Detecting Faults in Cascaded H-Bridge Multi-level Inverters using Machine Learning

Introduction

Cascaded H-bridge multilevel inverters (CHMLIs) have gained significant attention in recent years due to their ability to generate high-quality output waveforms, reduce harmonic distortion, and improve power conversion efficiency.

CHMLIs consist of a series of H-bridge inverters cascaded together to achieve high voltage levels with low switching frequencies.

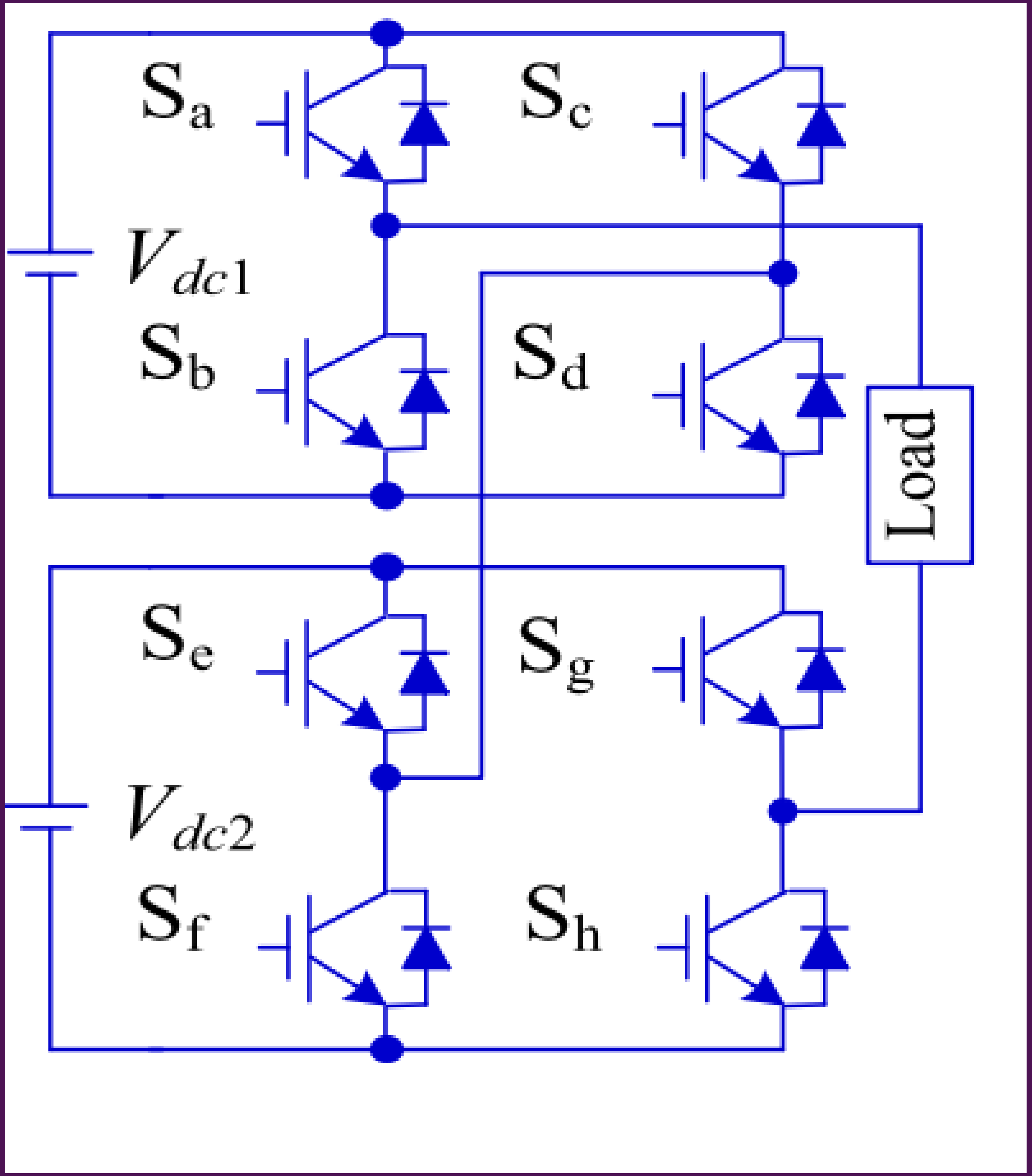
This technology has numerous applications in various fields, such as renewable energy, motor drives, and electric vehicles.

However, the CHBMLI also has some challenges, including fault detection. Faults can occur for various reasons, such as component failure, environmental factors, or external disturbances. Detecting faults in the CHBMLI is crucial to prevent system damage and ensure safe operation.

Working of CHMLI

- An H-bridge inverter is a circuit that can convert DC voltage to AC voltage by switching the direction of current flow in the load. It consists of four switches, typically MOSFETs or IGBTs, arranged in an "H" shape. Two switches are connected to the positive DC source, and the other is to the negative DC source.

- The CHMLI uses pulse width modulation (PWM) to control the output voltage waveform. This involves adjusting the H-bridge switches' switching frequency and duty cycle to generate the desired output waveform. By adjusting the duty cycle of the switches, the average voltage across the load can be controlled, thereby controlling the output voltage waveform.



Type of fault in CHMLI

Open-circuit fault

This occurs when one or more switches in the H-bridge inverter become open, resulting in a loss of current flow to the load.

Short-circuit fault

This occurs when two or more switches in the H-bridge inverter become shorted, causing a high current flow through the load.

Overcurrent fault

This occurs when the current flowing through the CHMLI exceeds its rated current. This can cause the switches to overheat and fail

Overvoltage or Undervoltage fault

This occurs when the output voltage of the CHMLI exceeds or falls below its rated voltage, respectively.

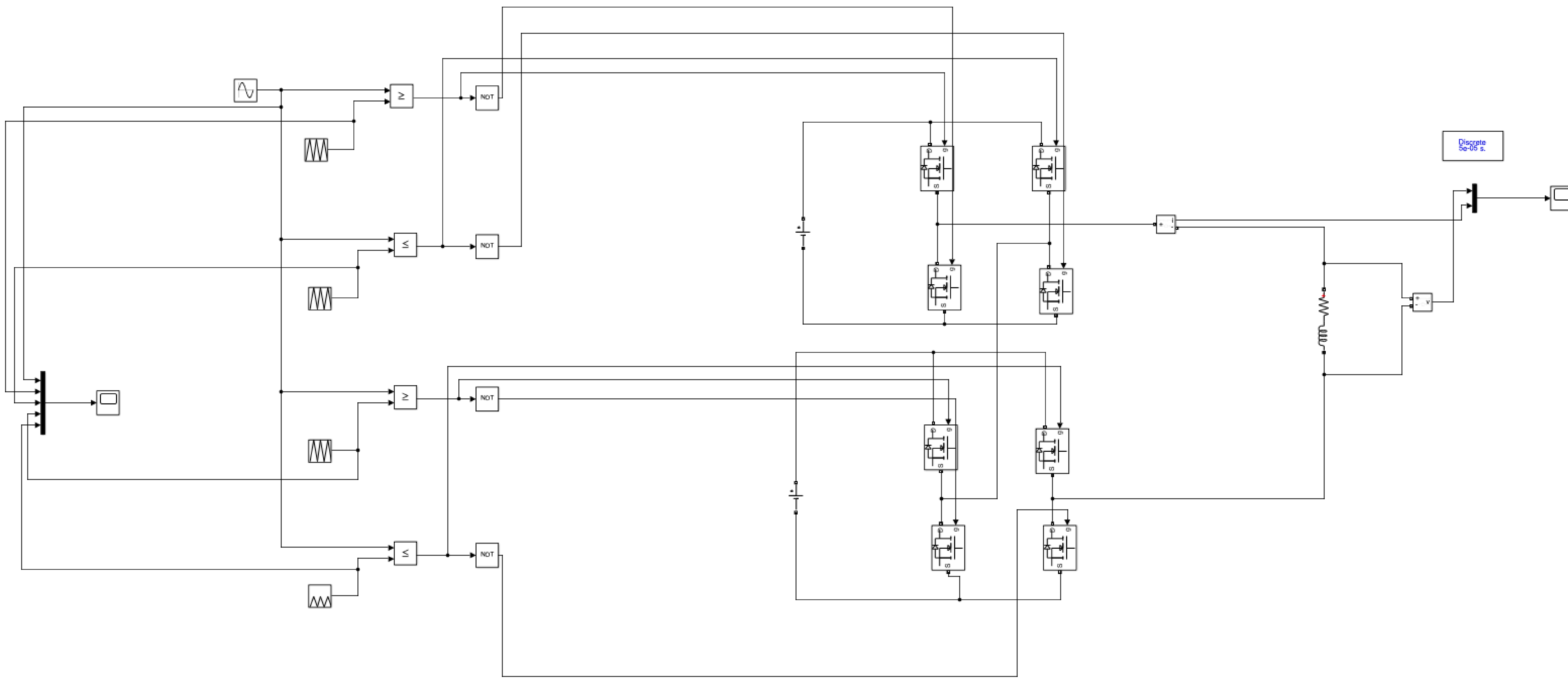
Temperature fault

This occurs when the temperature of the switches or other components in the CHMLI exceeds its rated temperature. This can cause the switches to fail or the system to shut down.

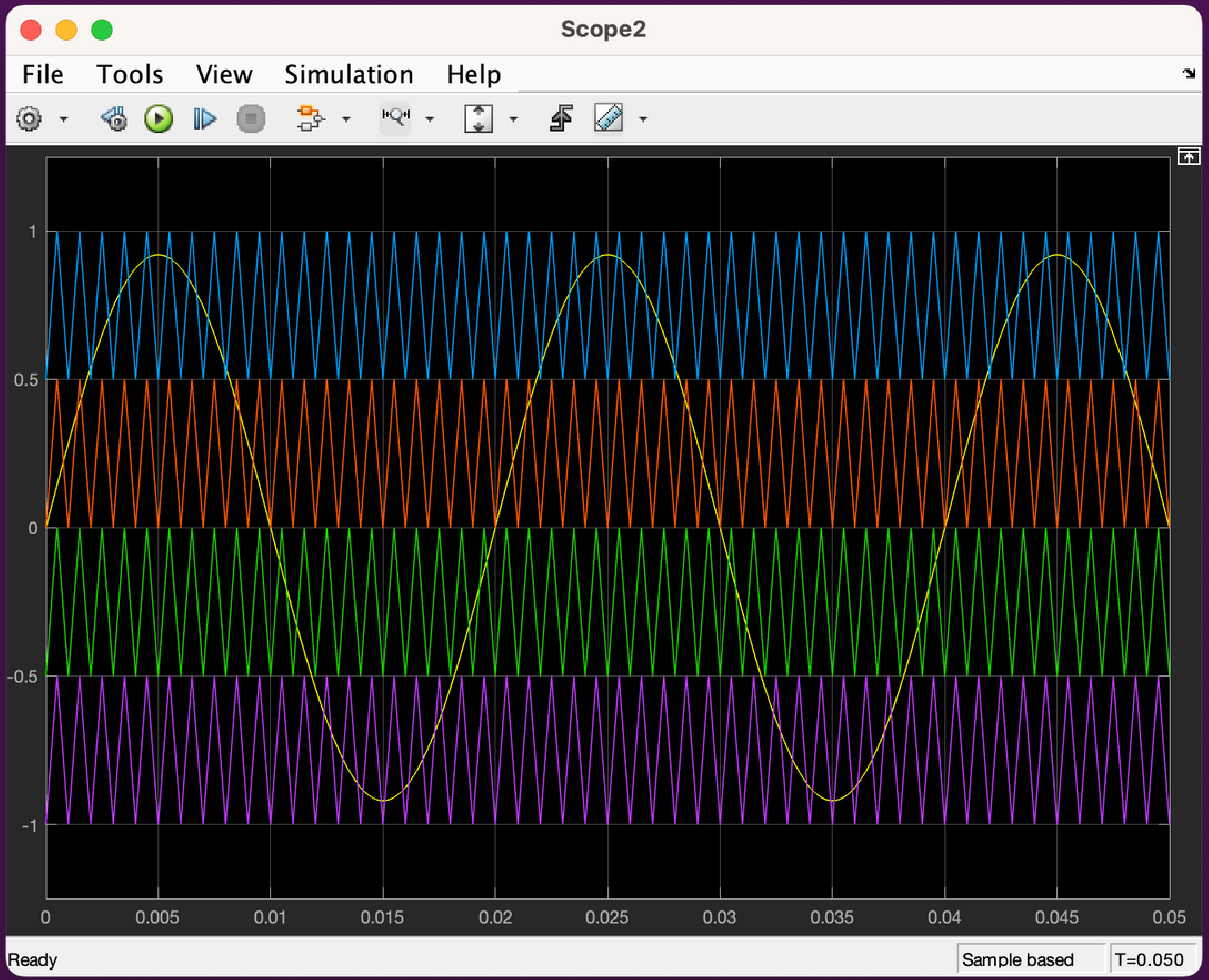
Control fault

This occurs when there is an error in the control signals used to operate the CHMLI, leading to incorrect switching or other issues that can cause a system failure.

*(In this project, we're addressing Open-circuit and Short-circuit fault)



5-level CHMLI MATLAB Simulation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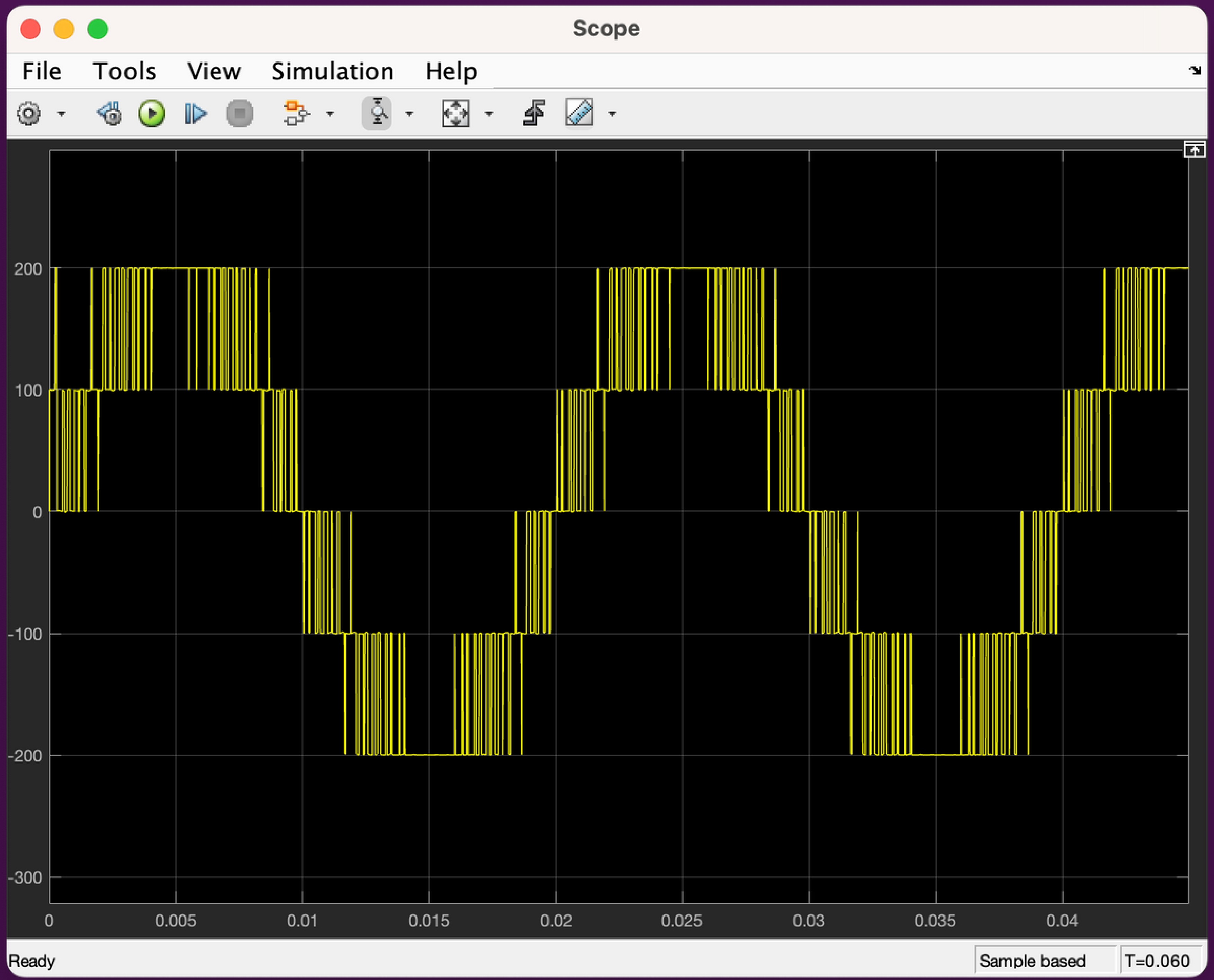
Sample based
T=0.050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Ready
Sample based
T=0.060

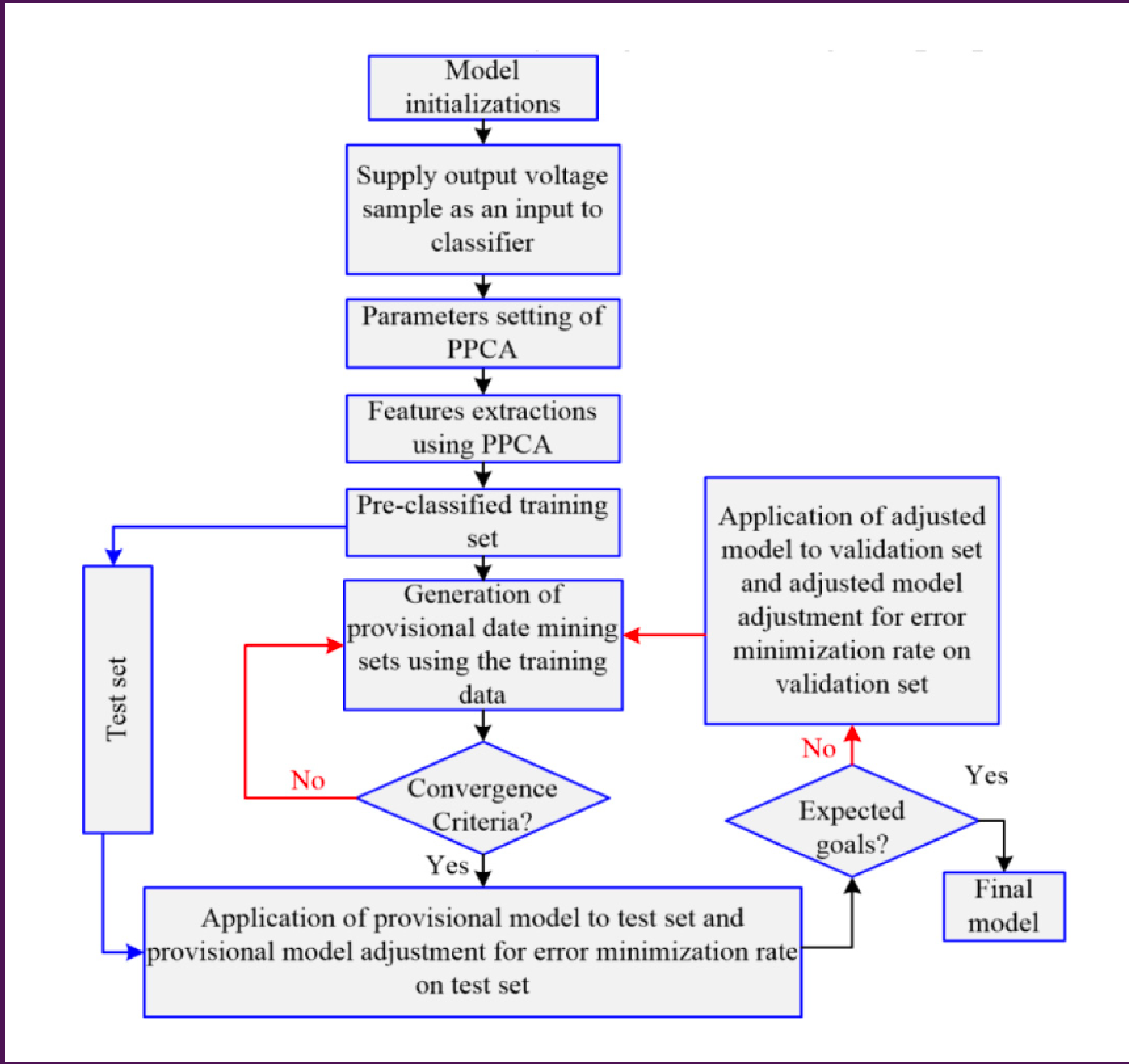
How can we detect faults in the inverter?

- Using the output voltage waveform, we can use machine learning to predict which switch is not working in the inverter. Using machine learning algorithms such as k-NN and SVM.
- For this, we must train the machine learning model using the following process.

1. Data Collection
2. Feature Extraction
3. Data Labeling
4. Data Preparation
5. Model Training
6. Model Testing

How we Implemented

- The project uses a method based on the PPCA-kNN algorithm to increase the accuracy of fault analysis in the CHMLI system and reduce the diagnosis duration time.
- The fault diagnosis method could determine the fault location from the CHMLI system output voltage waveform.
- The voltage signal is treated as a fault signal under the scenarios of OC at MOSFETs.
- First, take the output voltage waveform signal data from the sensitive load side of the CHMLI and then give this output data to the Probability PCA algorithm.
- The PPCA algorithm is applied to that output data. PPCA methods reduce high- to low-dimensional data and optimize the binary data without changing the original properties.
- The training of the k-NN is fulfilled with normal and abnormal data for the CHMLI system, with the output being approximately 1 and 0 (binary code).
- The k-NN and SVM algorithms played an important role in classifying and locating the fault.
- Then the fault analysis tool is then adopted to decode the corresponding fault types and locations.

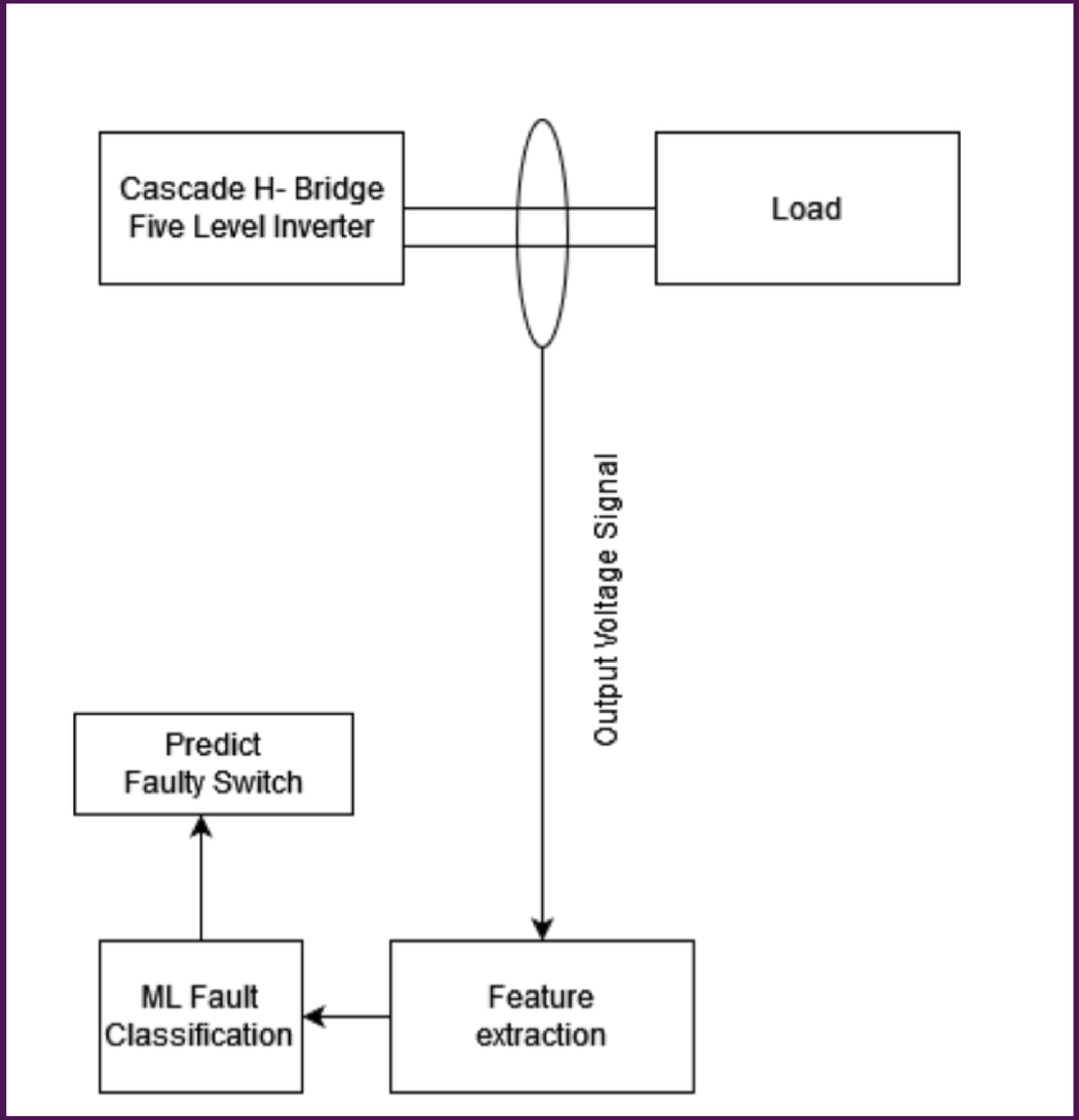


Flowchart of proposed PPCA-based k-NN.

The PWM technique is used in this project to control the CHMLI because of easier implementation and high modularity as compared to other modulation techniques.

Quantity	Simulation
DC-link voltage	100V
Load	5Ω
System frequency	50Hz
Modulation index	0.85
Sampling time	0.06s

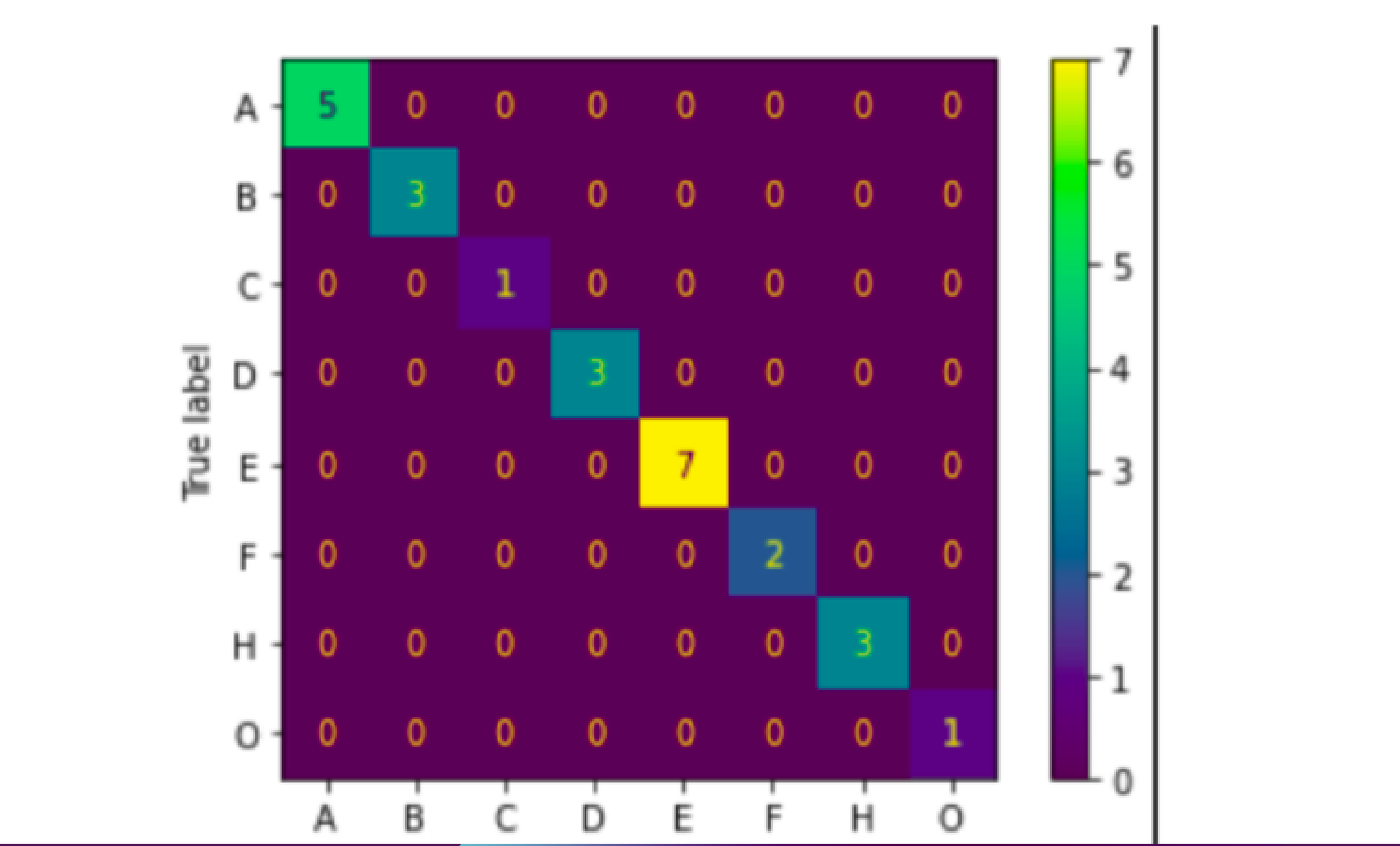
PCA k-NN Method



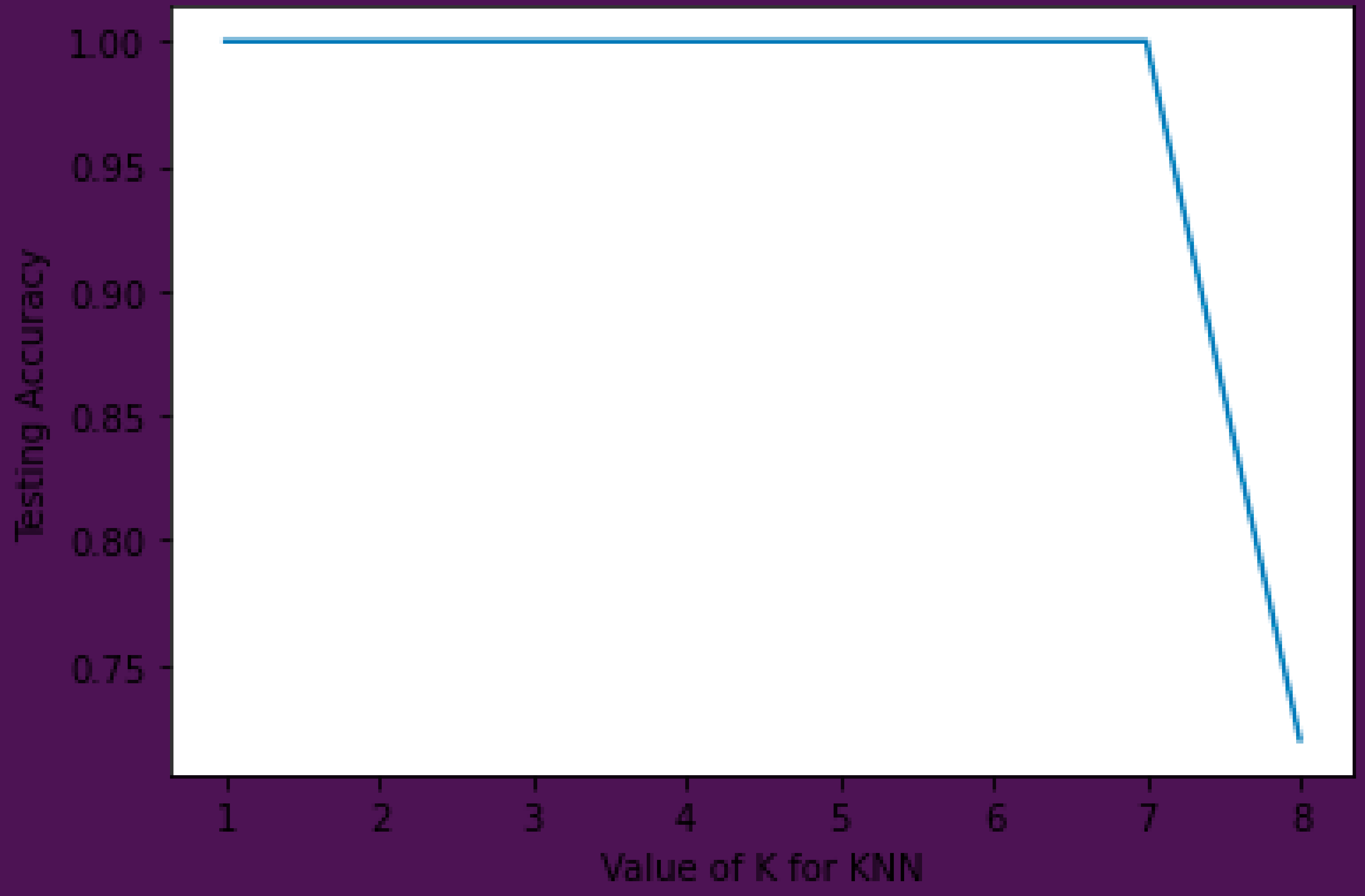
- PCA is a dimensionality reduction technique that transforms high-dimensional data into a lower-dimensional space while preserving the variance of the data. In the context of fault diagnosis, PCA is used to extract relevant features from the output voltage waveform of the CHMLI. The extracted features are then used to train a k-NN classifier for fault detection.
- We created a plot to see which value of K is most optimal for our model. We have taken K=3 and implemented the model using different parameters like euclidian and manhattan distance metrics. Finally , different faults are classified using the proposed k-NN technique

Results and Plots

For both 75 and 95 per cent training data and with Euclidian and Manhattan Metric, the accuracy is 100 per cent.



Accuracy of model for the different values of k



Reference

- https://ieeexplore.ieee.org/document/9605501
- https://www.datacamp.com/tutorial/k-nearest-neighbor-classification-scikit-learn
- https://www.javatpoint.com/principal-component-analysis
- https://www.sciencedirect.com/science/article/pii/S2352484721012038

Thank You

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