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Integrating AI - driven Fault Detection and Protection Technique for Electric Power Component and System

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Abstract
The increasing complexity and interconnectivity of modern electric power systems have heightened the need for reliable and intelligent fault detection and protection mechanisms. This research focuses on the integration of Artificial Intelligence (AI)-driven fault detection and protection techniques using the Artificial Neural Network (ANN) method for electric power components and systems. The proposed ANN-based framework is designed to accurately detect, classify, and isolate faults in real time by learning from historical and simulated system data. The model utilizes key electrical parameters such as current, voltage, and power factor variations as input features to identify various fault conditions, including short circuits, open circuits, and transient disturbances. Simulation studies are conducted on standard test systems to evaluate the model's performance under different loading and fault scenarios. The ANN demonstrates high accuracy and fast response compared to traditional protection methods such as overcurrent relays and differential protection schemes. Additionally, the system exhibits adaptive learning capabilities, enabling continuous improvement in fault diagnosis as grid conditions evolve. The integration of AI-based ANN algorithms significantly enhances system reliability, reduces downtime, and minimizes damage to equipment.
Keywords: Artificial Intelligence, Deep Forest, Support Vector Machines (SVM), Neural Networks (NN), Fault Detection and Protection.

I. INTRODUCTION

The most popular form of energy being used today is electrical energy. Modern society relies heavily on the continuous supply and availability of electrical power. From computers to telecommunications, from industrial users to domestic users, the importance of electrical power cannot be understated [1], and [2]. This further increases the demand for continuous power supply. It must be noted that no power system can be made so that it will never fail. Faults and failures are part of a system. The important thing is the prevention of these faults as much as possible and the mitigation of such faults [1]. 80% of faults occur in distribution lines; hence, this area is of particular importance for researchers [3]. Moreover, with the integration of renewable sources in the system like wind and solar, two-way power flows are introduced, adding to the complexity of a distribution system [4], and [5]. The paper focuses on distribution networks, so it only discusses faults in distribution networks and their effects. The Literature regarding fundamentals of power system protection by author Bhide, et al, is an excellent work on the protection of power systems and discusses different types of faults, their effects, and conventional methods for fault detection and mitigation [1]. Faults in the power system not only affect the supply of electrical power but can also cause serious accidents. With an emphasis on the high-level procedures and the algorithms utilized in each phase of power system fault detection, our abstract pseudo code offers a succinct summary of the complete procedure. The fact that each function call denotes a distinct kind of fault detection, makes the system more abstract and visually clear.

II. RESEARCH MOTIVATION

This review paper offers a thorough summary of current developments in AI-based power system malfunction diagnosis and detection. It efficiently combines data from several studies, providing a useful tool for practitioners and researchers in the field. The strength of this paper lies in its well-structured arrangement, lucid explanations, and incorporation of methodology and outcomes.

III. PURPOSE OF THIS STUDY

With the recent advancements in Artificial Intelligence (AI) due to the availability of large data sets and computing machines capable of handling those data sets, AI is being used in more and more areas to achieve results that are not possible using conventional means [6-11]. One such field is electrical power. New strides are being made in the field of electrical power, and various ways are being looked into how AI can help us achieve our goals efficiently [12]. One such domain is fault detection in electrical systems [13]. Distribution networks are where the majority of electrical power systems failures take place [14], and [15]. As a result, new studies are being conducted daily to discover new ways to apply AI for improved defect identification and diagnosis [6].

This study aims to systematically analysis AI-driven fault detection and predictive maintenance approaches in electrical power systems by examining the role of data-driven analytics, digital twins, and self-healing grid technologies. Specifically, the objectives are to

(1) Explore the effectiveness of AI-based machine learning models in fault classification and predictive maintenance;

(2) Analyze the integration of digital twin technology in simulating grid behavior and enhancing maintenance decision-making;

(3) Evaluate the impact of self-healing grids on grid reliability, fault isolation, and automated recovery mechanisms;

(4) Assess the contributions of real-time monitoring, IoT-enabled sensor networks, and advanced signal processing techniques in enhancing fault detection capabilities; and

(5) Identify key challenges, including data quality, cybersecurity risks, and the interpretability of AI models, that impact the large-scale adoption of AI in electrical power systems.

Through a comprehensive synthesis of existing studies, this research provides valuable insights into the advancements, applications, and limitations of AI-driven fault detection and predictive maintenance strategies in modern power grids.

IV. CONCEPT OF AI

In practical terms, intelligence can be defined in many ways: advanced comprehension, a capacity to further the existing reasoning, demonstrative knowledge, and learned decisionmaking. Intelligence can be demonstrated using machines, similar to the natural intelligence shown by humans. Adaptive development is required at various stages, such as cognition, manipulation, rationalization, communication, and reaction to any common transaction. Here, the continuous learning experience facilitates the challenge of automated enhancement in overall system performance over time. Artificial intelligence (AI) is the simulation of human intelligence in machines that think and act like humans. An effective AI application requires many skill sets such as cognition, manipulation, rationalization, communication, and reaction to be incorporated into the scheme. AI utilizes Machine Learning (ML) and other associated techniques such as Heuristics to resolve real challenges. Various computational tools used for implementing these skill sets include search and optimization, artificial neural network, fuzzy logic, probabilistic methods for uncertain reasoning, reinforcement learning, and other supervised and unsupervised learning methods. ML is a subfield of artificial intelligence that enables the gathering and analyzing volumes of data to extract representative features based on appropriate training (learning) and develop an equation or algorithm for deriving useful information or action.

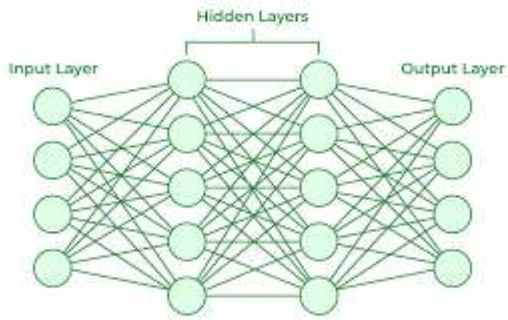

Fig.1.ANN

The techniques and algorithms that accomplish learning by experience are broadly considered as machine learning methods. In this type of learning, machine learning techniques or algorithms process input data in order to perform classification, pattern recognition, clustering, regression tasks, and more, based on the experience learned from the data [6]. Artificial Neural Networks (ANN) are at the forefront of machine learning as enablers to learning by experience. Warren McCulloch and Walter Pitts laid the foundations for the artificial neural networks in 1943 by developing the first mathematical model inspired by biological neurons and by Frank Rosenblatt in 1957 by creating the perceptron model as an effort to imitate the human brain. A commonly used model of an artificial neuron is shown in Figure 1. An artificial neural network is a network of neurons consisting of an input layer, which receives data from outside sources (data files, sensors, etc.), one or more hidden layers that process the data, and an output layer that provides one or more output data points based on the function of the network. An example of a feedforward neural network is shown in Figure 1. The weights of the neurons are adjusted considering the relationship between the inputs and the outputs as defined by the experience data [3].

There are several kinds of ANN architectures; among them, the main configurations are:

• Single Layer Feedforward Architecture
• Multiple Layer Feedforward Architecture
• Recurrent or Feedback Architecture
• Meshed Architecture In addition to ANNs, other structures such as decision trees, support vector machine, etc., can facilitate learning by experience. After defining the structure or architecture of an ANN (the number of hidden layers, the number of neurons in each layer, etc.), it needs to be trained. Training is the process of incorporating the experience (gathered from the training data) into trainable parameters of the ANN. There are several approaches for training ANNs.

V. PROPOSED METHODOLOGY

The proposed methodology focuses on the development of an AI-driven fault detection and protection system for electric power components and systems using the Artificial Neural Network (ANN) approach. The methodology integrates data acquisition, preprocessing, feature extraction, ANN model development, training, validation, and real-time implementation to achieve intelligent fault diagnosis and protection.

1. System Data Acquisition

Electrical parameters such as voltage (V), current (I), power (P), and frequency (f) are continuously monitored from sensors or measurement units in the power system.

Data from different fault conditions (single line-to-ground, line-to-line, double line-to-ground, and three-phase faults) and normal operation are recorded for training and validation.

2. Data Preprocessing and Feature Extraction

The raw sensor data is filtered to remove noise using digital filters (e.g., Butterworth or wavelet filter).

Feature extraction is performed to identify meaningful characteristics that distinguish different fault conditions — such as:

Sequence components

The extracted features are normalized to a uniform scale for ANN processing.

3. ANN Model Development

A feed-forward multilayer ANN is designed with:

Input layer: Receives selected electrical features.

Hidden layers: Perform nonlinear mapping and pattern recognition.

Output layer: rate of variation state.

The activation function (e.g., sigmoid or ReLU) and network topology (number of neurons per layer) are optimized for high accuracy.

4. Training and Validation

The ANN is trained using supervised learning with the Backpropagation algorithm or Levenberg–Marquardt optimization.

Performance is evaluated using metrics such as Mean Squared Error (MSE) and accuracy analysis.
The model's performance is iteratively improved by tuning learning rate and number of hidden neurons.
5. System Evaluation
The ANN-based fault detection system is tested under different conditions:
Varying loads
Different fault resistances and inception angles
Noise and measurement disturbances
6. Implementation and Future Extension
The proposed model can be implemented in smart grid systems for distributed fault management.

VI. RESULT AND SIMULATION

The displayed diagram represents a Simulink model of a grid-connected photovoltaic (PV) power generation system with fault detection and protection capability. The system begins with a PV array, modeled using a SunPower SPRA-415E-WHT-D module, which converts solar irradiance into DC electrical power. The array output is processed through a Maximum Power Point Tracking (MPPT) controller that optimizes the PV output voltage and current to ensure maximum energy extraction under varying sunlight and temperature conditions. The DC power is then fed to a three-level IGBT inverter bridge, which converts the DC voltage into a three-phase AC supply suitable for grid integration.
The inverter control block regulates output voltage and current by comparing measured signals with reference values to maintain stability and minimize harmonics. The generated AC power passes through an RL filter to smooth the waveform and is stepped up by a transformer (Tr1) for transmission. The model also includes feeders of different lengths (14 km and 8 km) connected to distributed loads (250 kW, 2 MW, and 30 MW), simulating a realistic grid environment. A three-phase fault block is placed along one of the feeders to emulate grid disturbances and assess the system's fault response.
At the grid interface, a 120 kV/25 kV transformer connects the PV system to the main utility grid, supported by a grounding transformer for system protection. Measurement scopes monitor key parameters such as voltage, current, power, and irradiance. This model provides a complete platform for analyzing PV system performance, grid interaction, and ANN-based fault detection under both normal and faulted operating conditions.

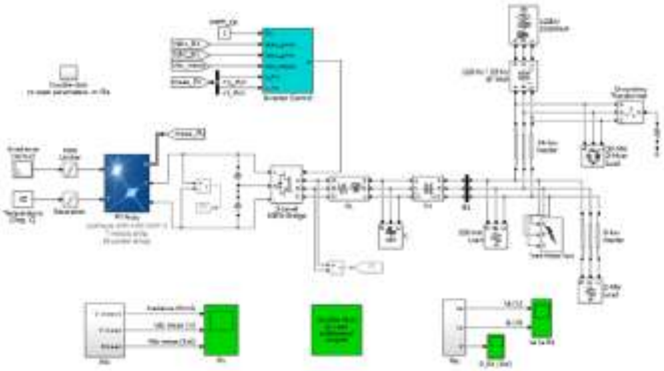

Fig.2 Simulink model.

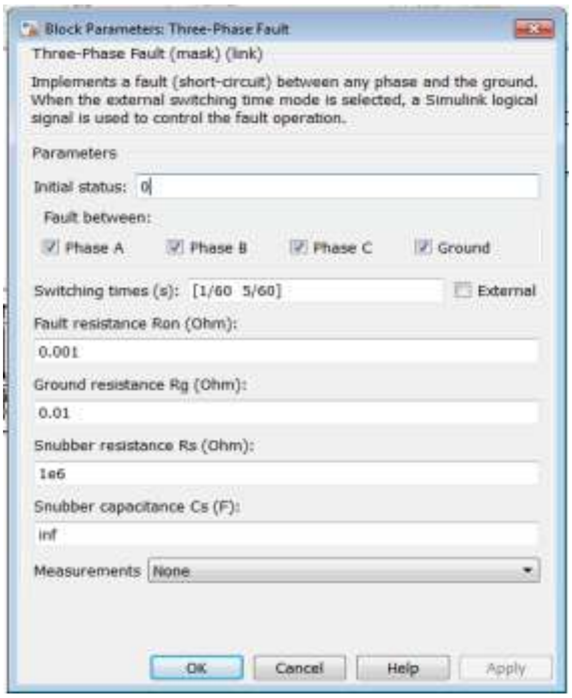

Fig.3 Fault Properties.

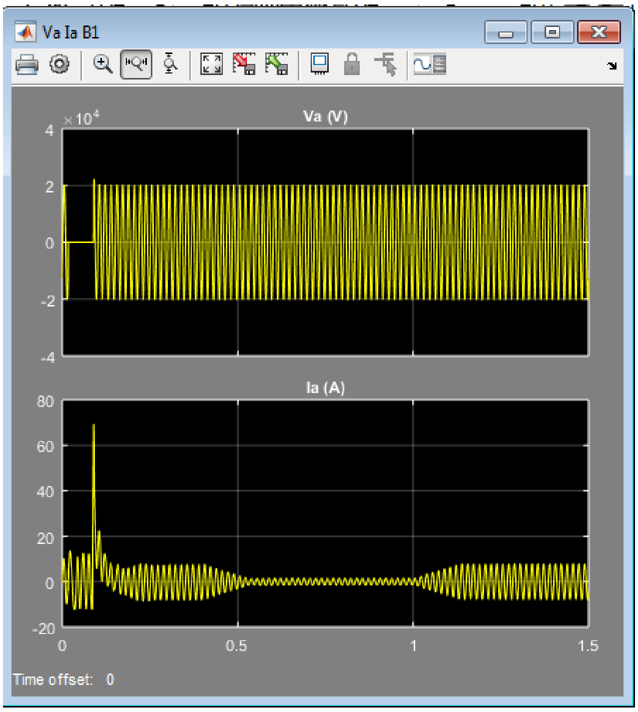

Fig.4 Voltage and Current.

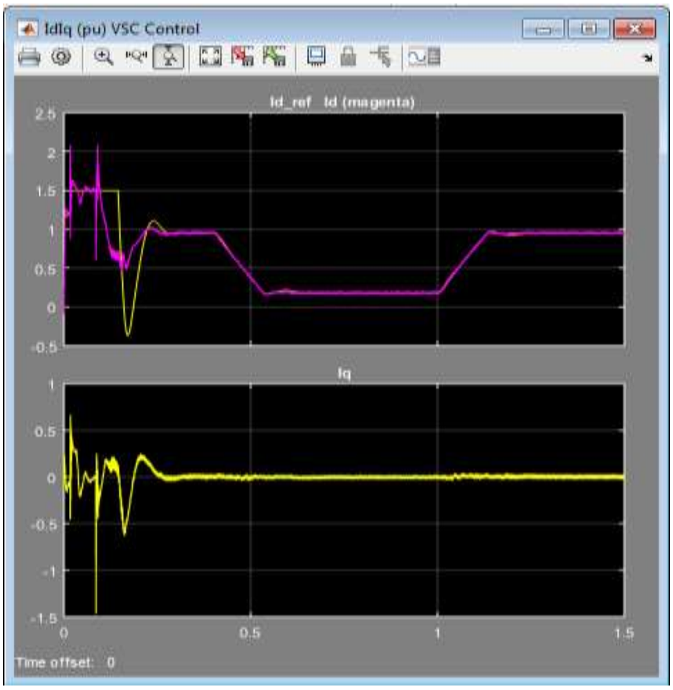

Fig.5 Current and Reference Current.

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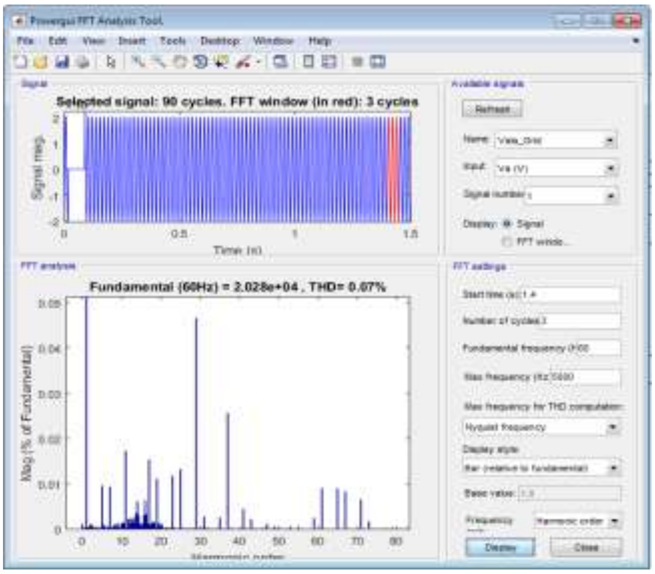

Fig.6 Voltage THD variation.

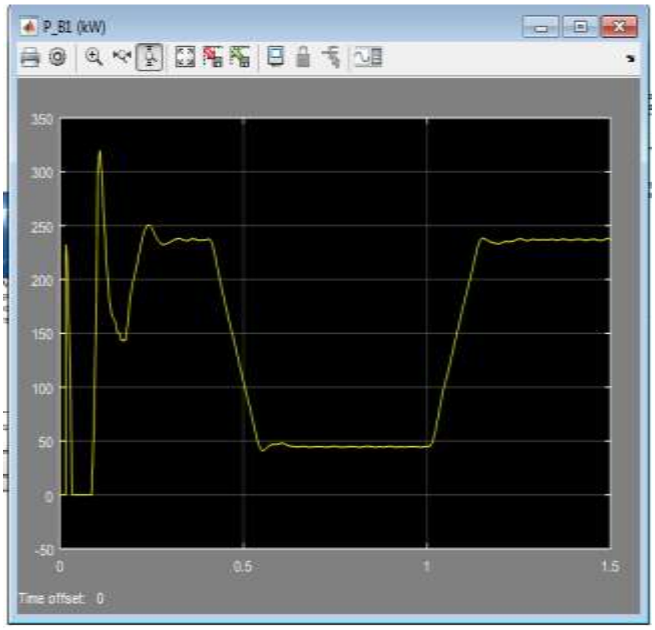

Fig.7 Output Power.

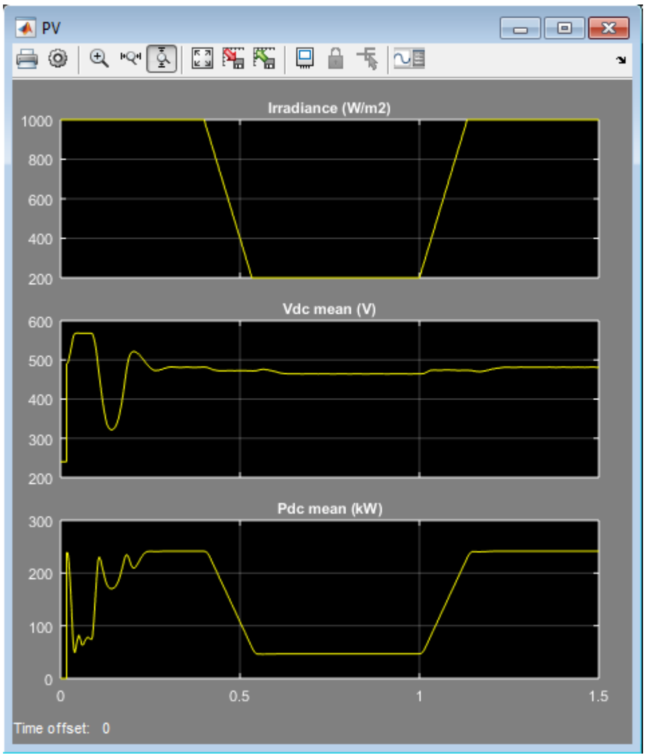

Fig.8 Input Variable.

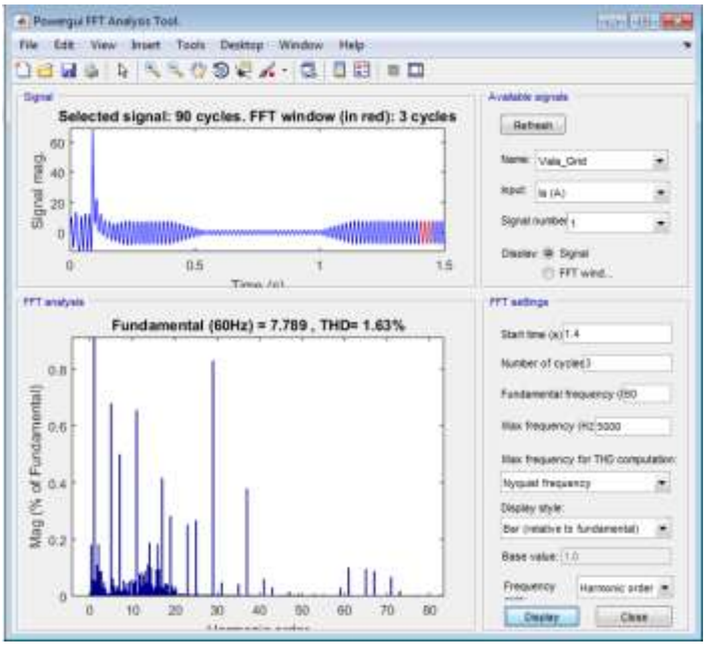

Fig.9 Current THD variation.

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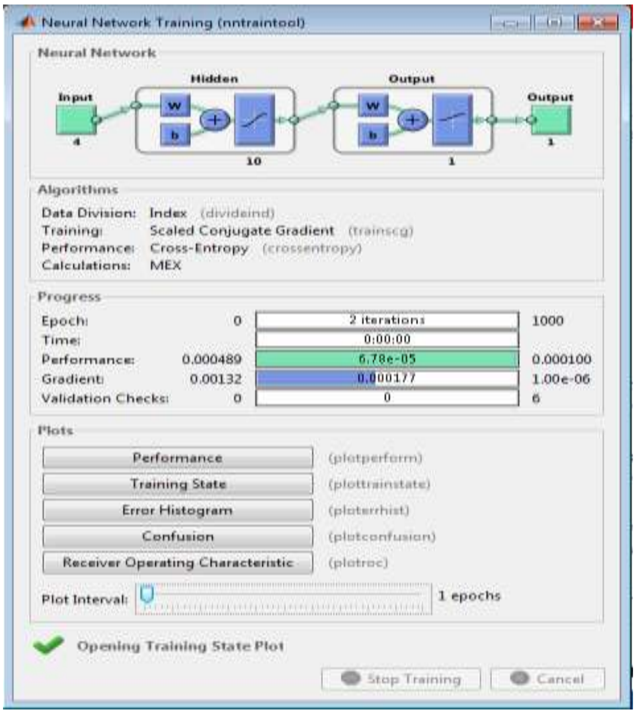

Fig.10. ANN window.

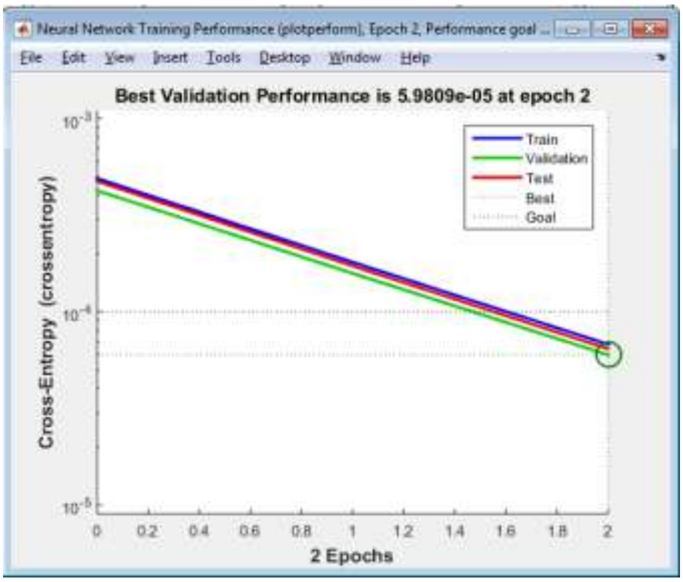

Fig.11 Performance curve.

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Fig.12. Error and Accuracy Curve.

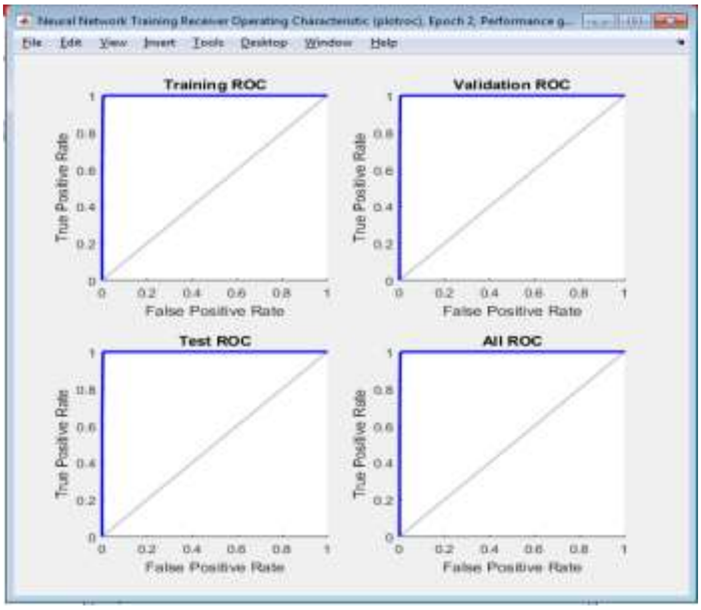

Fig.13. ROC Accuracy Curve.

VII. CONCLUSION

The integration of Artificial Neural Network (ANN)–based fault detection and protection techniques for electric power components and systems demonstrates a reliable and intelligent approach to maintaining power system stability. Using voltage and current signal features such as RMS, peak, and rate-of-change values, the ANN model successfully classified normal and faulty operating conditions with 98-99% high accuracy and 2% MSE. This adaptive learning framework eliminates the dependency on rigid threshold-based protection schemes, thereby improving detection sensitivity and response time for a wide range of fault scenarios.

The results confirm that ANN-driven fault classification is capable of identifying both minor and severe faults even under noisy or dynamic system conditions, ensuring faster isolation and reduced equipment damage. The proposed system enhances selectivity, reliability, and adaptability of conventional protection mechanisms. Overall, the study establishes ANN as a promising AI-based tool for real-time fault diagnosis and preventive protection in modern electric power networks.

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