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Design of Sepic Converter as Battery Charger with Artificial Neural Network - PID Method for Load Variation

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ABSTRACT

More adaptable charging methods are required as a result of the growing variety of electronic gadgets that use rechargeable batteries brought about by technological advancements. When trying to charge different battery types with a same charger, differences in battery parameters, like voltage and capacity, present difficulties. This study suggests an adaptive charging system that can charge several battery types using a single port connection in order to solve this problem. To transform a 24 V DC input into an output voltage appropriate for the particular battery requirements, the system uses a SEPIC converter whose duty cycle is controlled by a microprocessor. The duty cycle rises until a specific current level is measured when a battery is attached and the limit switch is activated. The measured voltage and current data are then processed by an Artificial Neural Network (ANN) algorithm to determine the battery type and set the appropriate charging voltage setpoint. After that, a PID controller is used to keep the charging conditions steady. LiFePO4 (12.8 V, setpoint 14.6 V), Li-ion (14.8 V, setpoint 16.8 V), and Lead Acid (12 V, setpoint 14.4 V) batteries were used to test the system. The system successfully charged all three battery types with an average error of 0.174%, according to experimental findings, demonstrating precise and reliable control performance.

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1. INTRODUCTION

Battery Battery charging is the process of charging a battery until it reaches the voltage specified in the battery's datasheet. Generally, the battery charging process requires an external power source, but in this study, a 24 VDC power supply was used [1].

The increasingly diverse technology of rechargeable electronic devices requires flexible charging systems. Batteries used in electronic devices have limited storage capacity; therefore, if their capacity decreases, they must be recharged immediately for the device to operate properly. Typically, each battery has a dedicated charger tailored to its characteristics and specifications. However, a problem arises when a single charger must be used for multiple devices with different battery specifications. This can pose a risk of overcharging, potentially affecting battery lifespan [5].

Given these issues, a flexible battery charging system that can operate at various battery voltages is needed [6]. Because conventional battery charging systems are designed for a single type of battery, they usually do not detect the type of battery being charged. Therefore, this adaptive battery charging system uses an Artificial Neural Network (ANN) technique to determine the battery type and PID (Proportional-Integral-Derivative) control to perform the charging process [4].

The first steps in this adaptive charging system are battery type identification, charging setpoint voltage determination, and charging process stabilization. In this study, the input voltage from a 24 V DC power source was converted to an output voltage that satisfies the requirements of the battery using a SEPIC Converter (Single-Ended Primary Inductor Converter) acting as a DC-DC converter. Because it can adjust the voltage as needed, the SEPIC Converter has an advantage over buck or boost converters [7].

Constant Voltage (CV) is the charging technique that is employed because of its straightforward circuitry and controllability [8]. The charging voltage can be stabilized in accordance with the setpoint voltage established by the ANN through the use of PID control with a feedback mechanism [9] to maintain a consistent output voltage.

2. RESEARCH METHOD

A sepic converter with an artificial neural network and proportional, integral, and derivative control makes up this research system, which can charge a variety of battery types with a single converter output. In this study, three distinct battery types with differing capacities and voltages were used: LifePO4, Li-ion, and lead acid batteries. Below is a block schematic of the system as it appears in **Figure 1**. Several charging voltage levels are available in this adaptive charging system, depending on the load requirements as determined by sensor inputs.

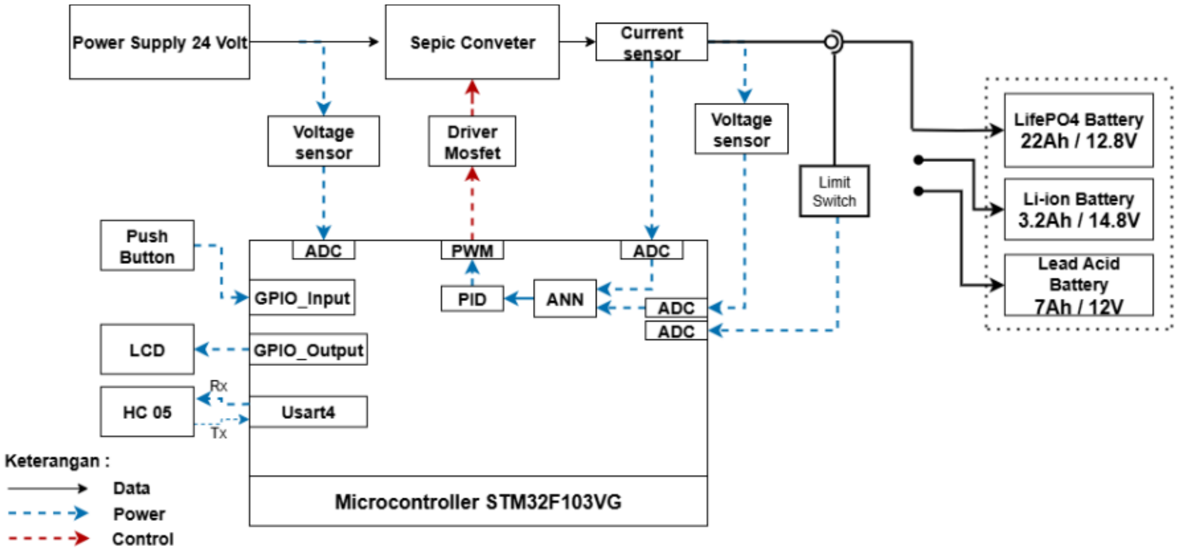


Figure 1. Block diagram system

According to **Figure 1**, the system operates using a 24 V DC source, which delivers power to the SEPIC converter before being directed to the battery load. During the charging process of a LiFePO4 battery, the voltage and current values are monitored through sensor measurements. The Artificial Neural Network (ANN) then identifies the battery type and provides the appropriate setpoint. Subsequently, the PID controller adjusts the duty cycle through the switching driver to regulate the converter operation, ensuring the output voltage matches the required charging setpoint.

2.1. Design of Sepic Converter

The evolution of the buck-boost topology led to the creation of the SEPIC (Single-Ended Primary Inductor Converter) kind of DC-DC converter. The output voltage can be greater or lower than the input voltage by using this converter to step up or step down the voltage. Because SEPIC keeps the output voltage polarity positive, unlike traditional buck-boost, it is safer and more adaptable for usage in a variety of applications, including power supplies with variable voltage sources and battery charging systems [12]. A 24 V DC source input voltage was used in this investigation. Figure 2 shows the sepic converter's basic circuit.

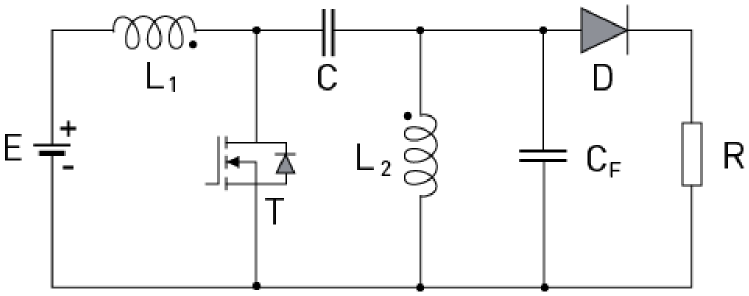


Figure 2. Sepic Converter Circuit

$$V_o = \frac{V_o}{V_{in} + V_o} \tag{1}$$

$$\Delta IL = 20\%\ x\ Iin \tag{2}$$

$$L = \frac{Vin\ x\ D}{\Delta IL\ x\ F} \tag{3}$$

$$\Delta Vo = 1\%\ x\ Vo \tag{4}$$

$$R = \frac{Vo}{Io} \tag{5}$$

$$C = \left(\frac{Vo\ x\ D}{R\ x\ \Delta Vo\ x\ F}\right) \tag{6}$$

Note :

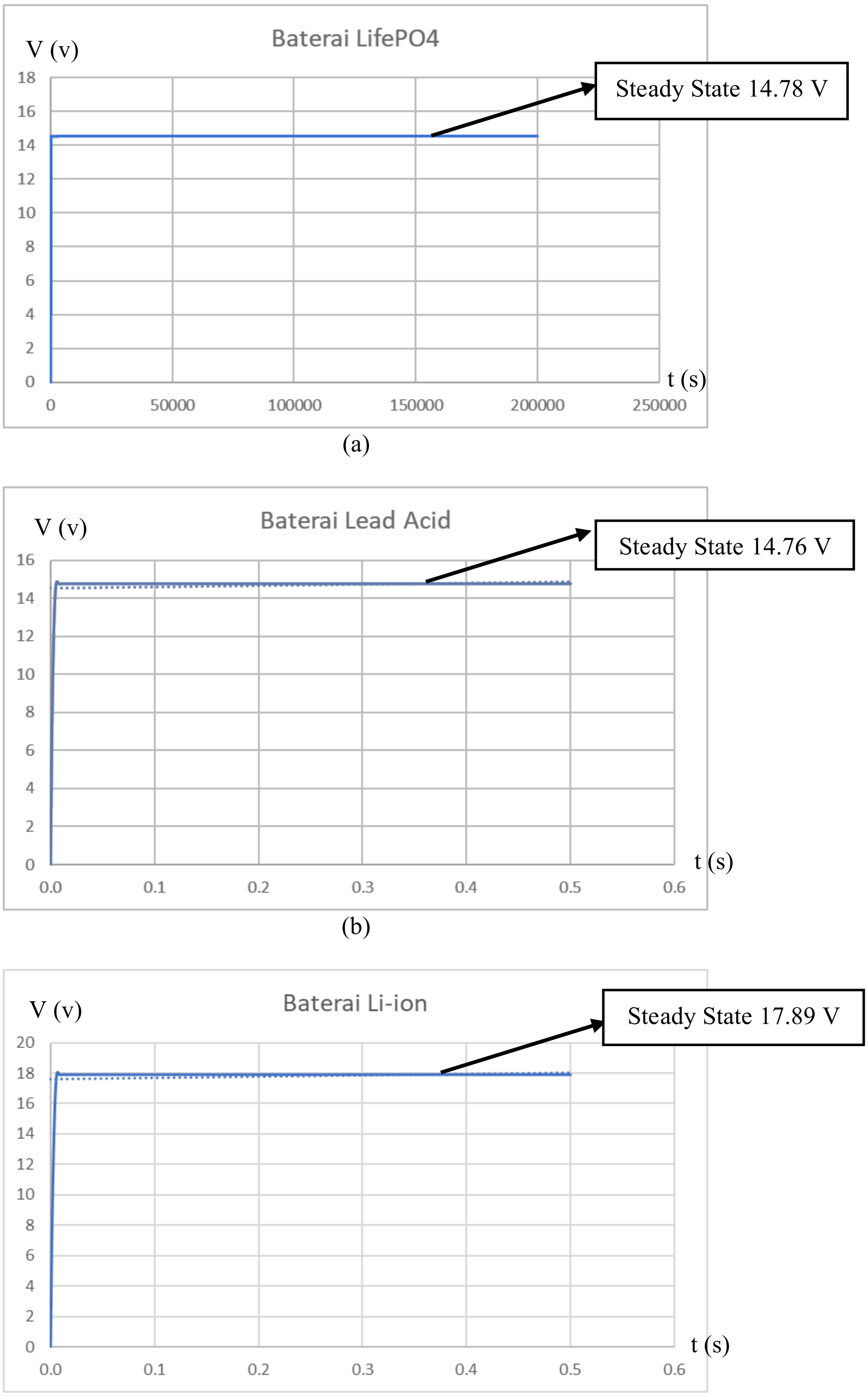
Vin	: Input Voltage	(V)
Vo	: Output Voltage	(V)
Iin	: Input Current	(A)
R	: Resistance Output	(Ω)
L	: Inductance Value	(uH)
C	: Capasitance Value	(uF)
D	: Duty Cycle	
F	: Frequency	(Hz)
ΔVo	: Forward Reverse	(V)
ΔiL	: Ripple Current	(A)

Table 1. Parameters design of Sepic Converter

Parameters	**Symbol**	**Value**	**Units**
Input Voltage	Vin	24	V
Output Voltage	Vo	16.8	V
Frequency	F	40	kHz
Inductor	L	256	uH
Capasitor	C	2200	uF
Ripple Current	ΔiL	0.88	A

The Sepic converter's parameter design is shown in **Table 1**, after which a PowerSIM simulation circuit is created. After that, use equation 1 to make calculations. Because the battery voltage requirements of 14.6 V, 14.4 V, and 16.8 V have been adjusted, there are three duty cycle calculations. The duty cycle of each load is 30.7%, 40.4%, and 47.19% if Vin is taken to be stable at 24 V based on the open loop simulation.

The open-loop response of the Sepic converter is tested using this simulation. It is evident from **Figure 3**'s open-loop Sepic converter simulation results that there is steady-state inaccuracy and voltage overshoot. A straight line indicates the output voltage, whereas a dotted line indicates the setpoint value. **Table 2** displays more specific information.



(a)

(b)

(c)

Figure 3. Simulation curve of sepic converter with load variation : (a) LifePO4 with duty cycle 30.7%, (b) Lead Acid with duty cycle 40.4% and (c) Li – ion with duty cycle 47.19%

The comprehensive simulation results for battery improvements based on the open-loop sepic converter simulation's findings are shown in **Table 2**. displays the thorough simulation results for battery modifications based on the findings of the open-loop sepic converter simulation. The three duty cycle variations have been adjusted to the setpoints of the three battery types: Li-ion, Lead Acid, and LifePO4.

Table 2. Sepic Converter simulation open loop result

No	**Type of Battery**	**Duty Cycle (%)**	**Vo theory (Volt)**	**Vo simulation (Volt)**	**Error Vo (%)**
1	LifePO4	30.7	14.6	14.78	1.21
2	Lead Acid	40.4	14.4	14.76	2.43
3	Li - ion	47.19	16.8	17.89	6.09
Averages Error (%)					3.92

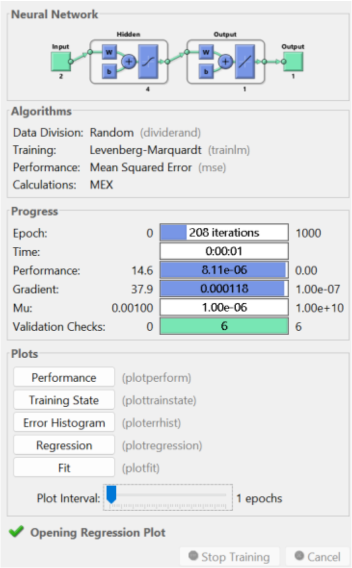
Based on the statistics in **Table 2**, the average open-loop voltage output error for the three batteries is 3.92%. The Li-ion battery type has the highest error value, measuring 16.8 volts with an error value of 6.09%. Control is therefore necessary for the sepic converter to reach the battery's setpoint in order to keep the output voltage of the converter at the setpoint value.

2.2. Design of ANN-PID Controller

The control strategy in this adaptive charging study combines ANN and PID controllers. The PID controller uses an artificial neural network (ANN) to compute the charging setpoint voltage value. It is noteworthy that artificial neural networks can tackle problems of different types and interpretations [10].

LifePO4 had a charging voltage of 14.6 V, Lead Acid had a charging voltage of 14.4 V, and Li-ion had a charging voltage of 16.8 V. These three types of battery loads provided the training data for the charging voltage and charging current characteristics. In order to modify the output voltage to match the detected battery voltage, which is 14.6 V, 14.4 V, and 16.8 V, an ANN target—that is, the setpoint for each battery—is necessary because these values change.

This study uses a particular kind of ANN algorithm known as feed forward backpropagation. An ANN with two inputs (voltage and current), a first hidden layer (four neurons), and an output layer (one neuron) with a 208-iteration epoch is depicted in block diagram form in **Figure 4**. Logsig-tansig is the activation function that is employed. In this study, the back-propagation ANN model was trained using the Levenberg-Marquardt learning strategy. **Figure 5's** learning objectives produced a regression value of 0.99998.



Data Division: Random (dividerand)
Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Calculations: MEX

Epoch:	0	208 iterations	1000
Time:		0:00:01	
Performance:	14.6	8.11e-06	0.00
Gradient:	37.9	0.000118	1.00e-07
Mu:	0.00100	1.00e-06	1.00e+10
Validation Checks:	0	6	6

Plot Interval: 1 epochs

✓ Opening Regression Plot

Figure 4. NNTool training

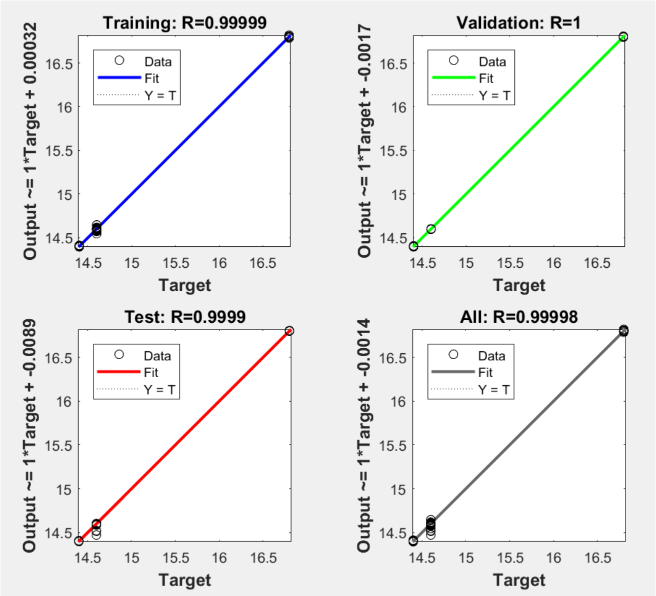


Figure 5. Regresi value NNTool

The input layer, the hidden layer, and the output layer are the three primary parts of the backpropagation algorithm's architecture. Without doing any calculations, the input layer's sole function is to receive the input signal and forward it to the hidden layer. Weight and bias calculations take place in the output and hidden layers. A particular activation function is used to determine the output of both layers [4]. Tansig is the activation function utilized in the layer 1 output of this ANN architecture.

$$Tansig\ (n) = \frac{2}{(1-exp^{=2n})} - 1 \tag{4}$$

After obtaining the setpoint values from different types of batteries, the PID controller will next execute the ANN output for the constant voltage charging process. By calculating the setpoint error value in relation to the feedback value, the PID controller unifies three control systems: proportional control (P), integral control (I), and derivative control (D). **Figure 6** shows the block diagram for the PID controller.

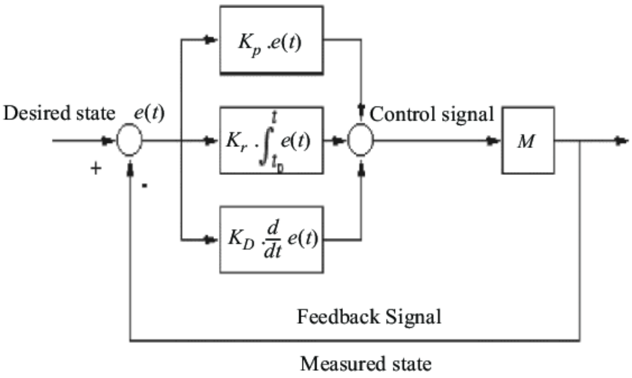


Figure 6. Block diagram of a system with PID controller [11]

Kp, ki, and kd design values for PID control.

$$Kp = 0.48102 \tag{5}$$
$$Ki = 21.2621 \tag{6}$$
$$Kd = 0.0113 \tag{7}$$

Note :

Kp	: proportional gain
Ki	: integral gain

Kd : derivative gain

3. RESULTS AND DISCUSSION

PowerSimulation software was used to design the simulation circuit for variable battery charging that is shown in **Figure 7**. The three battery types utilized in this circuit are Li-ion batteries with a charging voltage of 14.4 V, LifePO4 batteries with a setpoint voltage of 14.6 V, and Li-ion batteries with a setpoint voltage of 16.8 V. It consists of a circuit for a Sepic converter that is ANN-PID driven.

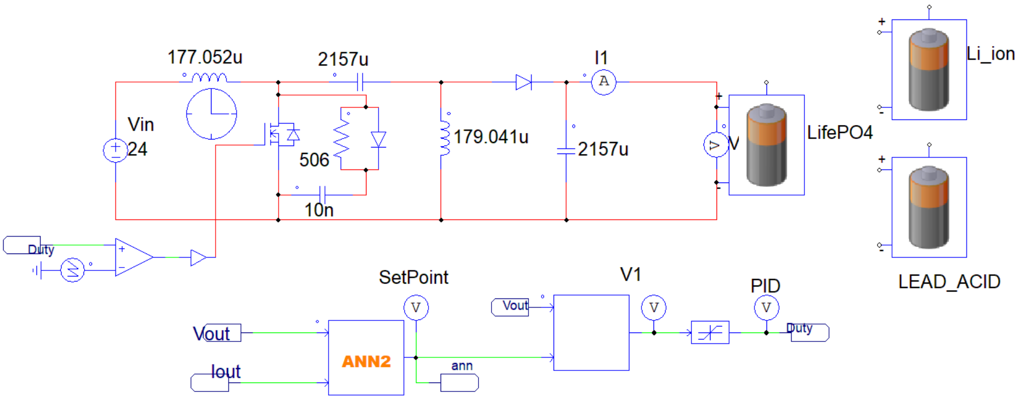
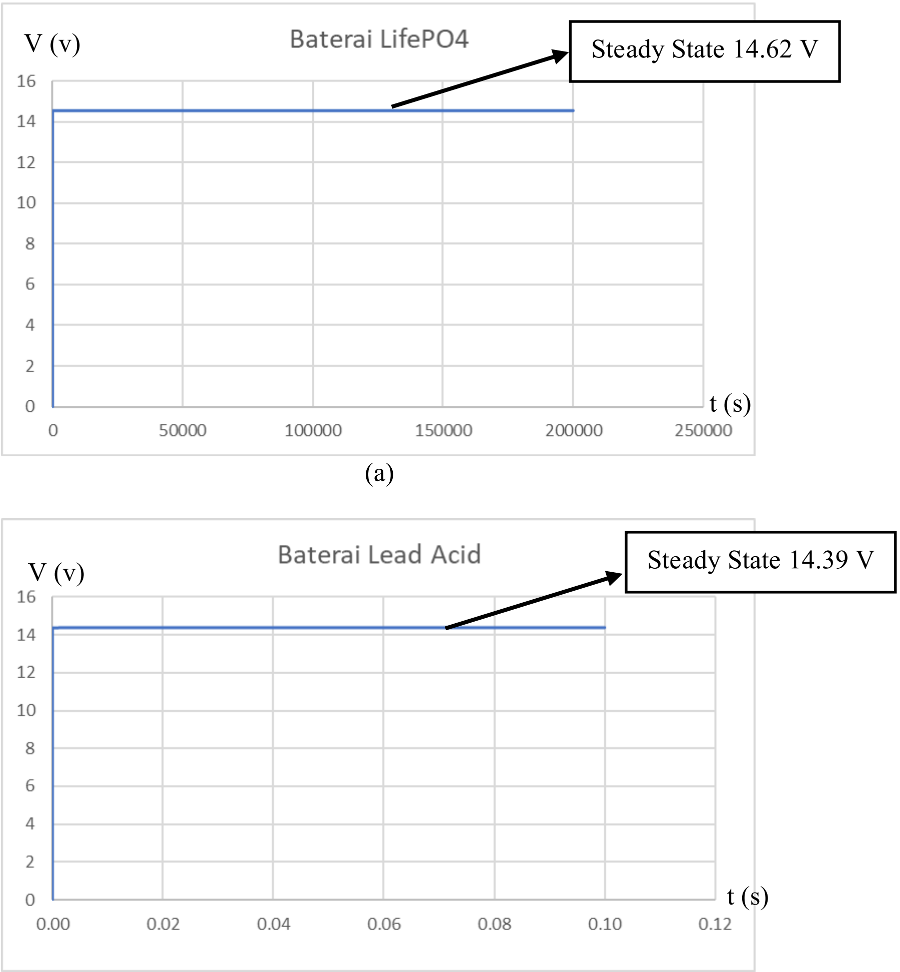
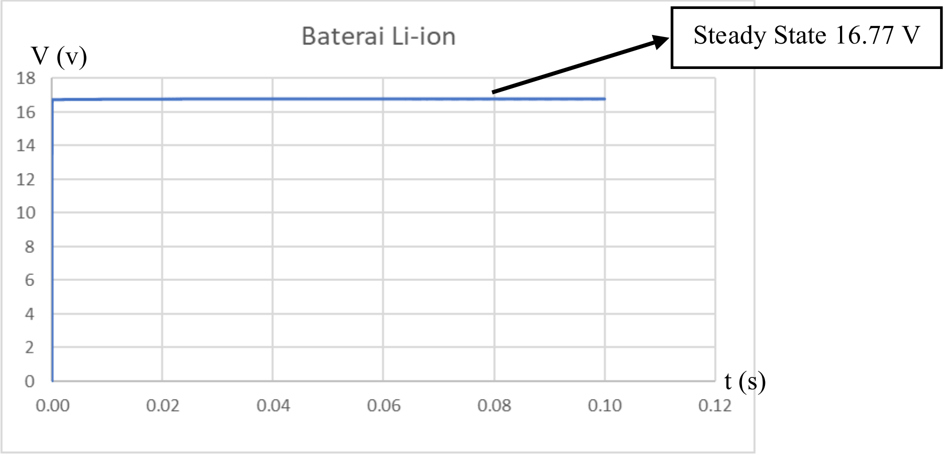


Figure 7. Closed-loop adaptive charging system simulation circuit



(a)

(b)



(c)

Figure 8. Adaptive charging with variable load using the ANN-PID method (a) LifePO4 Battery, (b) Lead Acid Battery and (c) Li-ion Battery

Figure 8 (a) shows the charging curve for a Lifepo4 battery with a setpoint of 14.6 volts, while **Figure 8 (b)** shows the charging curve for a Lead Acid battery with a setpoint of 14.4 volts, and **Figure 8 (c)** shows the charging curve for a Li-ion battery with a setpoint of 16.8 volts.

Table 3. ANN-PID output result

No	Type of battery	Setpoint Voltage (Volt)	Output Voltage	Error (%)
1	LifePO4	14.6	14.62	0.27
2	Lead Acid	14.4	14.39	0.069
3	Li-ion	16.8	16.77	0.178
Averages error				0.174

One of three battery types is linked to the SEPIC converter output, as shown in **Figure 9**. The ANN-PID control method regulates the converter's output voltage when a LiFePO4 battery is connected. In order to establish the battery status and the proper charging setpoint, which in this case is 14.6 V, the ANN analyzes the measured voltage and current data. After comparing the feedback signal and the ANN-generated setpoint, the PID controller determines the error and modifies the duty cycle until the feedback reaches the target value. The other battery kinds, each of which has a different charging voltage setpoint, go through the same process.

According to the performance evaluation, which is shown in **Table 4**, there is very little difference between the ANN output and the desired reference data. The observed inaccuracy for the LiFePO4 battery with a setpoint of 14.6 V is 0.27%. The error for the Li-ion battery at 16.8 V is 0.178%, whereas the error for the Lead Acid battery at 14.4 V is 0.069%. The calculated average system error is 0.174% overall. These findings show that the suggested ANN-PID control approach provides great precision and stability in supporting the adaptive charging process.

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4. CONCLUSION

The results of a number of experimental tests verify that the suggested approach's application is in good agreement with earlier research. The findings show that by examining the voltage and current profiles of three distinct battery types, They can be effectively identified by the Artificial Neural Network (ANN) in combination with Proportional-Integral-Derivative (PID) control. The ANN-PID control technique created in this work is quite appropriate for adaptive battery charging applications, as seen by the charging system's average variance of just 0.174% between its output and the desired setpoint.

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