Journal of Engineering, Science and Technology
ISSN: 2714-2396, Volume 8 Issue 1

DEVELOPMENT OF A VOLTAGE CONTROLLED BATTERY MULTI-CHARGING SYSTEM

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Received Date: 31 March 2025 Accepted Date: 30 April 2025 Published Date: 4 June 2025

Abstract. This paper presents the design and construction of a voltage-controlled multi-charging system capable of charging up to four 12V batteries connected in series. The system can also charge one, two, or three batteries and features a 16×2 LCD that displays battery percentage, voltage, input AC voltage, and charging status. Charging automatically terminates upon full charge to prevent overcharging and prolong battery life. The system supports battery capacities from 60 AH to 200 AH. A multi-input, multi-output step-down transformer was designed, with rectification achieved using a full-wave rectifier diode. The control panel comprises nine relays, an Arduino IC ATmega328P, an Analog-to-Digital Converter, and filters. Experimental tests were conducted by applying AC input voltages of 222, 220, 208, and 202 V to configurations of single, two-series, three-series, and four-series batteries, respectively, for 30 minutes. Measured results include charging currents, initial and final battery voltages, and percentages: 3.56 A (12.31–14.1 V, 79%–86%), 2.51 A (25.5–26.5 V, 67%–72%), 3.34 A (38.5–39.0 V, 89%–93%), and 3.38 A (49.5–50 V, 87%–90%). The system effectively prevents overcharging, enhances battery performance, saves time and cost, and extends battery lifespan, making it a valuable solution for efficient multi-battery charging.

Keywords: Overcharging, charging status, portable charger, multi-charging, transformer testing

1. Introduction

The new types of automobiles use complex battery systems to power engines. This reason necessitates the development of an intelligent battery charging system which is important in the design of nowadays electronics systems. Many commercial charging systems consist of an insulated transformer and rectifiers. Though they are cheap they are not efficient enough and can damage battery life because of the less current. Many intelligent chargers in the market discharge instead of charging the battery (Dericioglu et al., 2018).

The commonly used type of charger for charging purposes is the iron core-based transformer. It is commonly used because of easy maintenance, easy repair or troubleshooting, and simple operation (Hrishikesh et al., 2021). Some lead acid battery chargers in the market do not use the appropriate methods of battery power and this has damaged many battery lives. This is because it is not easy to develop efficient lead acid battery chargers using the appropriate methods considering battery life (Freitas et al., 2016). Electrical energy can be converted from its alternating current (AC) to direct current (DC). It is also made to provide the voltage that will be suitable for electronic equipment. This is achievable in a DC power supply unit (PSU) (Onuorah et al., 2014).

Another usefulness of batteries apart from supplying energy to vehicles is that they can also be used to provide electricity for instance, in the inverter. The research on global environmental change made the use of energy more efficient. Also, it makes energy optimization technologies possible in many areas of everyday life. Transportation and automobile industries are some of the major consumers of energy

(USEIA 2023). For this reason, there is a need for more efficient use of vehicle charging stations. The need for more efficient use of vehicle charging stations causes competition because of the improvement of embedded information systems. The benefits of energy conversion are improved accuracy, a decrease in energy losses, and stability (Hassoune et al., 2020).

Overcharging is one of the dangers associated with batteries connected in series. The effects of overcharging are damaging to the battery, causing gassing of the electrolyte and making the battery explode at times. However, the quest to solve the problem of overcharging necessitated the construction of a voltage-controlled multi-charging system. A typical risk with recharging batteries connected in series is the overcharging and undercharging of batteries that set in once there is mismatch among the batteries (Atusiuba, 2020).

The lifespan of a battery is highly influenced by the running cost of inverter systems. This lifespan is determined by the charging temperature, cycles, and other parameters. The quality of the charger determines the performance and life span of a rechargeable battery. But it is painful to know that the inverter inbuilt chargers are not durable and as a result, the batteries may be left in an uncharged state which can shorten the batteries' life span. Therefore, the quest to find a solution to this problem necessitated the development of a voltage-controlled multi-charging system. Also, in industries where there is more than one generator, there must be a means of charging the kick starter batteries when a generator is not powered in order not to cause damage to the battery. Hence, there is also a need for the development of a voltage-controlled multi-charging system. There are battery chargers that fail to charge when the supply voltage is less than 220V from Utility. The voltage-controlled multi-charging system will charge the battery or batteries when the supply voltage is between 160V and 240V.

1.1 *Relevant Literature Review.*

Umahon *et al.* (2018), worked on a 12V automatic battery charger. The main components of the battery charger are a step-down transformer, rectifier circuit, voltage regulator, and cut-off circuit. The transformer was designed to stepdown a 220/230V to 25V. It has a rectifier circuit and an LM 315 regulator which facilitates the battery charging. However, the 12V automatic battery charger cannot perform heavy duty and it can only charge one battery.

Also, Krishnamurthy et al, (2014) worked on a 12V automatic battery charger that has similar components to the one designed by Umahon *et al,* (2018). Their circuits are similar but with differences highlighted. The circuit of Umahon et al. was simpler and cheaper while the other was smarter. The only differences are the use of a liquid crystal display, DC electric motor, and microcontroller. The components were used to make the charger more intelligent and display the output readings. But the charger cannot also handle heavy-duty charging, for instance, it cannot charge a trailer battery and it can only charge one battery.

Fina *et al,* (2016) developed a solar charger. The battery charger was developed to charge a 12V battery using a solar panel. The charging system consists of solar panel, battery, charger, circuit, and monitor. The charger can be used to charge lead acid batteries from 6V to 12V. However, it can only charge one battery at a time. It cannot charge heavy-duty batteries.

Moreover, Odia and Okpor (2017), developed a microcontroller-based automatic battery charger whose voltage can be varied from 6V up to 12V. The charger consists of a 220V/15V step-down transformer, a 7805 IC regulator that ensures 5V DC to power the microcontroller, a current limiting resistor which reduces the current across the light emitting diode (LED). The modes used by the battery charger are constant current, burst, and trickle charging modes. However, the charger cannot charge two or more batteries connected in series.

Furthermore, Hossain *et al.* (2020) design a 24V solar charger. The charging system consists of a photovoltaic cell that changes solar energy into electricity, and a charge controller that prevents the battery from overcharging. However, the charger can only charge two batteries. It cannot charge one battery or more than two batteries. Also, the batteries can only be charged during the day.

2. Methodology

The materials used for the development of the voltage-controlled multi-charging system are as listed in Table 1:

Table 1: List of Materials used for the battery multi-charging system

S/N	List of material
1	Copper wires Size wire gauges 19 and 17
2	E and I laminations
3	10mm and 15mm insulators
4	Relays.
5	Full wave bridge rectifier
6	Arduino IC.
7	Analog to Digital Converter
8	Crystal Oscillator
9	LM7805 voltage regulator
10	Potentiometer
11	Buck converter
12	C1815 NPN transistors
13	Capacitors
14	Soldering led
15	Power cables
16	13A plug
17	Casing
18	LCD screen

2.1 Transformer Design

The transformer was designed using the transformation ratio shown in equation (1) to calculate the number of turns and voltages required.

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} \tag{1}$$

where

N_1: number of turns in the primary winding
N_2: number of turns in the secondary winding
V_1: primary side voltage
V_2: secondary side voltage

The transformation ratio was used to determine the number of turns for primary windings when the voltages are 160V, 180V, 200V, 220V, and 240V. Table 2 shows the corresponding number of turn to various voltages using the transformation ratio.

Table 2: Corresponding number of turn to various primary AC voltages using the transformation ratio

S/N	Voltage (V)	No Turns
1	160	238
2	180	268
3	200	298
4	220	328
5	240	350

The secondary AC voltages were also obtained using equation (1) as shown in Table 3.

Table 3: Corresponding number of turn to various secondary AC voltages using the transformation ratio

S/N	Voltage (V)	No Turns
1	15.4	23
2	27.5	40
3	39.05	57
4	51.15	75

The secondary DC voltages after rectification are shown in Table 4 and they are for one, two, three, and four batteries respectively.

Table 4: Secondary DC voltages after rectification

Number of Battery	One Battery	Two Batteries	Three Batteries	Four Batteries
Secondary DC Voltage (V)	13.4	25.5	37.05	49.15

2.2 Battery Charging Systems Design

The charging aspect of the design was done with the equations (2)-(13).

2.2.1 Battery Charging Equations

Charging Current:

$$I_{charge} = \frac{V_{charger} - V_{battery}}{R_{internal}} \tag{2}$$

where:

$V_{charger}$: $Charger\ output\ voltage\ (V)$
$V_{battery}$: $Battery\ terminal\ voltage\ (V)$
$R_{internal}$: $Internal\ resistance\ of\ the\ battery\ (\Omega)$

State of Charge (SoC) Estimation:

$$SoC = SoC_{initial} + \frac{1}{C_{bat}} \int I_{charge} \tag{3}$$

where:
$SoC_{initial}$: initial state of charge
C_{bat}: Battery capacity(Ah)

Battery Energy Storage Capacity:

$$E = V_{nom} I_{nom} t \tag{4}$$

where:
E: Stored energy (Wh)

I_{nom}: Nominal current (A)
t: Time (h)

V_{nom}: Nominal battery voltage (V)

Charging Power:

$$P = VI \tag{5}$$

where:
P: Power (W), V :Voltage (V), I : Current (A)

2.2.2 DC-DC Converter Equations (for Voltage Control in Multi-Charging)

Buck Converter (Step-Down):

$$V_{out} = D \cdot V_{in} \tag{6}$$

where:
D: Duty cycle (0 < D < 1)

V_{in}: Input voltage (V)

Boost Converter (Step-Up):

$$V_{out} = \frac{V_{in}}{1-D} \tag{7}$$

where D is the duty cycle.

2.2.3 Control System Equations (For Voltage Regulation and Multi-Charging)

Proportional-Integral-Derivative (PID) Controller:

$$V_{control}(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \tag{8}$$

where:
K_p, K_i, K_d : PID controller gains
$e(t)$: Error signal = $V_{set} - V_{actual}$

Transfer Function of a Voltage Controlled Charging System:

$$G(s) = \frac{V_{out}(s)}{V_{in}(s)} \tag{9}$$

2.2.4 Efficiency and Power Loss Equations

Efficiency of Converter:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \tag{10}$$

Power Losses in Switching Circuit:

$$P_{loss} = P_{conduction} + P_{switching} \tag{11}$$

2.2.5 Multi-Battery Charging Equations

Total Current in Parallel Charging (Constant Voltage Mode):

$$I_{total} = I_1 + I_2 + \dots + I_n \tag{12}$$

where I_n is the current through each battery.

Voltage Regulation for Multiple Batteries:

$$V_{charge} = V_{desired} + I_{total} R_{eq} \tag{13}$$

where R_{eq} is the equivalent resistance of the circuit.

2.3 Implementation /choice of simulation software

Proteus is the implementation software chosen. It is good software for electronic design and simulation. With the aid of related information gathered about the voltage-controlled multi-charging system, a circuit was designed using Proteus software. With the aid of Proteus software, a transformer, resistor, rectifier diode, AC source, and switch were selected. The values of the selected components could be changed. After the selection, the components were interconnected to form a circuit as shown in Figure 1.

After designing the circuit using proteus software, the next was simulation. A simulation was done to know how the system would behave practically. After the first simulation, the necessary adjustments were made. The simulation was done using 12V, 24V, and 48V respectively. The voltage regulation was done automatically by the control panel as programmed.

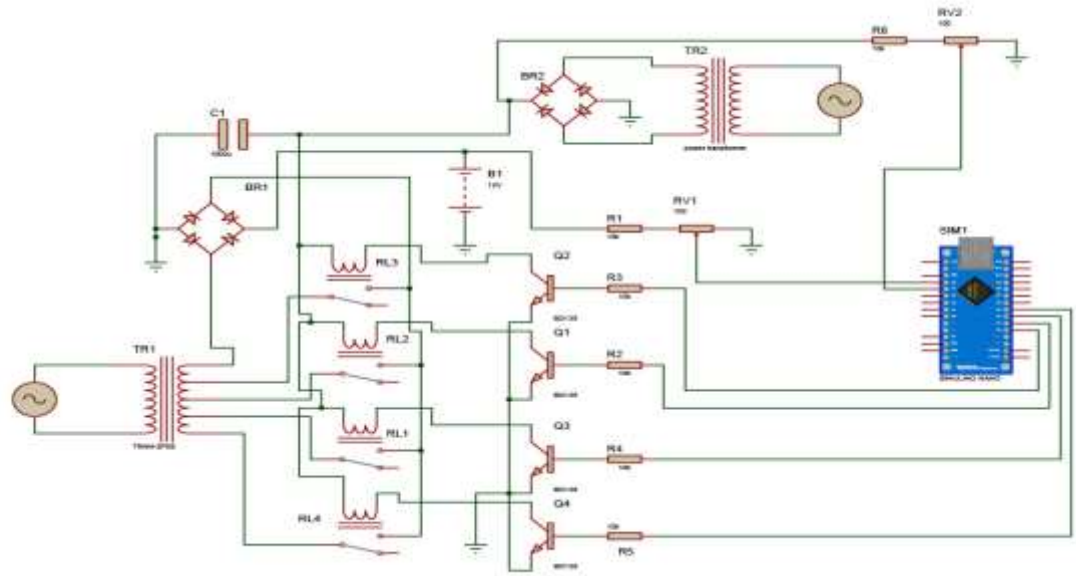

Figure 1: Circuit diagram for the voltage-controlled multi-charging system.

2.4 Construction of the transformer/ connection of other components

i. The length and width of the laminations (a bunch) were measured.
ii. The measurements were used for markings on the 15mm insulator to develop the former.
iii. The winding aspect was done using the copper wires of size wire gauges 19 and 17 for primary and secondary windings respectively and number of turns are shown in Tables 2 and 3. The copper wire of size wire gauge 19 was used for primary winding to achieve 2.5A at the primary side. Whereas, size wire gauge 17 was used for secondary windings because more current is required for the secondary side to charge the battery or batteries. Also, the turns for secondary windings are small compared with primary turns. Size wire gauge 17 will give 5A.
iv. After completion of the winding's aspect, the E and I laminations were properly

2.4.1 Assembly and connection of components.
i. Secondary windings/ AC outputs were connected to a rectifier diode.
ii. The DC outputs were connected to the relays (output relays).
iii. The input AC voltages were connected to the relays (input relays).
iv. Arrangements of the transformer and other components in a casing.
v. All the joints were soldered and properly insulated using insulation tape.
vi. The power cables (2.5mm) were connected.
vii. The switch was connected.
viii. The 13A plug was connected.

2.5 Testing and performance

2.5.1 The transformer testing

i. Short circuit test:
A short circuit test was carried out to ensure that there was no electrical connection between primary and secondary windings. Short circuit test was also carried out to ensure that there was no connection between the soft iron core (laminations) and the windings. There was no short circuit after carrying out the test.

ii. Continuity test:

A continuity test was carried out to ensure that there was no open circuit in both primary and secondary windings. The test showed that there was continuity.
iii. Voltage readings: the secondary voltage of the transformer was read using a digital voltmeter.
iv. Resistance reading: The primary winding had a resistance of 8 ohms, and the secondary windings had 1and 2 ohms for regulators and batteries respectively.

2.5.2 Diode test:

Rectifier diode will only read in one direction. Using a meter, the rectifier diode was tested.
After the assembly and the connection of the components, the voltage-controlled multi-charging system output was tested.

3. Results and Discussion

The charging current, initial and final battery voltages and initial and final battery percentages for the input voltages are shown in Table 5.

Table 5: The charging current, initial and final battery voltages and initial and final battery percentages for the input voltages

AC input (V)	Number of batteries	Battery %	Battery voltage (V)	Battery ampere hour (AH)	DC current (A)	Charging Time
238	No battery	0	0	0	0	0
0	One	79	12.31	90	0	0
222	One	86	14.1	90	3.56	30 minutes
0	Two	67	23.07	75	0	0
220	Two	72	26.5	75	2.51	30minutes
0	Three	89	38.5	75	0	0
208	Three	93	39.0	75	3.34	30minutes
0	Four	87	49.5	75	0	0
220	Four	90	50	75	3.38	30 minutes

when one 12V, 90AH battery was connected. The voltage-controlled multi-charging system displayed a 79% battery percentage, 12.31V battery voltage, and Zero input AC voltage, and indicated that the battery was not charging because it was not powered but when it was powered, it showed the battery now charging with 238V input voltage displayed.

Also, when two 75AH batteries were connected in series. The voltage-controlled multi-charging system displayed that two batteries were connected in series. 67% battery percentage and 23.07V battery voltage were displayed as shown in Figures 2, 3 and 4respectively.

Figure 2: Two batteries in series

Figure 3: 67% battery percentage

Figure 4: Two 12V, 75AH batteries.

Likewise, when three 12V, 75AH batteries were connected in series, the LCD showed the following details;

i. Three batteries connected in series.

ii. 89% battery percentage.

iii.38.5V battery voltage

iv. Not charging

Finally, when four 12V, 75AH batteries were connected, the LCD displayed the following details.

i. Four batteries connected in series.

ii. 87% battery percentage.

iii. 49.5V battery voltage.

Figure 3: Four batteries in series

Figure 4. Four batteries connected in series

The voltage-controlled multi-charging system was designed to charge a maximum number of four batteries (12V each of 65AH, 75Ah, 85AH, 90AH, 100AH, 180AH, 190AH, and 200AH) when they are connected in series.

The minimum battery voltages the multi-charging system can detect and recharge for one, two series, three series, and four series 12V batteries are 10V, 20V, 30V, and 40V respectively.

However, if the minimum voltage is below the stated values, the voltage-controlled multi-charging system will display "BATTERY TYPE NOT FOUND" when powered because the microcontroller did not know which relay to switch.

4. Conclusion

The voltage-controlled multi-charging system was able to detect the number of 12V batteries connected to it and switched the appropriate relays. It can charge rechargeable batteries starting from 65AH battery to 200AH battery with 5A current or less. The voltage-controlled multi-charging system was able to charge one battery, two batteries in series, three batteries in series, and four batteries in series by avoiding overcharging and preventing self-discharge. The voltage-controlled multi-charging system was able to display battery voltage, percentage, and input AC voltage.

Hence the voltage-controlled multi-charging system can be used to charge heavy-duty batteries.

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