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Smart Battery Charger for E-Tricycle

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ABSTRACT

Abstract
This paper presents a low cost custom designed and built smart battery charging system for electric tricycle named E-Keke. It was not possible to purchase and use a commercial unit for the project because it was not affordable and also because there would be no technological transfer in that approach. Hence a unit was designed with the capability to apply battery management system using a microprocessor; it was built, tested and used for Electric Tricycle project called E-Keke. The advantage of this approach is that the unit was constructed within the set low cost budget and because it was locally built, it can be easily maintained by the local technicians.

Keywords: Environmental sanitation, Malarial, Parasite, Prevalence, Transmission, Seasonality, Awka, Nigeria

Aims Research Journal Reference Format:
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1. BACKGROUND STUDY

Batteries were needed to provide power to drive an electric hub motor which provided mechanical power for E-keke Project and it was important to review battery technology. Batteries have been in use since the mid to late 1800s, and in a limited way at first. Some of the earliest public works gaining attention were streets lights in Berlin in 1882, lighting up the Chicago World's Fair in 1893 with 250,000 light bulbs, and illuminating a bridge over the river Seine during the Paris 1900 World Fair (Batteryuniversity.com, 2018).

A battery management system (BMS) was required to manage rechargeable battery, in order to prevent the battery from damage. This system protects the battery from operating beyond its safe operating region, it monitors the state of the battery, calculates and reports secondary data. (Wikipedia, 2018). The battery being managed can be a single unit cell, or a battery bank comprising of two or more battery cells connected in parallel or series configuration depending on how the setup is required. This process of managing batteries can be done with respect to various properties of the battery, some of these properties include voltage, current, temperature, State Of Charge (SOC), state of health etc. The battery management system (BMS) selected was able to cut off the battery from the load (to which it is connected) when the battery is low, automatically connect the battery to a power source for charging when its voltage falls below a certain value.

1.1 Statement of problem.

The continuous charging and discharging of rechargeable batteries if not properly monitored can lead to the damage of the battery cells. The manual method whereby a person monitors some of the battery parameters while it is being charged or connected to a load unit cannot be applied in this project because it is used for a moving vehicle; hence a need for automated system.

1.2 The aim of the project.

The aim of this project is to design and construct a system which can properly charge, monitor and manage a battery bank of six 12V batteries in parallel configuration and also protect a battery bank of six 12V batteries in series configuration using a microprocessor based BMS.

1.3 Importance of the project

Without a BMS, the process of charging and discharging the battery bank will reduce the life span of the battery. With a properly functioning BMS, the cost of replacing the batteries in a short period of time after installing the system is eliminated, the hazard of explosion as a result of overcharging the battery bank is also eliminated. Thus, the BMS has both economic and safety implications.

2. OVERVIEW OF EXISTING SYSTEMS

Despite the advances in battery chemistry and manufacture brought about by advances in mobile electronics, battery management in electric vehicles has not followed up in the progress made. The main reason is that battery usage patterns in an Electric Vehicle (EV) are considerably different to most other application with requirements of both short high current bursts for acceleration and long periods of constant load for highway driving (MASKEY, M. et al., 1999). This means that battery management system developed for other means such as telecommunication don't necessarily suit the application to EVs. Below are some already existing ideology relative to a battery management system.

2.1 Smart Charging

This involves the use of a micro-controller to compensate for temperature rise and adjust the charge current and charge time accordingly to the battery specifications. This extends battery life and is used with Li-ion battery types. This battery management circuit or unit can be fitted externally to the charger. A number of the power semiconductor manufacturers offer control circuits to perform this function (Power-topics.blogspot.com, 2018).

2.2 Constant Voltage

This allows the full current of the charger to flow into the battery until the power supply reaches its pre-set voltage. The current will then taper down to a minimum value once that voltage level is reached. The battery can be left connected to the charger until ready for use and will remain at that "float voltage", trickle charging to compensate for normal battery self-discharge. A typical example would be a low cost auto battery charger for home use or basic back up power systems. This method enables fast charging rates and is suitable for lead acid types, but not for Nickel Metal Hydride (Ni-MH) or Lithium-Ion (Li-ion) types (Power-topics.blogspot.com, 2018).

2.3 Constant Current

This is a simple form of charging batteries, with the current level set at approximately 10% of the maximum battery rating. Charge times are relatively long with the disadvantage that the battery may overheat if it is over-charged, leading to premature battery replacement. This method is suitable for Ni-MH type of batteries. The battery must be disconnected or a timer function used once charged (Power-topics.blogspot.com, 2018).

2.4 Constant Voltage / Constant Current (CVCC)

This is a combination of the above two methods. The charger limits the amount of current to a pre-set level until the battery reaches a pre-set voltage level. The current then reduces as the battery becomes fully charged. This system allows fast charging without the risk of over-charging and is suitable for Li-ion and other battery types (Power-topics.blogspot.com, 2018). The prime objective of the charger/battery combination is to permit the incorporation of a wider range of protection circuits which prevent overcharging of, or damage to, the battery and thus extend its life. Charge control can be in either the battery or the charger.

The objective of the application/battery combination is to prevent overloads and to conserve the battery. Similar to the charger combination, discharge control can be in either the application or in the battery (Mpoweruk.com, 2018).A publication on research gate; Improvement on LiFePO4 Cell Balancing Algorithm explains that battery life has strong dependence on cell imbalance. If imbalance is persisting continuously, the overall capacity of the battery pack decreases with significantly higher rate during operation and therefore reduces the efficiency of the EV. The passive cell balancers are most widely used, as they are reliable and cost effective solutions. To balance the cells they reduce energy from a charged cell through a dissipating resistor. The discharge is discontinued when the cell equals the lowest voltage in the pack or predefined reference. Several charge cycles are needed to finish the process (Researchgate.net, 2018).

In the second chapter of Battery Power Management for Portable Devices, it was stated that a lead-acid battery charger usually has two main tasks to achieve. The first is to charge the battery such that capacity can be restored as quickly as possible. The second is to maintain the battery's capacity by compensating for capacity loss due to self-discharge by applying a constant voltage to a fully charged battery. Because battery voltage is a function of its cell temperature with -3.9mV/deg cell charge, the charge voltage needs to be adjusted according to its temperature. If such temperature compensation is not considered, loss of capacity could happen below the nominal design temperature, and overcharge with a subsequent degradation of cycle life could occur at higher temperature (books.google, 2018).Teofilo explained how correct charging is important to achieve maximum capacity and therefore range of the EV. Lithium ion batteries can receive 30-60% of their capacity under 'taper' charging or a constant voltage stage. Specialized chargers, usually microprocessor controlled, are needed that can operate in different modes in order to maximize range (TEOFILO, V. L. et al., 1997).

Series connected battery packs in electric vehicles (EVs) and hybrid electric vehicles (HEVs) require monitoring equipment that is capable of measuring the voltages of individual segments (several modules/cells connected in series) in order to prevent damage and identify defective segments. All types of batteries can be damaged by excessively high or low voltages, and in some cases the results can be catastrophic. Lithium ion cells, for example will ignite if they are overcharged (Namith T., Ms. Preetham Shankpal, 2012). Kroeze, R. C. Et al (2008) developed a model for batteries in the paper, "Electrical Battery Model for Use in Dynamic Electric Vehicle Simulations." The goal of this model is to provide more accurate results in simulating use in an electric vehicle.

Use of models like these could be applied to design and simulate better battery management systems. Galdi (2006) produced a model based on fuzzy logic by which the battery management systems can limit the vehicles performance to a degree in order to maximize the battery life when the SOC begins to get low. This autonomous control is shown, in simulation, to increase the range of the simulated electric vehicle. Bruno G. S. designed a battery charger with multiple outlets with overcharge protection. This design however lacked the reversed polarity protection which protects the battery from damage if the terminals of the battery are wrongly connected to the terminals of the charger. (Sabastine, 2017).

3. DESIGN SPECIFICATION

Table 3.1 shows the Charger Specification Table

Input Voltage	230V
Output Voltage	12V
Supply Frequency	50-60Hz
KVA Rating	0.36KVA
Number of Phases	Single Phase
Cooling Medium	Natural Air (NA)
Design Type	Core Type
Conductor Material	Copper
Maximum Output Current	30A
Maximum Input Current	2A
Charger Type	Automatic
Charging Mode	Smart charging
Charged/Cut-off Voltage Limit	86V
Protection	Short Circuit, Reversed Polarity Protection,
Indicator	LED
Charging Frequency	20KHz
Efficiency	90%

Table 3.2 Low Battery Cut-off Specification Table

Input Voltage	5V
Low Voltage	75V
Cut-off Voltage	70V
Indicator	LCD Screen
Cut-off Component	Electromechanical Relay

3.1 Calculation

12V output Charger Transformer Design

This charger requires an output 12V to charge the battery bank efficiently in order to prevent the premature replacement of the batteries. The various steps employed in order to achieve this aim are stated below.

a. Core Design

1. Voltage per turn

The voltage (V_t) per turn is obtained from the equation (3.1)

$E = 4.44 f \phi N$ - - - - - - - - - -3.1

Where E = RMS value of the applied voltage
f = Supply frequency
N = Number of turns
Ø = Magnetic flux

Also, $Ø_m = B_m A$ - - - - - - - - - 3.2

Where B_m = Maximum magnetic flux density

A = Area of the core

The core area was calculated from the measurement and of the lamination core length and height.
Core length = 5.4cm
Core height = 8.1cm
Core area = Core length x Core height
Core area = 5.4x8.1
Core area = 43.74cm^2

From equation 3.2, therefore
Ø = BA - - - - - - - - - - 3.3
Putting equation 3.3 into equation 3.1 yields
E = 4.44fBAN - - - - - - - - -3.4
Voltage per turn = $\frac{E}{N}$ - - - - - - - - -3.5

From equation 3.4, therefore

$\frac{E}{N}$ = 4.44fB_mA - - - - - - - - - -3.6

Where f = 50Hz

B_m = 1.3wb/m^2

A = 43.74cm^2 = 43.74x10^{-4}

$\frac{E}{N}$ = 4.44 x 50 x 1.3 x 43.74x10^{-4}

$\frac{E}{N}$ = 1.2323Volts/turn

From equation 3.2,

$Ø_m$ = 1.3 x 43.74x10^{-4}

$Ø_m$ = 5.6862x10^{-3}wb

b. Winding Calculation

Determining the Number of Primary Turns

Primary voltage = 230V

From equation 3.6, the number of primary turns was calculated.

$\frac{Primary\ voltage}{\mathrm{Np}}$ = 1.2623volts/turn

Making N_p, the number of turns subject of the formula yields

$N_p = \frac{Primary\ voltage}{1.2623}$

$N_p = \frac{230}{1.2623}$

N_p = 182.2071turns.

Therefore, the number of primary turns = 182.2071turns.

Determining the Number of Secondary Turns

Secondary voltage = 230V

From equation 3.6, the number of secondary turns was calculated.

$\frac{\mathrm{Secondary}\ voltage}{\mathrm{Ns}}$ = 1.2623volts/turn

Making N_s, the number of turns subject of the formula yields

$N_s = \frac{\mathrm{Secondary}\ voltage}{1.2623}$

$N_s = \frac{18}{1.2623}$

N_s = 14.2597turns ≈ 15turns. This is because there cannot be 0.2597turns.

Therefore, the number of secondary turns is 15 turns.

For design efficiency of 90%, the estimated loss = 10%.

For the compensation of losses in the windings, an additional 10% is included.

Therefore, the total secondary turns is obtained as

$N_s = 15 + (\frac{10}{100}\ x\ 15)$

N_s =16.5turns ≈ 17turns.

Therefore, the total secondary turns is 17 turns.

3.2 Principle of Operation for the Charger Circuit
When the 13A plug of the charger is connected to mains, if the polarity of the charger is wrongly connected to the battery bank, the reversed polarity protection circuit prevents the charger from coming up so as to prevent the batteries from getting damaged. If the polarity is correct, the step-down transformer steps down the input voltage from 230V main to 12V, this voltage is fed into a H-bridge as shown in fig. 3.5.The H-bridge acts as a rectifier to rectify and regulate the 12V ac received from the transformer to a 12v dc. The 12V from the step-down transformer is also tapped out to a rectifier and then to a 5V regulator to supply the MCU with the required 5V.

The MCU controls the output current of the H-bridge with the aid of its drivers, depending on the SOC of the battery bank to give the required supply of current to the battery bank. The H-bridge supplies the battery bank with the required current to charge the batteries. The battery bank is connected to the MCU which senses the SOC of the battery bank in order to communicate with the H-bridge. Depending on the SOC of the battery bank, the MCU communicates with the H-bridge to either charge the battery bank with constant voltage, float charge, or trickle charge the battery bank. The block diagram for the charger is shown below:

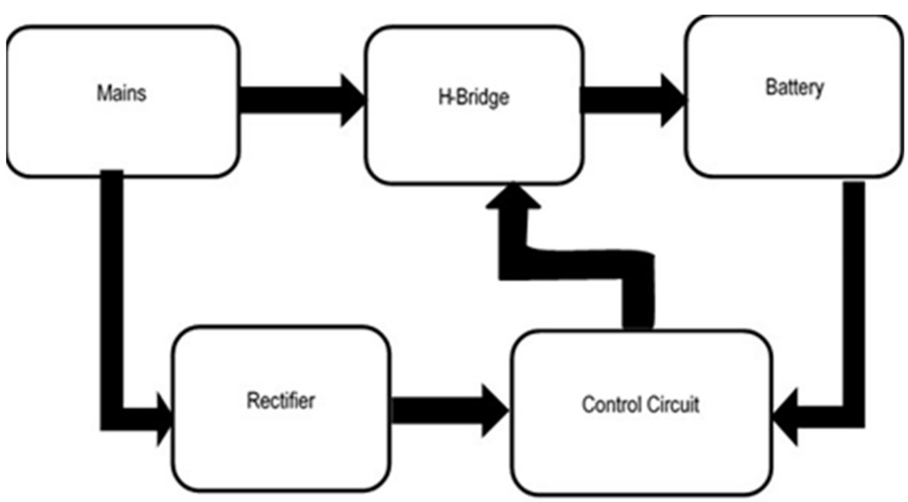

Fig. 3.1 Block Diagram for Charging Circuit

3.3 Principle of Operation for the Low Battery Cut-off Circuit

For powering the Hub motor, the batteries are connected in series to give a battery bank of 72V as required and depicted in fig. 3.6. A 12V dc source is tapped from the first battery in the battery bank, it is then regulated to a 5V and used to sup ply the MCU its required 5V to power the unit. Then the positive of the battery bank in series connection is the connected to the MCU via a voltage divider with a factor of 10. This voltage connected to the MCU via the voltage divider is what the microcontroller measures to give the various displays on the LCD screen. Being that the voltage is stepped down by the voltage divider, the displayed value on the LCD screen is multiplied with a factor of 10 before it is displayed.

An electromechanical relay was employed as an interface between the battery bank and the Hub motor. The MCU displays a low battery warning on the LCD screen when the battery gets low and sends a signal to the buzzer unit in order to alert the user. When the battery gets below its safe operating region, the MCU sends a signal to the relay which cuts off the battery from the hub motor. The block diagram for the low battery cut-off is shown in fig. 3.2.

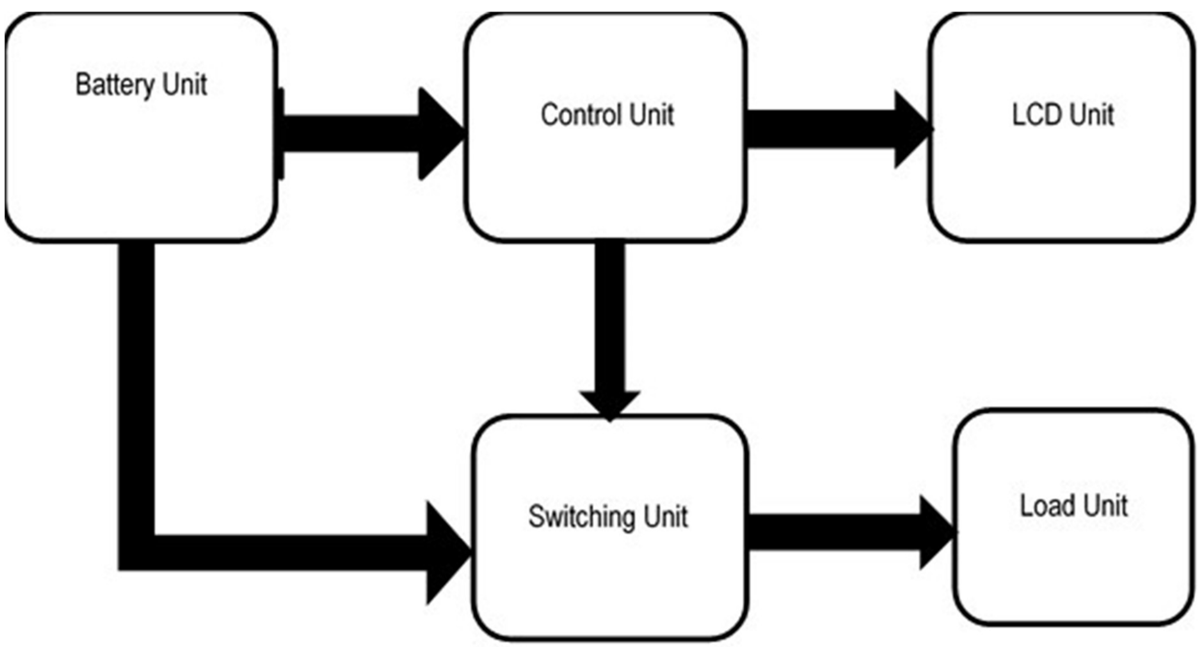

Fig. 3.2 Block Diagram for Battery Cutoff Circuit

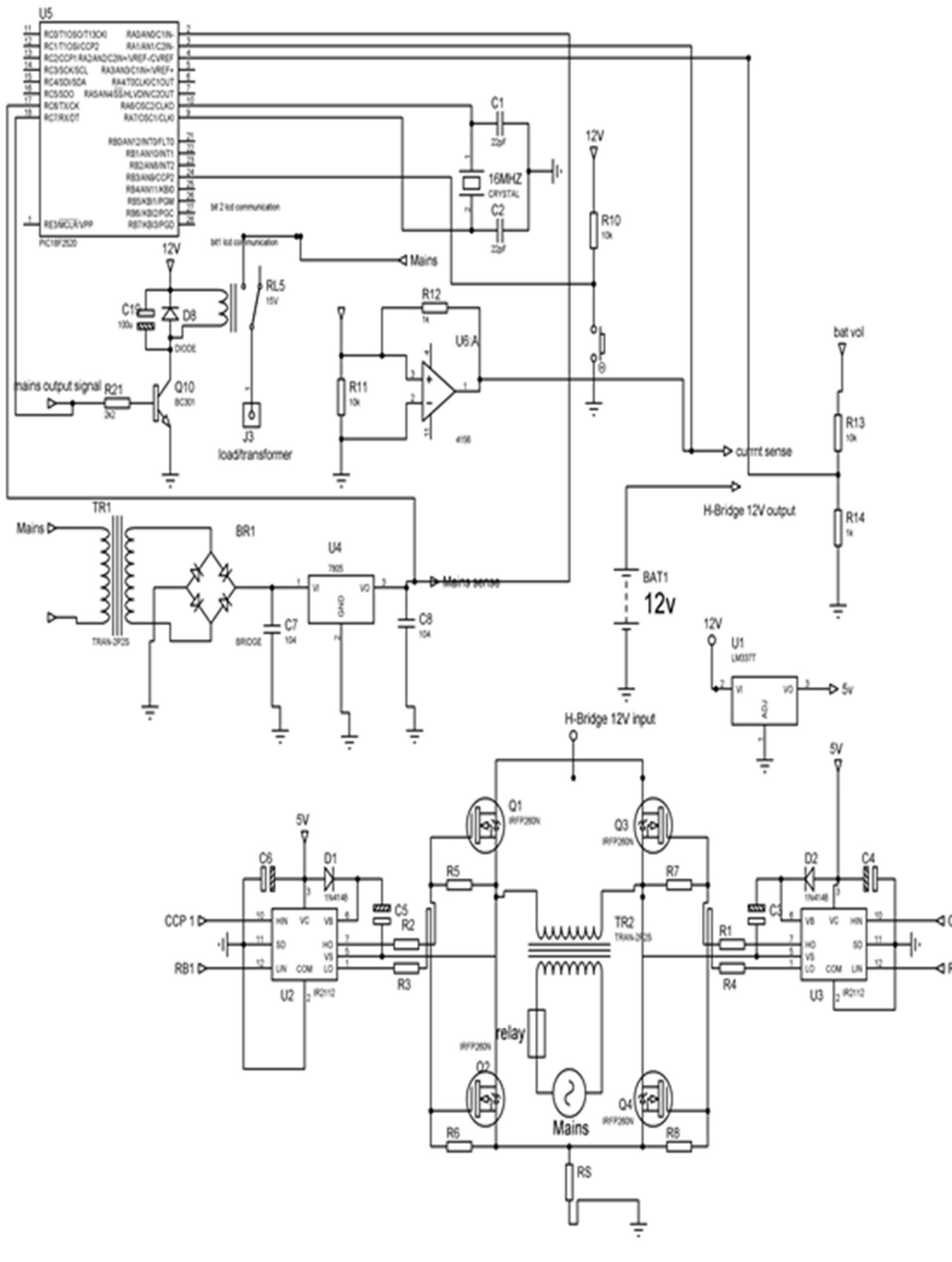

Fig 3.3: The Charger Circuit

4. IMPLEMENTATION, TESTS AND RESULT

4.1 Implemetation Phase

Simulation

The charging and low battery cut-off circuits were first designed using Proteus v8.6 workbench. On the workbench, the circuits were designed individually to obtain a suitable design that could perform the required task of managing the battery bank. After the design, the circuits were simulated individually to see where various errors could possibly exist and corrections were made until the individual simulations ran appropriately. Proteus was used because of its user friendly interface and wide range of electrical and electronic components for designing both digital and analogue systems. Designing of circuit on Proteus involves a drag and drop process making it easy to design a circuit, it also allows one to import a written programming code from source files into a programmable integrated circuit.

Hardware Design

The circuits were implemented on separate boards based on the circuits that were successfully simulated on Proteus and were soldered permanently.

Program Flowchart

The MCU executes functions in a specified order, based on the program instructions written to it. Thus, the program instructions must be properly organized in order to avoid improper co-ordination of events during operation. The flow charts for the various operations are shown below in the figures 4.1 and 4.2

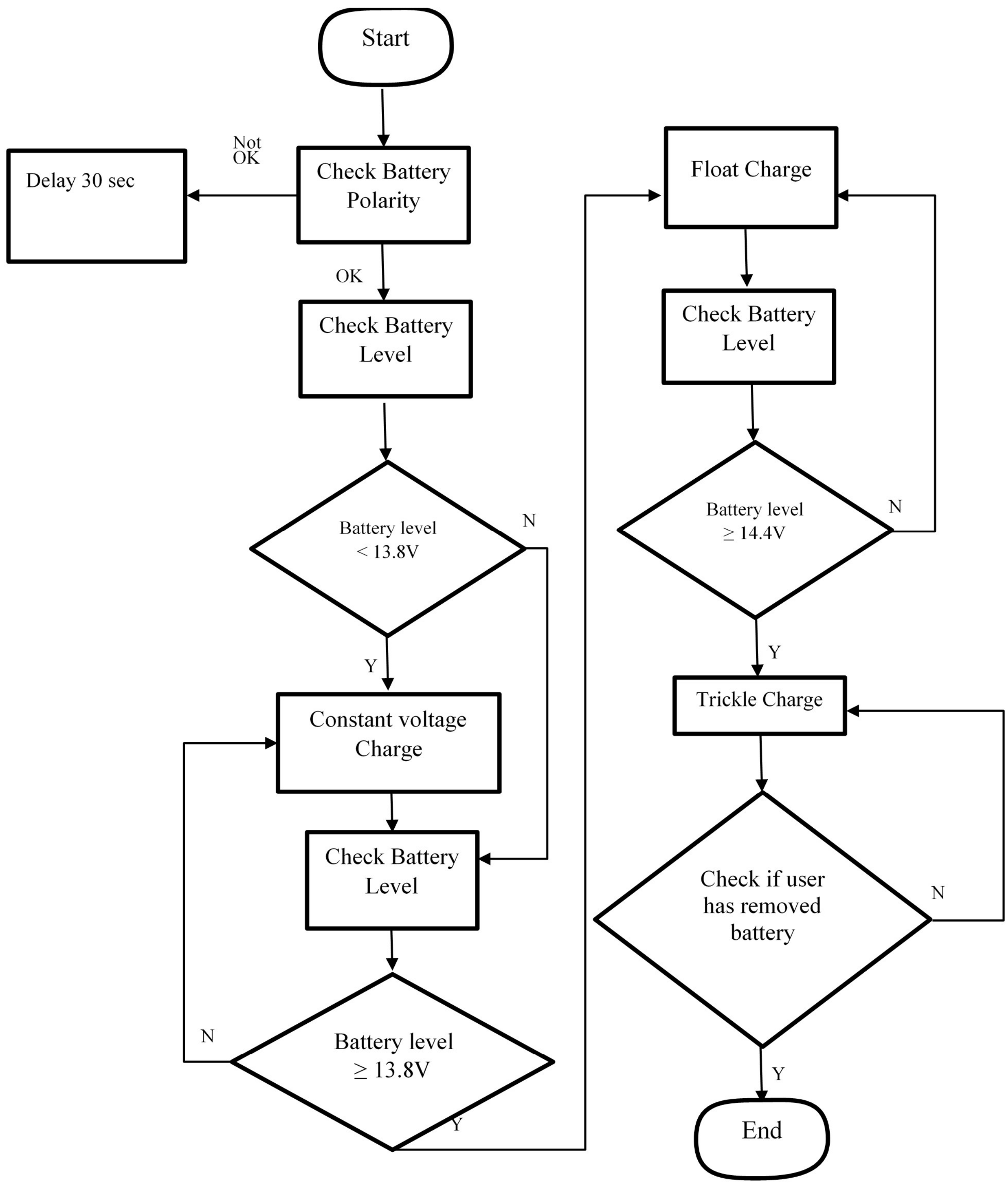

Fig. 4.1 Charging Flowchart

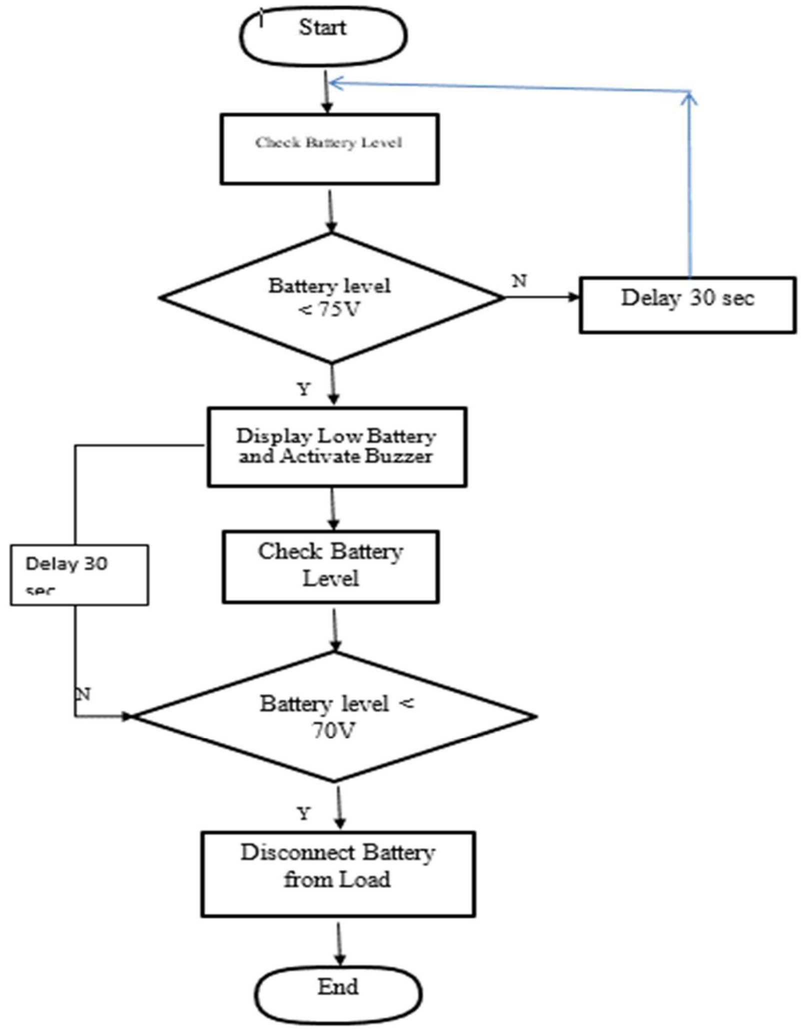

Fig. 4.2 Battery Cutoff Flowchart

4.2 TESTS

Various tests were carried out on the battery charger and the low battery cut-off circuit during and after the implementation of the circuits. These tests were carried out in order to ensure that the circuits function properly as required, and to prevent the circuits from damaging the batteries. Some of these tests carried out are discussed below.

Continuity Test

This was conducted in order to ensure that there is continuity between the components electrically joined together.

Open-circuit Test

This test is similar to the aforementioned test (continuity test), it was carried out in order to detect the various areas on the circuit that were not properly soldered together so that adequate corrections can be made.

Short-circuit Test

This test is essential because if there exist any short circuit anywhere on the various charger or low batter cut-off circuits, this can lead to the damage of the electronic components and the batteries which these systems were made to properly manage. During this test, it was discovered that there was a short-circuit between the two terminals of the electromechanical relay in the low battery cut-off circuit. This connected the batteries and the load together, preventing the relay from cutting off the load from the batteries when the battery bank gets below its safe operating region. This error was corrected and the system then functioned properly.

Voltage Test

Voltage test was carried out on various point in the networks to ascertain that the voltage on each points was correct. Also, the output of the charger was tested to ensure that the voltage on the output of the charger was correct. A multi-meter was employed in carrying out this test.

Current Test

This test was carried out to ensure that the current demand of the circuits were obtained. It was performed using a multi-meter within the circuits, and a clamp-meter to get the output current of the charger. The multi-meter was connected in series with the circuit whose current demand is to be measured.

Charging Test

A multi-meter was used to test and measure the output voltage of the charger when the terminals of the charger were connected to the battery bank, and the plug to main. A clamp-on meter was used to measure and ascertain the output current of the charger for the various charging modes.

5. RESULT AND OBSERVATION

This part contains two steps, the first is the simulation section, and the second the hard ware section. For the first step, all the circuits were properly tested on Proteus Software. After tests, there were successive failures due to the improper placing of some components preventing the circuits from simulating properly. These failures were checked and corrected to ensure that the components were properly placed with their values. After the corrections were made, the circuit for the charger was successfully simulated, and that of the low power cut-off was also successfully simulated. During the various modes in charging the batteries, the output from the charger was seen to be the expected values based on the SOC of the battery bank. During the simulation of the low batter cut-off circuit, the necessary actions were taken by the control system. When the battery was less than 75V, the LCD displayed low battery and the voltage of the battery bank and the buzzer buzzed. When the battery was less than 70V, the LCD displayed the low battery and the voltage of the battery bank, the buzzer buzzed and the control system cut off the load from the battery bank.
For the hardware section, the circuits were carefully implemented on printed PCBs and Vero boards. After carrying out the tests, it was observed that there was a difference of 1.9V on the LCD voltage value over the multi-meter voltage value. The charger did not deliver any output initially, this was because there existed an open circuit between the mains sensing circuit and the mains. This fault was corrected and the system when retested functioned properly.

5. CONCLUSION

The aim of this project which is to design and implement a battery Charger / management system - to properly manage the battery bank with reversed polarity protection, over charge protection, and low battery cut-off was achieved. Hence, a battery bank of six 12V 75AH batteries was properly managed with this project without the stress of monitoring the batteries manually while charging the battery bank. This is because the charger based on the SOC of the battery bank regulates the flow of current into the battery bank to efficiently charge and prevent the battery bank from getting damaged even when is fully charged with the charger still connected to the battery bank.

The low battery cut-off system protects the battery by alerting the user when the battery bank is low, and by cutting off the load when the voltage of the battery bank falls below its safe operating region. Hence, this project was successfully carried out.

REFERENCES

1. Batteryuniversity. (2018, August 4). *Batteryuniversity*. Retrieved from https://batteryuniversity.com/index.php/learn/article/when_was_the_battery_invented
2. books.google. (2018, July 8). *books.google.com.ng*. Retrieved from books.google.com.ng: https://books.google.com.ng/books?id=r_QfAgAAQBAJ&printsec=frontcover&source=gbs_book_other_versions#v=onepage&q&f=true
3. Britannica.com. (2018, August 13). *britannica.com/technology/diode*. Retrieved from britannica.com: https://www.britannica.com/technology/diode
4. edgefxkits.com. (2018, August 13). */www.edgefxkits.com/*. Retrieved from www.edgefxkits.com/blog/types-of-mosfet-applications/: http://www.edgefxkits.com/blog/types-of-mosfet-applications/
5. ElectronisTutorials. (2018, August 25). *Voltage Multiplier: electronics-tutorials*. Retrieved from electronics-tutorials.ws: https://www.electronics-tutorials.ws/blog/voltage-multiplier-circuit.html
6. GALDI V., A. PICCOLO, and P. SIANO. (2006). A Fuzzy Based Safe Power Management Algorithm for Energy Storage Systems in Electric Vehicles. *Vehicle Power and Propulsion Conference* (pp. 1-6). Institute of Electrical & Electronics Engineering .
7. KROEZE R. C., and P. T. KREIN. (2008). Electrical battery model for use in dynamic electric vehicle simulations. *Power Electronics Specialists Conference* (pp. 1336-1342.). Institute of Electrical & Electronics Engineering.
8. Mpoweruk. (2018, July 8). *www.mpoweruk.com/bms.html*. Retrieved from www.mpoweruk.com: https://www.mpoweruk.com/bms.html
9. Namith T., Ms. Preetham Shankpal. (2012). Design and Development of Efficient Battery. *SASTECH Journal* , 15.
10. Pc-control.co.uk. (2018, August 13). *www.pc-control.co.uk/relays.htm*. Retrieved from www.pc-control.co.uk: https://www.pc-control.co.uk/relays.htm
11. Power-topics. (2018, July 8). Retrieved from Power-topics: http://power-topics.blogspot.com/2016/05/constant-voltage-constant-current.html
12. Researchgate. (2018, July 8). *Researchgate*. Retrieved from Researchgate: https://www.researchgate.net/publication/323630002_Improvement_on_LiFePO4_Cell_Balancing_Algorithm
13. V.L. Teofilo ; L.V. Merritt ; R.P. Hollandsworth. (2018, July 8). *ieeexplore.ieee.org*. Retrieved from ieeexplore.ieee.org: https://ieeexplore.ieee.org/document/574108/
14. Wikipedia. (2018, August 4). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Battery_management_system
15. wikipedia. (2018, August 13). *en.wikipedia.org/wiki/Amplifier*. Retrieved from en.wikipedia.org: https://en.wikipedia.org/wiki/Amplifier
16. Wikipedia. (2018, August 13). *en.wikipedia voltage_regulator*. Retrieved from en.wikipedia.org/: https://en.wikipedia.org/wiki/Voltage_regulator