CHAPTER THREE

3.1 Project Methodology

The methodology employed in the research project consists of three main stages. First, the design and construction of the 2kVA locally made inverter, second, the installation and thirdly, the performance analysis.

3.2 Design and Construction of 2KVA Solar Powered Inverter

The design and construction of the 2KVA solar-powered inverter system are central to achieving a reliable and efficient power solution. The system is engineered to deliver a pure sine wave output at 220V, 50Hz, capable of powering essential household or small business loads up to 1600W (assuming a power factor of 0.8). The design process integrates solar energy harvesting, energy storage, and power conversion, with careful consideration of environmental and operational constraints.

3.2.1 Design Process

The design process begins with defining the system's specifications:

i. **Power Rating:** 2KVA (2000VA, equivalent to 1600W at 0.8 power factor).
ii. **Input Voltage:** 24V DC from a battery bank charged by solar panels.
iii. **Output Voltage:** 220V AC, 50Hz, pure sine wave.
iv. **Efficiency:** Targeted at 90% to minimize energy losses.
v. **Load Types:** Resistive (e.g., lights), inductive (e.g., fans), and capacitive (e.g., electronics).

The system comprises four primary subsystems:

i. **Solar Photovoltaic (PV) Array:** Converts sunlight into DC electricity.
ii. **Charge Controller:** Regulates battery charging from the solar array.
iii. **Battery Bank:** Stores energy for use during low or no sunlight periods.
iv. **Inverter Circuit:** Converts DC to AC for load consumption.

Component Selection and Sizing:

- **Solar PV Array:** A 600W array, consisting of two 300W monocrystalline panels connected in series, is selected to charge a 24V battery bank. Monocrystalline panels are chosen for their high efficiency (18–22%) and performance in Nigeria's high-temperature climate. The array is sized to deliver approximately 3.6–4.8 kWh/day (600W × 6–8 hours of sunlight), sufficient to charge a 200Ah battery bank and support daily load demands.

- **Charge Controller:** A 30A MPPT charge controller is used to maximize energy harvest and protect the battery. MPPT technology adjusts the panel's operating voltage to track the maximum power point, improving charging efficiency by up to 30% compared to PWM controllers. The controller includes features like overcharge protection, reverse current prevention, and temperature compensation.
- **Battery Bank:** Two 12V, 100Ah tubular batteries are connected in series to form a 24V, 100Ah bank (effectively 2400Wh capacity). Tubular batteries are selected for their long lifespan (8+ years with proper maintenance) and deep-cycle capability, ideal for solar applications. The capacity supports a 1600W load for approximately 1.5 hours (2400Wh ÷ 1600W) at full discharge, though the system is designed to maintain a 50% depth of discharge to extend battery life.
- **Inverter Components:** The inverter circuit uses a full-bridge topology with MOSFETs (e.g., IRF3205) for switching, controlled by a PIC16F877A microcontroller. A step-up transformer converts the low-voltage AC to 220V, with multiple windings for flexibility (180V, 240V, 280V). Additional components include capacitors (e.g., 1000µF for filtering), resistors (e.g., 4.7kΩ for signal conditioning), and a voltage regulator (L7805CV for 5V supply to the microcontroller).

3.2.2 Construction Process

The construction phase involves assembling the components into a functional prototype, with an emphasis on local manufacturing techniques to reduce costs and enhance accessibility. The process is divided into several steps:

1. **Circuit Board Fabrication:** A printed circuit board (PCB) is designed and fabricated locally using a milling machine or chemical etching process. The PCB layout is optimized to minimize signal interference and ensure efficient heat dissipation. Components such as MOSFETs, capacitors, and the microcontroller are soldered onto the PCB using a soldering iron and lead-free solder for environmental compliance.
2. **Transformer Construction:** The step-up transformer is wound locally using a toroidal core to reduce electromagnetic interference and improve efficiency. Copper wires of appropriate gauge (e.g., 16 AWG for primary, 20 AWG for secondary) are used to handle the calculated currents (92.6A input, 9.09A output). The windings are insulated with high-temperature varnish to prevent short circuits.
3. **Enclosure Assembly:** The inverter circuit, charge controller, and associated wiring are housed in a metallic or reinforced plastic enclosure to protect against dust, moisture, and physical damage. The enclosure includes ventilation slots and a cooling fan to manage heat generated by the transformer and MOSFETs. An LCD display and LED indicators are mounted on the front panel for user interaction.
4. **Battery and Solar Panel Integration:** The battery bank is connected to the charge controller and inverter using heavy-duty cables (e.g., 4 mm^2) to minimize voltage drop. The solar panels are wired in series-parallel and connected to the charge controller, with fuses installed to protect against overcurrent.
5. **Quality Control:** Each construction step is followed by visual inspections and continuity tests to ensure proper connections. The assembled prototype is subjected to initial power-on tests to verify functionality, with adjustments made to correct any issues (e.g., loose connections, incorrect soldering).

The construction process leverages locally available tools and materials, such as soldering stations, multimeters, and copper wires, sourced from markets in Ilorin, Nigeria. This approach reduces costs by approximately 20–30% compared to imported systems and supports local vendors, contributing to economic growth.

3.3 INSTALLATION OF THE 2KVA SOLAR POWERED INVERTER SYSTEM

The installation phase ensures that the 2KVA solar-powered inverter system is deployed effectively in a real-world setting, such as a household or small business. The installation process is designed to be user-friendly, with clear guidelines for local technicians to follow, promoting scalability and adoption.

3.3.1 Installation Steps

1. **Site Assessment:** The installation begins with a site survey to determine the optimal location for the solar panels, battery bank, and inverter. The panels are placed on a rooftop or open area with unobstructed sunlight exposure, ideally facing south at a tilt angle of 10–15° to maximize solar irradiance in Nigeria's equatorial climate. The inverter and battery bank are installed indoors in a well-ventilated, dry area to protect against heat and humidity.
2. **Solar Panel Mounting:** The 600W solar array is mounted on a galvanized steel frame, secured with bolts and nuts to withstand wind and weather conditions. The panels are wired in series to achieve a 24V output, with cables routed through conduits to prevent damage.
3. **Battery and Inverter Setup:** The battery bank is placed on a stable, insulated platform to prevent short circuits. The inverter is mounted on a wall or rack, with sufficient clearance for ventilation. All connections are made using color-coded cables, and terminal covers are used to enhance safety.
4. **Wiring and Integration:** The solar panels are connected to the charge controller, which is linked to the battery bank. The battery bank is then connected to the inverter's DC input terminals. The inverter's AC output is wired to a distribution board, which supplies power to the load. A bypass switch is installed to allow manual changeover to grid power (if available) during maintenance.
5. **Commissioning:** The system is powered on, and initial tests are conducted to verify solar charging, battery operation, and inverter output. The LCD display is checked to ensure accurate reporting of battery status, voltage, and load conditions. Users are trained on basic operation and maintenance, such as cleaning solar panels and monitoring battery electrolyte levels.

3.3.2 Practical Considerations

The installation process accounts for Nigeria's environmental and infrastructural challenges. For example, the system is designed to operate in high temperatures (up to 40°C), with cooling mechanisms to prevent overheating. The use of locally sourced mounting frames and cables reduces logistical delays and costs. The installation manual is written in simple language, with diagrams to assist technicians with limited formal training, ensuring accessibility in rural areas.

3.4 Electronics of the Circuit diagram

This section explicitly deals with some of the electrical technicalities considered in the making of the project. Some explanations take authority or support from manufacturer guides or handbooks and datasheets of some of the components used.

3.4.1 The Transformer

The input to the primary winding of the transformer (T1) is 240V. The secondary winding can be raised up to 27 volts if the value is at least 24 volts running 4 amps. The fuse (FS1) acts as a mini circuit breaker for protection against short circuits or a defective battery cell. The presence of electricity will cause LED1 to light. The light of LED will set off upon power outage, and the UPS battery will take over. The circuit was designed to offer a more flexible pattern wherein it can be customized by using different regulators and batteries to produce regulated and unregulated voltage. Utilizing two 24-volt batteries in series and a positive input 7815 regulator can control a 27V supply.

3.5 The Electronics of an Inverter System

The basic principle in terms of operation of a UPS is a device that can convert the chemical energy stored in a battery to electrical energy. Although the process of conversion (inverting) requires some stages to be fulfilled, some of the stages are discussed next.

1. **The Rectification Stage:** It is a rectifier stage that simply means the conversion of an alternating signal (AC) into a direct signal (DC). It has two main functions. Firstly, to convert alternating current (AC) into direct current (DC) through the supply of filtered load or the supply inverter. Secondly, to provide battery charging voltage, therefore, it also plays a role in the charging section.
2. **Batteries Bank:** The batteries are used as storage energy devices, consisting of several cells in series, with a capacity to maintain their size, which determines the discharge (supply) time. Their main function is that when electricity is normal, the energy is converted into chemical energy stored in the battery; when electricity fails, the chemical energy is provided to the inverter or the load.

3. **Inverting Stage:** Generally, inverting is a direct current (DC) to alternating current (AC) process. It mainly consists of the oscillation stage.
4. **Static Switch:** It is a contact-type switch; in this project design, FET and electromechanical relays are employed for the switch stages.
5. **Oscillator Stage:** This stage receives voltage from the battery and generates frequency from DC to AC. It is a device (stage) that increases the power of a signal by taking energy from a power supply and controlling the output to match the input signal shape but with a larger amplitude. In this case, the amplifier modulates the output of the power supply. This stage is coupled with electronic components like transistors, resistors, capacitors, variable resistors, and integrated circuits (IC). We use an IC with a chip, and all the output it generates will not be more than 5 volts (7805).
6. **Integrated Circuit:** Also called IC, they are very complex in construction. An IC has pins numbered anticlockwise around the chip starting at the notch or dot. In this circuit, we use CD4047 with 14 legs.
7. **Bipolar Junction Transistor (BJT):** It has a base, collector, and emitter as terminals. The base is a very thin layer with fewer doping atoms than the emitter and collector, allowing a very small current to flow from emitter to collector.
8. **Driver Stage:** This is where lower voltage is converted to high current through the use of MOSFETs. The MOSFET is the main component in this stage, with three terminals: source, drain, and gate (S, D, G). When the driver stage receives the signal, it will free or force the gate to generate high current. The MOSFET is coupled with a 1000-ohm resistor connected to it. In the circuit, we have six MOSFETs connected together with six resistors.
9. **Transformer Stage:** We use a transformer in this stage to generate the final alternating current (AC), i.e., 220V 50Hz. This stage mainly consists of a transformer, but to construct it, it is coupled with some components and follows some laws.

3.6 Design Equations and Calculations

Since magnetic components, i.e., transformers, are indispensable parts of most power electronic inverters, they are not commercially available, so they have to be designed and constructed for a particular application. The following values were assumed for the project:

- Specific magnetic loading "β" = 1.0 wb/m^2
- Output power rating = 2000 VA
- Efficiency = 90% = 0.9
- Primary voltage = 24 V

- Secondary voltage = 220 V
- Frequency = 50 Hz

Input power

2000 / 0.9 ≈ 2222.2 watts

Input Current

2222.2 / 24 ≈ 92.6 A

For the secondary side:

Output Current

2000 / 220 ≈ 9.09 A

Determining the number of turns:

Assuming a similar transformer design, with Np ≈ 16 turns (rounded for simplicity), since the voltages remain the same.

Therefore, for Vs = 180, 240, 280 V:

Given Np = 16

Vp = 24 V

For Vs = 180 V

Ns = (180 / 24) * 16 = 120 turns

For Vs = 240 V

Ns = (240 / 24) * 16 = 160 turns

For Vs = 280 V

Ns = (280 / 24) * 16 ≈ 187 turns

3.7 Circuit Diagram of the Project

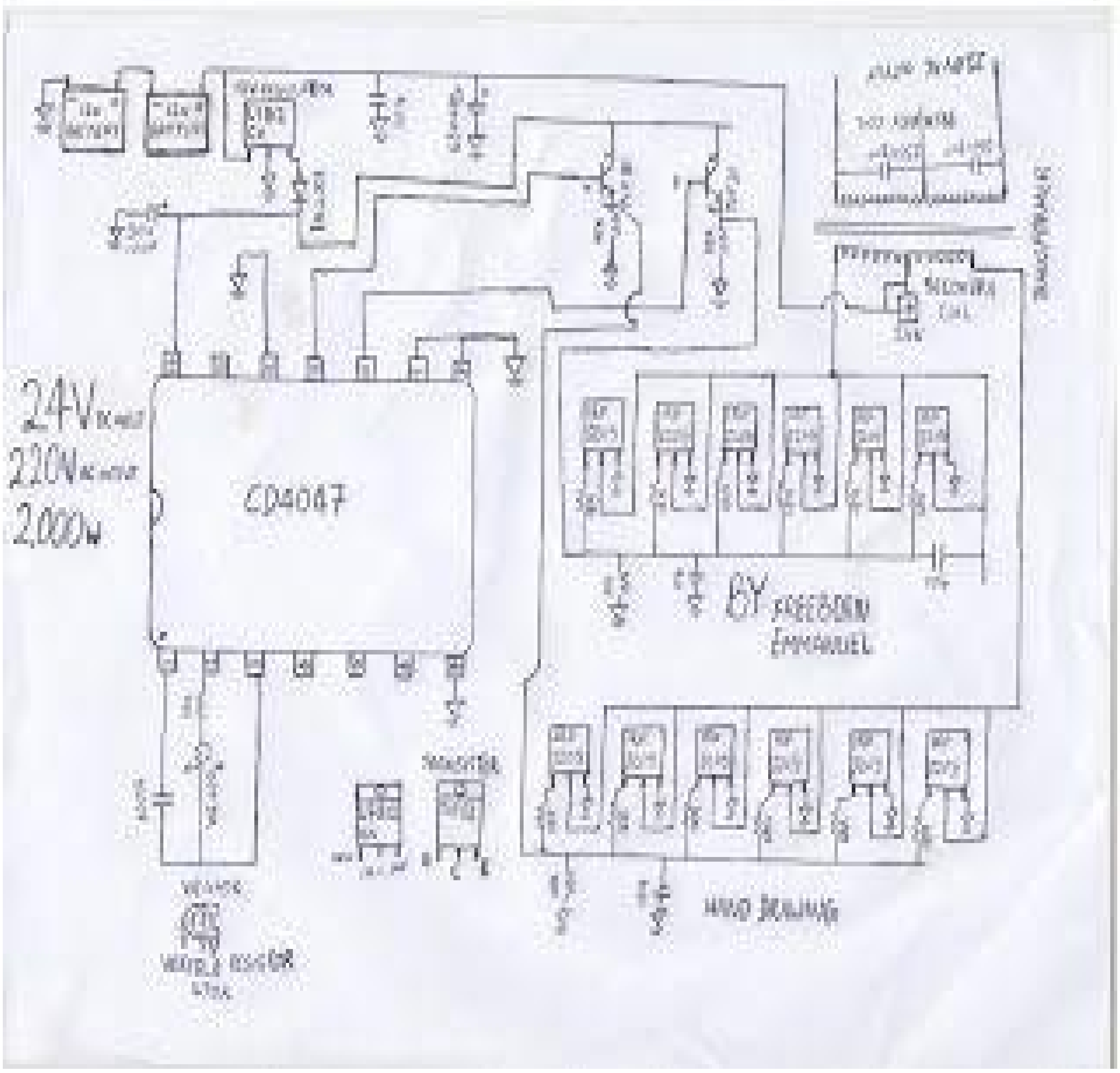

Figure 3.1: Circuit Diagram for 2kVA Inverter System

3.7.1 Circuit Diagram Explanation

The circuit diagram illustrates the integration of the solar panels, charge controller, battery bank, inverter circuit, and load. Key elements include:

i. **Solar Input Section:** Solar panels connected to the MPPT charge controller.

ii. **Charge Controller Section:** Regulates battery charging with MPPT algorithms.

iii. **Inverter Active Section:** Full-bridge MOSFETs driven by PWM signals.

iv. **Microcontroller Section:** PIC16F877A with PWM outputs and ADC inputs.

v. **Transformer Section:** Steps up the AC to 220V.

vi. **Protection and Monitoring:** Fuses, relays, and LCD display for safety and user interaction.

Circuit Explanation:

i. The solar panels feed DC to the charge controller, which charges the battery bank.
ii. The battery supplies 24V DC to the inverter's full-bridge circuit, where MOSFETs switch to produce low-voltage AC.
iii. The microcontroller generates PWM signals, amplified by the driver IC, to control the MOSFETs.
iv. The transformer steps up the AC to 220V, delivering power to the load.
v. Protection circuits and indicators ensure safe and reliable operation.