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Development and Performance Evaluation of Alternating Current- Direct Current Device for Electrochemical Treatment of Wastewaters

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Abstract

This study evaluates the performance of a locally developed AC–DC power supply unit designed for electrochemical treatment of water and wastewater at the laboratory scale. The device converts alternating current (AC) into direct current (DC) within a range of 0–13.4 V and 0–20 A using a step-down transformer and a full-bridge rectifier constructed with 20 A diodes. Output voltages were measured with standard analog voltmeters, and the influence of input AC voltage on DC output was assessed. Performance comparisons were made between the developed unit, another locally fabricated unit, and a commercially available device. Statistical analyses—including ANOVA, total error (Er^2), coefficient of determination (CD), and model selection criterion (MSC)—were conducted to evaluate accuracy and reliability. Results showed that the Er^2, CD, and MSC values across the three devices were 27.215–27.891, 0.069–0.090, and -0.544 to -0.370, respectively. ANOVA results indicated no statistically significant difference in DC output among the devices ($F_{11,44} = 1.2593$, $p = 0.279$), while input AC voltage had a highly significant effect on output ($F_{4,44} = 1323.9$, $p = 3.0 \times 10^{-45}$), at a 95% confidence level. The findings confirm the operational viability of the locally developed unit for electrochemical water treatment applications.

Keywords
Alternating Current,
Direct Current,
Power Supply Unit,
Water and Wastewater,
Electrochemical Treatment

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INTRODUCTION

Potable water is a valuable source of liquid for animal and plant life (Zuo et al., 2023). A healthy life of a living thing rests on the utilization of clean, potable and safe drinking water, indicating that quality water plays an important role in essential functions of pH, electrolyte balance and nutrient transport in living organisms (Oladimeji et al., 2024; Qu et al., 2024; Zhu and Li, 2025; Wang et al., 2025; Lin and Volkenborn, 2025; Eid et al., 2025).

In summary, water is perilous to sustainable socio-economic development, energy and food production, healthy ecosystems and human survival. Nonetheless, the heavy development of the industries and rapid population increment have escalated water contamination, which has become a big challenge worldwide for chemical, water and environmental engineers (Vasudevan, 2012; de Vargas Brião et al., 2024; Randazzo et al., 2024; Li and Zhang, 2025; Teku, 2025; Zhou et al.,2025).

It is well known that utilisation of a combination of biological, physical, and chemical processes, known as conventional wastewater and water treatment processes, cannot remove, eliminate, or destroy a wide range of contaminants such as emerging pollutants (Amoko et al., 2025, de Vargas Brião et al., 2024; Zuo et al.,2023; Salazar- Banda et al., 2021; Ghosh et al., 2019). Nevertheless, these conventional wastewater and water treatment processes are facing increasing problems and challenges, available sources of water (surface and ground) are becoming perilously insufficient and contaminated, requiring elimination of emerging and persistent chemicals that cannot be removed by conventional treatment processes.

Furthermore, combating global climate change and Sustainable Development Goals require environmental engineers to minimize chemical and energy consumption in the purification of water and wastewater (Oke and Ogedengbe, 2007; Oke et al., 2007b; Oke et al., 2007a; Panizza, 2010; Abdollahi et al.,2023; Asefaw et al., 2024; Fehintola et al., 2024; Garomsa et al., 2024; Guadalupe et al., 2024; Lu et al., 2024; Thamarai et al., 2024).

These new problems and challenges have generated strong interest in the utilization of electrochemical treatment processes (Amoko et al., 2025; de Vargas Brião et al., 2024; Zuo et al., 2023; Oliveira et al., 2023; Islam, 2023; Amoko et al., 2025; Arora et al., 2025; Liu et al., 2025). In recent decades, electrochemical treatment processes have succeeded as environmentally friendly and ecological technologies for the treatment of water and wastewater (de Vargas Brião et al., 2024). Its advantages (such as high energy efficiency, ease of automation, cost-effectiveness, low sludge production and consumption of chemical products (Comnea-Stancu et al., 2021; Zuo et al., 2023; Martínez-Huitle et al., 2023).

Figure 1 shows publications on electrochemical treatment techniques from selected countries between 1977 and 2022. The essential equipment for electrochemical treatment of water and wastewater are electrochemical reactor (cell), electrodes (anode and cathode) and a power supply unit. Power supply unit provides the direct current (DC) or alternating current (AC) needed to drive electrochemical reactions. The importance of a power supply unit includes (Nidheesh and Gökkuş, 2023; de Vargas Brião et al., 2024):

o Controls the voltage and current for different treatment processes.

o Essential for initiating and sustaining redox reactions.

o Determines energy efficiency and treatment performance.

In the literature, research and documentation on the development and evaluation of a power supply unit (AC-DC device) for electrochemical treatment of water and wastewater are limited. The main aim of this study is to provide a circuit diagram, develop and evaluate the performance of a power supply unit for electrochemical treat

MATERIALS AND METHODS

The power supply unit (AC-DC device) for electrochemical treatment of water and wastewater was fabricated using indigenous and available materials (such as copper, plastic and electric cables, sockets aluminium plates) by the adoption of the basic principle as stated in Oke (2006), Oke and Ogedengbe (2007) and Oke *et al.* (2007a,b). The power supply (alternating current) of the circuit was rectified fully by a bridge rectifier, which converts the alternating current to direct current (DC) voltage of root mean square values of 0 – 13.4 volts. The major components of the rectifier and the equipment are four 20 A Zenier diodes (a capacitor of 63 V, 1000×10^{-6} F, step-down transformer, 20

A fuse, a control, voltmeters, and an ammeter. Figures 2a to 2g present a circuit diagram and view of the equipment invented and other devices. In the comparison and calibration, the DC outputs from the equipment were measured using digital voltmeters and compared with two similar power supply units (AC-DC devices) for electrochemical treatment of water and wastewater (imported and locally developed by Oke and Ogedengbe (2007) and Oke et al. (2007a).

A variable alternating current source (using both desktop and portable Variac, manufactured by Zenith Electric Company Ltd, Figure 3 (a, b, and c) was the view of the Variac utilised. Figure 4 provides a 13.4 DC back- up from 18650 type of 46000 mAh Lithium-Ion Batteries Pack of 3.7 DC V (rechargeable) connected in series (S) and parallel (P).

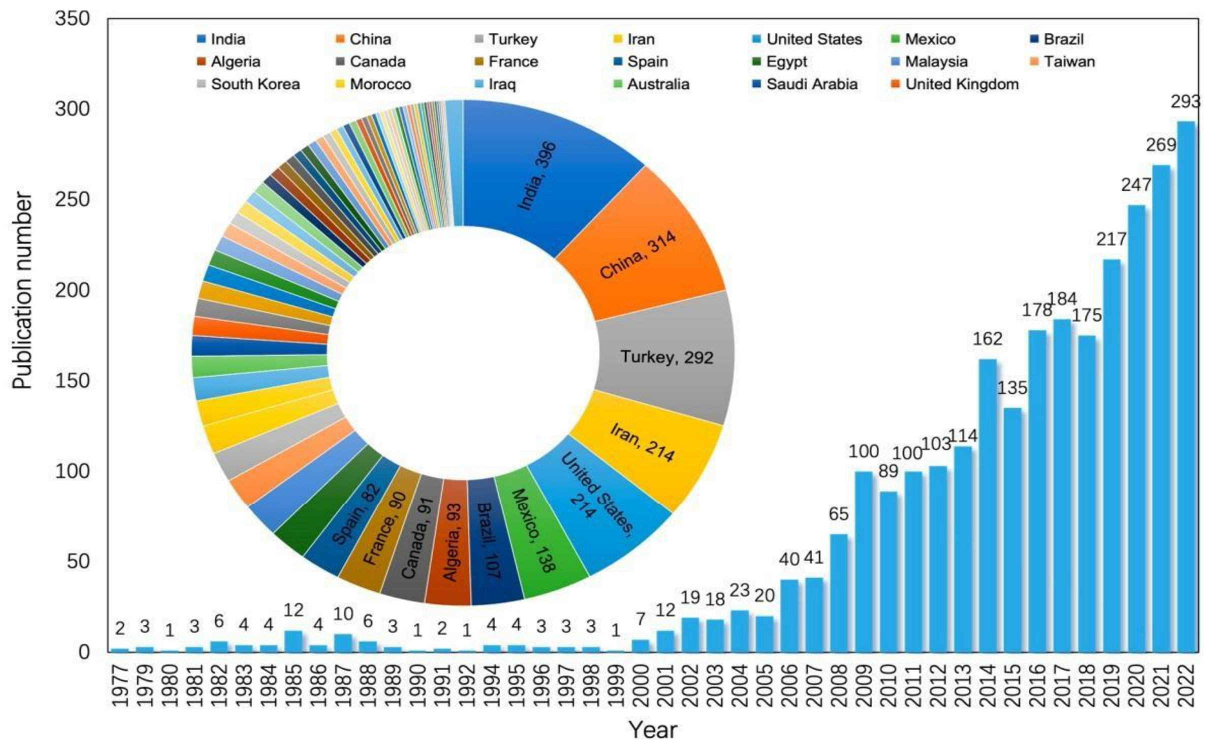

Figure 1. Publications on electrochemical treatment techniques from selected countries between 1977 and 2022 (Source: Amoko et al., 2025)

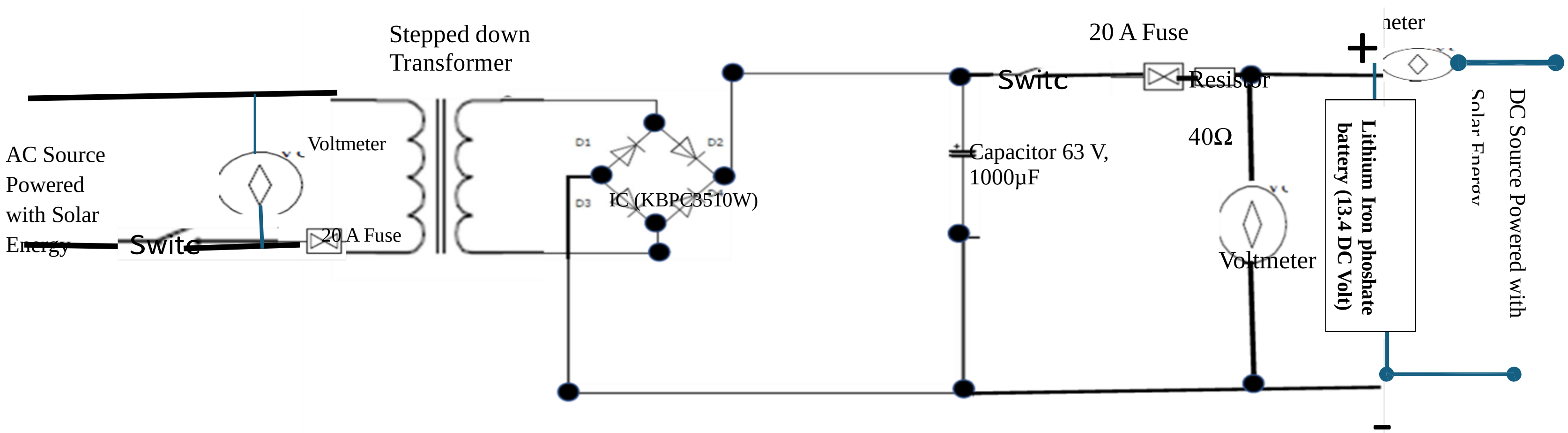

Figure 2a: Schematic diagram the circuit of the equipment

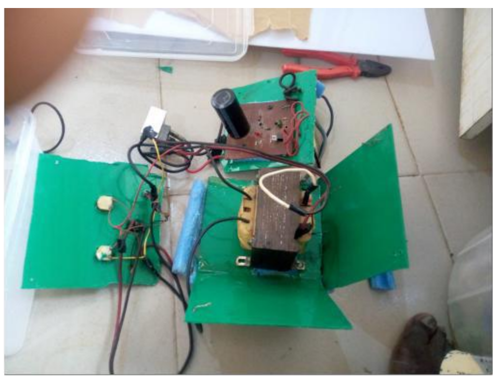

Figure 2b: Some of the components in the
AC-DC device

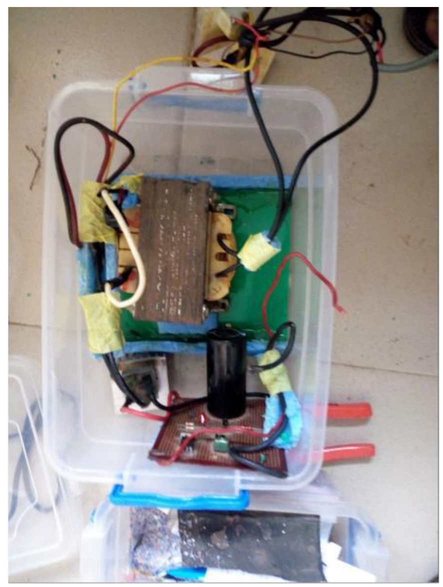

Figure 3d: Side view of the DC Outlet

Figure 2c: Plan view of the developed device

Figure 2e: Front View of the AC inlet section

Figure 2f: Front view of the fabricated device (Oke et al., 2007a)

Figure 2g: Front view of the commercially available device

Figure 3a: Desktop Variac for Voltage regulation

Figure 3b: Plan view of Portable Variac for Voltage regulation

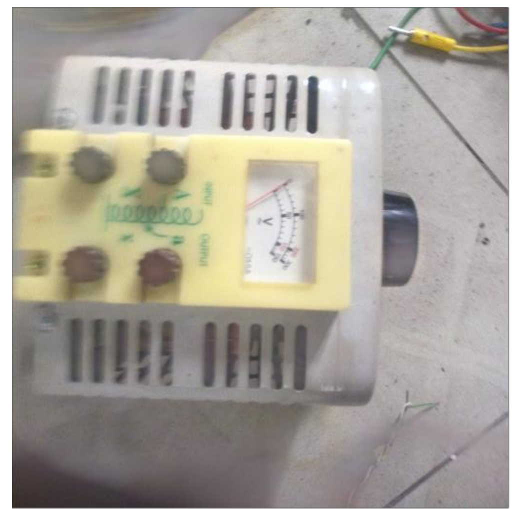

Figure 3c: Side view of Portable Variac for Voltage regulation

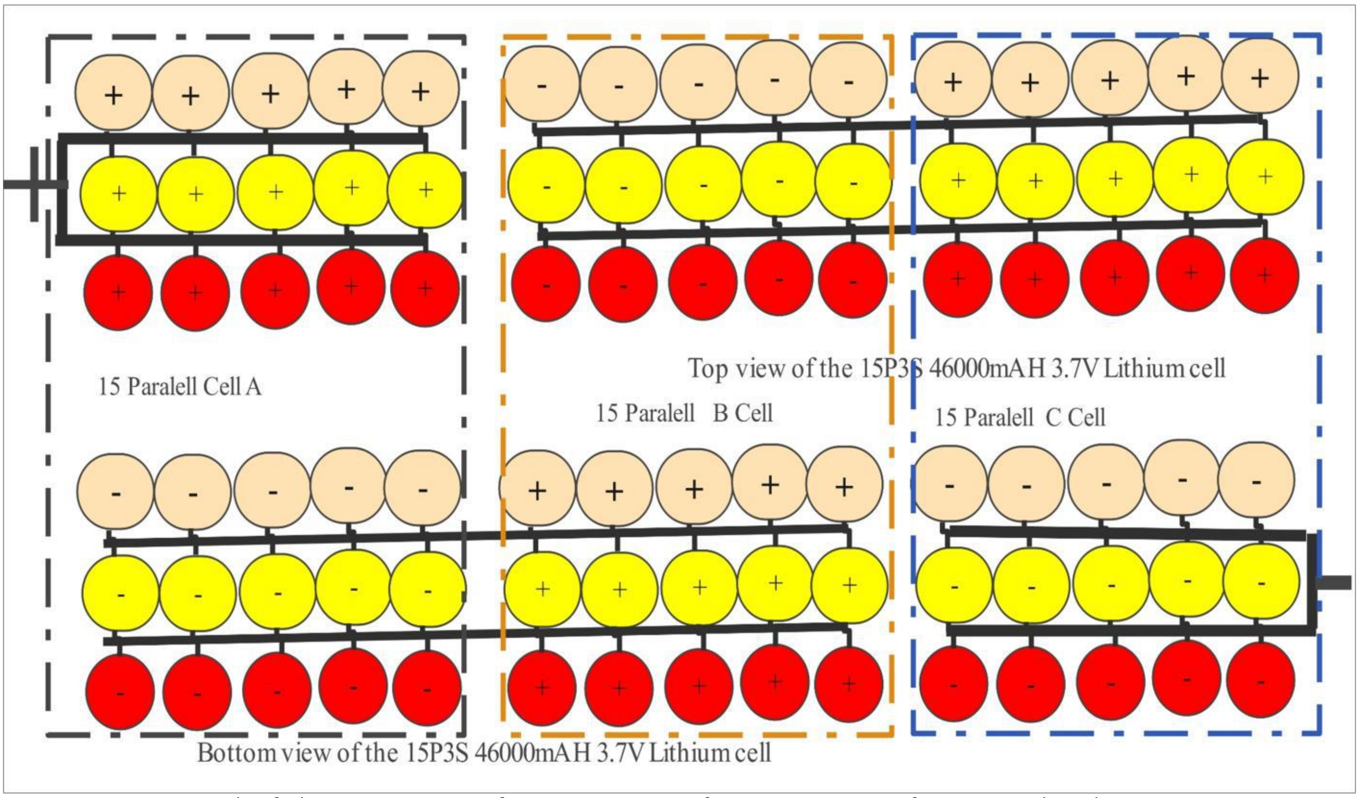

Figure 4a: a sketch of the arrangement of 13.4 DC back-up from 18650 type of 46000 mAh Lithium-Ion Batteries Pack of
3.7 DC V (rechargeable) connected in series (S) and parallel (P).

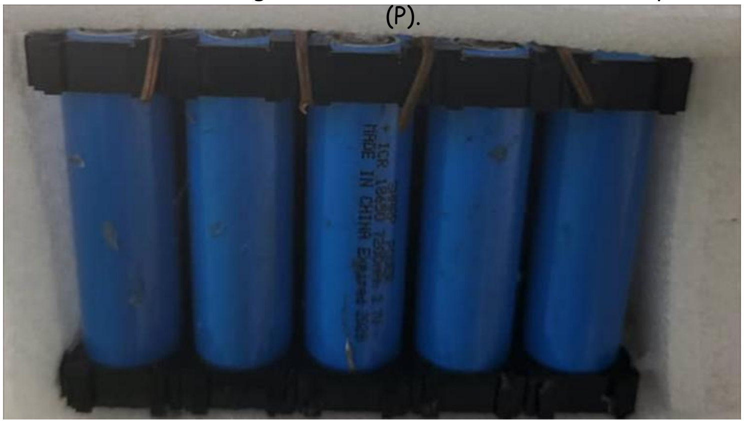

Figure 4b: side view of 13.4 DC back-up from 18650 type of 46000 mAh Lithium-Ion Batteries Pack of 3.7 DC V (rechargeable) connected in series (S) and parallel (P).

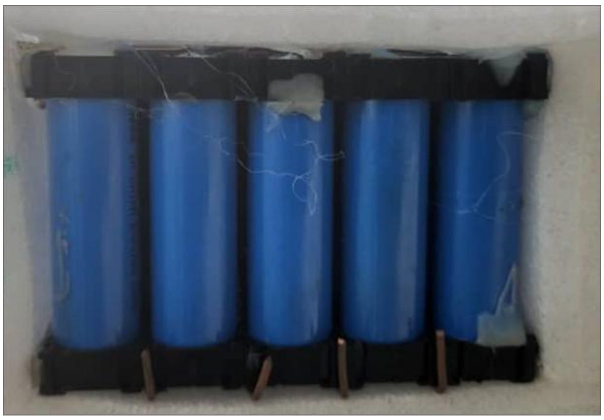

Figure 4c: Back view of 13.4 DC back-up from 18650 type of 46000 mAh Lithium-Ion Batteries Pack of 3.7
DC V (rechargeable) connected in series (S) and parallel (

The effects of the variable input (alternating current) on the direct current output were monitored using a standard digital voltmeter. The results of the DC outputs and the effects of the input alternating current source on the DC outputs were analysed using statistical evaluation measuring techniques such as Coefficient of Determination (C_D), total error, Model Selection Criterion (MSC), Analysis of Variance (ANOVA), and relationship between input AC and output DC using Microsoft Excel data analysis technique. Coefficient of Determination (C_D), total error, and Model Selection Criterion (MSC), were computed as follows:

a) Total error (Er^2) was computed utilising equation (1):

$$Er^2 = \sum_{i=1}^{n} \left(P_e - P_o\right)^2 \tag{1}$$

Where, P_e is the expected performance of the device, n is the total number of experiments or observations, and P_o is the observed performance of the device.

b) C_D was determined using the expression (equation 2):

$$C_D = \frac{\sum_{i=1}^{n}\left(P_o - \overline{P_e}\right)^2 - \sum_{i=1}^{n}\left(P_e - P_o\right)^2}{\sum_{i=1}^{n}\left(P_o - \overline{P_e}\right)^2} \tag{2}$$

c) MSC was computed utilising equation (3) as follows:

$$MSC = \ln\left[\frac{\sum_{i=1}^{n}\left(P_o - \overline{P_o}\right)^2}{\sum_{i=1}^{n}\left(P_o - P_e\right)^2}\right] - \frac{2p}{n} \tag{3}$$

In the computations of ANOVA and the relationship equation (based on 2 general equations), the Microsoft Excel data analysis technique was utilised. The general equations are as follows (equations 4 and 5):

With intercept: $$Y = A + Bx \tag{4}$$

Where; Y is the output DC, A is the intercept DC output at zero input AC, B is the correlation coefficient between AC input and DC output, and x is the AC input of the device

Without intercept: $Y \quad Bx$ (5)

Figure 5 shows the summary and the flow chart of the methodology.

Results and Discussions

The results from this design and development of the power supply unit (AC-DC device) for electrochemical treatment of water and wastewater is presented and discussed in the following categories: performance behaviour of the three devices, effect of input AC on the performance of the three devices, statistical evaluation of the performance of the three devices, ANOVA and relationship between the input AC and DC of the three devices.

a) **Performance behaviour of the three devices:** Figure 4 presents the output (DC) performance behaviour of the three devices. The figure revealed that between zero (0) and 120 AC input volts, there were no DC output volts, which indicates that 120 AC volts was below the breakpoint voltage for DC voltage generation by the three devices (Figure 6a). Table 1 shows the results of the ANOVA for the effects of AC volts on the voltameter reading of the three devices and the effects of input AC (between 0 and 250) on expected and observed DC volts. At above 120 AC volts, the three devices started generating DC voltage at various magnitudes depending on the device (Figure 6b). The voltages were 8.0, 7.9 and 9.4 DC voltages for imported (commercially), Oke and Ogedengbe (2007) and the new power supply unit (AC-DC device) for electrochemical treatment of water and wastewater.

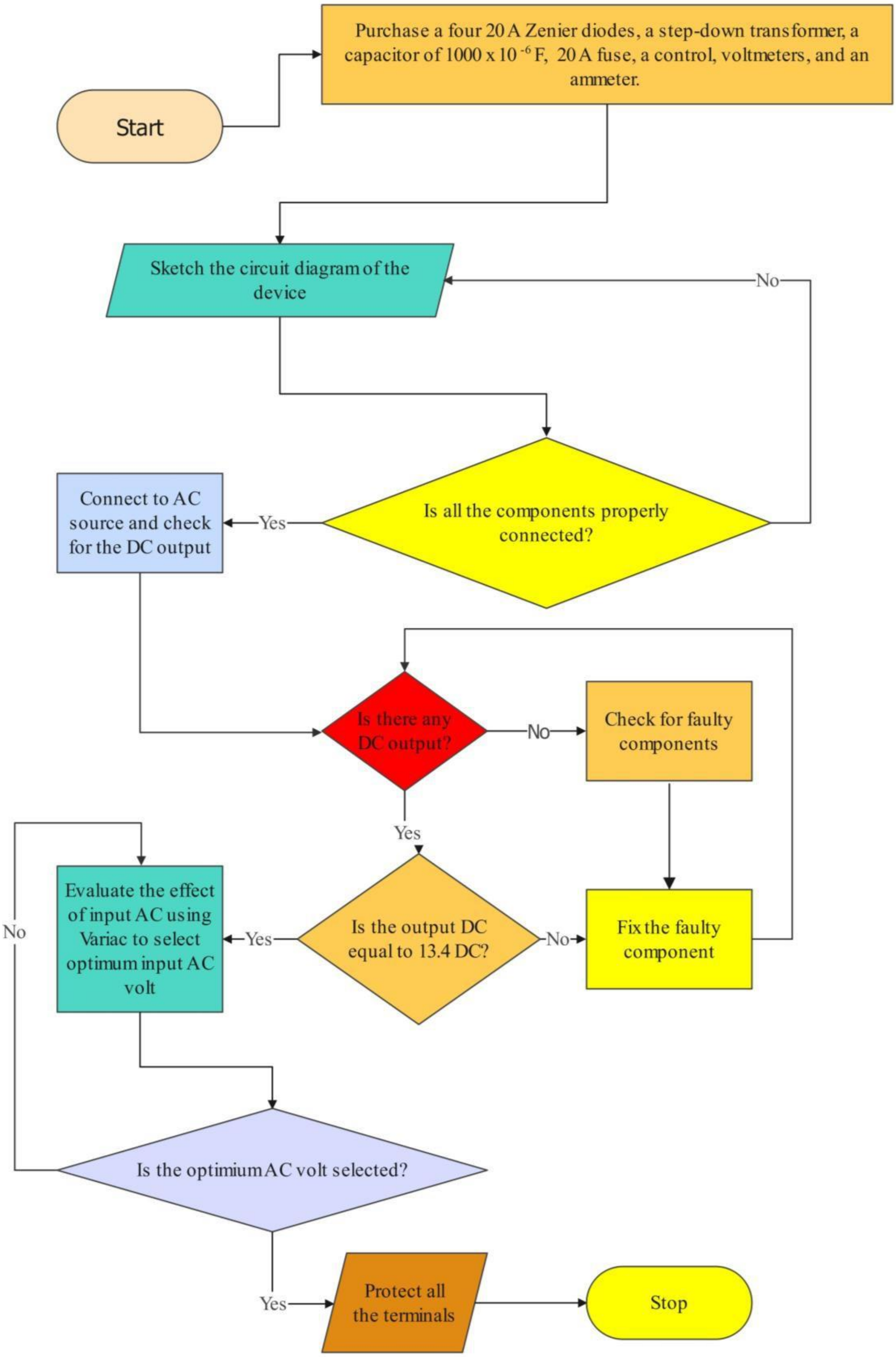

Figure 5: the summary and the flow chart of the methodology

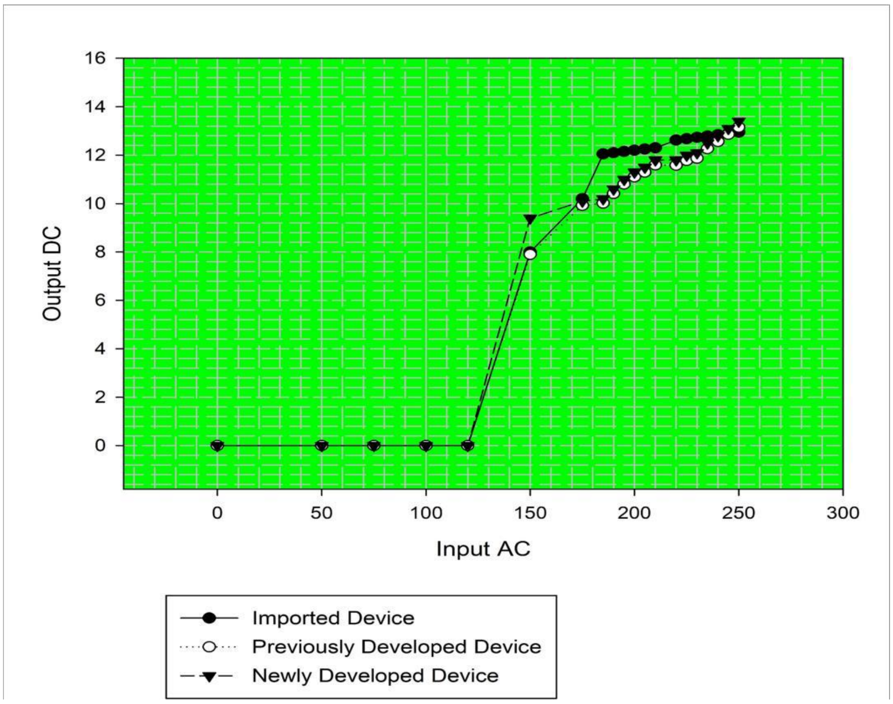

Figure 6a the output (DC) performance behaviour of the three devices between 0 and 250 input AC voltages

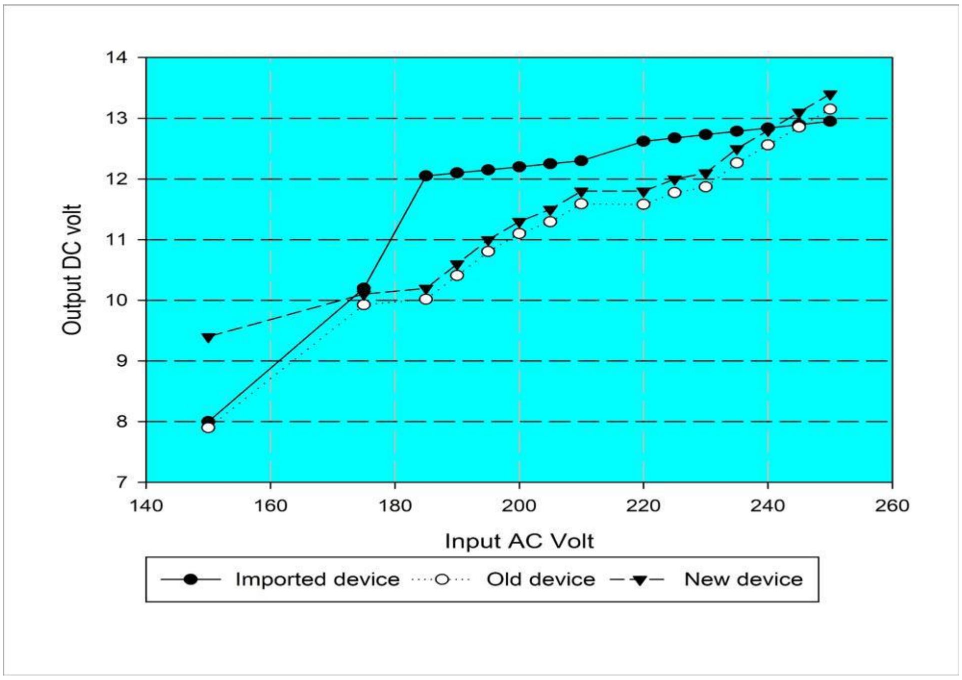

Figure 6b the output (DC) performance behaviour of the three devices between 150 and 250 input AC voltages

Table 1 The results of the ANOVA for the effects of AC volts on the voltameter reading of the three devices and the effects of input AC on expected and observed DC volts.

Source of Variation	*Sum of Squares*	*Degree of*	*Mean Sum of Squares*	*F-value*	*P-value*	*F crit*
Expected and observed	1402.569	19	73.81944	11.8838	1.68×10^{-13}	1.771972
Voltmeters and expected	221.879	3	73.9596	11.90637	3.70×10^{-06}	2.76643
Error	354.071	57	6.211772			
Total	1978.519	79				

The Table revealed that there are significant differences between the DC voltages between expected and observed, ($F_{19, 57}$ = 11.8838 and p = 1.68×10^{-13}, which is less than 0.05), as well as DC voltages between within the three devices ($F_{3, 57}$ = 11.90637 and p = 3.70×10^{-06}, which is less than 0.05) at a 95 % confidence level. Furthermore, the initial higher value of DC voltage for the new power supply unit (AC- DC device) for electrochemical treatment of water and wastewater can be attributed to the lithium iron phosphate backup provided in the design and development. Table 2 shows the results of the ANOVA for the effects of AC volts on the voltameter reading of the three devices and the effects of input AC (between 150 and 250) on expected and observed DC volts. This result revealed that the presence of backup provides a steady DC source at various lower (between 150 AC volts and 180 AC volts) AC inputs, which provides an advantage over the other two devices. The Table revealed that there are significant differences between the DC voltages between expected and observed, ($F_{14, 42}$ = 21.5392 and p = 1.33×10^{-08}, which is less than 0.05), as well as DC voltages between within the three devices ($F_{3, 42}$ = 6.6999 and p = 7.240×10^{-07}, which is less than 0.05) at a 95 % confidence level. These results establish that input AC is a significant factor in the generation of output DC voltages (Ki et al., 2012; Abdelsalam et al., 2014; 2015; Minami , 2021; Memon et al., 2022; Ahmed et al., 2023).

b) **Effect of input AC on the performance of the three devices:** Table 3 shows the results of the ANOVA for the effects of input AC volts on the voltameter reading of the three devices and the effects of input AC (between 0 and 250) on expected and observed DC volts from the developed device. The Table revealed that input AC volts have significant effects on the voltameter reading of the three devices ($F_{19, 38}$ = 486.8605 and p = 1.61×10^{-39}, which is less than 0.05), which indicates that input AC controls the DC outputs of the three devices.

These three devices' output patterns are similar and agree with the literature on the relationship between input and output of step-down transformers (Shneen et al., 2022; Ashraf et al., 2022a and b; Ildarabadi and Zadehbagheri, 2023). In addition, the different input AC volts produced different DC volts in the three devices, and the values of the magnitude of these DC volts were significantly different ($F_{3, 39} = 10.07327$ and $p = 3.09 \times 10^{-4}$, which is less than 0.05) at a 95 % confidence level. This result

indicates that the response by each of these devices varied, which can be attributed to the components used in the development of the devices (Jia et al., 2021; Petrauskas and Svinkunas,2022; Katiyar et al., 2023).

Table 2 The results of the ANOVA for the effects of AC volts on the voltameter reading of the three devices and the effects of input AC (between 150 and 250) on expected and observed DC volts.

Source of Variation	Sum of Squares	Degree of	Mean Sum of Squares	F-value	P-value	F crit
Between the reading at	46.8295	14	3.344971	6.69984	7.24 x 10 -	1.935009
Within the expected and observed DC volts along the device by AC						
Error	20.9689	42	0.499261			
Total	100.0596	59				

Table 3 The results of the ANOVA for the effects of input AC volts on the voltameter reading of the three devices and the effects of input AC (between 0 and 250) on expected and observed DC volts.

Source of Variation	Sum of Squares	Degree of freedom	Mean Sum of	F-value	P-value	F crit
Effects of the Input AC on	1584.60	19	83.40016	486.860	[illegible]	1.867332
Effects of Input AC with DC Readings from the devices						
Error	6.50947	38	0.171302			
Total	1594.56	59				

c) **Statistical evaluation of the performance of the three devices**: Table 4 presents the summary of the statistical evaluation of the performance of the three devices. The Table shows the values of total error, MSC and CD of the three devices compared with the expected DC volts. The Table revealed that for Commercially available device, Oke and Ogedengbe (2007) developed device and Newly (currently) Developed Device, the total errors were 27.215, 27.891 and 27.484, respectively, which indicates that the highest error is from Oke and Ogedengbe (2007) developed device, and the least error was from Commercially available device. In the case of MSC, the MSC were -0.370, -0.544 and -0.477 for Commercially available device, Oke and Ogedengbe (2007) developed device and Newly (currently) Developed Device, respectively, which indicates that the best performance came from Commercially available device and the least performance was from Oke and Ogedengbe (2007) developed device. In addition, CD for Commercially available device, Oke and Ogedengbe (2007) developed device and Newly (currently) Developed Device were 0.090, 0.069 and 0.078, respectively, which indicates that the correlation between the expected DC volts and the output DC volts from these three devices were in order of Oke and Ogedengbe (2007) developed device less than the newly (currently) Developed Device less than Commercially available device.

d) **Relationship between the input AC and DC:** Table 5 presents the summary of the relationship between the input AC and output DC of the three devices.

Table 4: Summary of statistical Evaluation of the performance of the three devices

Summary	Commercially available	Oke and Ogedengbe	Newly (currently) Developed
Total error	27.215	27.89	27.48
MSC	-0.370	-	-
CD	0.090	0.06	0.07

Table 5: Summary of the relationship between the input AC and output DC of the three devices

	Commercially available device			[illegible]			[illegible]		
	Coefficients	*t Stat*	*P-value*	*Coefficients*	*t Stat*	*P-value*	*Coefficients*	*t Stat*	*P-value*
[illegible]	-3.549	-2.803	0.012	-3.528	-3.251	0.004	-3.467	-3.016	0.007
[illegible]	0.072	10.684	3.197×10^{-9}	0.068	11.868	$^{-10}$	0.069	11.357	1.22×10^{-9}
[illegible]	0.9294			0.9416			0.9368		
[illegible]	0.8638			0.8867		6.029 x 10	0.8775		
No Intercept									
[illegible]	[illegible]	[illegible]	1.14×10^{-17}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.91×10^{-21}
[illegible]	[illegible]			[illegible]			[illegible]		
[illegible]	[illegible]			[illegible]			[illegible]		

The Table revealed that for Commercially available device, Oke and Ogedengbe (2007) developed device and Newly (currently) Developed Device, the correlation coefficients were 0.072, 0.069 and 0.068, the t-statistical and the p-values were 10.684 and 3.197×10^{-9}; 11.868 and 6.029×10^{-10}; and 11.357 and 1.22×10^{-9}, respectively, which indicates that the relationships with intercept were significant for all the three devices. In the case of the relationships without the intercept, the Table revealed that for Commercially available device, Oke and Ogedengbe (2007) developed device and Newly (currently) Developed Device, the correlation coefficients were 0.072, 0.069 and 0.068, the t-statistical and the p-values were 10.684 and 3.197×10^{-9}; 11.868 and 6.029×10^{-10}; and 11.357 and 1.22×10^{-9}, respectively, which indicates that the relationships with intercept were significant for all the three devices.

CONCLUSIONS

Based on the study (design and development of the power supply unit (AC-DC device) for electrochemical treatment of water and wastewater) and the results obtained from the study, the following conclusions are drawn:

i. the AC-DC conversion of the locally developed power supply unit (AC-DC device) for electrochemical treatment of water and wastewater was successful, adequate and similar to the power supply unit (AC-DC device) for electrochemical treatment of water and wastewater.

ii. Good statistical results (ANOVA, total error, coefficient of determination and model selection criterion) showed that there was similarity between the performances of these power supply units (AC-DC device) for electrochemical treatment of water and wastewater devices.

iii. Locally developed power supply unit (AC-DC device) for electrochemical treatment of water and wastewater) offers a new low-cost solution to AC-DC conversion and for electrochemical treatment process applications, with energy backup to prevent fluctuation in the power supply..

iv. Input AC voltage of range 195-250, which is the main power source in Nigeria, is the effective range for effective DC output.

v. The limits of locally developed power supply unit (AC-DC device) for electrochemical treatment of water and wastewater are voltage and current, which at present are irregular public electricity sources, 13.4 DC-Volt and 20 DC-A respectively. However, implementing a simple modification to the equipment and provision of solar solar-powered system can significantly decrease this deficiency

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