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An Improved Microcontroller Based Lead Acid Battery Charger

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Abstract- With the continued demand for renewable energy of which the battery is an important energy (charge) storage unit, it is therefore imperative to develop a device that will effectively maintain the charge voltage of the battery in a bid to improve and maintain its functionality over time. In this work, a microcontroller based lead acid battery charge has been developed. The developed charger is an improvement over existing designs as it is equipped with wrong polarity detection, over charge protection, float charge and a digital display. The charging rate is displayed in percentage on the digital display for easy charge status monitoring and display of other related technical information. A Printed Circuit Board was also developed for the device. The battery charger was designed for 12V and 6V lead acid battery types and performed well when compared to existing models sold in the market.

Keywords: Battery Charger, lead acid batteries, renewable energy, battery, microcontroller.

1. Introduction

A battery is a device consisting of one or more electrochemical cells that converts stored chemical energy into electrical energy for later use. Each cell contains a positive terminal (cathode) and a negative terminal (anode). Electrolytes allow ions to move between the electrodes and terminals, which allows current to flow out of the battery to perform work.

A lead acid battery consists of a number of 2V nominal cells that are connected in series. Each 2V cell consists of an independent enclosed compartment with positive and negative plates dipped in electrolyte composed of diluted sulphuric acid solution of 33.5% v/v sulphuric acid and water [7]. The sealed lead acid batteries find applications in emergency lightning system, inverters, power electric motors in submarines, generators, etc.

Battery charging is an aspect of engineering technology in which a full-wave rectified filtered output of a transformer is fed to a battery in order to restore it to its fully charged state. The battery charger is used to put energy into a secondary cell by forcing electric current through it. An efficient battery charger requires a charge controller whose main function is to keep the batteries properly charged and safe for the long term and prevent it from deep discharging [5] and [6].

Battery can only be charged by a pulse current at a safe value rate determined by the differential voltage [4]. The three basic methods of charging batteries are constant current, constant voltage and a combination of both. Constant current charging requires maintaining the current at a fixed value throughout the charging process with the advantage that it requires lesser time compared to constant voltage charging which achieved by maintaining the voltage at a fixed value. The combination methods is used to overcome the disadvantages of both methods such that charging starts with constant current and when the emission of gas starts it continues with constant voltage [2].

The voltage of a lead acid battery rises when charged. When a charge current is applied to the battery through a charge controller circuit, the internal resistance of the battery resists the current flow leading to increase in the battery voltage. The voltage rises sharply as the battery begins to gas towards the end of charge. If gassing is left to continue for a long period of time, the battery will overcharge, thereby resulting in accelerated corrosion of the battery electrodes, loss of electrolyte and physical damage of the electrodes [6]. Gassing also called electrolysis is the decomposition of the liquid water into hydrogen and oxygen gasses [3].

It is a common problem to always overcharge batteries thereby shortening the life span of the batteries and increasing the Mean Time To Failure (MTTF) of such batteries. This research effort overcame these challenges by developing a microcontroller based battery charger that automatically cut-off the charging voltage and maintain a float charge when the battery is fully charged even where the user forgets to manually stop the charging process. It is an improvement over a charging unit developed by [1] for use in a rechargeable electric fan.

2. Materials and Methods

2.1 Principle of Operation

Figure 1 shows the functional block diagram upon which the design is based. The power supply stage is composed of a rectifying circuitry in which 220V AC is rectified to a regulated and filtered DC using a full-wave bridge network. The charge controller circuit comprises of electronic components such as capacitors, resistors, op-amps, diodes, transistors and light emitting diodes. The charge controller circuit in conjunction with the microcontroller is manipulated such that it can detect presence or absence of battery at the charging terminal, wrong battery polarity connection at the charging terminals, charging status of the battery, full charge status of the battery and float charge.

The ATmega328 microcontroller was used in the work to monitor the battery charge status and to further drive the liquid crystal display to enable the user have a deep knowledge of the system functionalities. The design uses a combination of constant current and constant voltage to charge batteries connected across its terminals at a charge current of 1000mA for 12V batteries and 300mA for 6V batteries.

2.2 Software Design

An ATmega328 microcontroller used in this research work was operated according to the program written into its memory. The program was written using the Arduino C++ language structure. The objective of the program is to give instruction, control and execute tasks such as charge monitoring, liquid crystal display and automatic cut-off to avoid over charging of the battery. Figure 2 shows the program algorithm developed for this work.

2.3 Circuit Design and Development

Figure 3 shows the rectified power circuit for charging the battery. A recycled UPS transformer steps down the 220V AC to around 18V AC, which was further rectified using a full bridge diode connection to a voltage of around 24V DC, which was then subsequently filtered by capacitor C1.

Figure 4 shows the designed and improved charging battery charging circuit with controller connections. The op-amps were operated as non-inverting amplifier and the reference voltage at each non-inverting input was set by the choice of resistors (which were computed using the voltage divider rule). TL431 is used as U1 to set a reference threshold of 2.5V. The battery is charged through Darlington pair transistor T1 which is operated as a switch controlled by OP-A2 which cuts off the base supply when the battery is fully charged. Diodes D7 and D8 prevents discharging from the battery to the electronic components when the charging source is not unavailable.

OP-A4 is used to monitor the charging status of the battery. R24 and R27 are both used to set the reference voltage to around 50mV. If the voltage at the inverting end of OP-A4 falls slightly below this value, the output of OP-A4 becomes high and switched on diode D8 while also sending a digital logic value of 1 to the microcontroller which notifies the user via the LCD that the battery is fully charged. R28, R26 and R30 are used to set the charging currents for the battery depending on the battery being charged. If a 12V battery is being charged, the switch is closed and a parallel combination of resistors R28, R26 and R30 gives a charging current of around 1000mA. But, if a 6V battery is to be charged, the switch is open and a parallel combination of resistors R26 and R30 gives a charging current of around 300mA.

OP-A3 is designed as a current limiter for the charging circuit with the output switched high when the current is at about 0.1C. AD-4 is used to monitor the charging level of the battery by the ADC section of the microcontroller. A voltage divider network is used to scale down the voltage at AD-4 to around 5V since the microcontroller operates well within this voltage and behaves erratically at higher voltages.

Figure 5 shows the float charge and battery charging status indicator circuit as well as microcontroller connections. When the voltages at the non-inverting terminals is greater than the inverting terminal at OP-A4, it means the battery is charging and as such the output of OP-A1 is high thereby forward biasing the base of transistor T2 which in turn switches on charging LED D2 and sends a digital logic High through AD-2 to the microcontroller for onward display on the LCD screen. Similarly, when the voltages at both inverting and non-inverting terminals of OP-A4 are equal, OP-A1's output will be switched low and transistor T1 conducts thus causing the float charge LED and pin AD-1 of the microcontroller to be switched High, which subsequently switches on LED D1 and also displays a float charge message on the LCD display.

Figure 6 has two circuits, the first one is a simple circuit designed to monitor battery polarity connections at the charging terminals. This circuit was incorporated owing to the fact that wrong polarity connection shortens life span of a battery thereby reducing its efficiency greatly. When the battery polarity is wrongly connected, LED D5 switches on and the AD-A3 sends a login HIGH to the microcontroller which notifies the user of the wrong connection. This also makes transistor T3 to conduct and the microcontroller prevents charging of the battery until the polarity connection is corrected by the user. The second circuit of figure 6 is designed as a charging voltage selector whose choice is determined depending on the battery being charged.

Figure 7 shows the charge controller unit of the device which is done by a microcontroller whose activity is manipulated using the program algorithm of Figure 2 to control the messages output on the LCD display as well as monitor the charging status and other parameters of interest of the battery being charged. The microcontroller operates as a voltage of 5V. When the battery charger is switched on, the microcontroller scans the charging terminals and notifies the user if no battery is connected to the terminals. Where the polarity is wrongly connected, the controller detects this displays it on the LCD screen. When the battery is charging, the controller computes the percentage charging using a program embedded into it and displays this on the LCD screen. The controller also detects float status as well full charge status of the battery and displays same on the LCD screen.

A metal structure casing unit was fabricated for the battery charger and large heat sinks was used for power transistor PT which was bound to heat up during use considering the charging current used in the charging the battery especially when a 12V battery is being charged. Figure 9 shows a setup of the complete design.

2.4 Printed Circuit Board (PCB) Development

For effective performance and commercial viability of the improved battery charger designed in this work, a printed circuit board was developed for the battery charger. Express PCB (available as license free PCB design software on the internet) was used in drawing the PCB circuit connections shown in Figure 8. The laser-toner transfer and ironing method was used in producing the PCB board for this work while ferric chloride was used to etch unwanted copper from the board leaving only the toner transfer trace or outline. Tinner solution was used to wipe away toner traces from the board to reveal the copper connections. Subsequently, a drilling machine was used to make components holes on the board after which the electronic components were laid and soldered onto the board.

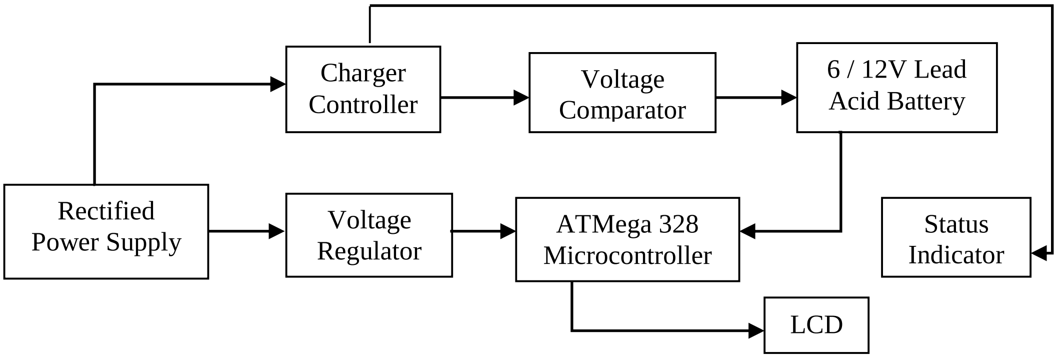

Figure 1: Block Diagram of the Microcontroller based lead acid battery charge

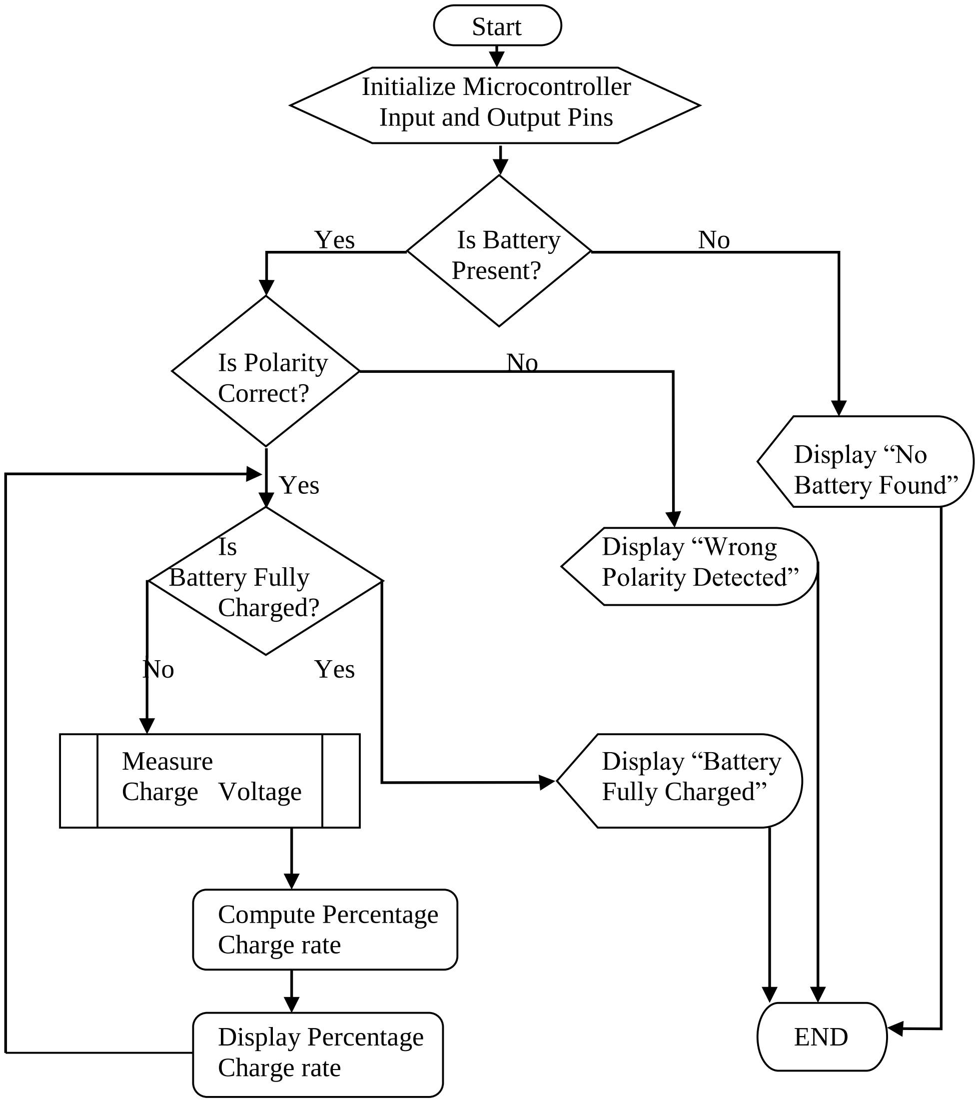

Figure 2: Program Algorithm for the Microcontroller Based Battery Charger

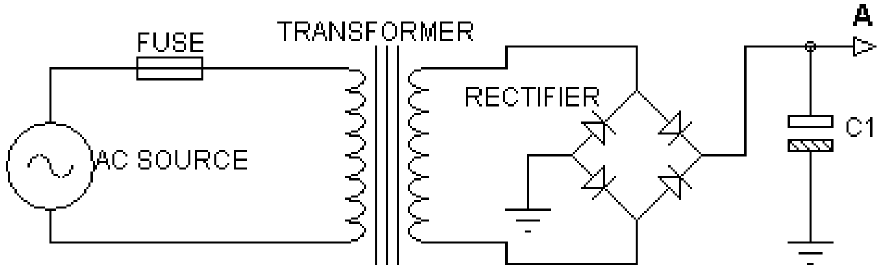

Figure 3: Rectified Power Source for the developed Charger

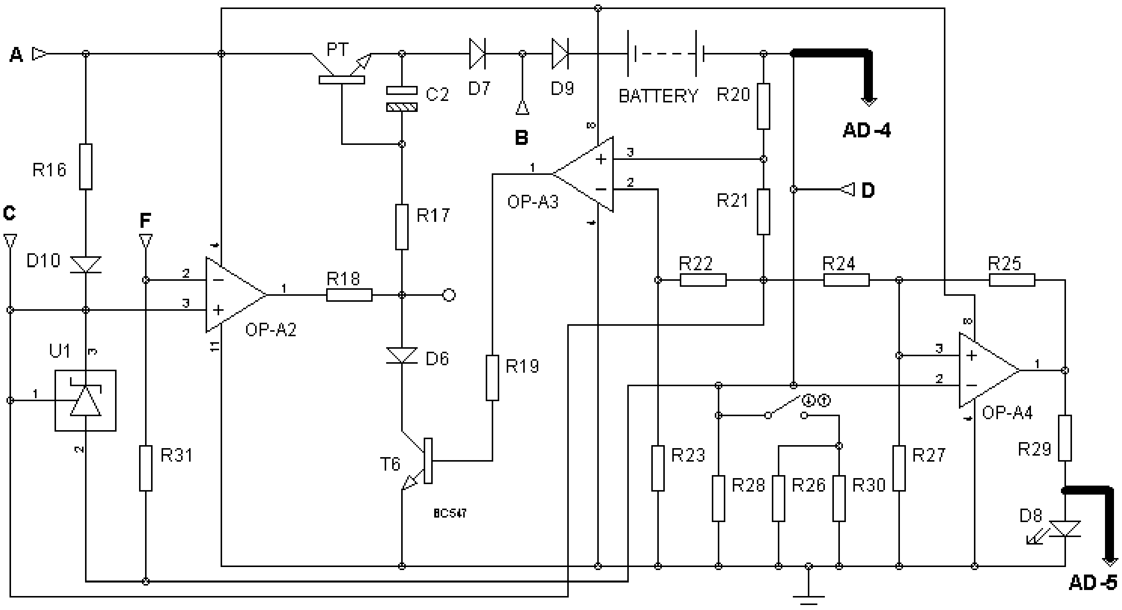

Figure 4: Charging Circuit with Full Charge Status Indicator

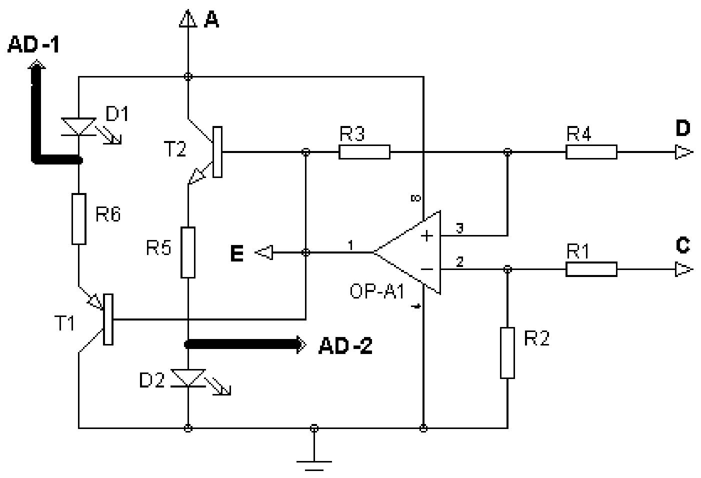

Figure 5: Float Charge and Charging Status Indicator Section

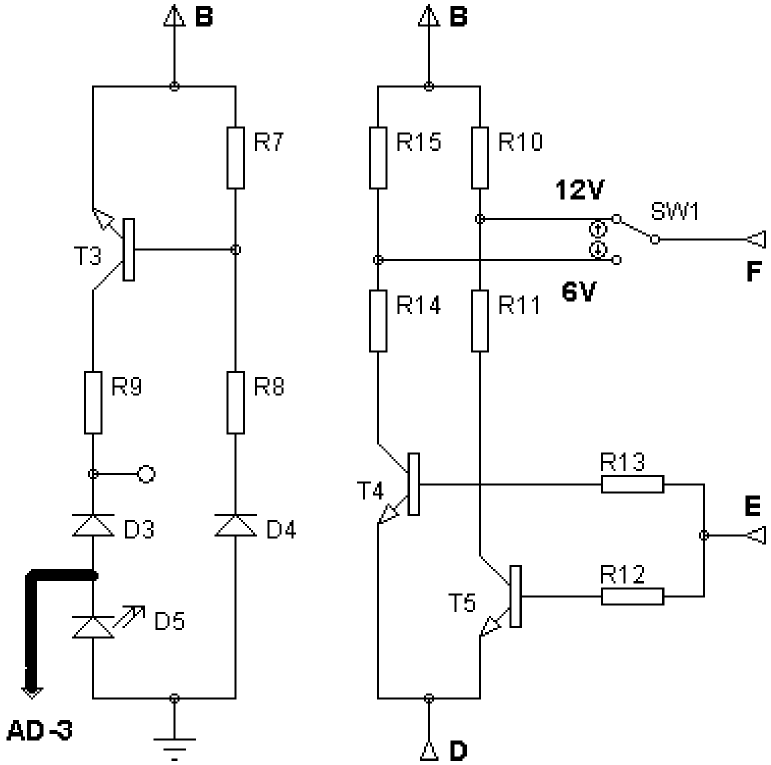

Figure 6: Battery Polarity Monitor and Charging Voltage Selector sections

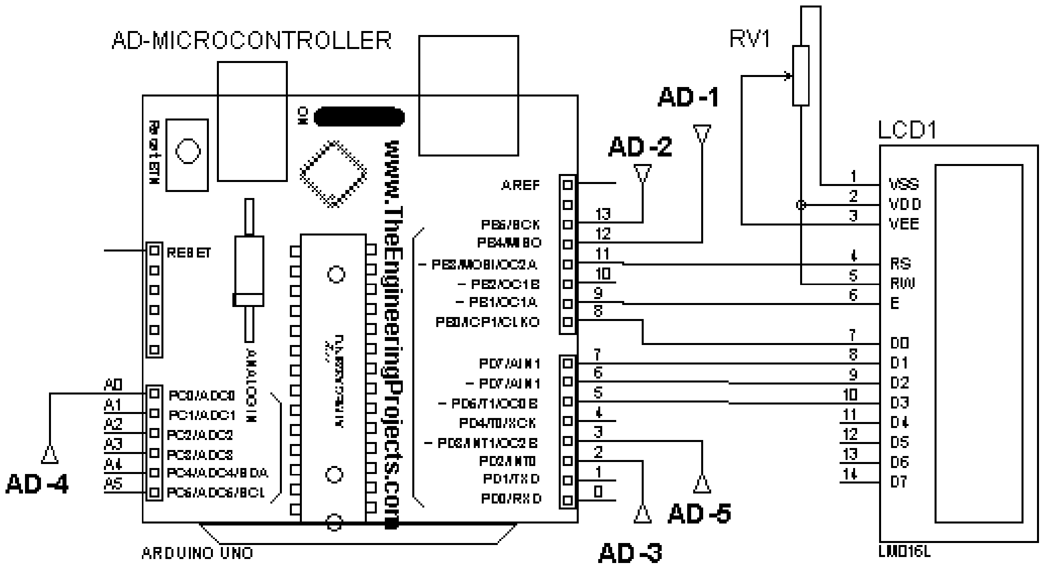

Figure 7: Charger Controller Section with LCD connections

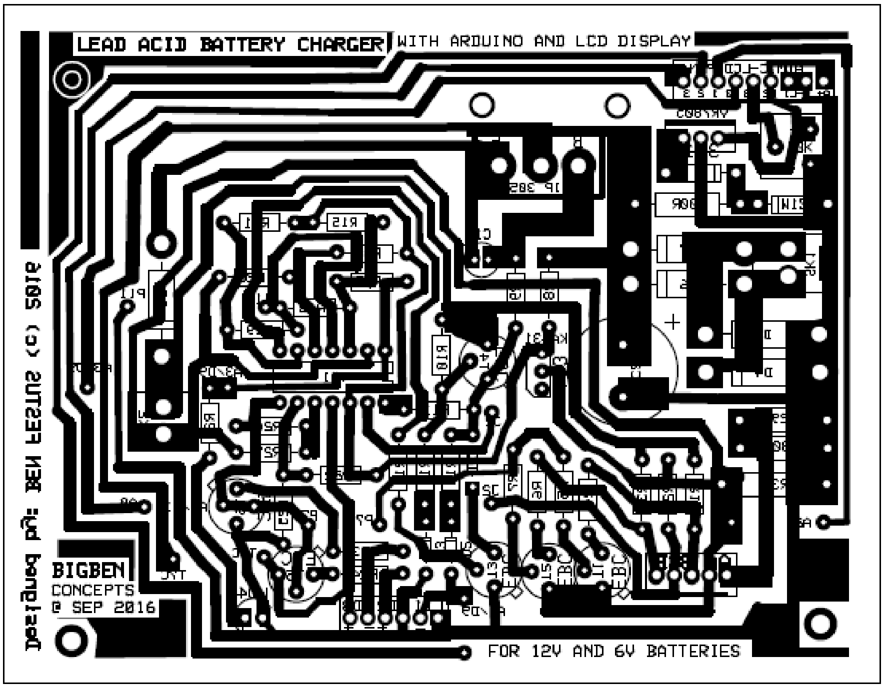

Figure 8: PCB developed for the improved battery charger project

Figure 9: Setup of the developed digital battery charger

Figure 10: Cross-section of the Digital Battery charger showing charging rate

3. Results and Discussion

When the digital battery charger was switched on, and no battery was connected to the charging terminals, *"No Battery Found, Please Connect One"* message was displayed on the LCD screen. When the battery was connected in the wrong polarity, *"Wrong Battery Polarity Detected. Cannot Proceed"* message was displayed on the LCD screen.

The battery was then properly connected to the charging terminals; the yellow LED came on indicating that the battery was charging while the percentage charge rate was displayed on the LCD screen as shown in Figure 10. Table 1 and table 2 shows the charging test results for 12V and 6V batteries respectively under test while Figure 11 shows the graphical plot of the charging test for voltage against time.

When the battery was fully charged, the red LED switched on while the yellow charging led switched off. *"Battery Full. Please Unplug"* message was displayed on the screen. When the charge voltage equaled the preset voltage for a full charge, none of LEDs came on except the float charge LED and *"Float Charge is activated"* message was displayed on the screen.

Table 1: Charging test result for 12V 7AH battery using the developed battery charger

Time (min)	Battery Voltage (V)	Charge rate (%)	Status
10:00am	12.06	14%	Charging
10:30am	12.45	25%	Charging
11:00am	12.61	30%	Charging
11:30am	12.73	37%	Charging
12:00noon	12.88	45%	Charging
12:30pm	12.97	51%	Charging
13:00pm	13.08	58%	Charging
13:30pm	13.22	64%	Charging
14:00pm	13.46	72%	Charging
14:30pm	13.63	80%	Charging
15:00pm	13.81	85%	Charging
15:30pm	13.98	90%	Charging
16:00pm	14.05	95%	Charging
16:30pm	14.20	98%	Float Charge
17:00pm	14.42	100%	Battery Full

Table 2: Charging test result for 6V 4.5AH battery using the developed battery charger

Time (min)	Battery Voltage (V)	Charge rate (%)	Status
10:00am	4.01	14%	Charging
10:30am	4.34	25%	Charging
11:00am	4.47	30%	Charging
11:30am	4.55	37%	Charging
12:00noon	4.63	45%	Charging
12:30pm	4.71	51%	Charging
13:00pm	4.85	58%	Charging
13:30pm	4.99	64%	Charging
14:00pm	5.20	72%	Charging
14:30pm	5.31	80%	Charging
15:00pm	5.49	85%	Charging
15:30pm	5.67	90%	Charging
16:00pm	5.80	95%	Charging
16:30pm	5.92	98%	Float Charge
17:00pm	6.05	100%	Battery Full

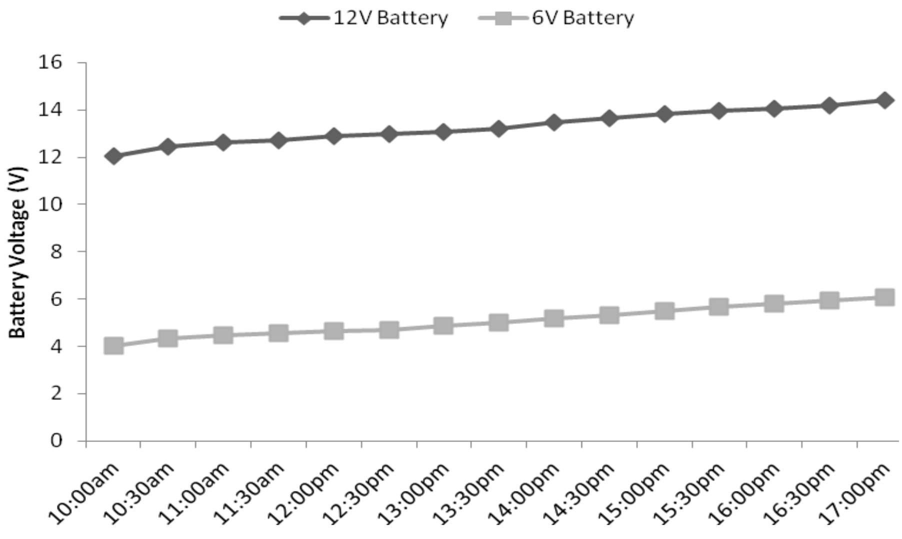

Figure 11: Graphical plot of voltage against time for 12V and 6V battery charging test

4. Conclusion

An improved microcontroller lead acid battery charger with digital display system was developed in this research work. The improved battery charger has many advantages like battery detection, wrong polarity detection, overcharge protection, battery discharge protection and percentage monitoring of battery charge status via an LCD display. The battery charger was used to charge 12V 7AH and 6V 4.5AH batteries respectively.

An improvement of the developed battery charger over existing ones is the digital display incorporated for monitoring charging status. Also, when the battery is fully charged, the system is equipped with a float charge which prevents overcharging by supplying a float charge which maintains the battery voltage, thereby prolonging the battery's life.

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