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Development of Mini Electrical Power Module from Generation Station to the Consumers Terminal

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Abstract: The study presents the design and development of a mini electrical power module that demonstrates the fundamental processes involved in power generation, transmission, and distribution. The objective of the work is to provide a compact and practical system that helps bridge the gap between theoretical knowledge of electrical power systems and real-world engineering applications, particularly for educational and laboratory purposes. The developed module integrates key components of a typical power system, including a generator unit, transformers, and transmission lines. In the prototype system, electrical power is initially generated at 24 V AC and stepped up to 415 V AC using a step-up transformer to simulate high-voltage transmission. The voltage is then progressively stepped down through a series of transformers to 220 V AC, 110 V AC, and 60 V AC to represent different distribution stages. In addition, a village transformer was incorporated to step down the voltage to 12 V AC in order to simulate rural electrification, while consumer transformers further reduce the voltage to 12 V AC and 6 V AC for end-user applications. Experimental testing confirmed that the developed module operates effectively and accurately demonstrates the operational principles of a national electrical power system. The results show that the system can serve as a practical instructional tool for engineering students and researchers studying electrical power systems. Furthermore, the proposed module provides a useful prototype for understanding decentralized and small-scale power supply systems that may be applicable in remote or underdeveloped regions.

Keywords: *Electrical Power System, Mini Power Module, Power Generation and Distribution, Transformer Design, Power System Education Model.*

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I. INTRODUCTION

Electric power systems play a critical role in modern society by providing the energy required for residential, industrial, and commercial activities. A facility where electricity is produced is commonly referred to as a power station, where generators convert mechanical energy into electrical energy through the principle of electromagnetic induction. In this process, a conductor moving within a magnetic field produces an electric current.

Globally, most power stations rely on fossil fuels such as coal, oil, and natural gas for electricity generation[3]. However, the growing concern over environmental sustainability has encouraged the adoption of renewable energy sources such as hydroelectric, solar, and wind power[5]. In Nigeria, electricity generation is largely dominated by thermal power plants fueled mainly by natural gas, while hydroelectric power stations also contribute a significant portion of the total energy supply[6]. In 2023, an estimated 79.5% of the country's electricity was generated from thermal power, of which a majority was natural gas, whereas hydroelectric contributed around 20.4%[7]. Egbin, Alaoji, Afam, Ughelli, and Olorunsogo are significant thermal power plants, whereas significant hydroelectric plants include Kainji, Jebba, and Shiroro[7].

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Table 1 List of Some of the Generating Stations in Nigeria and Their Rated Capacity.

S/N	GENERATING STATION	CAPACITY
1.	Kinji Hydro Electric Plc	1330MW
2.	Shiroro Hydro electric Plc	600MW
3.	Olorunshogo I power plant	335MW
4.	Olorunshogo II power plant	375MW
5.	Gereku I Power plant	414MW
6.	Gereku II power plant	434MW
7.	Afam power plant 1-V	977MW
8.	Afam power plant VI	624MW
9.	Egbin power plant	1320MW
10.	Sapele power plant	1020MW
11.	Ibom power plant	190MW
12.	Ihorbor power station	450MW
13.	Okapi	336MW
14.	Omoku I power plant	150MW
15.	Omuku II power station	225MW

A plant that generates electricity is also called a power station[2], [3]. The structures house one or more generators, which are mechanical devices utilized to convert kinetic energy into electric energy by electromagnetic induction, wherein an electric current is produced by the movement of a conductor in a magnetic field[4].

Despite having an installed electricity generation capacity of approximately 13,000 MW, Nigeria often experiences a much lower actual power output. For instance, in March 2025 the country recorded a peak generation of about 5,801.84 MW. This gap between installed capacity and actual generation highlights the technical and operational challenges faced by the power sector [9].

In trying to curb the necessity of enhanced understanding and education in the power sector, a reduced scale model of an electrical power system was developed[9]. This model mimics the generation, transmission, and distribution of electric power and serves as a perfect classroom teaching tool for power and machine laboratories.

The module gives a scale model of the national grid so that students can learn how electricity is generated and transmitted to customers. Usually, energy is generated at stations located remotely from heavy consumption areas, or load centers[5]. The locations of these station sites take into consideration aspects such as safety, environmental factors, and cost, making it usually not feasible to have them close to populated regions.

For bringing the electricity generated at such remote locations to points of demand, there must exist an efficient transmission system. Electricity is first generated at lower voltage and, subsequently, stepped up to very high voltage levels to allow for efficient transmission over long distances with less loss of energy[1]. The voltage is then dropped again when reaching the points of distribution in order to meet consumers' demands[1].

The most common means of distributing electricity is by way of high voltage alternating current (AC) transmission lines. Power loss in transmission is minimized through higher voltage since electric power is equal to the product of voltage and current, and greater voltage implies smaller current for a specific power. Transmission lines are typically installed in pairs or with redundancy to ensure continuous operation, convenience during maintenance, and system security[1]. This study therefore focuses on the design and development of a mini electrical power module that simulates the key stages of a national electrical grid, including generation, transmission, and distribution. The developed module serves as a practical teaching aid for electrical and mechatronics engineering laboratories and also provides a foundation for understanding decentralized power supply systems.

II. METHODOLOGY

The section described step by step how the work was designed and was constructed, as well as the principal operation of the circuit.

➢ *List of Tools Used*

- Screwdriver
- Plier
- Hack saw
- Scissors

➢ *Component Description*

The major components used in constructing this work are as follows:

- Generator
- Transformers
- Circuit breakers
- Switches
- Tower & poles
- Aluminuim conductors

➢ *Generator*

A generator can typically be defined as a machine converting mechanical to electrical energy for use in an

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external circuit[10]. But in this case electronic devices are utilized to simulate that function. An oscillator is employed especially to convert a 12-volt direct current (DC) to a 24-volt alternating current (AC) at 50 Hz. A power transistor, especially a MOSFET, is employed to be utilized as the generator herein.

➢ *Transformer*

Transformer is an electric device employed to alter voltage levels boost or diminish them along with inversely fluctuating current levels without altering the frequency of the power supply. It is based on Faraday's Law of electromagnetic induction and relies on the ferromagnetic characteristics of an iron core for efficient energy transfer. Essentially, when the voltage is boosted, the current is decreased proportionally, and so forth [10]. In this project, a number of transformers were used within the system with four of rating 600 VA and two units of 100 VA and 200 VA respectively.

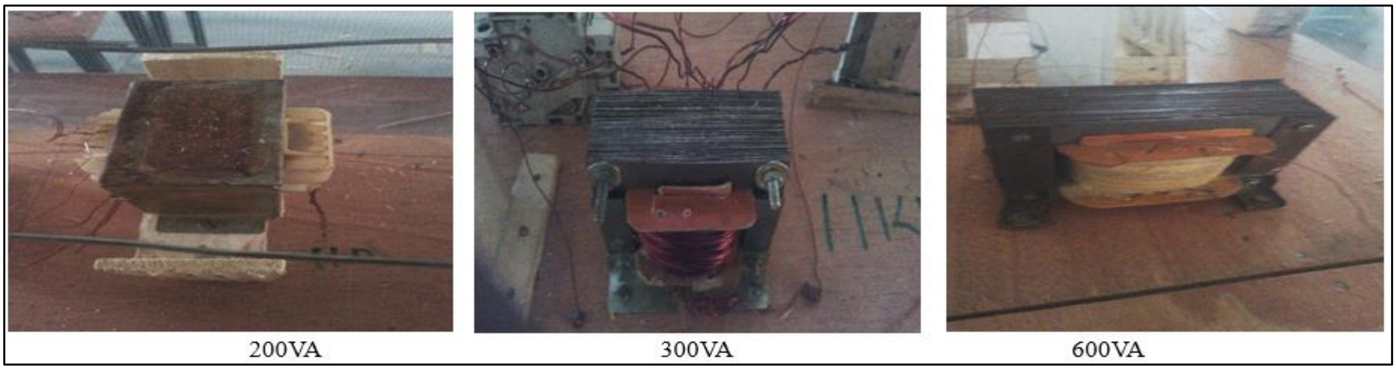

Fig 1 Transformer

➢ *Circuit Breaker*

It is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by over current or overload or short circuit.

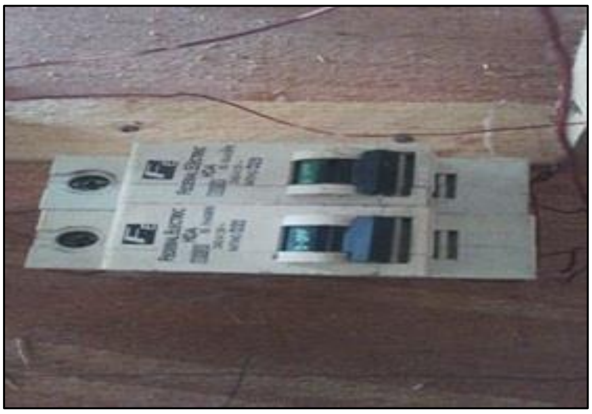
Fig 2 Circuit Breaker

➢ *Switch*

It is an electrical component that can break an electrical circuit interrupting the current or diverting it from one conductor to another.


Fig 3 Switch

➢ *Pole/Tower*

Are utility or post used to support overhead power lines and various utilities such as cable, fiber optic cable and related equipment such as transformers.


Fig 4 Pole/Tower

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➢ *Indicators*

Thus, are devices which provide a visual or remotes indication/display of electrical power (voltage, current) reading.

Fig 5 Indicators

➢ *Aluminum*

We made use of Aluminum of $2.5mm^2$, a type of high capacity, high strength stranded conductor typically used in overhead power lines.

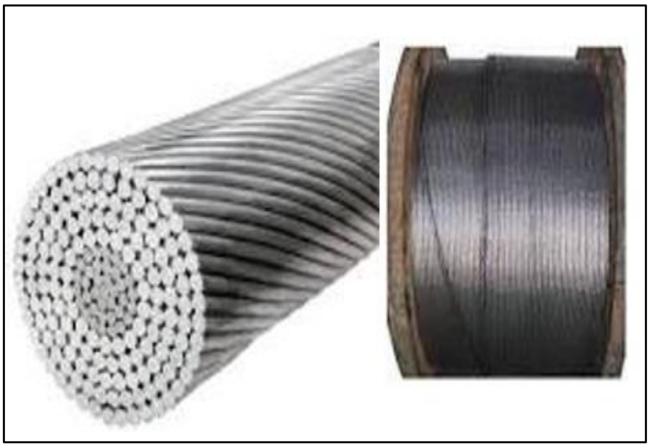

Fig 6 Aluminum Conductor

➢ *Module Assembling*

Material and size specifications are used for casing/covering of the complete system.

- *Dimension of Housing*

✓ Length=240cm
✓ Wide=50.08cm
✓ Depth=60.22cm

- *Materials for Housing*

✓ Plywood (1inch, ½ Inch)
✓ Wood (2 by 2)
✓ Ceiling
✓ Net
✓ Nail/crews

➢ *Construction Procedure*

The construction of this work was carried out by winding of transformer first, then construction of electronics circuit oscillator that act as Generator that converts 12VDC to 24VAC.

➢ *Construction of Transformer*

The construction of the transformer was done according to the standard method, where the ratio between the input winding and the output winding is equal to the ratio of input voltage and output voltage.

$E_1/E_2=N_1/N_2$

And the winding (turn) is depend upon the operating voltage and area of the winding space

$T_N= 45/A \times V$

Where 45 is constant for copper wire resistivity and A is the square root of the transformer capacity ($A=\sqrt{P}$), therefore

$T_N=45/\sqrt{P} \times V$

The size of the wire is chosen from the American wire gauge (AWG) table of wire size and current rating, the current rating of the conductor is found by the formula

$P=IV$, where $I=P/V$.

So, we started winding 600VA transformers that have input voltage of 24V AC and output voltage of 415V AC, the number of input voltage turns (primary winding)

$T_N=45/\sqrt{P} \times V$

Where the capacity of the transformer (P) is 600VA, converting to watt

$600 \times 0.75 = 450W$,

Therefore, for primary winding

$T_N=45/\sqrt{450} \times 24= 50.9$

Approximately 51turns. While for the secondary windings

$T_N=45/\sqrt{450} \times 415= 879.9$

Approximately 880turns. The current rating of the primary windings is

$I=P/V=450/24=18.7A$

Approximately 19A while for the secondary winding

$I=P/V=450/415= 1.08A$

Approximately 1.1A, so we check the American wire gauge (AWG) and selected the wire gauge that match the

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current rating of the winding, the size of wire that match 19 is gauge 17AWG and that of 1.1A is 29AWG. Therefore, the size of primary winding wire is gauge 17AWG and 29AWG for the secondary winding according to American wire gauge table of wire size and current rating. However, the same procedure was applied to other transformers and the data are recorded in the table 2.

Table 2 Transformer Winding Turns and their Wire Size

Input voltage (V)	Output voltage (V)	Input turns	Output turns	Input current (I)	Output current (I)	Input cable size (AWG)	Output cable size (AWG)
24V	415V	52N	880N	19A	1.1A	17	29
415V	220V	884N	468N	1.1A	2A	29	26
220V	110V	468N	234N	2A	4A	26	23
110V	60V	234N	127N	4A	8A	23	21
110V	12V/6V	234N	26N	4A	40A	23	12
60V	12V/6V	127N	26N	8A	40A	21	12

➢ *Construction of Oscillator*

The oscillator circuit in this system is constructed using transistors, capacitors, and resistors, arranged in a multivibrator configuration. This setup generates an alternating current (AC) signal of approximately 12V with a 100mV pulse waveform at a frequency of 50 Hz. The two output terminals of the oscillator are 180 degrees out of phase with each other. These outputs are then directed into power transistors (MOSFETs), which amplify the current. Each side of the MOSFET output delivers 12V AC at 20A relative to the positive terminal of the battery. Collectively, this results in a 14V AC potential difference across the two output terminals of the power transistors.

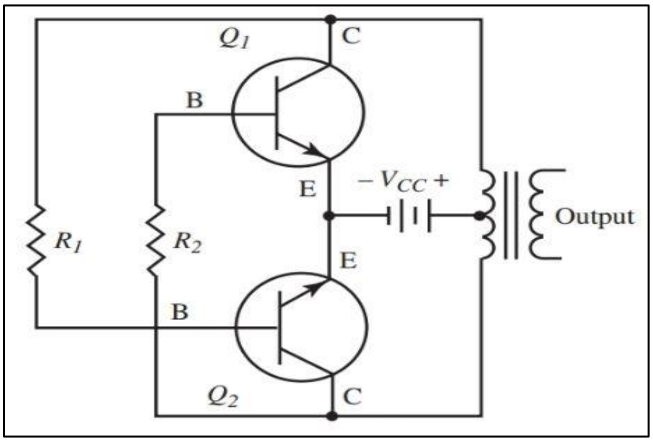

Fig 7 (a) Circuit Diagram of Oscillator [11]

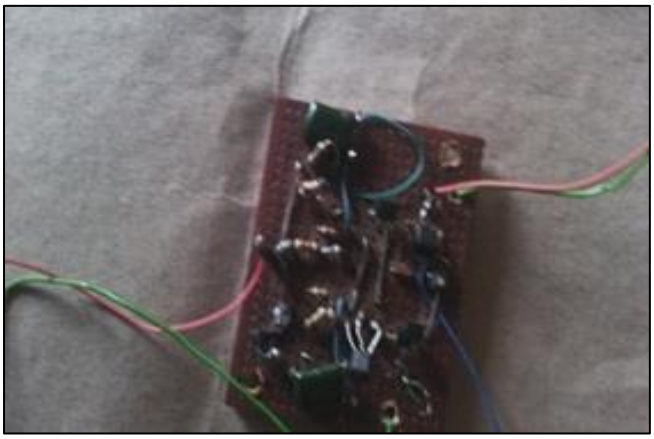
Fig 7 (b) Pictorial Diagram of Oscillator

➢ *Installation Procedure*

Below is the step-by-step procedure on how the system was installed.

- The position for each of the component parts of the system was marked on the installation board.
- The transformers were mounted on their specific positions, and this was followed by the erection of the poles and the towers.
- The running of cables was done simultaneously with the mounting of the circuit breakers Finally, the oscillator and the battery were installed, and different tests were then carried out.


Fig 8 (a) Pictorial Diagram of the Power System

➢ *Circuit Diagram and Principle of Operation*

The principal operation is based on the replication of principle operation of national grid system as shown in the figure 8.

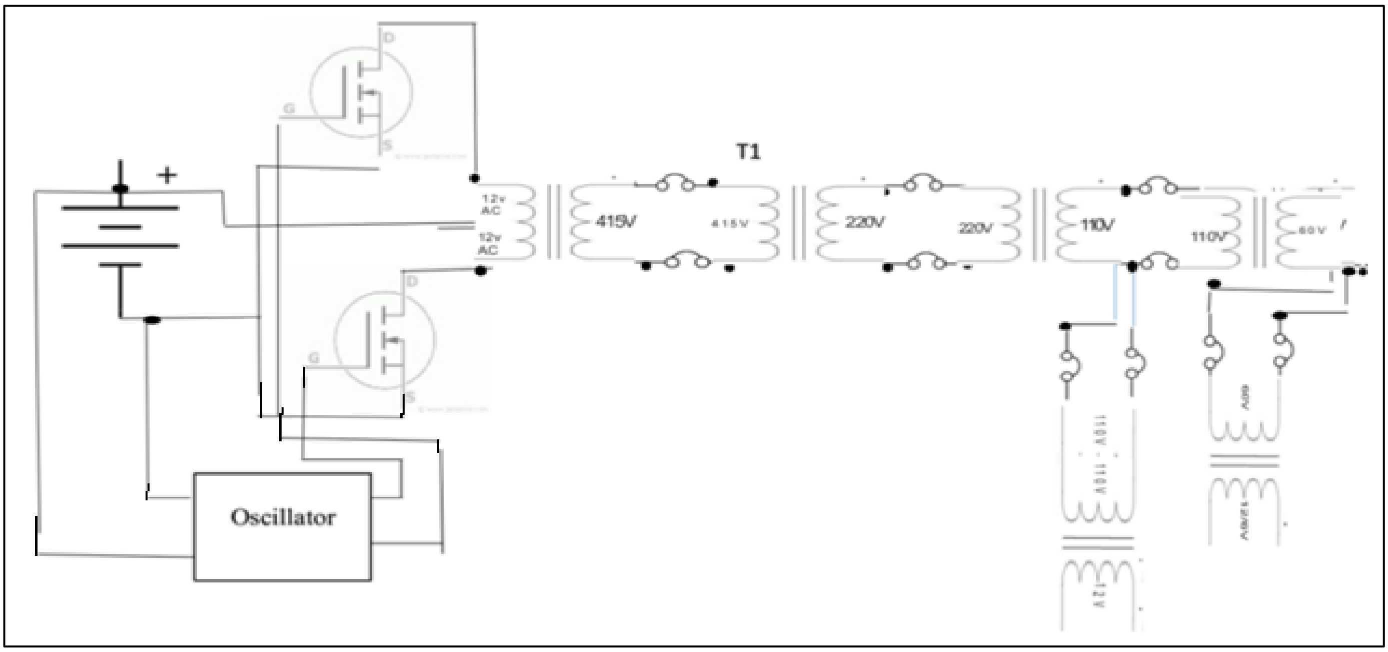

Fig 8 (b) Circuit Diagram of the Power System

The power from generator (24V AC) was fed to step-up transformer T1 primary winding to step-up to 415V AC at the secondary winding. The output voltage of the transformer (415V AC) is connected to the primary winding (input) of step-down transformer T2 that will step down the voltage to 220V. The output of the T2 (220V) is then connected to primary winding (input) through circuit breaker of the T3 to step it down to 110V AC. The output of T3 (110V AC) is fed to the output of the T4 through breaker to step it down to 60V AC. Along the 110V AC, a rural transformer T5 is installed to step-down the 110V AC directly to 12V AC through isolator to power the rural areas, the 60V AC output of the T4 is then fed to consumers transformer to step it down to 12V AC/ 6V AC for the final consumption.

III. RESULT AND DISCUSSION

The developed mini electrical power module was subjected to a series of tests to evaluate its functionality and verify the correctness of electrical connections and component operation. The testing procedure included continuity testing, generator output verification, and transformer performance evaluation.

The continuity test was conducted using a digital multimeter to ensure proper electrical connections between the generator, circuit breakers, transformers, and transmission lines. The results confirmed that all connections were properly established without open circuits or wiring faults.

➢ *Testing*

The testing of the result was divided into the following:

- Continuity test
- Generator test
- Transformer test

➢ *Continuity Test*

This test was carried out to verify proper electrical connections between the components. A multimeter was set to the continuity mode and used to check the link between the generator output and the circuit breaker, then from the breaker to the primary winding of transformer T1. Further checks were made from the secondary winding of T1 to the loading relay, and from the relay to the transmission line. The same procedure was repeated for transformers T2 through T6, along with their respective protective components, to ensure all paths were correctly connected and functioning.

➢ *Generator Test*

To evaluate the electronic generator, it was powered on and a multimeter, set to the AC voltage range, was connected in parallel with the oscillator output. The multimeter displayed a voltage of 13V AC, which was documented. Subsequently, the power transistors (MOSFETs) were activated, and a multimeter was placed in parallel with the MOSFET output. This reading showed 24V AC. Additional measurements were taken between each MOSFET output and the positive terminal of the battery, with each displaying 13V AC. All readings were recorded in the results table provided below:

Table 3 Generator Test

Generator output	Result
Oscillator	12V AC
Between Mosfet terminals	12V AC
Between Mosfet right terminals to Battery positive	12V AC
Between Mosfet left terminals to battery positive	12V AC

➢ *Transformer Test*

The primary transformer was switched On and the multimeter was placed at the primary winding and the meter display 25V AC, then the meter was place at the secondary winding of the T1, the meter display 435V AC, the same procedure was applied to the other transformers and the result was recorded at table 4 and 5 below:

Table 4 Individual Transformer Testing

Transformers	**Output (V)**	**Input (V)**
T1	25	435
T2	428	231
T3	227	116
T4	112	63
T5	112	12.4/6.2
T6	63	2.4/6.2

Table 5 Transformer Testing When Connected

Transformers	**Output (V)**	**Input (V)**
T1	24.6	422
T2	422	226
T3	220	112
T4	112	62
T5	112	12.4/6.10
T6	62	2.4/6.05

IV. CONCLUSION

The study successfully designed and developed a mini electrical power module that simulates the fundamental processes of power generation, transmission, and distribution. The developed system integrates key electrical components including transformers, oscillators, circuit breakers, and transmission structures to replicate the operation of a typical national power grid.

Experimental testing confirmed that the module performs according to the design expectations, with voltage levels accurately stepped up and stepped down across the transformer stages. The results demonstrate that the system can effectively illustrate the operational principles of electrical power systems.

The developed module serves as a valuable educational tool for engineering laboratories, enabling students to gain practical insight into power system operation. Furthermore, the concept of the mini power module provides a useful platform for future research in decentralized and small-scale electrical power systems, particularly for applications in rural or remote areas.

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