Jurnal Scientia
Volume 13, Number 03, 2024, DOI 10.58471/ scientia.v13i03
ESSN 2723-7486 (Online)
https://infor.seaninstitute.org/index.php/pendidikan

An Analysed Design Of Charger Automatic Battery Based On Thyristor

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Article Info
Keywords:
battery,
charger,
automatic,
thyristor

ABSTRACT
Lead-acid batteries (batteries) are one of the most widely used resource components. Starting from small capacity for motorbikes, uninterruptible power supplies (UPS), up to hundreds of amperes for industrial use. When used, this battery needs to be recharged after use to obtain a stable voltage and current. In the charging process there are many ways that can be done, from rectifiers without filters, using filters to automatic ones (can detect the battery voltage level and turn itself off if the battery is fully charged). Automatic Battery Charger (ABC) is an electronic device designed to charge batteries automatically with high efficiency. One of the key components in ABC is the thyristor, a power control semiconductor that allows fast and safe battery charging. This research aims to design and implement ABC using a thyristor as a switch to control battery charging current. The methods used in this research include analyzing system requirements, designing electronic circuit schemes, selecting appropriate components, making and testing prototypes, and evaluating system performance. The designed ABC has features such as battery voltage detection to stop charging when the battery reaches full level, protection against overcurrent, and an LED indicator to display charging status. Test results show that ABC with thyristors can charge batteries with high efficiency and safely. The system is able to charge the battery quickly without producing excess heat which can damage the battery. In addition, this ABC is also equipped with security features that ensure safe and reliable operation. This research contributes to the development of more efficient and environmentally friendly battery charging technology. Implementing ABC with a thyristor as a battery charging current control switch can be an effective and energy-saving solution for automatic battery charging.

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INTRODUCTION

Lead-acid batteries (batteries) are one of the most widely used resource components. Starting from small capacity for motorbikes, uninterruptible power supplies (UPS), up to hundreds of amperes for industrial use. When used, this battery needs to be recharged after use to obtain a stable voltage and current. In the charging process there are many ways that can be done, from rectifiers without filters, using filters to automatic ones (can detect the battery voltage level and turn itself off if the battery is fully charged).

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In this research, an automatic battery charger circuit was designed using*Silicon Controlled Rectifier*(SCR). This component functions as an electronic switch, to switch the current if the battery voltage level is below the setting condition, and turns it off automatically once the battery voltage level has reached full voltage. With this circuit, it is hoped that the lead-acid battery recharging system will not overcharge which can damage the battery elements.

Literature Review

Previous research

Automatic battery chargers with thyristors have been a topic of research and development for decades. Here are several sources that can be used as references to understand the concept and application:

Sheikh, PP, Riyad, T., Tushar, BD, Alam, SS, Shufian, A., & Ruddra, IM(2024). Thyristor-based Rechargeable Battery Charger. Journal of Engineering Research and Reports, 26(3), 104-112.

This article presents the basic design and construction of an automatic battery charger using thyristors. Along with explanations of required components and circuit schematics, this resource is suitable for understanding basic working principles.

*Zhang, 2019,*Analysis, Design, and Implementation of a Single-Stage Multipulse Flexible-Topology Thyristor Rectifier for Battery Charging in Electric Vehicles*IEEE Transactions on Energy Conversion*

This source discusses battery charger circuits that combine multi-stage thyristors for electric vehicle chargers. In this project the main focus is designing an automatic battery charger with SCR and simulating its operation

Udezue, C.U., Eneh, J., Unachukwu, A., Onyemelukwe, I., & Onyeka, H. (2016). 12V Portable Battery Charging System. Pacific Journal of Science and Technology, 17(1), 5-11.

This article focuses on battery charger circuits lead acid for heavy vehicles and the battery suddenly loses power. This charger is used for such purposes.

Lead Acid Battery

Lead acid batteries are widely used for general purposes. This battery consists of two plates dipped in a solution of sulfuric acid (H2SO4) with a specific gravity of around 1.28. The positive plate (anode) is lead-peroxide (PbO2) which is brown and the negative plate (cathode) is lead (Pb) which is gray.

When the cell supplies current to the load (discharging) chemical action forms lead sulphate (PbSO4) on both plates with water formed as an electrolyte. After withdrawing a sufficient amount of energy from the cell, both plates are transformed into the same material (PbSO4) and the specific gravity of the electrolyte (H2SO4) is lower. At this time the cell is said to discharge.

To charge the cell, direct current is applied to the cell in the opposite direction, to the cell that provides the current. This will reverse the chemical process and form lead peroxide (PbO) again2) positive plate and pure lead (Pb) negative plate. At the same time, H2SO4 is formed in the water, keeping the electrolyte (H2SO4) in its original state.

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In a 6 V lead acid battery there are three cells connected in series, while for a 12 volt battery there are 6 cells connected in series. Figure 2.1 shows a section in a lead acid battery.

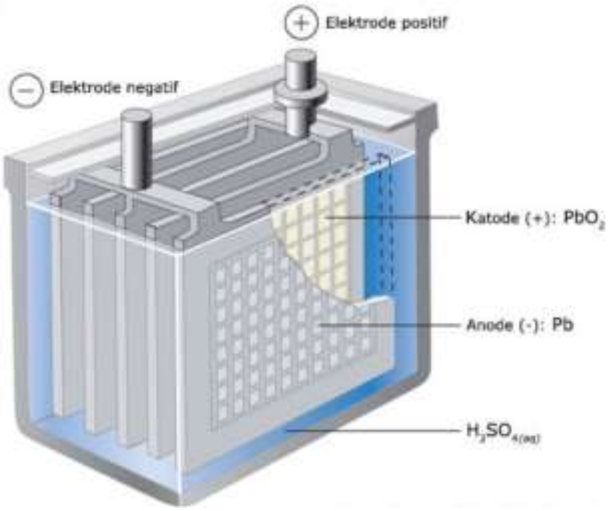

Figure 1. Construction of a lead acid battery

a. Containers. It is a storage house for plates and electrolytes. Made from transparent synthetic material or hard rubber depending on the service required. This container is sealed at the top so that the electrolyte fluid does not spill.
b. Plate. The capacity of a lead acid cell depends on the area of the plate. To increase the effective area of the plates without increasing the cell size, we use multiple thin plates on the cells instead. The positive and negative plates are arranged alternately with an insulator called a separator. The negative plate is connected together with the positive plate. Commercial cells always have an odd number of plates such as 11, 13, 15 or 17. The number of negative plates is always more than the number of positive plates, the outer plate becomes the negative plate. A separate compartment is provided for each cell and each compartment has a large area at the bottom, where sediment from the plates can collect.
c. Separators.To save space and to reduce internal resistance in the cells, the plates are placed close together. To prevent the plates from touching one another when placed, they must be separated by a non-conducting material (such as wood, rubber, etc.) which is called a separator.
d. Electrolyte.The electrolyte is a solution of sulfuric acid (H2SO4) mixed in sufficient portions so that the battery can fully discharge, having a specific gravity of around 1.28. Sometimes we change the water when it evaporates. To ensure normal battery life conditions, only pure water should be used.
e. Cell Cover.Each cell compartment has a cover. Usually made from hard pressed rubber.
f. Close Vent.Each cell has a hole that matches the ventilation cap. This lid has ventilation holes so that the gas formed can escape. This lid can easily be opened to add water or read the hydrometer.

g. Intercellular Connectors.This is a connector made of lead alloy material that connects the cells in series. The positive terminal is marked with a large + sign or in red.
h. Cell Terminal.Each cell has two terminals. Terminals are usually made of tin which does not erode due to the influence of acidic electrolytes.

Characteristics of Lead Acid Cells

Lead acid cells are the most popular cell type for secondary cells. The characteristics are as follows:

1. EMFsE..MF of a cell that is fully charged is about 2 volts. When the cell sends current its emf also decreases by a very small amount. The amount of emf depends on
   a. charging time
   b. electrolyte specific gravity
   c. temperature

   When the cell is charged, the emf is high but gradually decreases, even leading to an open circuit. The emf in the cell will increase with an increase in the specific gravity of the electrolyte. Surrounding temperature also affects emf; will increase its value slightly with increasing temperature.
2. Terminal voltage.When a cell sends current, the terminal voltage is less than its emf because of the voltage drop due to internal resistance in the cell. If the discharge continues, the terminal voltage will drop rapidly for a short time, then slowly or sometimes counterattack rapidly at the end of the discharge.
3. Internal Resistance.Internal resistance in cells is caused by resistance in the plates, active material and electrolyte. The internal resistance of lead-acid cells is very small (a typical value of 0.01Ω) depending on several factors, namely:
   a. The area of the plates decreases with increasing plate area
   b. The distance between the plates decreases as the distance decreases
   c. The specific gravity of H_2SO_4 decreases with increasing specific gravity

   The internal resistance of the lead-acid cell should be as small as possible to reduce internal drop. This is achieved by using a multi-plate construction in a cell.
4. Capacity.The capacity of a cell is the amount of electricity that can be supplied during discharge until the terminal voltage falls to 1.8 volts. It is measured by multiplying the current in amperes and the time in hours. The capacity of a cell is

   Id x TDampere-hour or Ah

   Where: Id = fixed discharge current in amperes

   Td = time in hours during which the cell can supply current until the voltage falls to 1.8 volts

   The capacity of a cell depends on several factors, namely:
   a. Discharge rate, the higher the discharge rate, the less capacity.
   b. Temperature, increases with increasing temperature.
   c. The area of the plates, with increasing plate area.
   d. Specific gravity of electrolyte, increases with specific gravity.

   ηwh is always smaller than ηAh. The watt-hout (energy efficiency) of a lead-acid cell is about 75%.

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Indication of cells that have been fully charged

During the charging process, it is very important that the battery is removed from the charging circuit as soon as the battery is fully charged. Overcharging or undercharging is not desirable and should be avoided. Indications of cells that have fully discharged are as follows:

a. Voltage
b. Specific gravity of the electrolyte
c. Gas coming out
d. Color of plates

1. Voltage. During the charging process, the terminal potential on the cell will increase and this is an indication of the state of charge. A fully discharged lead-acid cell has a terminal voltage of about 2 volts.
2. Specific gravity. During the charging process, the specific gravity of the electrolyte (H2SO4) increases and this is an indication of the state of charge in the cell. The specific gravity of the electrolyte in a fully discharged cell is approximately 1.28. This can be measured with a hydrometer. The following table can be used to determine whether the cell has fully discharged.

Table 1. Specific Gravity Of Electrolytes

Specific Gravity of H2SO4	Charge State
1.13	Discharge
1.19	25% Charge
1.22	50% Charge
1.25	75% Charge
1.28	100% Charge

3. Emitted Gas.When the discharge cell is full, the charging current starts to electrolyze the water. The result is hydrogen coming out at the cathode and oxygen at the anode; This process is known as gassing. Gas coming out of both plates indicates that the charging current is not working well and must be stopped.
4. Color of Plates.Visually seeing the color of the plates on the lead acid cell can indicate the charge condition. When the discharge cell is full, the positive plate will be converted into PbO2 (brown) and the negative plate will become spongy lead (gray).

Charging Lead Acid Batteries

To ensure normal battery life, it must be in good condition when charging. The following points must be considered when charging the battery:

1. The charging source must be DC current. If there is AC voltage, it must be rectified before being applied to the battery.
2. During charging, the polarity must be correct. Correct polarity if the positive DC terminal of the charging source is connected to the positive terminal of the battery.
3. The charge voltage must be greater than the emf of the battery to be charged. The charge voltage is around 2.5 volts per cell. For example, if a battery being charged has 6 cells, a voltage of around 15 volts must be applied.

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Charging Rate

What is the actual charge current? The answer is as large as possible as long as the battery is capable without producing excessive heat and causing gas to escape. Providing too much charging current will produce excessive heat. This will result in the plates being damaged and a short circuit occurring. Also, electrolyte water will be lost due to the electrolysis process and evaporate, and will increase the concentration of sulfuric acid. Strong acids can damage the separator resulting in total damage to the battery. The electrolyte temperature should not exceed 40°C. We also have to pay attention to the charging current recommended by the manufacturer. If not available, we can use the following rules:

1. The charging current is 1 A for each positive plate. So if a cell contains 13 plates, six of them are positive. The charging current for this battery must be 6 amperes.
2. The charge rate for a full charge can be achieved in 8 hours. So a 100 Ah battery must be charged at a rate of 100/8 = 12.5 A. This will guarantee the maximum battery life.
3. The charge current should not make the battery temperature exceed 40°C, and the release of gases that can cause damage should be avoided. Instead of a constant charge current, in practice it is usual to charge the battery at a gradual rate. The current is high at first but gradually decreases when the battery becomes full.
4. After charging, water must be added to compensate for water lost by gas and evaporation. The electrolyte level should be 1 cm above the plates. If water is not added, the high concentration of H_2SO_4 acid can damage the battery, which can cause permanent damage to the battery.

Thyristors

Thyristors are one of the most important types of power semiconductor devices and have been used extensively in power electronic circuits. Thyristors are usually used as switches/bistable, operating between non-conducting to conducting states. In many applications, thyristors can be assumed to be ideal switches, but in practice thyristors have certain limitations and characteristics.

Thyristor is a 4 layer semiconductor device with a pnpn structure with three pn-junctions. This device has three terminals: anode, cathode, and gate. Figure 4-1 shows the thyristor symbol and a diagram of three pn-junctions. Thyristors are made through a diffusion process. When the anode voltage is made more positive than the cathode voltage, the junction J1 and J3 are in a forward bias condition. Connection J2 is in reverse bias condition, and a small leakage current will flow between the anode and the cathode. In this condition the thyristor is said to be in forward blocking condition or off-state condition, and the leakage current is known as off-state ID current. If the anode to cathode voltage of VAK is increased to a certain voltage, junction J2 will leak. The anode current must be greater than a value called latching current IL, in order to obtain a sufficient flow of free charge carriers through the connections; otherwise the device will return to blocking condition when the anode to cathode voltage decreases. Latching current IL is the minimum anode current required to keep the thyristor in the on condition once a thyristor has been turned on

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and the gate signal is removed. The general vi characteristics of a thyristor are given in figure 4-2b.

When in the on condition, the thyristor will act like a diode that cannot be controlled. This device will continue to be in the on condition because there is no depletion layer at the J2 connection because the charge carriers are moving freely. However, if the anode forward current is below a level called holding current IH, a depletion region will form around J2 due to the reduction in the number of free charge carriers and the thyristor will be in a blocking state. Holding current occurs on the order of milliamperes and is smaller than latching current IL, IH > IL. Holding current IH is the minimum anode current to maintain the thyristor in condition

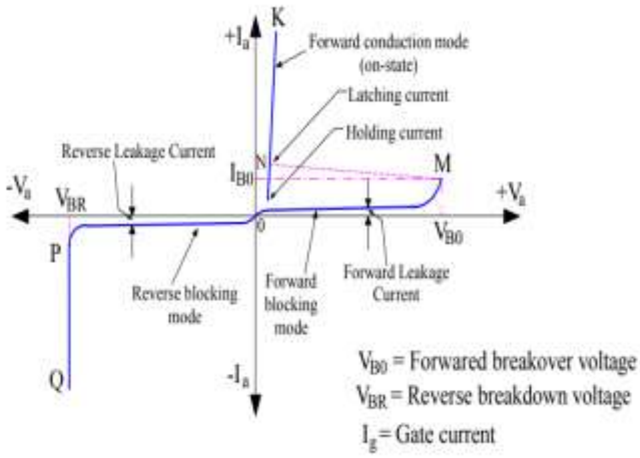

Figure 2. Characteristics of VI thyristor

METHOD

The design begins with a block diagram as in Figure 3.

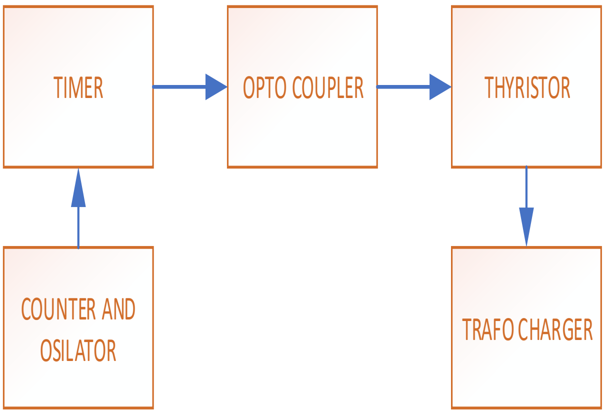

Figure 3. Block diagram of the tool

Jurnal Scientia
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https://infor.seaninstitute.org/index.php/pendidikan

From the block diagram above it can be seen that the system consists of a counter and oscillator formed from IC CD 4066, then a timer from IC 555, optocoupler MOC 3041 and thyristor 60T12DBW and then fed to the charger transformer. The way this tool works is as follows: the 14-stage ripple counter and IC 4060 oscillator produce pulses, which are the clock signals of the circuit. This clock signal is fed to the 555 timer which reduces the length of the active output. With the switch we can select long or short pulse output. The output of the 555 timer triggers the MOC 3041 zero crossing triac optoisolator driver via a transistor. This gives the charging transformer a soft start via the triac and snubber circuit. The snubber circuit functions as thyristor protection from reverse current which can damage the thyristor when it is off. A small power supply is required for the circuit and consists of a secondary 15V 0.5A transformer T1, a bridge rectifier, a regulator and two capacitors. This small power circuit functions to supply voltage to the IC 555 so that the pulse does not change if the main circuit supplies large pulse swings to charge a large capacity battery.

This circuit can work very well not only for new batteries, but is also very effective for charging batteries that have not been used for a long time. Where a battery has not been used for a long time, there will be a buildup of sulfate on the battery poles. With this charger circuit, the desulfation process can be carried out easily. Because the charging system uses a series of pulses which can destroy the sulfate buildup on the battery poles.

The goal is to get the cell voltage high enough for the sulfate to dissolve without boiling or melting the battery. This is achieved by applying a higher voltage for a shorter period and letting the battery rest for a while. The short pulse range is about 0.5 seconds at 3 seconds and the long pulse range is 1.4 seconds at 2 seconds. This time may vary depending on component tolerances. Use a TRIAC with type 60T12DBW 60A, 600V to ensure that the thyristor is able to supply a large current for a large battery capacity.
A picture of the complete battery charger circuit is as shown in Figure 4.

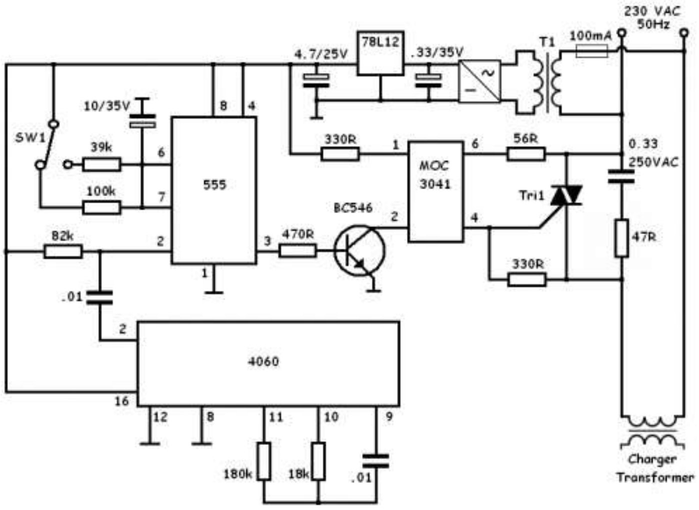

Figure 4. Image of complete battery charger circuit

Flow chart of how the system works:

1. Start
2. Check Input Voltage

Is input voltage available?

a. No: Wait
b. Yes: Continue

3. Transformer (T1) Steps Down AC Voltage
   The 230V AC voltage is reduced to a lower AC voltage.
4. Rectifier Converts AC to DC
   AC voltage is converted to DC voltage.
5. 78L12 Voltage Regulator
   Stabilizes DC voltage to 12V.
6. IC 555 Generates PWM Signals
   IC 555 is configured in astable mode.
   Generates PWM signals based on R and C configuration.
7. PWM Signal Controls BC546
   The BC546 transistor is activated or deactivated based on the PWM signal.
8. BC546 Enables MOC3041
   The LED in the MOC3041 optocoupler lights up.
9. MOC3041 Enable Triac (Tri1)
   The triac is activated, allowing current to flow to the battery.
10. Battery Charging Begins
11. IC 4060 Sets Charging Time
    IC 4060 calculates time based on R and C configuration.
12. Is Charging Time Complete?
    No: Go back to Step 11
    Yes: Turn off the Triac
13. Battery Charging Completed
14. End

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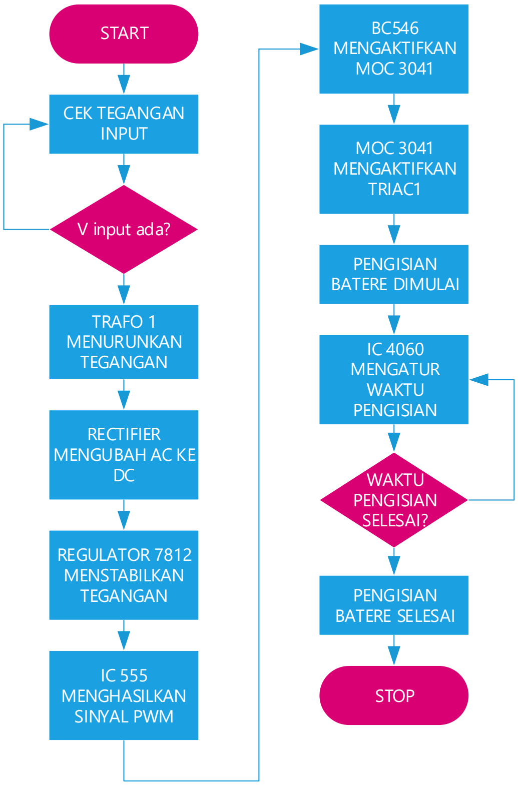

Figure 5. Flow chart of how the system works

ANALYSIS AND RESULT

Result Circuit.

To see the dynamic behaviour of an electrical circuit, it is necessary to create a transfer function for the circuit. And it also functions to determine whether a circuit is stable or not. This function connects the input signal (excitation) with the output signal (response) of the circuit in the frequency domain. To see the transfer function of this circuit, we have to break the circuit into several parts. IC 555 in astable mode produces a square wave signal which we can represent as an RC system. The oscillation frequency (f) of the IC 555 in astable mode can be calculated by the formula:

$$f = \frac{1.44}{(R_1 + 2R_2)C_1} \quad \text{....(2.4)}$$

Where :
R1 is 39 kΩ
2R2 is 10 kΩ
C1 is 10 μF

However, for the transfer function, we need to convert this to the s domain. In the s domain, the oscillator can be represented as a low-pass filter with a cut-off frequency (ωc) related to the charge and discharge times.

$$H(s) = \frac{\omega_c}{s + \omega_c} \quad \text{.....(2.5)}$$

Where ωc is the cut-off angular frequency related to the oscillation frequency f:

$$\omega_c = 2\pi f = 2\pi \frac{1,44}{(R_1 + 2R_2)C_1}$$

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https://infor.seaninstitute.org/index.php/pendidikan

Transfer Function For IC 4060 (Counter/Timer)

IC 4060 functions as a timer/counter. The transfer function of a counter is not as clear as an oscillator, but we can represent it as a delay or integrator. If we consider IC 4060 as a delay:

$$H_{4060}(s)=e^{-sT}$$

Where T is the delay time set by the resistor (180kΩ) and capacitor (0.01μF):

$$T=2.22\ x\ R\ x\ C=2.22\ x\ 180\ k\Omega\ x\ 0.01\ \mu F$$

We assume that the output of the IC 555 is the input for the IC 4060, so the transfer function total Htotal(s) is the product of two transfer functions:

$$H_{total}(s)=H_{555}(s)\,x\,H_{4060}(s)$$

By plugging in the values above, we can construct the final transfer function.

Calculating Values

1. IC 555 Oscillation Frequency

   $f=\frac{1.44}{(39K+2+10K)x10\mu F}=\frac{1.44}{59K\ x\ 10\mu F}=\frac{1.44}{0.59}\approx 2.44\ Hz$

   $\omega_c=2\pi\ x\ 2.44\approx 15.34\ rad/s$

   $H_{555}(s)=\frac{15.34}{s+15.34}$

2. Delay IC 4060

   $T=2.2\ x\ 180K\ x\ 0.01\mu F=2.2\ x\ 1.8\approx 3.96$ s

   $H_{4060}(s)=e^{-3.96s}$

Total Transfer Function

$$H_{total}(s)=\frac{15.34\ x\ e^{-3.96s}}{s+15.34}$$

So, the transfer function of this battery charger circuit is:

$$H_{total}(s)=\frac{15.34\ x\ e^{-3.96s}}{s+15.34}$$

This transfer function describes how the system responds to input to produce output in domain s.

To graph the transfer function of the system we have defined, we need to observe the frequency response and time response of the transfer function $H_{total}(s)$. The total transfer function of the circuit is shown in equation (2.16). However, for plotting purposes, we can ignore the exponential factor e–3.96s because it only shifts the phase but does not affect the magnitude of the frequency response.

Simplified Transfer Function

$$H(s)=\frac{15.34}{s+15.34}\ldots(2.17)$$

We will depict two graphs:

1. Bode Plot (Magnitude and Phase)to analyze the frequency response.
2. Step Responseto analyze the response time.

Bode Plot

The bode plot shows how the magnitude and phase of the system change with frequency. For the transfer function equation (2.17) we can describe this plot using a logarithmic function.

Step Response

Step response shows how the system responds to step input (input that suddenly changes from 0 to 1). This is important to see how the system responds in real time.

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Expected Output

1. Bode Plot
   a. The magnitude will show a decrease with increasing frequency, indicating low-pass filter characteristics.
   b. The phase will show a decrease consistent with the low-pass filter.
2. Step Response
   The step response will show how the system reaches steady state after the step input is applied.

The following is a MATLAB program to describe the Bode plot and step response of the transfer function for press (2.17)

```
% Define Transfer Function
num = 15.34;
den = [1, 15.34];

% Create Transfer Function
system = tf(num, den);

% Plot Bode
figure;
bode(system);
title('Bode Plot of H(s) = 15.34 / (s + 15.34)');
grid on;

% Step Response
figure;
steps(system);
title('Step Response of H(s) = 15.34 / (s + 15.34)');
grid on;
```

Run the program above in MATLAB then we will get a graph like the one below.

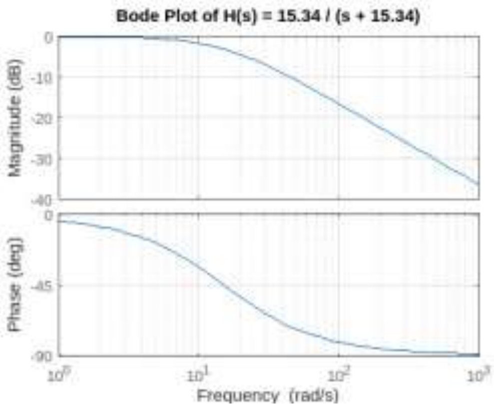

Figure 6. Bode Plot graph of the system

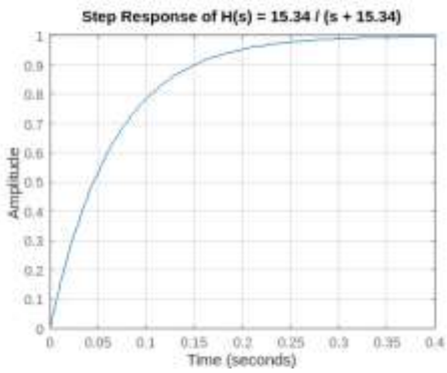

Figure 7. Step Response Graph of the system

The Bode plot graph (figure 4.1) consists of two main parts: a magnitude plot (dB) and a phase plot (degrees) against frequency (rad/s). The following is an explanation of the two graphs:

Magnitude Plot (dB)

1. X-axis (Frequency in rad/s)
   Shows frequency in radians per second on a logarithmic scale.
2. Y-axis (Magnitude in dB)
   Shows the response magnitude of the system in decibels (dB).
3. Characteristics:
   a. At low frequencies, the magnitude of the response is almost constant.
   b. As the frequency increases, the magnitude begins to decrease with a slope of about -20 dB/decade. This is a characteristic of a low-pass filter.
   c. The point at which the magnitude begins to decrease significantly is known as the cut-off frequency. In this case, the cut-off frequency occurs around 15.34 rad/s

Phase Plot (degrees)

1. X-axis (Frequency in rad/s)
   Shows frequency in radians per second on a logarithmic scale.
2. Y-axis (Phase in degrees)
   Shows the phase shift of the system response in degrees.
3. Characteristics
   a. At low frequencies, the phase starts from about 0 degrees.
   b. As the frequency increases, the phase starts to fall.
   c. The phase shift reaches -45 degrees at the cut-off frequency.
   d. Finally, the phase approaches -90 degrees at high frequencies.

Analysis of Battery Charging Calculations

After measuring the voltage and current and calculating the average power produced by the battery charging current during the test, the author can then analyze the time (t) in one day for charging a 12 V 7.2 Ah (86.4 Wh) battery. Here's the calculation:

a. Charging Voltage: 13.8 volts
b. Charging Current: 2.5 A
c. Battery Capacity: 12 V 7.2 Ah
d. Battery Power: 12 x 40 = 86.4 watts

So to fully charge the battery it takes:

$$t = .7.2\ A - 2.5\ A. = 2.88\ jam$$

After ≈ 3 hours of charging the battery, the battery voltage will be 13.8 V≅14V. Initially start charging the battery with an initial voltage of 9V and a constant current of 2.5A. So it can be seen that charging the battery is around 3 hours when fully charged.

Battery charging data is in table 2.

Table 2. Battery Charging Data

No	Measurement Time	Battery Voltage (V)
1	09:00 WIB	9.3
2	09:15 WIB	9.7
3	09:30 WIB	10.2
4	09:45 WIB	10.5

Jurnal Scientia
Volume 13, Number 03, 2024, DOI 10.58471/ scientia.v13i03
ESSN 2723-7486 (Online)
https://infor.seaninstitute.org/index.php/pendidikan

No	Measurement Time	Battery Voltage (V)
5	10:00 WIB	11.1
6	10:15 pm	11.3
7	10:30 WIB	11.5
8	10:45 WIB	11.7
9	11:00 WIB	12.3
10	11:15 pm	12.8
11	11:30 WIB	13.3
12	11:45 WIB	13.8

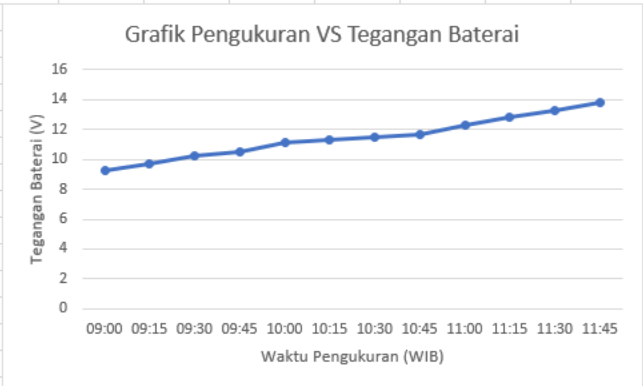

Figure 8. Battery Charging Graph

The following is an analysis of the graph:

1. Measurement Time
   Measurements were carried out from 09:00 WIB to 11:45 WIB, with measurement intervals every 15 minutes.
2. Battery Voltage
   The battery voltage increases gradually from around 10 V at 09:00 WIB to around 14.5 V at 11:45 WIB.
3. The pattern
   The pattern of increase in battery voltage looks quite consistent and linear over the measurement time period. This indicates that the battery is charging at a fairly steady rate.

Analysis

1. Filling Consistency
   A consistent increase indicates that the charging source (e.g. solar panel or charger) is functioning properly and providing stable power to charge the battery.
2. Battery Health
   A battery voltage that rises steadily also shows that the battery is in healthy condition and is able to store power well.

3. Charging Efficiency
   Judging from the rate of voltage rise, battery charging appears to be efficient without any significant voltage spikes or drops, which could indicate a problem in the charging process.
4. Potential for Overcharging
   Although there is no indication of overcharging in this graph, it is important to ensure that the voltage does not exceed the safe limits of the battery to avoid damage.

Overall, this graph shows that the battery charging process is running well and efficiently. If additional data is available regarding battery capacity or charging system specifications, more detailed analysis can be performed to ensure optimal performance of the charging system.

CONCLUSION

The conclusions from this research are as follows: This circuit works by converting 230V AC voltage from a power source into a stable DC voltage and regulating battery charging through switching control and timing. The battery charger circuit that has been analyzed is effective and efficient for controlled battery charging, with low-pass filter characteristics that are clear from the Bode plot analysis. This transfer function shows that the system acts as a low-pass filter with a cut-off frequency of around 15.34 rad/s. The bode plot shows that at low frequencies, the system has high gain and phase close to 0 degrees, while at high frequencies, gain decreases and phase approaches -90 degrees. This indicates that the system allows low frequencies to pass with little attenuation and phase shift, while high frequencies are suppressed with significant attenuation and large phase shifts. Step response indicates that the system reaches a steady state after receiving a step input, which means the system is stable and responsive to changes in input. This circuit can be used to charge batteries in a controlled and efficient manner, preventing overcharging through accurate timing. Meanwhile, suggestions for further development of this research are: Implement additional protection for further safety, such as protection against overcurrent and overvoltage. Integrate micro controllers or IoT systems for remote monitoring and control. Consider developing a more efficient version of this circuit for applications that require fast charging.

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