Intelligent Fault Diagnosis In Cascaded Multilevel Inverters Using Multiscale Kernel CNN

S. Das Vignesh[1], S. Sathishkumar[2], S. Tamilarasan[3], L. Priyadharsan[4], Mr. D. Saravanan[5]
[1, 2, 3, 4] Dept of Electrical and Electronics Engineering
[5]Head of Dept, Dept of Electrical and Electronics Engineering
[1, 2, 3, 4, 5] Paavaicollege of Engineering,Namakkal,Tamil Nadu,India.

Abstract- *This paper proposes an intelligent fault diagnosis method for cascaded multilevel inverters using a multiscale kernel convolutional neural network (CNN). The approach leverages the ability of CNNs to extract features from signals and diagnose faults in inverters. By utilizing multiscale kernels, the method can effectively capture fault characteristics at different scales, enhancing diagnosis accuracy. The proposed method is validated through experiments, demonstrating its effectiveness in detecting and classifying faults in cascaded multilevel inverters.*

Keywords- Fault Diagnosis, Multiscale Kernel CNN, Improved Accuracy, Experimental Validation, Fault Classification.

I. INTRODUCTION

Increasing global demand for clean, renewable energy has led to significant advances in solar energy technologies. Solar energy, being abundant and eco-friendly, has become a preferred source for electricity generation in both residential and industrial applications. A typical solar energy system involves converting sunlight into electrical energy using photovoltaic (PV) panels, storing the energy in batteries as direct current (DC), and converting it into alternating current (AC) using inverters for practical usage. The inverter stage is crucial, as most electrical appliances operate on AC power. To improve efficiency, power quality, and performance, multilevel inverter configurations have gained popularity, especially the cascaded H-bridge multilevel inverter, which offers multiple output levels, reduced harmonic distortion, and higher voltage handling capabilities.

Among various inverter topologies, cascaded multilevel inverters are highly suitable for renewable energy applications due to their modular structure, ease of control, and ability to operate without transformers. In a cascaded setup, multiple H-bridge inverter cells are connected in series, and each stage contributes a part of the total output voltage. This arrangement results in a stepped output waveform that closely approximates a sinusoidal AC signal. As the number of voltage levels increases, the quality of the waveform improves, leading to better power delivery with minimal filtering requirements. Despite these advantages, the

complex structure and the increased number of power switches and components also introduce a higher possibility of faults, such as open-circuit and short-circuit failures in switches, unequal voltage levels from the DC sources, or distortion due to partial failure in one of the inverter cells.

Faults in the inverter system can severely affect the performance and reliability of the power supply. A minor malfunction in any of the inverter stages can result in voltage imbalances, waveform distortion, increased losses, or even complete system shutdown. Traditional fault detection techniques are often based on simple threshold-based monitoring, hardware protection circuits, or manual inspection. These methods are time-consuming, inefficient under dynamic conditions, and incapable of identifying the type and location of faults accurately. As solar systems become more autonomous and are deployed in remote areas, there is a growing need for intelligent, automated, and real-time fault diagnosis systems.

II. LITERATURE SURVEY

Existing System

A. Fault Diagnosis of Cascaded Multilevel Inverter Using Multiscale Kernel Convolutional Neural Network

This paper introduces a fault diagnosis methodology for cascaded multilevel inverters utilizing a Multiscale Kernel Convolutional Neural Network (MK-CNN). Cascaded multilevel inverters (MLIs) are widely used due to their ability to produce high-quality AC output from a DC source, but they are prone to faults, especially with the growing complexity of their configuration. Traditional fault detection methods often struggle to detect faults in a timely and accurate manner, making it crucial to develop an intelligent, automated approach.The authors propose an MK-CNN, which incorporates multiple kernel sizes to analyse inverter waveform data at different scales, making it possible to capture both fine-grained and large-scale fault-related features. The MK-CNN model processes real-time voltage and current signals from the inverter, identifying deviations that signify potential faults such as open-circuit switches, short-circuits, or malfunctioning devices. The system's ability to identify faults accurately and in real time is demonstrated through simulations and experimental results, showing promising results in diagnostic accuracy and reduced computational load.

B. Intelligent Diagnosis of Cascaded H-Bridge Multilevel Inverter Combining Sparse Representation and Deep Convolutional Neural Networks

In this paper, the authors propose an advanced fault diagnosis method for cascaded H-bridge multilevel inverters (CHB-MLIs), which combines sparse representation with deep convolutional neural networks (DCNNs). The CHB-MLI is a popular topology due to its modular structure and ability to generate high-quality output. However, its complex nature increases the likelihood of faults, necessitating effective diagnostic methods.

The authors' approach starts by transforming the inverter's time-domain voltage and current signals into time-frequency images using sparse representation. This transformation enhances the relevant fault-related features, allowing for better feature extraction. These time-frequency images are then processed by a deep convolutional neural network (DCNN), which learns to classify different fault types based on the features extracted from the images.

C. Fault Diagnosis Method of a Cascaded H-Bridge Inverter Based on a Multisource Adaptive Fusion CNN-Transformer

This paper presents a fault diagnosis technique for cascaded H-bridge inverters using an innovative approach that combines Convolutional Neural Networks (CNNs) with Transformer models. The method involves multisource adaptive fusion, where the system uses multiple sources of information (e.g., current, voltage, temperature) to enhance diagnostic accuracy. The CNN is employed for feature extraction from the inverter's signal data, while the Transformer model processes temporal information to capture long-range dependencies between signal features.

The key innovation of this approach is the adaptive fusion of CNN and Transformer models, which allows the system to detect faults under various dynamic conditions. This hybrid model improves the system's ability to generalize across different fault types, ensuring that it performs well even when the inverter operates in suboptimal or non-ideal conditions.

D. Machine Learning Based Fault Detection Technique for Hybrid Multilevel Inverter Topology

This paper explores a machine learning-based fault detection technique for hybrid multilevel inverter topologies, which combine various inverter stages to enhance system flexibility and performance. The hybrid topology is widely used in high-power applications due to its ability to generate multilevel AC output efficiently. However, its complexity increases the probability of faults, making accurate and fast fault detection essential.

The proposed method leverages wavelet transform for feature extraction from the inverter's output signals. The wavelet transform helps decompose the signals into multiple frequency bands, making it easier to isolate and analyze fault-induced changes. Once the features are extracted, they are fed into a machine learning classifier, which identifies different fault conditions, such as open-circuit faults or short-circuit faults.

The system is evaluated through simulations, where it shows excellent accuracy in detecting faults even under noisy conditions. The machine learning-based approach is shown to be more effective than traditional methods, which often rely on predefined rules or thresholds. Furthermore, the method is computationally efficient and suitable for real-time applications in industrial inverter systems.

This research provides a novel and robust fault detection solution, enhancing the reliability and safety of hybrid multilevel inverter systems. The integration of wavelet transform and machine learning enables effective monitoring and maintenance, ensuring the inverter's optimal performance and reducing the risk of system failure.

III. PROPOSED SYSTEM

The proposed system integrates several key components to optimize energy conversion and management in a solar power application. The architecture includes a solar panel for energy harvesting, a boost converter to step up the voltage from the solar array, a controller for managing system operations, a battery for energy storage, a multilevel inverter for converting DC to AC, and a fault identification mechanism to ensure reliable operation.

1. **Solar Panel**: The system begins with solar panels that capture sunlight and convert it into direct current

(DC) electricity. The efficiency of the solar panels is crucial for maximizing energy harvest.

2. **Boost Converter**: Following the solar panels, a boost converter increases the voltage level of the generated DC electricity to match the requirements of the battery and the inverter. This step is essential for ensuring that sufficient voltage is available for charging the battery and for the inverter's operation.
3. **Controller**: The controller plays a vital role in managing the entire system. It regulates the operation of the boost converter, monitors the state of charge of the battery, and ensures optimal energy flow between the solar panels, battery, and inverter. The controller can also implement algorithms for maximum power point tracking (MPPT) to extract the highest possible energy from the solar panels.
4. **Battery**: The battery serves as an energy storage solution, allowing excess energy generated by the solar panels to be stored for use during periods of low sunlight or high demand. The capacity and management of the battery are critical for maintaining a stable power supply.
5. **Multilevel Inverter**: The multilevel inverter converts the stored DC energy from the battery into alternating current (AC), suitable for powering household appliances or feeding into the grid. The use of a multilevel inverter enhances the quality of the output voltage, reduces harmonic distortion, and improves overall system efficiency.

Fault Identification: An integral feature of the proposed system is a fault identification mechanism. This system continuously monitors various parameters such as voltage, current, and temperature to detect anomalies that may indicate faults within the solar panels, boost converter, battery, or inverter. Early detection of faults facilitates timely maintenance and enhances overall system reliability.

Load: Finally, the AC output from the multilevel inverter is delivered to the load, which could be residential appliances, industrial equipment, or even a connection to the electrical grid. The system is designed to meet the energy demands of the load while ensuring efficient operation and minimal downtime.

In summary, this proposed system effectively combines renewable energy generation with advanced power electronics and fault management strategies, creating a robust and reliable solution for harnessing solar energy. The integration of these components not only optimizes energy conversion but also enhances the sustainability and resilience of the energy supply.

Hardware Requirements

A step-up transformer is used to increase the voltage level of the input power. A voltage sensor monitors the voltage output and provides feedback to the control system. Solar panels serve as the renewable energy source, generating power that is regulated by a regulator circuit to ensure stable output. An Arduino microcontroller acts as the brain of the system, processing data from sensors and controlling the overall operation. A lamp serves as the load, while a relay module enables the system to switch the load on or off as needed. An LCD display provides real-time information on system parameters, such as voltage and operating status. A battery stores excess energy generated by the solar panels, ensuring a stable power supply. A multilevel inverter converts the DC power from the solar panels or battery into AC power, suitable for powering the lamp or other loads. This integrated setup enables efficient and reliable operation of the solar-powered system.

MODULE LIST

- VOLTAGE SENSOR
- SOLAR
- REGULATOR CIRCUIT
- ARDUINO
- LAMP
- RELAY
- LCD DISPLAY
- BATTERY
- MULTILEVEL INVERTER

BLOCK DIAGRAM:

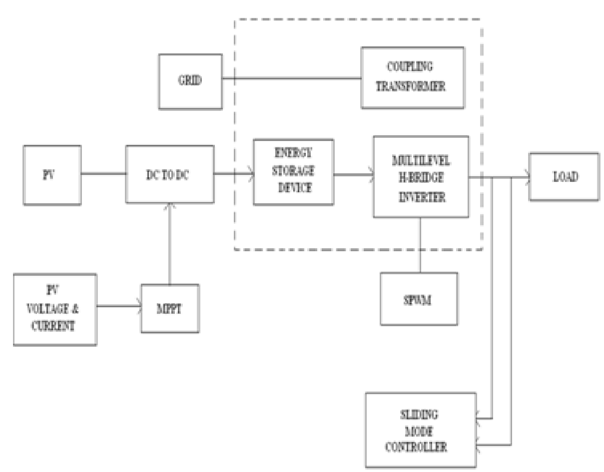

Fig.1.Proposed Block Diagram

VOLTAGE SENSOR

A voltage sensor measures and monitors voltage levels within an object, detecting either AC or DC voltage. It inputs voltage and outputs various forms such as switches, analog voltage signals, current signals, or audible signals.
Sensors are devices that can sense or identify and react to certain types of electrical or optical signals. The implementation of a voltage sensor and current sensor techniques have become an excellent choice for the conventional current and voltage measurement methods.

In this article, we can discuss a voltage sensor in detail. A voltage sensor can determine, monitor, and measure the supply of voltage. It can measure the AC level and/or DC voltage level. The input to the voltage sensor is the voltage itself, and the output can be analog voltage signals, switches, audible signals, analog current levels, frequency, or even frequency-modulated outputs.

That is, some voltage sensors can provide sine or pulse trains as output, and others can produce amplitude modulation, pulse width modulation, or frequency modulation outputs.

In voltage sensors, the measurement is based on a voltagedivider. Two main types of voltage sensors are available: capacitive type voltage sensor and resistive type voltage.

Fig.2.Voltage Sensor

REGULATOR CIRCUIT

The next and the last stage before load, in a power supply system is the Regulator part. Let us now try to understand what a regulator is and what it does.

The part of electronics that deal with the control and conversion of electric power can be termed as Power Electronics. A regulator is an important device when it comes to power electronics as it controls the power output.

For a Power supply to produce a constant output voltage, irrespective of the input voltage variations or the load current variations, there is a need for a voltage regulator.

A voltage regulator is such a device that maintains constant output voltage, instead of any kind of fluctuations in the input voltage being applied or any variations in current, drawn by the load. The following image gives an idea of what a practical regulator looks like.

Types of Regulators

Regulators can be classified into different categories, depending upon their working and type of connection.

Depending upon the type of regulation, the regulators are mainly divided into two types namely, line and load regulators

ARDUINO

Arduino was a project started at Interaction Design Institute Ivrea (IDII) in Ivrea, Italy, with its primary goal being creating affordable and straightforward tools for non-engineers to use and create digital projects. During its infancy, the project consisted of just three members- Hernando Barragán, Massimo Banzi, and Casey Reas. Hernando Barragán worked under the guidance of Massimo Banzi and Casey Reas and created a development platform called Wiring as his masters' thesis project at IDII. The development platform consisted of the ATMega168 microcontroller as its brains and used an IDE based on Processing, which was co-created by Casy Reas. Later, Massimo Banzi, along with two other students from IDII, namely- David Mellis and David Cuartielles, added support for the cheaper ATMega8 microcontroller. The three, instead of working on developing and improving Wiring, they forked it and renamed the project to Arduino. The initial core Arduino team consisted of Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, and David Mellis, but Barragán was not included.

Now that you know the origin of Arduino, it is essential to get yourself acquainted with the hardware that Arduino as a company offers. One of the main reasons for Arduino being so accessible and affordable across the globe is because all of the Arduino hardware is open-source. Being open-source has a plethora of advantages- anyone can access the design and build of the device and make improvements; anyone can use the same hardware design to create their product lineup. Since Arduino is open-source, it has its own devoted community that strives to help the core company develop and improve its hardware products. Another significant advantage of being open-source, especially in the case of hardware, is that local companies can create replicas of the products, making it more accessible and affordable to the local consumers as it avoids hefty customs and shipping charges. All of these advantages contribute to Arduino being so widespread, affordable and ever-improving.

Fig.3. Arduino

SOLAR PHOTOVOLTAIC CELL

Conversion of light energy in electrical energy is based on a phenomenon called photovoltaic effect. When semiconductor materials are exposed to light, the some of the photons of light ray are absorbed by the semiconductor crystal which causes a significant number of free electrons in the crystal. This is the basic reason for producing electricity due to photovoltaic effect. **Photovoltaic cell** is the basic unit of the system where the photovoltaic effect is utilised to produce electricity from light energy. Silicon is the most widely used semiconductor material for constructing the photovoltaic cell. The silicon atom has four valence electrons. In a solid crystal, each silicon atom shares each of its four valence electrons with another nearest silicon atom hence creating covalent bonds between them. In this way, silicon crystal gets a tetrahedral lattice structure. While light ray strikes on any materials some portion of the light is reflected, some portion is transmitted through the materials and rest is absorbed by the materials.

The same thing happens when light falls on a silicon crystal. If the intensity of incident light is high enough, sufficient numbers of photons are absorbed by the crystal and these photons, in turn, excite some of the electrons of covalent bonds. These excited electrons then get sufficient energy to migrate from valence band to conduction band. As the energy level of these electrons is in the conduction band, they leave from the covalent bond leaving a hole in the bond behind each removed electron. These are called free electrons move randomly inside the crystal structure of the silicon. These free electrons and holes have a vital role in creating electricity in **photovoltaic cell**. These electrons and holes are hence called **light-generated electrons and holes** respectively. These light generated electrons and holes cannot produce electricity in the silicon crystal alone. There should be some additional mechanism to do that.

REGULATOR 7805

Voltage sources in a circuit may have fluctuations resulting in not providing fixed voltage outputs. A voltage regulator IC maintains the output voltage at a constant value. 7805 IC, a member of 78xx series of fixed linear voltage regulators used to maintain such fluctuations, is a popular voltage regulator integrated circuit (IC). The xx in 78xx indicates the output voltage it provides. 7805 IC provides +5 volts regulated power supply with provisions to add a heat sink.

All voltage sources cannot able to give fixed output due to fluctuations in the circuit. For getting constant and steady output, the voltage regulators are implemented. The integrated circuits which are used for the regulation of voltage are termed as voltage regulator ICs. Here, we can discuss about IC 7805.The **voltage regulator IC 7805** is actually a member of 78xx series of voltage regulator ICs. It is a fixed linear voltage regulator. The xx present in 78xx represents the value of the fixed output voltage that the particular IC provides. For 7805 IC, it is +5V DC regulated power supply. This regulator IC also adds a provision for a heat sink. The input voltage to this voltage regulator can be up to 35V, and this IC can give a constant 5V for any value of input less than or equal to 35V which is the threshold limit

7805 IC Rating

- Input voltage range 7V- 35V
- Current rating $I_{c\,=}$ 1A
- Output voltage range $V_{Max=5.2V}$, $V_{Min=4.8V}$

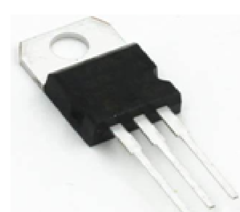

Fig.4. Voltage Regulator

RELAY DRIVER

A relay driver circuit is a circuit which can drive, or operate, a relay so that it can function appropriately in a circuit.

The driven relay can then operate as a switch in the circuit which can open or close, according to the needs of the circuit and its operation

In this project, we will build a relay driver for both DC and AC relays. Since DC and AC voltages operate differently, to build relay drivers for them requires slightly different setup. We will also go over a generic relay driver which can operate from either AC or DC voltage and operate both AC and DC relays.

All the circuits are relatively simple to understand.

DC Relay Driver Circuit

We will first go over how to build a relay driver circuit for relays which operate from DC power.

To drive a DC relay, all we need is sufficient DC voltage which the relay is rated for and a zener diode.

All relays come with a voltage rating. This is called on a relay's datasheet its rated coil voltage. This is the voltage needed in order for the relay to be able to operate and be able to open or close its switch in a circuit. In order for a relay to function, it must receive this voltage at its coil terminals. Thus, if a relay has a rated voltage of 9VDC, it must receive 9 volts of DC voltage to operate. So the most important thing a DC relay needs is its rated DC voltage. If you don't know this, look up what relay you have and look up its datasheet and check for this specification.

And the reason why a diode is needed is usually because it functions to eliminate voltage spikes from a relay circuit as the relay opens and closes. The coil of a relay acts an inductor. Remember that inductors are basically coils of wires wrapped around a conductive core. This is what relay coils are as well. Therefore, they act as inductors. Inductors are electronic components that resist changes in current. Inductors do not like sudden changes in current. If the flow of current through a coil is suddenly interrupted, for example, a switch opening, the coil will respond by producing a sudden, very large voltage across its leads, causing a large surge of current through it. From a physics or physical perspective, this phenomen is a result of a collapsing magnetic field within the coil as the current is terminated abruptly. Mathematically, this can be understood by noticing how a large change in current (dI/dt) affects the voltage across a coil (V=LdI/dt). Since we are opening the switch, in this case, the current literally goes from full mode to 0 instantaneously. This creates a large voltage spike.

Surges in current that result from inductive effects can create very high voltage spikes (as high as 1000V) that can have nasty effects on neighboring devices with in the circuits, such as switches and transistors getting zapped. Not only are these voltage spikes damaging to other electronic components in a circuit but thye are also damaging to the relay's switch contacts. The contacts will suffer from these spikes as well.

The diode must be rated to handle currents equivalent to the maximum current that woudl have been flowing through the coil before the supply current was interrupted. Therefore, if the relay normally passes a certain amount of current through it during normal operation, the diode must be rated for a current rating above this value, as to not stop normal operation.

Components Needed

- DC Relay.
- DC Voltage Source.
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DC Relay Driver Circuit Schematic

Below is the DC relay driver circuit which we will build

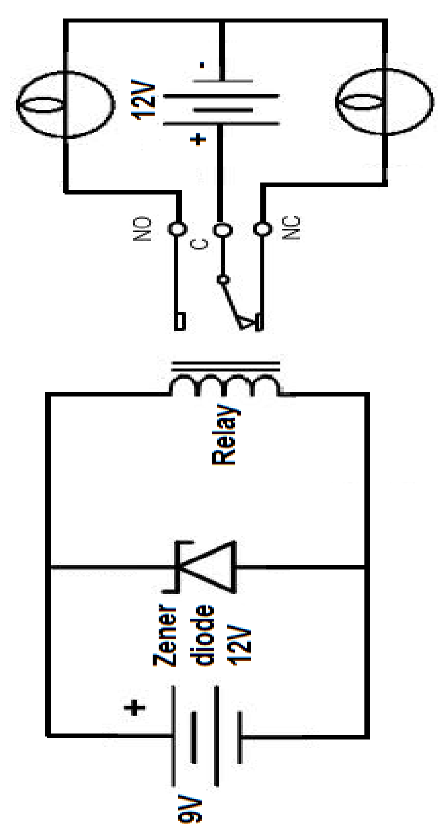

Fig.5.DC Relay Driver Circuit Schematic

LCD

A liquid-crystal display (LCD) is a flat-panel display or other electronic visual display that makes advantage of liquid crystals' light-modulating characteristics. Liquid crystals do not directly emit light. The command register holds the LCD's command instructions. A command is an order issued to an LCD to do a specific action such as initializing it, clearing its screen, setting the cursor location, managing the display, and so on. The data register saves the information that will be presented on the LCD. Computer monitors, TVs, instrument panels, aircraft cockpit displays, and signs are all examples of electronic displays. They are widespread in consumer gadgets such as DVD players, gaming devices, clocks, watches, calculators, and telephones, and have virtually completely replaced cathode ray tube (CRT) displays.

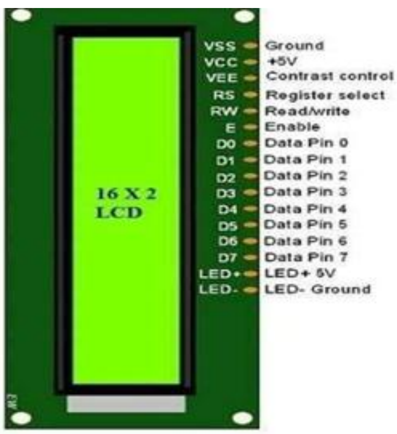

Fig.6. LCD

STEP UP TRANSFORMER

A step-up transformer is an essential electrical device that transforms voltage levels in alternating current (AC) circuits. It increases the voltage from a lower level to a higher one while simultaneously decreasing the current. This process is crucial in various applications, particularly in power transmission, where high voltages are necessary to reduce energy losses over long distances.

Working Principle

The operation of a step-up transformer is based on Faraday's law of electromagnetic induction. It consists of two coils of wire, known as the primary and secondary windings, wound around a magnetic core. When an AC voltage is applied to the primary winding, it generates a magnetic field that induces a voltage in the secondary winding. The ratio of the number of turns in the primary coil (N1) to the number of turns in the secondary coil (N2) determines the transformation ratio:

VsVp = NsNp; *VpVs* = *NpNs*

Where:

- Vs*Vs* = Secondary voltage
- Vp*Vp* = Primary voltage
- Ns*Ns* = Number of turns in the secondary winding
- Np*Np* = Number of turns in the primary winding

C. For a step-up transformer, Ns>Np*Ns* >*Np*, resulting in Vs>Vp*Vs*>*Vp*.

MULTILEVEL INVERTER

Multi-level inverters (MLIs) are advanced power electronic devices that convert direct current (DC) into alternating current (AC) through a multi-level output waveform. Unlike traditional two-level inverters, which generate a square waveform, MLIs produce a staircase-like waveform that approximates a sinusoidal output more closely. This technology has gained significant attention in recent years due to its efficiency, reduced harmonic distortion, and enhanced performance in high-power applications.

Working Principle

The fundamental operation of a multi-level inverter involves the use of multiple voltage levels to synthesize the desired AC output waveform. The basic configuration consists of several series-connected voltage sources, which can be capacitors, batteries, or renewable energy sources. The inverter switches are controlled to create various combinations of these voltage levels, resulting in a stepped output waveform.

IV. RESULT

The proposed Multiscale Kernel Convolutional Neural Network (MK-CNN) model was implemented and evaluated for the purpose of intelligent fault diagnosis in cascaded multilevel inverters. These inverters, which are widely used in industrial and renewable energy applications, are prone to complex fault conditions that are often difficult to detect using traditional monitoring techniques. In this study, the MK-CNN was specifically designed to enhance diagnostic performance by incorporating multiscale convolutional filters that extract features from multiple receptive field sizes simultaneously. This approach enables the network to capture both localized waveform anomalies and broader contextual patterns, which are essential for accurately identifying faults.

During experimentation, the MK-CNN was trained on a dataset composed of voltage and current signals under various fault and non-fault conditions. The dataset included faults such as single switch open-circuit faults, dual switch faults, and symmetrical and asymmetrical short-circuit scenarios occurring at different levels of the cascaded inverter structure. The training data was preprocessed and normalized to ensure consistency, and the MK-CNN model architecture was tuned through multiple trials to determine the optimal number of layers, kernel sizes, and activation functions. The model used a combination of large and small kernels in parallel branches to process the data at different scales, improving its sensitivity to subtle changes in waveform behavior.

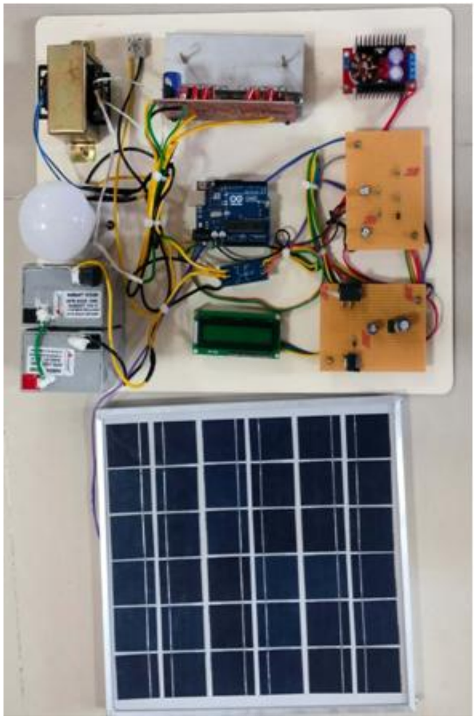

Fig.7 Prototype Model

V.CONCLUSION

The proposed Multiscale Kernel Convolutional Neural Network (MK-CNN) model was implemented and evaluated for the purpose of intelligent fault diagnosis in cascaded multilevel inverters. These inverters, which are widely used in industrial and renewable energy applications, are prone to complex fault conditions that are often difficult to detect using traditional monitoring techniques. In this study, the MK-CNN was specifically designed to enhance diagnostic performance by incorporating multiscale convolutional filters that extract features from multiple receptive field sizes simultaneously. This approach enables the network to capture both localized waveform anomalies and broader contextual patterns, which are essential for accurately identifying faults.

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