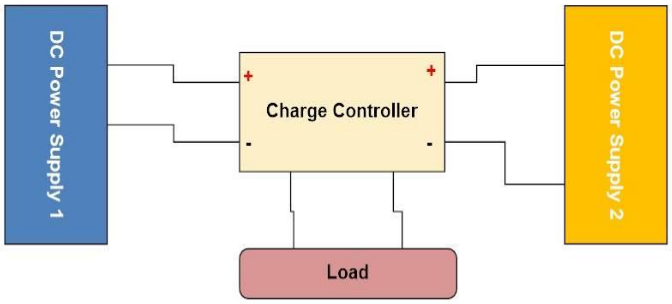

Fig 4.1: Schematic of SetPoint Test Via Power Supply

Setpoints were tested as fed into the system via code, then compared to the nominal values.

Each set point was tested several times to take an average value and minimize any experimental error.

The experimental data obtained are tabulated below:

Table 1: Experimental Data of Set Points

[1] No. of Obs.	[1] **LVD** (Volt)	[1] **LRV** (Volt)	[1] **ARV** (Volt)	[1] **VR** (Volt)
[1] 1	[2] 11	[2] 12.2	[2] 13.5	[2] 14.1
[1] 2	[3] 11	[3] 12.1	[3] 13.3	[3] 14.2
[1] 3	[4] 11	[4] 12.1	[4] 13.5	[4] 14.4
[1] 4	[5] 11	[5] 12.2	[5] 13.6	[5] 14.1
[1] 5	[6] 11	[6] 12.2	[6] 13.5	[6] 14.0

5.2 Test of Variation of Duty Cycle on Load During Different SOC of Battery

The test was set up, as arranged in the previous section. DC power supply voltage was reduced to simulate battery SOC conditions. The duty cycle on the load was measured using an oscilloscope. The brightness of the amount (LED Tube light) was noticed to decrease as SOC decreased to lower values gradually. The table below shows the SOC of charge of the battery according to terminal voltage. The duty cycle of the load is varied, using the program depending on the terminal voltage.

Practical calculation of duty cycle using Oscilloscope

At 100% SOC of battery, the load can consume energy continuously from the battery, the duty cycle is 100% here. The Time-division was set to 2ms/ div, and the Voltage division was set to 1 V/ div.

For 80% State of Charge

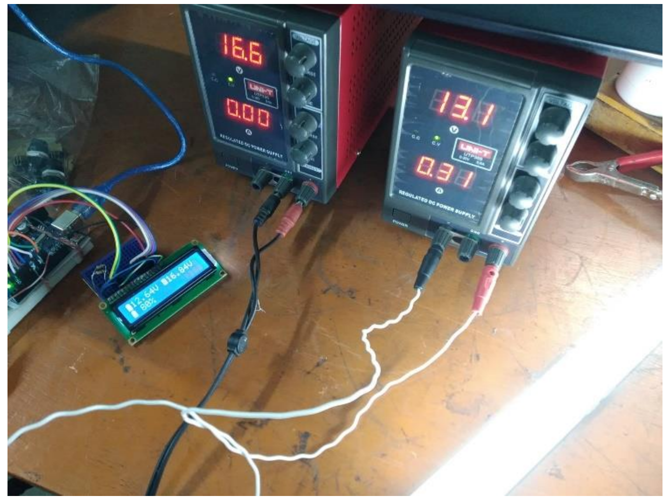

Fig 4.2: Duty Cycle of Load on 60% State of Charge

When the system detects 80% SOC of the battery, it is programmed to automatically send a PWM signal of 90% duty cycle to the load switching MOSFET. But the practical experimental result shows a slight variation in the duty cycle. The Time-division was set to 2ms/ div, and the Voltage division was set to 1 V/ div.

Time period, T = 8×2 ms = 16 ms, Frequency = f = 1 / T = 62.5 Hz

ON time, T_{on} = 7×2 ms = 14 ms

Duty Cycle, D = T_{on} / T = 87%

When the system detects 60% SOC of the battery, it is programmed to automatically send a PWM signal of 80% duty cycle to the load switching MOSFET. But the practical experimental result shows a slight variation in the duty cycle. The Time-division was set to 2ms/ div, and the Voltage division was set to 1 V/ div.

Time period, T = 8×2 ms = 16ms, Frequency = f = 1 / T = 62.5 Hz

ON time, T_{on} = 6×2ms = 12ms

Duty Cycle, D = T_{on} / T = 75%

For 40% State of Charge

When the system detects 40% SOC of the battery, it is programmed to automatically send a PWM signal of 70% duty cycle to the load switching MOSFET. But the practical experimental result shows a slight variation in the duty cycle. The Time-division was set to 2ms/ div, and the Voltage division was set to 1 V/ div.

Time period, T = 8×2 ms = 16ms, Frequency = f = 1 / T = 62.5 Hz

ON time T_{on} = 5.5×2ms = 11ms

Duty Cycle, D = T_{on} / T = 11/16 = 69%

When the system detects 20% SOC of the battery, it is programmed to automatically send a PWM signal of 60% duty cycle to the load switching MOSFET. But the practical experimental result shows a slight variation in the duty cycle. The Time-division was set to 2ms/ div, and the Voltage division was set to 1 V/ div.

Time period, T = 8×2 ms = 16ms, Frequency = f = 1 / T = 62.5 Hz

ON time T_{on} = 4.5×2ms = 9ms

Duty Cycle, D = T_{on} / T = 09/16 = 56%

6. Conclusion

The realization of Arduino based solar charge controller has been done at a competitive cost but crucial for small DC loads, and we can use this controller to implement other algorithms or to make comparisons. This thesis contains a battery charging system for using a direct connection between the photovoltaic solar panel and the battery system. With the help of this charge controller, solar power can be used effectively to ensure a prolonged battery lifetime. In this thesis, we have presented the experimental results using a 16x2 LCD display (panel voltage, battery voltage, SOC of the battery), LED indicators to test different SOC of the battery and the features of the system. Experimented data are also presented in the tabulated format along with analysis of the data for better understanding. The study and findings from this thesis may be used to develop a fully functioning solar charge controller with intelligence and autonomy, to be used with SHS, rather than a prototype version for laboratory testing only.

The model was designed on a breadboard, and due to this, the model could not handle currents higher than 5A. When PV modules were connected in several series-parallel combinations and connected with the system, the breadboard was getting very hot. The internal connection of the breadboard is not designed to handle high current. Further improvement can be made if the circuit is implemented on a PCB, and heavy gauge wire is used for solder joints.

Heat is the most crucial and anticipated enemy for batteries, especially for lead-acid. Including temperature compensation on a lead-acid charger to adjust for temperature variations is said to extended battery life by up to 15 percent. The recommended allowance is a 3mV drop per cell for every degree change in temperature. The code implemented on the system has no temperature compensation algorithm. If such a part was included in the law, then it could increase battery life and accurate SOC reading of the battery. [14]

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