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Design, Construction, and Performance Evaluation of a Variable AC and DC Power Supply System for Electrical Engineering Laboratories

Adeoti Adeshina J.[1*], Olalekan Emmanuel Ilufoye[2], Ibrahim Rasaq Ishola[3] & Mohammed Mohammed[4]

[1,2,3,4]Department of Electrical/Electronic Engineering Kwara State Polytechnic, P.M.B 1375, Ilorin, Kwara State, Nigeria

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ABSTRACT **Original Research Article**

This study presents the design, construction, and performance evaluation of a variable AC and DC power supply system for electrical engineering laboratory applications. The system was developed to provide a cost-effective and locally maintainable alternative to expensive commercial laboratory power supplies. It consists of a 2 kVA autotransformer for variable AC output, a full-wave bridge rectifier, filter capacitors, and protection and cooling units. The developed system delivers an adjustable AC output of 0–300 V and a corresponding DC output of up to approximately 422 V. Performance evaluation was conducted under different loading conditions to assess voltage regulation, output stability, thermal performance, and conversion efficiency. Experimental results showed stable AC operation with load regulation ranging from 2.0% to 3.5%, while the DC output closely agreed with theoretical values and exhibited acceptable ripple levels. Continuous operation over four hours demonstrated reliable performance with only moderate temperature rise. Although efficiency decreased from 59.8% at light load to 46.7% at higher loads due to internal losses, the system maintained satisfactory operation for laboratory experiments and equipment testing. The results demonstrate that the developed power supply is reliable, economical, and suitable for teaching, research, and practical electrical engineering laboratory applications.

Keywords: Variable AC Power Supply, Variable DC Power Supply, Autotransformer, Bridge Rectifier, Voltage Regulation, Laboratory Power Supply, Performance Evaluation.

**Corresponding author: Adeoti Adeshina J.*

Department of Electrical/Electronic Engineering Kwara State Polytechnic, P.M.B 1375, Ilorin, Kwara State, Nigeria

Introduction

Power supply units serve as the backbone of electrical and electronic laboratory operations by providing the electrical energy required for testing, experimentation, and practical demonstrations. Most laboratory activities require different voltage levels depending on the equipment or circuit under investigation. Consequently, adjustable power supplies have become indispensable tools in educational institutions, research laboratories, and industrial environments.

In many engineering laboratories, separate AC and DC power supplies are used to meet varying experimental requirements. While effective, this approach increases procurement costs and maintenance requirements. A single integrated unit capable of delivering both adjustable AC and DC outputs offers a more economical and convenient alternative.

Variable AC voltage is commonly obtained through the use of a Variac, which is a variable autotransformer capable of providing smooth voltage adjustment without altering the supply frequency. Variable DC voltage, on the other hand, can be achieved through rectification, filtering, and voltage regulation processes. Integrating these functions into a single system provides a versatile laboratory instrument capable of supporting a wide range of practical activities.

This study focuses on the design, construction, and performance evaluation of a variable AC and DC power supply system suitable for electrical engineering laboratories.

Problem Statement

Electrical engineering laboratories require reliable and adjustable power supplies for practical experiments and equipment testing. However, commercially available variable AC and DC power supply units are often expensive to procure and maintain, especially in developing countries with limited budgets. Dependence on imported components further increases maintenance costs and downtime. Consequently, many laboratories operate with inadequate power supply facilities, affecting effective practical training. Therefore, there is a need to develop a cost-effective, reliable, and locally maintainable variable AC and DC power supply system for laboratory applications.

Aim and Objectives

Aim

The aim of this study is to design, construct, and evaluate a variable AC and DC power supply system for electrical engineering laboratory applications.

Objectives

The specific objectives of this study are to:

1. **Design** a variable AC and DC power supply circuit incorporating transformer, rectifier, filter, and voltage regulation stages.
2. **Construct** the power supply system using locally available components and fabrication techniques.
3. **Develop** adjustable AC and DC voltage outputs suitable for electrical engineering laboratory experiments and equipment testing.
4. **Evaluate** the performance of the system in terms of voltage regulation, output stability, load capacity, and suitability for laboratory applications.

Literature Review

Power supply systems are essential components in electrical engineering laboratories, providing the electrical energy required for experiments, testing, and instructional activities (Theraja & Theraja, 2014). Conventional laboratory power supplies typically provide either AC or DC output, requiring multiple units to satisfy different experimental needs (Hughes, 2016). Variable AC supplies are commonly achieved using autotransformers (Variacs), which allow smooth adjustment of output voltage while maintaining a constant frequency (Chapman, 2012). Variable DC supplies are produced through transformer-based rectification, filtering, and voltage regulation stages to ensure stable and reliable output voltages (Boylestad & Nashelsky, 2019).

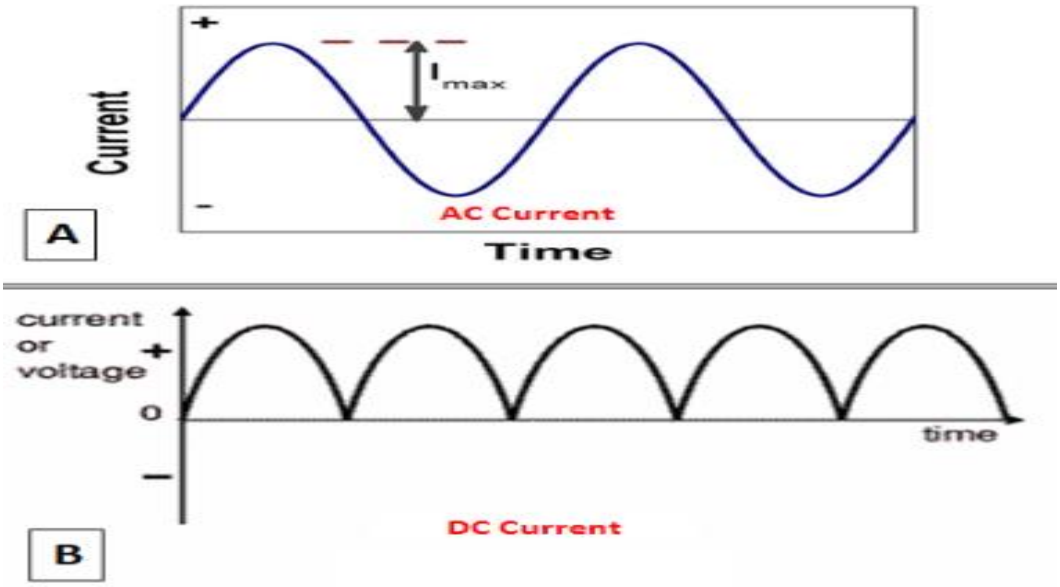

Figure 1. Schematic representation of AC current in (A) and DC current in (B)
(Source: Williams, 1995)

Previous studies have emphasized the importance of regulated power supplies in minimizing ripple voltage, improving voltage stability, and protecting connected equipment from electrical faults (Floyd, 2018). Modern power supply designs incorporate protective features such as overcurrent protection, thermal shutdown, and voltage monitoring to enhance safety and reliability (Horowitz & Hill, 2015). However, many commercial systems remain expensive and difficult to maintain in developing countries, creating a need for affordable and locally maintainable alternatives for laboratory applications.

Materials and Methods

System Design and Architecture

The power supply system is designed as a dual-output unit, with separate paths for DC and AC generation, both fed from a single-phase AC mains supply The overall system architecture is shown in Figure 1 and figure 2 show the constructed picture.

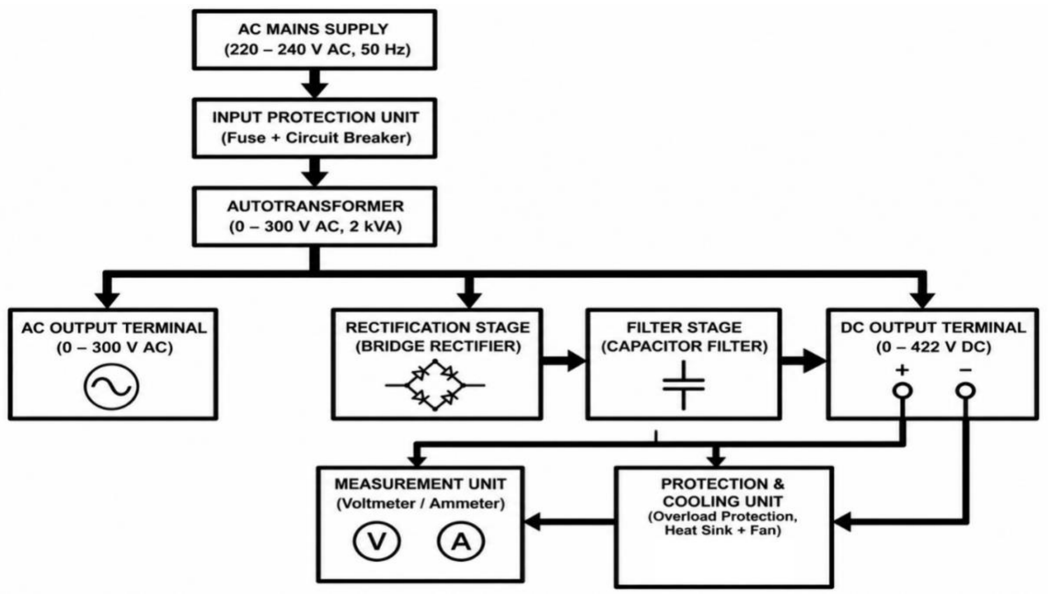

Figure 1: System Block Diagram

Block Diagram Description of the Proposed System

1. **Input Protection Unit: This stage connects to the mains and protects against over current and short-circuits using a calculated fuse and a resettable circuit breaker.**
2. **Autotransformer:** Provides variable voltage control via a single winding with a movable tap. Adjusting the tap continuously varies the AC output from 0{V) to 300 V AC at a 2 kVA capacity. This regulated AC serves as both the direct AC output and the input for the DC conversion path.
3. **AC Output Terminal:** Delivers the variable AC directly to the load, utilizing metering shunts and voltage dividers for real-time monitoring.
4. **Rectification Stage:** A heavy-duty bridge rectifier converts the variable AC into pulsating DC using four power diodes arranged in a full-wave configuration.
5. **Filter Stage:** High-capacity capacitor banks smooth the pulsating DC by charging during voltage peaks and discharging during valleys, dramatically minimizing ripple.
6. **DC Output Terminal:** Supplies the filtered DC (adjustable up to approximately 422 V DC via the autotransformer tap position) to the output panel.
7. **Measurement Unit:** Voltage dividers and current shunts enable real-time digital display of output parameters.
8. **Protection & Cooling Unit:** Consists of aluminum heat sinks and an active cooling fan to eliminate thermal build-up during extended high-load conditions

Figure 5: The Constructed Variable AC and DC Power Supply System

Connection from Autotransformer to Output Terminals

The autotransformer acts as the primary variable control unit. Its input terminals are connected to the protected AC mains supply through a safety fuse, circuit breaker, and a heavy-duty power switch. The movable wiper allows continuous adjustment of the output voltage. Internal insulated copper wiring routes this variable voltage safely to the front panel. One terminal is bonded to the neutral line, while the variable wiper terminal supplies the live output line. A panel-mounted digital voltmeter is connected in parallel across these terminals to monitor voltage variations instantly.

Two-Terminal AC/DC Output Interface

The front interface features distinct, color-coded terminal pairs for AC and DC modes. The live/positive terminals are marked in red, and the neutral/negative terminals are marked in black. The system allows an adjustable AC range of 0 - 300V AC and a corresponding rectified, filtered DC range of 0 - 422V DC

Mathematical Modeling and Design Calculations

The component parameters were mathematically determined to ensure safe, stable operation under maximum load. For the AC path, assuming a maximum load current (I max) of 5A, the maximum apparent power output (P) is calculated as

$P = V_{AC}$ (max) × Imax…………………………………….. (1)

P = 300V × 5A = 1500 W

Thus, an autotransformer rated safely above this limit at 2 kVA was selected.

For AC-to-DC conversion, a full-wave bridge rectifier was employed. The peak voltage was determined. If the AC section provides 0–300 V AC, then the DC output after rectification becomes higher because rectification converts the RMS AC voltage to peak voltage.

Mathematically, the ideal unfiltered peak DC voltage is represented by:

$V_{DC} = V_{AC}$ (rms) × √2…………………………………… (2)

For a maximum input setting of 300 V_{AC}:

V_{DC} =300 × 1.414

V_{DC} = 424.2V

However, in a practical bridge rectifier, two diodes conduct at a time, causing a voltage drop (about 1.4 – 2V total). Therefore: V_{DC}≈ 424.2V – 2V

V_{DC} ≈ 422V

Using the relationship between AC RMS voltage and rectified DC peak voltage

$V_{AC} = \frac{VDC}{\sqrt{2}}$……………………………………………….. (3)

$= \frac{422}{1.414}$ = 300V

To minimize ripple, the filter capacitor was calculated using:

$C = \frac{1}{2fVr}$…………………………………………………..… (4)

Assuming5 A, 50 Hz, and 5 V ripple, the capacitance obtained was **1**0,000 µF. A higher capacitor rating was selected to improve filtering and ensure stable DC output during varying load conditions.

Load Regulation Analysis

Load regulation indicates the power supply's capacity to maintain a stable output voltage despite varying load currents. It is calculated via:

Load Regulation (%) $=\frac{VNL-VFL}{VFL}$×100%

Results and Discussion

AC Section Performance Evaluation

The variable AC section was evaluated by coupling a 100 Ω resistive load across the terminals at 50 Hz. The output voltage was smoothly swept up to 300 V. Electrical measurements are detailed in Table 1.

Table 1: AC Electrical Measurements for Resistive Load (R=100 Ω,50 Hz)

S/N	Supply Voltage (V)	Load Current (A)	Calculated Current $I=\frac{V}{R}$ (A)	Real Power P = V × I (W)	Apparent Power S = V × I (VA)	Power Factor (PF)
1	30	0.30	0.30	9.0	9.0	1.00
2	90	0.90	0.90	81.0	81.0	1.00
3	150	1.50	1.50	225.0	225.0	1.00
4	210	2.10	2.10	441.0	441.0	1.00
5	300	3.00	3.00	900.0	900.0	1.00

Comparative Circuit Loading and Efficiency Analysis

Verification tests across varying standard loads were performed to evaluate basic AC and DC operation parameters, as shown in Table 2.

Table 2: Comparative AC/DC Circuit Loading Diagnostics

S/N	Supply Type	Applied Voltage(V)	Measured Current (A)	Load Resistance(Ω)	Power(W)
1	DC	5	0.10	50	0.50
2	DC	15	0.20	50	0.50
3	DC	30	0.60	50	18.00
4	AC	100	1.00	50	100
5	AC	200	2.00	100	400
6	AC	300	3.00	100	900

AC Output Voltage Drop and Load Regulation

The behavior of the AC voltage under full load compared to open-circuit conditions was analyzed to compute the load regulation capacity of the system as shown in Table 3.

Table 3: AC Output Voltage Drop and Load Regulation

S. No.	Autotransformer Setting (V)	Measured No-Load Voltage (V AC)	Measured Full-Load Voltage (V AC)*	Voltage Drop (V)	Load Regulation (%)
1	0	0.0	0.0	0.0	0.0
2	75	74.5	72.0	2.5	3.5
3	150	149.2	146.0	3.2	2.2
4	225	224.5	219.5	5.0	2.3
5	300	305.0	299.0	6.0	2.0

Output Stability Over Time and Thermal Performance

To confirm the reliability of the system for extended laboratory sessions, the unit was operated continuously for 4 hours at a steady 3.0Acurrent load as shown in Table 4.

Table 4: AC Output Stability and Thermal Variations Over Time

Time (Hours)	Set Voltage (V AC)	Measured Voltage (V AC)	Deviation (V)	Load Current (A)	Temperature (°C)
0	220	220.0	0.0	3.0	28
1	220	220.8	+0.8	3.0	35
2	220	221.2	+1.2	3.0	39
3	220	221.5	+1.5	3.0	42
4	220	221.3	+1.3	3.0	44

DC Output Performance

The DC output performance was characterized by measuring the output voltage and ripple under different load conditions using an oscilloscope and a digital multimeter. The voltage was measured across a range of settings and found to follow the relationship $V_{DC} \approx V_{AC} \times \sqrt{2}$, as expected. The ripple voltage was measured at full load and found to be within acceptable limits for the applications intended. The ripple magnitude was observed to increase with load current, which is typical for capacitor-filtered supplies as shown in Table 5.

Table 5: DC Output Performance – Voltage Variation and Load Regulation

S/N	Set AC Voltage (V_{AC}RMS)	Theoretical Peak Voltage ($V_{Peak}=V_{AC} \times\sqrt{2}$)	Measured DC Output (V_{DC})
1	50.0	70.7V	69.3V
2	100.0	141.4V	140.0V
3	150.0	212.1V	210.6V
4	200.0	282.2V	281.2V
5	250.0	353.6V	351.9V
6	300.0	424.3V	422.8V

Table 6 below shows the efficiency of the developed power supply system under varying load conditions by comparing AC input power with DC output power to evaluate overall energy conversion performance.

Table 6: System Efficiency Evaluation at Different Load Conditions

S/N	AC Input Voltage (V)	Input Current (A)	Input Power Pin (W)	DC Output Voltage (V)	DC Output Current (A)	Output Power Pout (W)	Efficiency η (%)
1	75	0.70	52.5	104.5	0.30	31.4	59.8
2	150	1.20	180	210.0	0.45	94.5	52.5
3	225	1.80	405	315.5	0.60	189.3	46.7
4	300	2.40	720	420.0	0.80	336.0	46.7

System Efficiency Evaluation under Different Load Conditions graph

Figure 5 plots system efficiency against output power (Pout), illustrating a clear downward trend as the load increases. The system hits its peak efficiency of 59.8% at a light load of 31.4 W, which drops to 52.5% at a mid-range load of 94.5 W. Under heavy loads (189.3 W to 336 W), the curve flattens out, stabilizing near 46.7%. This profile highlights that while escalating currents initially drive up I^2R copper and conduction losses, the system eventually reaches a stable operating equilibrium.

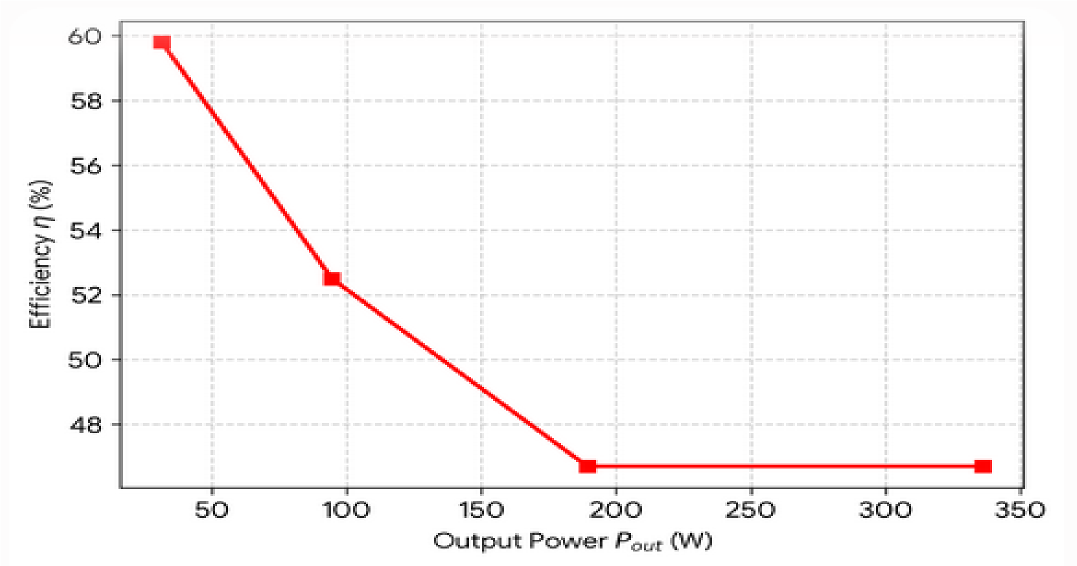

Figure 5: Efficiency vs Output Power Pout (W)

Discussion

The results show that the developed variable AC and DC power supply system performed reliably under different operating conditions. **Table 1** indicates a linear relationship between voltage and current for the AC section, consistent with Ohm's Law, with a power factor of 1.00 under resistive loading. **Table 2** confirms stable AC and DC operation, as power output increased with applied voltage. **Table 3** shows low voltage drops under load, with load regulation between 2.0% and 3.5%, indicating good voltage stability and minimal internal losses. **Table 4** demonstrates reliable long-term operation, as output voltage remained nearly constant despite temperature rising from 28°C to 44°C. **Table 5** confirms that the DC output closely matched theoretical rectified values with minimal losses. **Table 6** shows efficiency decreasing from 59.8% to 46.7% at higher loads due to internal losses, but remaining satisfactory for laboratory use.

Conclusion

This study successfully designed and evaluated a variable AC and DC power supply system for electrical engineering laboratories. The system delivered adjustable AC output from 0–300 V and DC output up to 422 V, meeting the required design specifications. Experimental results showed stable and predictable AC performance with minimal voltage drop and good load regulation between 2.0% and 3.5%. Thermal tests confirmed reliable operation during prolonged use despite moderate temperature rise. The DC output closely matched theoretical values with acceptable ripple levels for laboratory applications. Although efficiency decreased from 59.8% at light load to 46.7% at higher loads due to internal losses, the system maintained satisfactory overall performance. Therefore, the developed power supply provides a reliable, cost-effective, and locally maintainable solution for teaching, practical experiments, and electrical equipment testing in engineering laboratories.

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