A

Project Report

On

# Condition Monitoring of Distribution Transformer Using Machine Learning

*Submitted in partial fulfilment of the requirement for the award of the*

*Degree of*

**BACHELOR OF TECHONOLOGY**

*In*

**ELECTRICAL ENGINEERING**

*By*

**AHMAD HASAN (1615105001)**

**AJIT SINGH (1615105002)**

*Under the Guidance of*

Mr D.SARVANAN

(Assistant Professor)


**SCHOOL OF ELECTRICAL, ELECTRONICS AND COMMUNICATION ENGINEERING**

**(MAY2020)**

# DECLARATION

We declare that the work presented in this report titled "**CONDITION MONITORING OF DISTRIBUTION TRANSFORMER USING MACHINE LEARNING**", submitted to the Department of Electrical Engineering, Galgotias University, Greater Noida, for the Bachelor of Technology in Electrical Engineering is our original work. We have not plagiarized unless cited or the same report has not submitted anywhere for the award of any other degree. We understand that any violation of the above will be cause for disciplinary action by the university against us as per the University rule.

**Place:**

**Date:**

Signature of the Student

_____

AHMAD HASAN (1615105001)

_____

AJIT SINGH (1615105002)


**School of Electrical, Electronics and Communication Engineering**

**CERTIFICATE**

This is to certify that the project titled **"CONDITION MONITORING OF DISTRIBUTION TRANSFORMER USING MACHINE LEARNING''** is the work carried out by Ahmad Hasan, Ajit Singh, during the academic year 2019-20. We approve this project for submission in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Electrical Engineering, Galgotias University.

Mr D. Sarvanan

Project Guide(s)

**The Project is Satisfactory / Unsatisfactory.**

_____ _____

Internal Examiner (s) External Examiner

Approved by

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Dean

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Special thanks to our Dean Dr B. Mohapatra School of Electrical, Electronics and Communication engineering. Who gave the permission to use all required equipment ant the necessary material to complete our aim **"CONDITION MONITORING OF DISTRIBUTION TRANSFORMER USING MACHINE LEARNING"** We are also obliged to the staff of School of Electrical, Electronics and Communication Engineering for aiding us during the course of our project. We offer our heartiest thanks to my friends for their help in collection of data samples whenever necessary. Last but not the least; we want to acknowledge the contributions of our parents and family members, for their constant and never-ending motivation.

# ABSTRACT

The power transformer are the capital of the industry and the main part of the power system network. Transformer increases or decreases the voltage of the power system network to have non-encrypted power or safe power to the customers. if power transformer get damage it will be a great loss, in order to increase the life span of transformer its regular maintenances is important .Also prediction of faults before occurring will help in maintaining the health of transformer . The method like DGA (Dissolved gas analysis) is in use from years for the same purpose and had given great results but the problem of DGA is its human dependency and its reliance on the interpreter .So there is a chance of error and time consumption when dealing with different inspectors for interpretation. In this report we tried to use machine learning models in order to make prediction of fault using DGA data. The Machine learning models used are Multilayer Artificial neural network and support vector machine classifier. Both model have successfully predicted the faults with SVM showing higher accuracy.

## LIST OF FIGURES:

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## LIST OF ABBREVATIONS:

| Serial no | ABBREVATIONS | FULL FORMS |
|---|---|---|
| 1. | MLANN | Multilayer Artificial neural network |
| 2. | SVM | Support Vector Machine |
| 3. | DGA | Dissolved Gas Analysis |
| 4. | BPNN | Back-propagation neural network |
| 5. | PDC | Polarisation and depolarisation current test |
| 6. | FRA | Frequency Response Analysis |

# TABLE OF CONTENT

# Chapter 1: INITIATION:

## Overview:

Present chapter gives a brief introduction of report along with motivation, literature survey for the project and organisation of report.

## GENERAL:

Transformer are the static device .They are responsible for transfer of charge from on circuit to another without changing the frequency. In order to insure smooth supply of electricity it is important to take care of transformers.

They are the backbone of power system Transformers covers a large part of power system so there failure may lead to a great loss. In order to insure the smooth supply of electricity and health of transformer condition monitoring of transformer is an important tool .It has been used from years in order to keep a check on their health.

Mineral oil used in transformer for the cooling and insulation purpose but moreover it is used to identify the gasses produced in transformer .The examination may help in determining the fault before it occur for this Dissolved gas analysis technique is used .Through this technique we can identify the fault going to occur in transformer. It is a reliable technique and has been in use for years. But the results determined by the DGA are based on human expertise .So it is not the best technique possible .This report explains the use of dissolved gas analysis data with machine learning algorithm in order to predict the fault accurately .The two Machine learning Models are used namely Multilayer Artificial Neural Network and Support Vector machine classifier(C-SVM) .Both of them have yield satisfactory results in detecting the faults of transformer.

## MOTIVATION:

Although DGA is a great technique but it expertise depends on the human , the results predicted for same set of gases may be different when inspected by different inspectors .We may conclude that there is a chance of error in finding the faults when dealing with large dataset around 100 to 500 transformer because for each transformer there will be a set of gasses ratio

and to calculate fault of each transformer one has to look at each data and predict using that .The whole processes is time consuming and there is a definite chance of error .

Although when it comes to fast calculation computers are preferred because they act fast even with a large data set and are less prone to errors. Hence this report uses Machine learning algorithms to build models which can predict the faults accurately and quickly.

## OBJECTIVE:

The objective of this report is as follows:

- Understanding DGA (Dissolved Gas Analysis).
- Collection of DGA data.
- Learn about machine learning models.
- Preprocess data to use with Machine learning models.
- Build machine learning models.
- Train them to identify transformer faults using DGA data.
- Evaluate them.
- Come up with best model out of these.

## LIERATURE REVIEW:

Paper [38] gives study of the available transformer insulation techniques like DGA, PDC, FRA. They believe that these techniques require more accurate method to interpret the data collected. So they come up with the two Machine Learning Models i.e. SVM (support vector machine) and SOM (self organizing map) they implemented these Machine learning algorithms over the DGA data and come up with the conclusion .Paper [39] wanted to develop an intelligent framework or diagnostic tool that can be used to analyze insulation diagnosis of transformer

.The system can obtain data from the different transformers and can use that data and analyze it to identify the health condition of transformer i.e. faulty or not and there serviceability .

The proposed diagnosis system was divided into four important parts:

- A unit used for preprocessing the data
- A unit used for extraction of features from data
- Pattern recognition
- Knowledge representation

Data prep-processing unit use data from the DGA and implement purification , filtration and then send it to the Feature extraction unit ,here features are assign to data and features are kept as minimal as possible then data goes to pattern recognition unit which uses algorithm like Bayesian classifier , SVM , SOM . They concluded that by using these algorithms classification of faults can be successfully achieved .Paper [40] uses the DGA dataset of around 627 transformer with the machine learning algorithms like Back-propagation neural network ,Probabilistic neural network , Decision tree they concluded that decision tree showed the best result followed by BPNN. Paper [41] concluded that Dissolved gas analysis can be considered as one of the most important technique that is used for prediction of transformer faults by doing the analysis of gases present in the oil container. DGA data is used in order to analyse all the available techniques in order to predict fault using DGA data. They concluded that data has enormous amount of advantage s but the biggest advantage is the predetermination of fault using gas concentration [42]. Paper [43] uses different techniques like K-NN DNN and RFC along with DGA data in order to predict fault .The paper concluded that Deep Neural network gives the best accuracy among these. paper [44] uses Multilayer Artificial Neural network and support vector machine to predict the heart disease and the paper concluded that the SVM give better results in comparison with MLANN .Paper [45] uses MLANN in order to predict the

transformers faults using DGA data and come to this conclusion that MLANN method yield a high diagnosis accuracy .paper [46] uses MLANN in order to predict transformer fault along with relu tanh activation function they concluded that the MLANN give a high classification accuracy when used with DGA data .

## ARRANGEMENT OF REPORT:

The report contains 8 chapter arranged as follows

Chapter 1 gives brief about introduction, motivation ,objective ,literature review and report distribution .

Chapter 2 gives the introduction of transformers its types and importance

Chapter 3 gives the introduction of faults in transformer and method used for faults prediction like DGA RRM DTM etc.

Chapter 4 gives the brief introduction of the machine learning algorithms & its types.

Chapter 5 gives the machine learning models used in the simulation.

Chapter 6 gives the proper introduction of data and data preprocessing.

Chapter 7 gives the simulation and results

Chapter 8 gives the conclusion and future scope of project.

# Chapter 2: TRANSFORMER

Overview:

Present chapter gives a brief introduction transformers its types and some available models.

## 1. INTRODUCTION

A transformer is a device with no moving parts i.e. static that transfers electrical energy from one electric circuit to another electrical circuit. A flowing current in one of the coil can produce a variable magnetic flux in the core of the transformer which produces or varying EMF (electro motive force) to the other coil wound around the same core. In the transformer, we can transfer the electrical energy without the metallic connection of two separated coil [1]. Transformer working principle is electromagnetic induction which was proposed in 1831 .According to this principle when the flux passing through the conductor varies they generated EMF and as a results induces current Mostly the transformer is used for step-up and step-down. When you need a low voltage at high current we use the step-up transformer and when you need high voltage at low current we use a step-down transformer without changing their frequency [1].

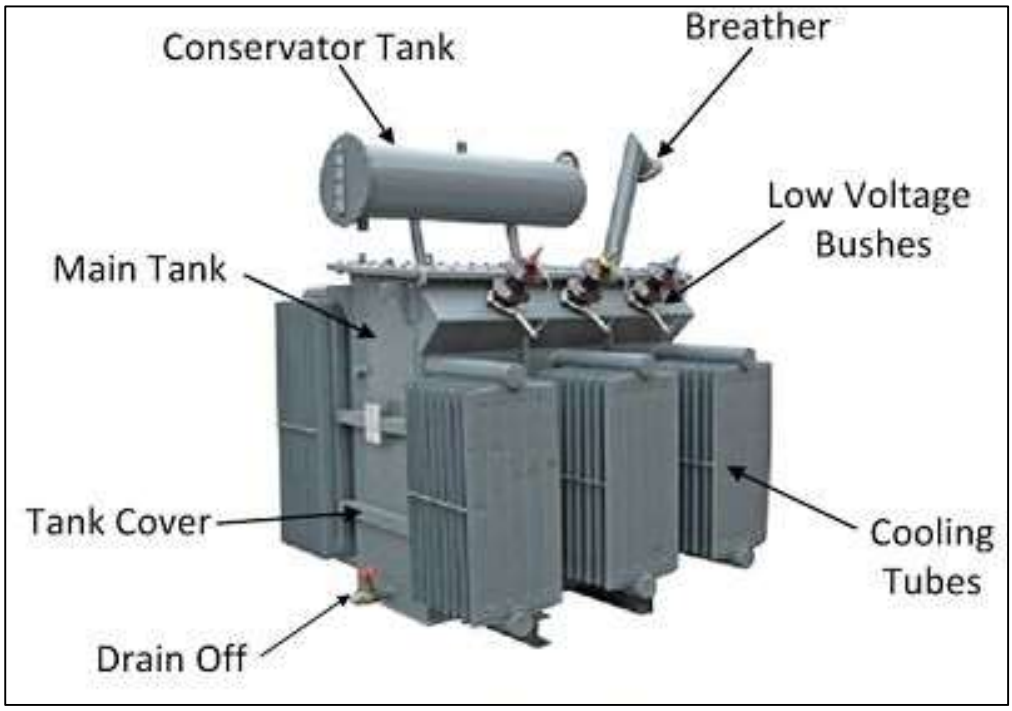


*Figure 1: Transformer*

## 2. TYPES OF TRANSFORMERS:

In electrical power system we use different type of transformer for their unique purposes like for Generation, Distribution, Utilization and Transmission. Type of transformer are as follows

Step Up and Step Down Transformer, Power Transformer, Three Phase Transformer, Auto Transformer, Distribution Transformer, Potential Transformer, Instrument Transformer, Single Phase, etc. [2].

### Step-Up &step-Down Transformer:

Step up transformer is defines as the transformer use to step up i.e. increase the voltage to higher level. The number of turn are greater in on the secondary side then the primary side. To raise the voltage of power system [2].

Step-down transformer are defined as the transformers required to step down i.e. decrease the voltage . Number of turn on the primary winding side will be greater than the winding on the secondary winding side .By using step-down transformer high voltage is converted into low voltage line and that supply we provide to our consumer with help of Distribution transformer [2].

### Power Transformer:

The power transformer are generally used on the generating station or at the substation this type of transformer are used at high voltage transmission line the rating of the unit are as mention 110KV, 33KV, etc. the size of the transformer is bigger than the normal transformer to their surrounding they install different type of cooling system to avoid heating of transformer. As this transformer continuously work thus copper loss and core loss will there. Power should be generated at the high level as it result in raised in voltage and reduce in current and maintain good voltage regulation.[2]

## Distribution Transformer:

Generally the rating of the distribution transformer are 11KV, 440KV, 6.6KVetc.. These transformer are used for the distribution purpose to lower the incoming voltage and supply to the consumer for utilization. The primary side of wire is thin as compared to the secondary side. Copper or Aluminum wire is used for the winding [2].

## Instrument Transformer:

Instrument transformer are classified into two main types which are current transformer and potential transformer these type of transformer are used for safety or isolation purpose. Whenever current or voltage is high at the primary side we use instrument transformer to reduce the value of current of voltage at the desired value so that further relay or other instrument connected to the secondary side will be saved from damage.[2]

## Single Phase Transformer

An electrical device used to change the voltage level without changing their frequency. Single phase transformer work on the principal of mutual induction .It transfer AC supply from primary winding to the secondary winding. Where load is connected to the secondary winding ,single phase transformer are used in electronic device where low voltage is required [2].

## Three Phase Transformer:

These are used in transmission, power generation or distribution, buying a single three phase transformer is costly rather than making it by using three individual single phase transformer. Take three single phase transformer and connect all primary side together and form a single

primary winding  same as on secondary side connect all secondary winding together and make a single secondary winding and this transformer will work like a three phase transformer.[2]

### Auto Transformer:

Auto transformer are the type of transformer which contain only one single winding wounded around the laminated core. In this transformer primary and secondary winding have input power. We have great advantage as ratio of input and output voltage come near to unity .Auto transformer are used to operate induction motor [3].

## 3. IMPORTANCE OF TRANSFORMER

Transformers become an essential part of our life because without the transformer we can't do transmission, distribution & generation and can't provide the required supply to our appliances, house.

The main reason for using a transformer it can provide electricity in the AC form. Power & distribution of the transformer have efficiency above 95%. After generating the electricity at the generating station we have to transmit at a long distance we require a step-up transformer which step-up the voltage at the receiving end of the distribution station, we need to step-down the voltage so here we required the step-down transformer .Hence we get the idea of the importance of transformer in power system. [4].

# Chapter 3: DISSOLVE GAS ANALYSIS

Overview:

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Present chapter gives a brief introduction of Dissolved gas Analysis its types.

## 1. INTRODUCTION

We need a reliable and non-encrypted power supply for all are major electrical, running units or companies. And this makes power transformer an important aspects of the investment in all over the world transformer operating or running at the high load or above the average the load. That is why transformer analysis become the subject to engineers.[5] Electrical stress and thermal stresses on an insulating material of a transformer can cause transformer fault and due to this cellulose insulation material will breakdown and produce the variable gases in transformer oil .Here the work of the engineers to detect the gases in the insulating oil by a reliable technique called DGA (dissolve gas analysis) through this technique we can determine the pre and post fault of the transformer [5].

ADVANTAGE of the DGA techniques

1. Alert or warning of the upcoming fault
2. Monitoring of the transformer and detect the overload condition.
3. And form the time-table to repair the transformer

## 2. TYPES OF FAULT:

To diagnosis the fault in the complete way it includes an alert alarm or warning of any key gases that increase to its standard value or the rate of change exceeds to much the standard limit. According to the electro technical commission 60599 gives the complete description of the faults types found in the power transformer. This type of faults can be distinguished by the visual inspection [8] [9].

1. Partial discharge: In this type of fault the insulation or cold plasma layer become lousy frequently due to high voltage stress which promote fault in the transformer.

2. Discharge of low energy D1- This type of fault can be identified the presence holes in paper or presence of carbon particles.

3. Discharge of high energy -Evidence by massive destruction and carbonized of the paper or metal fusion in very severe condition and tripping of the electrical equipment can be there.

4. Thermal fault 1: Temperature>300ºC paper turned brown and has carbonized.

5. Thermal fault 2: 300ºC < Temperature<700ºC this fault can be assured by the carbonization of paper and formation of carbon particles in the oil

6. Thermal fault 3: Temperature>700ºC metal change its color and carbon particle in the oil become high which cause thermal fault.

| Abridgment | Depict |
|---|---|
| PD | Partial discharge |
| D1 | Discharge of low energy |
| D2 | Discharge of high energy |
| T1 | Thermal fault ,T<300ºC |
| T2 | Thermal fault,300ºC<T<700ºC |
| T3 | Thermal fault ,T>700ºC |

*Table 1: Faults types*

## 3. DGA DIAGNOSTIC TOOL SELECTION

Diagnostic tool selection is an important process .We have a large number of available tools and it is important to know when to select which one. Here are some important and most commonly used tool for the interpretation of fault in the power transformer. these are key gas method (KGM), Doernburg Ratio Method (DRM), Rogers ration method, basic gas ratio method(IEC ratio method)(IRM) , Duval Triangle Method (DTM) .Most of these method are based on the gases ratio this means that ratio of gases are needed to analyze the fault so that it can fit in a specific range each ratio have some specific value.[9]

| Type | Fault Types | Gas involved |
|---|---|---|
| K.G.M | PD,AD,D1,D2 | $H_2$, $CH_4$, $C_2H_2$, CO, $CO_2$, $C_2H_4$, $C_2H_6$ |
| D.R.M | T1,T2,T3, D1,PD | $H_2$, $C_2H_4$,$CH_4$, $C_2H_2$, $C2H_6$ |
| R.R.M | PD, D1, T1,T3 | $C_2H_2$, $C_2H_4$,$H_2$, $CH_4$, $C_2H_6$ |
| I.R.M | PD, D1,D2, T1,T2,T3 | $H_2$, $C_2H_6$, $CH_4$, $C_2H_2$, $C_2H_4$ |
| D.T.M | D1,D2,T1,T2,T3 | $CH_4$, $C_2H_2$, $C_2H_4$ |

*Table 2 : Method and related gas, faults.*

## THE DOERNENBURG RATIO METHOD

The method mention about the three fault corona, thermal decomposition, arcing. By utilize these gas ratios R1,R2,R3,R4 we can diagnosis the transformer faults .The gases released in the transformer first compare with the specific concentration $L_1$ which is given below to assure that is there any problem with the transformer or not and then if the gases exceed the specific concentration then we apply ratio analysis. The Table 3 give limiting value of the gases dissolved in the oil [5].

| **Gases** | **Concentration Per Gas $L_1$ (ppm)** |
|---|---|
| Hydrogen-($H_2$) | **100** |
| Methane-($CH_4$) | **120** |
| Carbon Monoxide-(CO) | **350** |
| Acetylene-($C_2H_2$) | **35** |
| Ethylene-($C_2H_4$) | **50** |
| Ethane-($C_2H_6$) | **65** |

*Table 3: Gas and associated concentration.*

Flow chart given by Figure 2 explains the complete process of the given method:

- Obtain the gas concentration by extracting gases from the oil. And separated them by chromatography
- Transformer should be in fault condition if any one of these gases $C_2H_2$, $H_2$,$CH_4$,and $C_2H_4$ exceeds two times the value of the $L_1$ (Table 3) for the validation of ratio analysis proceed further

- R-1 , R-2 , R-3 , R-4 are the gases ratio if one of the gases exceed to its limiting value which is given in the Table 4 then the ratio analysis is valid if the value of the gases do not exceed to the limit then the oil should be re-sampled and retell by the other procedure.
- Once we validate the procedure the ratio of each gases is compared by the values in the Table 4
- All consecutive gas ratio for a particular category of fault come within the range of values given in the Table 4 then the imply analysis is valid.

| **MENTION FAULTS** | **(R-1) $CH_4/H_2$** | **(R-2) $C_2H_2/C_2H_4$** | **(R-3) $C_2H_2/CH_4$** | **(R-4) $C_2H_6/C_2H_2$** |
|---|---|---|---|---|
| **1.CORONA** | <0.1 <0.01 | Not valid | <0.3 <0.1 | >0.4 >0.2 |
| **2. ARCING** | >0.1 >0.01<br><1.0 <0.1 | >0.75 >1.0 | >0.3 >0.1 | <0.4 <0.2 |
| **3. THERMAL DECOMPOSITION** | >1.0 >0.1 | <0.75 <1.0 | <0.3 <0.1 | >0.4 >0.2 |

*Table 4: RATIO FOR KEY GASES*

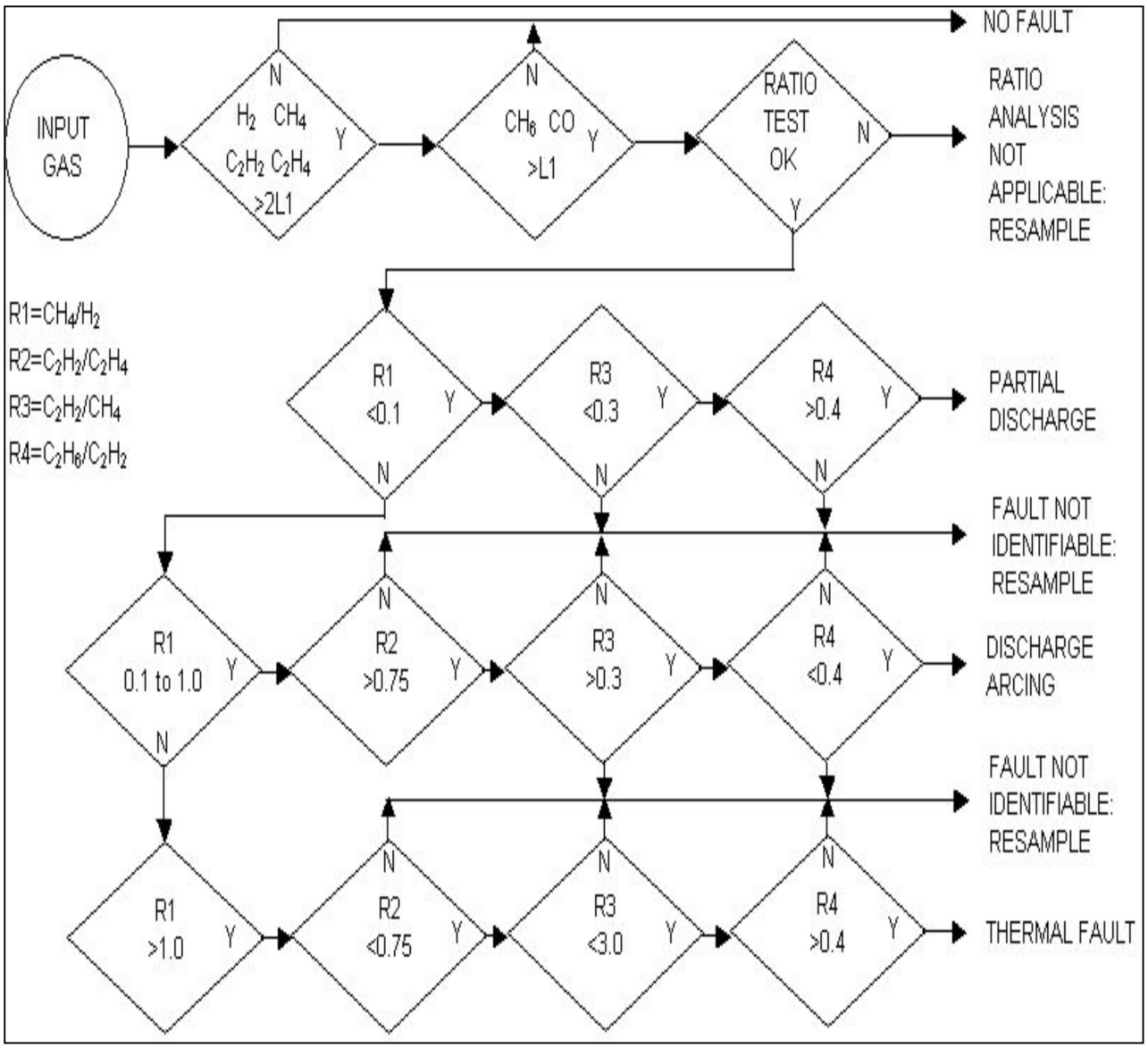


*Figure 2: DOERNENBURG RATIO METHOD FLOW CHART*

## THE-ROGERS-RATIO-METHOD

This method is similar to the Doernenburg ratio method it chase same set of steps as of doernenburg method but in the R-R-M they used only 3 gases for the analysis. The three gases ratio are R1, R2 and R5. [5]

R-R-M is also based on the principle of thermal degradation .In Table 5 the three key gas ratio gives the value corresponding to their diagnoses .These key gas ratio are valid for the both gases extracted from unit oil.[5]

| Number Of case | R2 $C_2H_2/C_2H_4$ | R1 $CH_4/H_2$ | R5 $C_2H_4/C_2H_6$ | Diagnosis |
|---|---|---|---|---|
| **0** | < 0.1 | > 0.1 | < 1.0 | Transformer Normal |
| **1** | < 0.1 | < 0.1 | < 1.0 | PD |
| **2** | 0.1-3.0 | 0.1-1.0 | > 3.0 | D1 |
| **3** | <0.1 | >0.1<br><1.0 | 1.0<br>3.0 | T1 |
| **4** | <0.1 | >1.0 | 1.0-3.0 | T2 |
| **5** | <0.1 | >1.0 | >3.0 | T3 |

*Table 5 : ROGERS RATIO FOR KEY GASES*

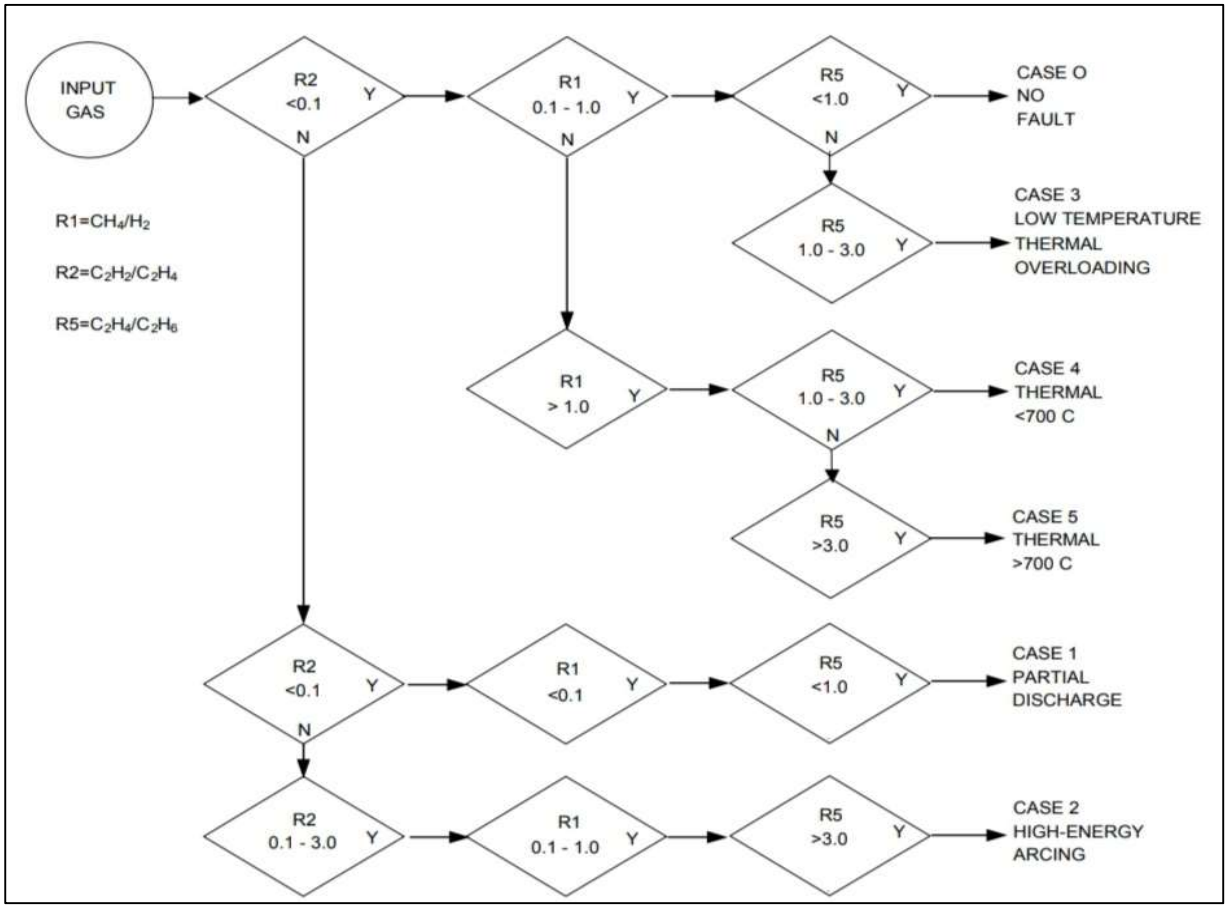


*Figure 3: Flow Chart of Rogers Ratio Method*

## THE-DUVAL-TRIANGLE-METHOD

Michel Duval is known for triangle & pentagon method used for the interpretation in DGA. This method help in interpretation of the DGA data of thousands of transformer and proven to be more correct [6] [7].

In this method we take three gas concentration(ppm) methane-($CH_4$), ethylene-($C_2H_4$), acetylene-($C_2H_2$) and percentage of each gases($C_2H_4$%,$C_2H_2$%,$CH_4$%) are plotted to the sides of triangle as mention in the figure 4 below and triangle is further divided into the fault zones. The label on the zone tell about the type of fault and combination of gases in that faults [7]

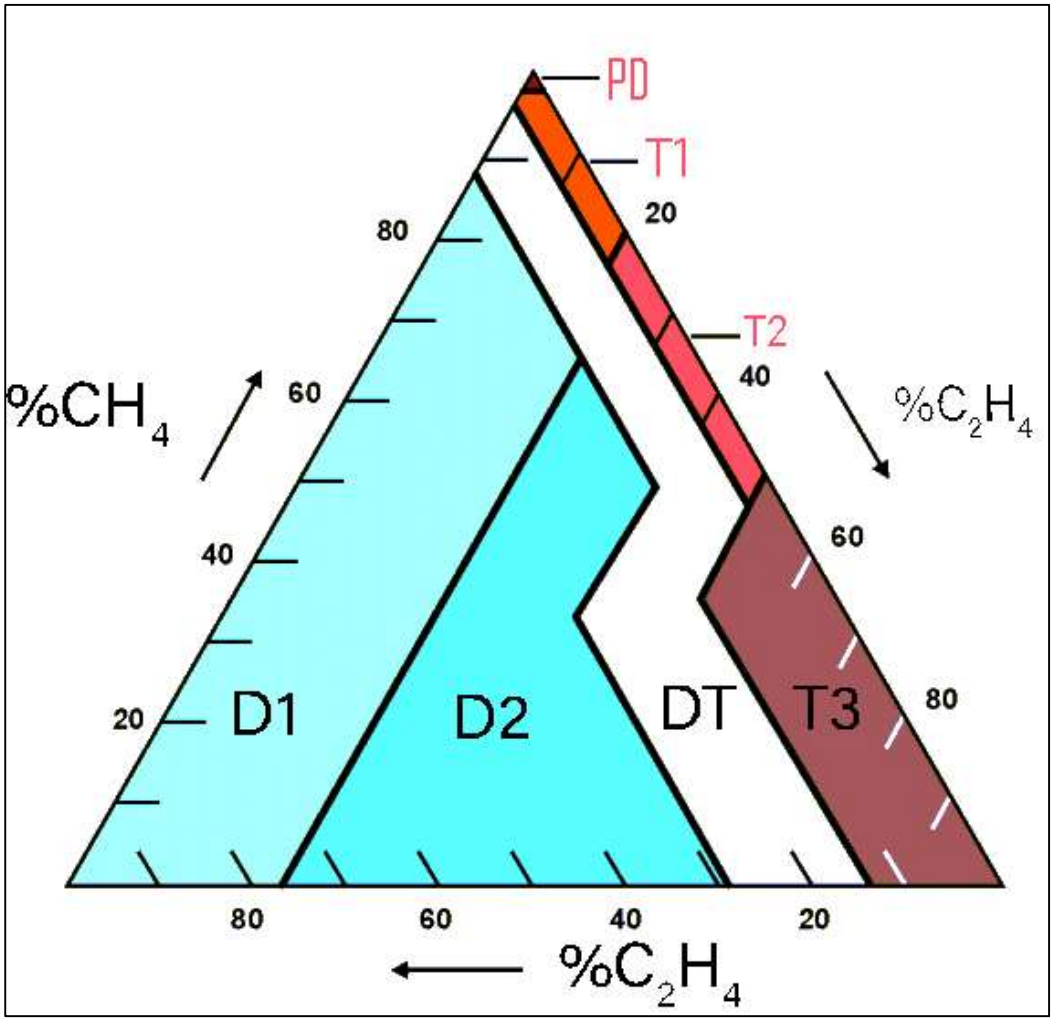


*Figure 4: Duval Triangle*

## KEY-GAS-METHOD

This method is based on the amount of gases released from the transformer oil. As chemical bond break in oil at different temperature in the unit. Method uses each of the single gas level to detect the faults [5].

| **Gases** | **Type of Faults** | **Proportion of Generated Gases** |
|---|---|---|
| $C_2H_4$ | Thermal oil Fault | Large amount of $C_2H_4$ Smaller of $CH_4$,$H_2$,$C_2H_6$, |
| CO | Thermal oil & cellulose | Mainly CO |
| $H_2$ | D2,PD | Mainly $H_2$ , Small portion of $CH_4$ |
| $H_2$&$C_2H_2$ | D1 | $H_2$ and $C_2H_2$ $CH_4$,$C_2H_6$ & $C_2H_4$ |

*Table 6: Key Gas Method*

# Chapter 4: MACHINE LEARNING

Overview:

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Present chapter gives a brief introduction of machine learning its types and some available models.

# 1 .INTRODUCTION

Machine learning subset of Artificial Intelligence (AI) which gives computer the potential to learn from examples and improves on a task without being explicitly programmed for the task. Machine learning basically deals with the exploration of data in order to learn from it [10] [11].

According to *Arthur-Sameul* "*Machine leaning is a field of study that enables the computer to learn without explicitly programed"*

Learning: The ability to improve behavior based on experiments.

Machine Learning: ML explores the algorithms that learns and build model using data in such a way that these models can be further used for different tasks like classification, regression, prediction.

*Tom Michell* defined Machine learning in a modern form:

**"***A computer program is said to learn from Experience E with respect to some class of tasks T and performance measure P, if the performance on task in T as measured by P improves with experience E*"

We can understand the elements of definition as:

- **Experience (E):** Examples given to ML model
- **Tasks(T):** Prediction , Classification , Regression
- **Performance measure (P) :** Accuracy measure

We can conclude that machine learning is the process of learning from data and using that learning in order to make predictions on new data of same kind. Fig 1.represents a machine learning model where:

Learner: Takes knowledge and experiences and build model

Reasoner : Use model and predict for new data

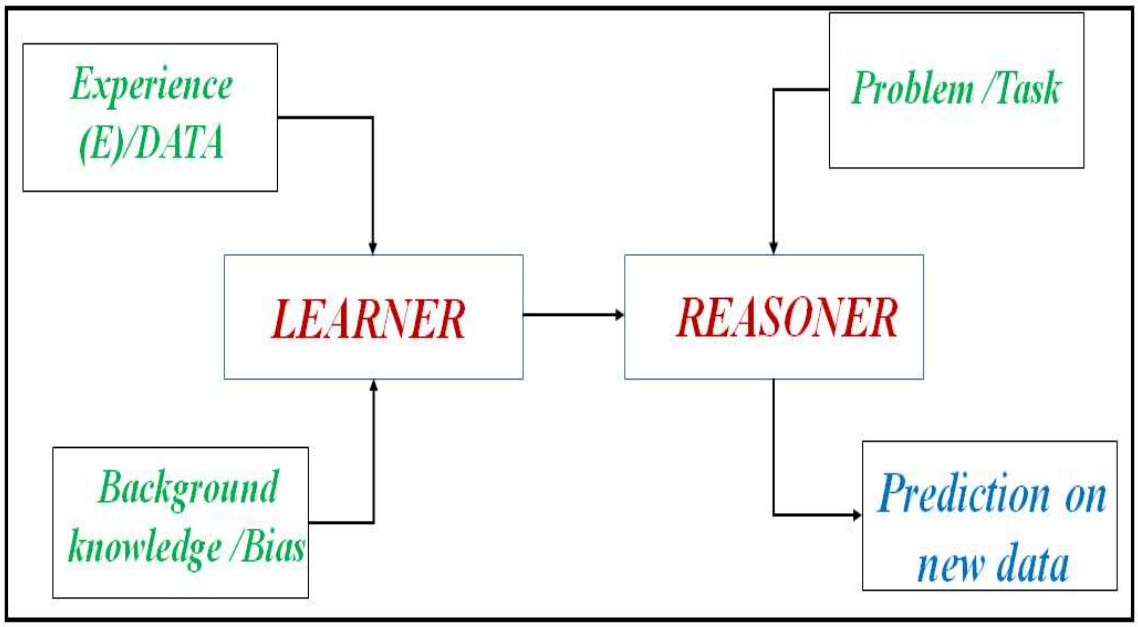


*Figure 5: Machine learning Model*

## 2. DIFFERENT TYPES OF MACHINE LEARNING ALGORITHMS:

Machine learning are basically divided into three types based on the data.

1. Supervised Machine Learning

2. Unsupervised Machine Learning

3. Reinforcement Machine Learning

4. Semi-supervised Machine Learning

## SUPERVISED-MACHINE-LEARNING:

Supervised Machine Learning is defined as a type of leaning having teacher or supervision .The data here is well labelled .In this learning the data set contains input features along with correct outputs labelled to each input .Supervised machine learning algorithms can be used in order to learn from labelled data and then the learning can be applied over new data to make predictions .The process start with feeding the algorithm with the learning data i.e. training data and the algorithm learn the mapping between the input and labelled output then this learning is applied over new data to predict output when given with inputs . [13].

In Supervised learning we have:

- Labelled Dataset.
- $(X_1, y_1), (X_2, y_2),(X_3, y_3),\ldots\ldots\ldots\ldots..,(X_n, y_n)$ (Pre classified training examples)
- X → Input , y →Corresponding output

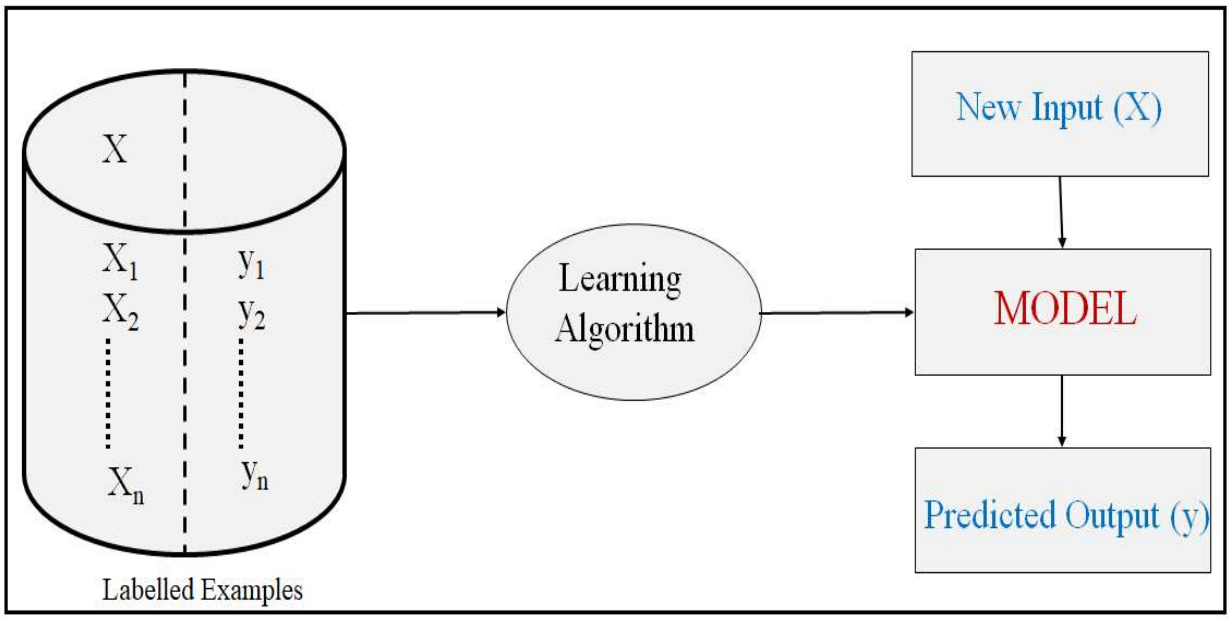


*Figure 6 : Supervised Learning*

## UNSUPERVISED-MACHINE - LEARNING

Unsupervised Machine learning is defined as a type of learning which has no supervision or don't require any teacher .It used when the data for learning is unlabelled. We have large number of inputs in our data and no labelled output. Unsupervised machine learning uses the data in order to understand it and organise same type o data into clusters .After the algorithm has finished training using unlabelled data the model trained is ready to use with new data for making the predictions. But the input given to the model will only be classified into categories assigned as clusters by Un-supervised learning Algorithm.

Unsupervised learning algorithm has:

- Unlabelled Data
- $X_1, X_2 \ldots\ldots\ldots\ldots\ldots X_n$ (Examples containing lot of unlabelled data)

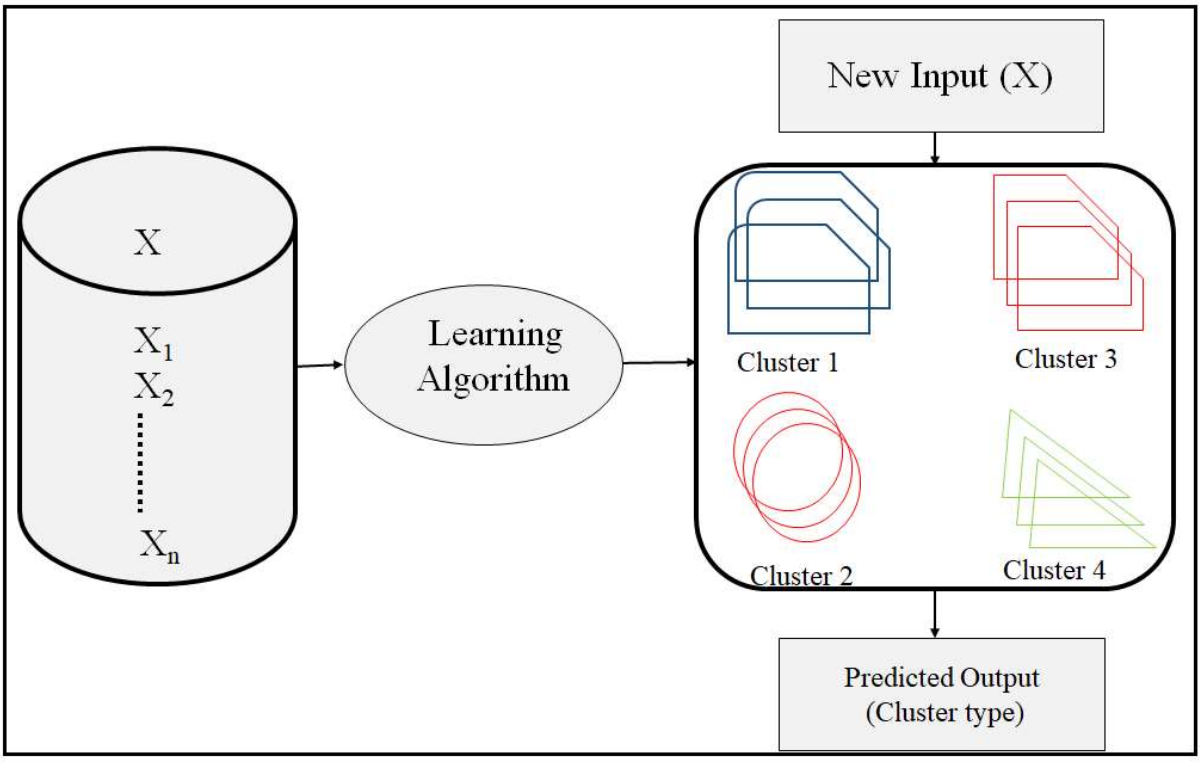


*Figure 7 : Unsupervised Learning*

## REINFORRCEMENT-MACHINE-LEARNING:

It is the learning in which final task is achieved by reinforcement. The Learning has an agent which is supposed to make it way through an unknown complex environment. The agent starts with random trail for each correct step it is rewarded and for each incorrect step it is punished. At last the learning is ensure by maximizing the reward. Reinforcement machine learning algorithms is a learning method that interacts with its environment by producing actions and discovers errors or rewards. Trial and error search and delayed reward are the most relevant characteristics of reinforcement learning. This method allows machines and software agents to automatically determine the ideal behaviour within a specific context in order to maximize its performance.

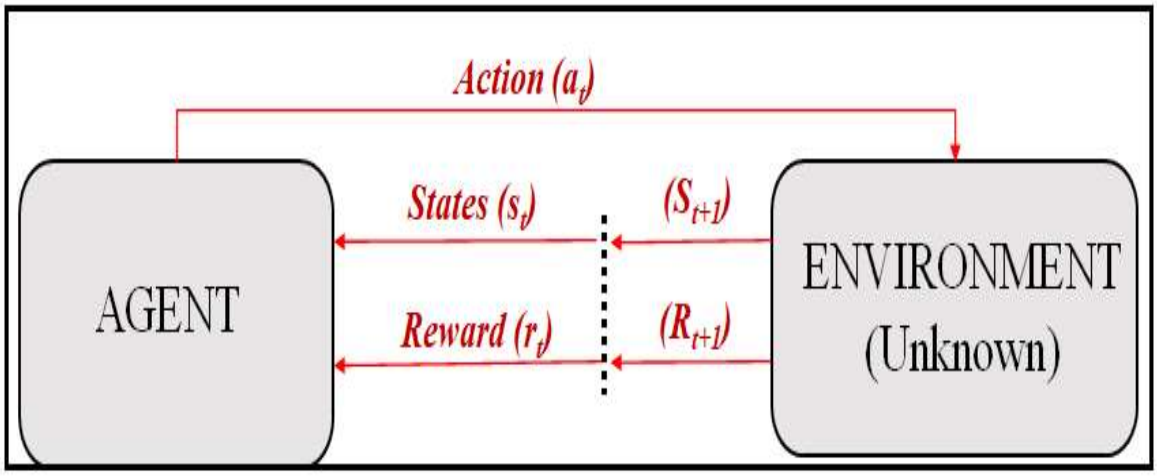


*Figure 8: Reinforcement Learning*

## SEMI-SUPERVISED- MACHINE-LEARNING:

As depicted by the name semi-supervised learning is the combination of Supervised and Unsupervised learning. Semi-supervised learning algorithm is used when we have a mixture of data in such a way that for some input we have corresponding labelled outputs and for some inputs we don't have outputs. This algorithm divides the labelled data accordingly and arrange unlabelled data into clusters.

Semi-supervised machine learning Algorithm has:

- $(x_1,y_1)$ ,$(x_2,y_2)$,…… ,$(x_n,y_n)$ (Labelled data)
- $X_1$, X2..... $X_n$ (Unlabelled data)

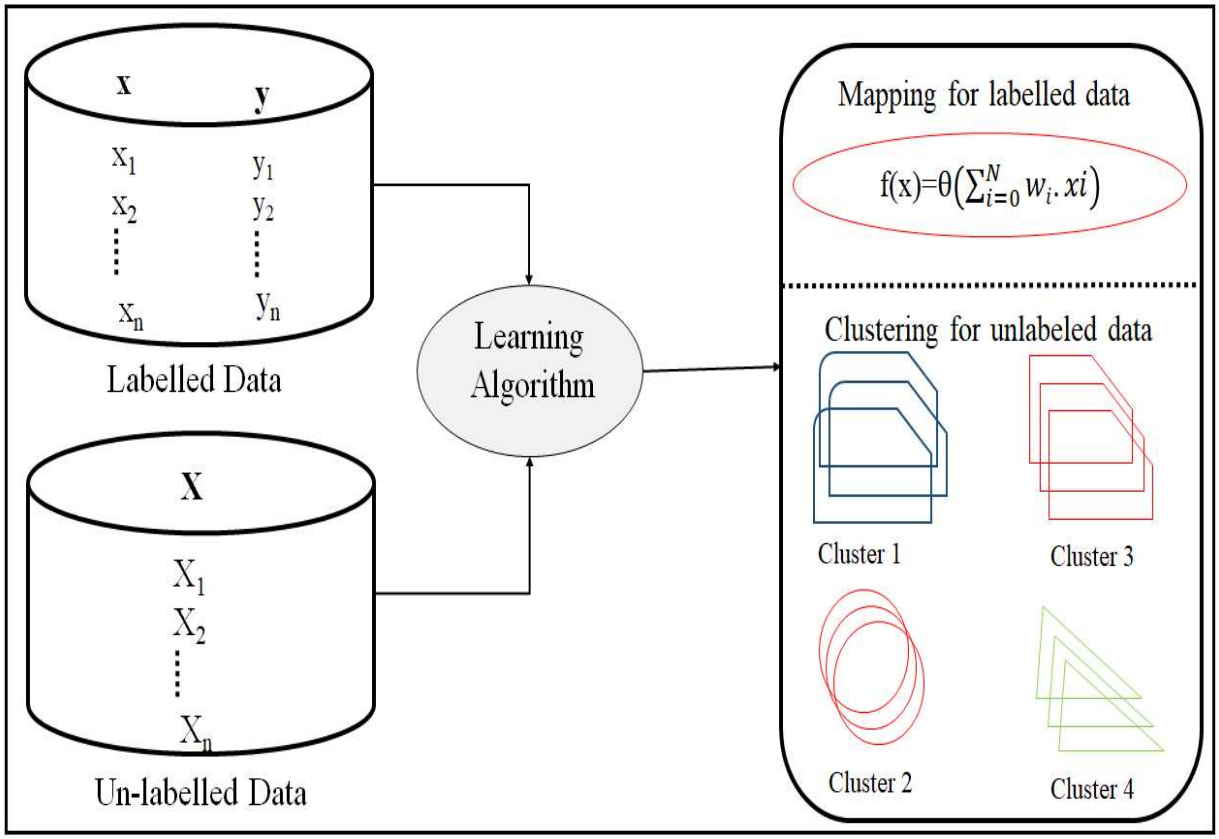


*Figure 9: Semi-Supervised Learning*

# Chapter 5: MACHINE LEARNING MODELS

Overview:

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Present chapter gives a brief introduction of machine learning Model its types and some available models.

# 1. INTRODUCTION:

In order to perform desired tasks be it classification or regression we have to build machine learning model. Models are build using available Learning algorithm and Hypothesis set .The Hypothesis set is the collection of available models be it Neural Networks, Linear regression, SVM .Whereas for each hypothesis set there is an associated machine learning algorithm .The Models are fed with the Training data and is trained over that data and then validated over test data .

## 1. Components of Machine learning Models:

Every Machine learning model has two main components:

- The Hypothesis Set {h € H}.
- The Learning Algorithm associated with the hypothesis set.

When put together these are referred as the Learning model.

| **Machine learning Model** | **Hypothesis Set** | **Learning Algorithm** |
|---|---|---|
| 1.Perceptron Model | Perceptron | PLA ( Perceptron learning Algorithm ) |
| 2.ANN Model | ANN | Back Propagation |
| 3.SVM model | SVM | Quadratic Programming. |

*Table 7: Machine learning model components*

## 2. Learning Approach by Models:

Every dataset has an associated function which is the exact mapping between the input and output of data. This function is called the ideal function. Our model try to learn this is deal function but most of the time it is impossible to learn this function. So Model which learn function quite similar to the ideal function is called the ideal model and this is used for future prediction .Learning starts when the data i.e. training data is fed to the machine learning model. Algorithm tries to find out the mapping between input and output and come up with function called g .Where g is the output function of machine learning model. The Models output function is then fed with the test data and its accuracy is checked over it. If there is very less difference between the training and testing accuracy the model is selected and is considered as final hypothesis or model.

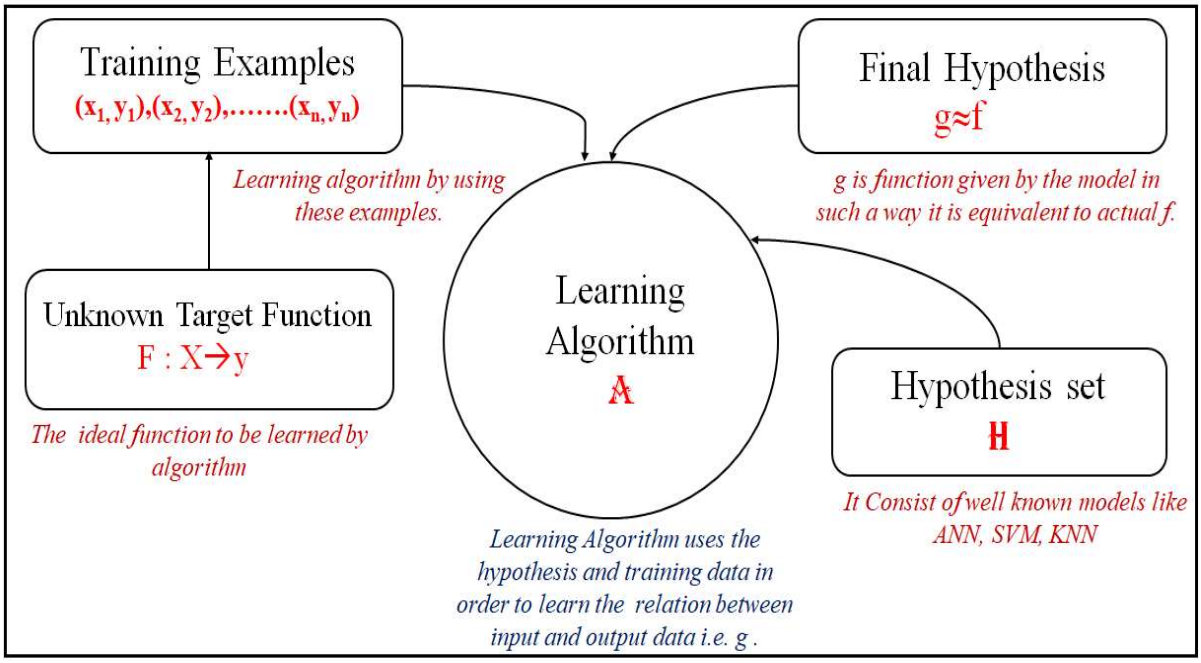


*Figure 10 : Learning Approach*

## 2. MODEL1: ARTIFIFCIAL NEURAL NETWORK:

### 1. INTRODUCTION:

Neural Network or artificial neural network are the inter connection of artificial neurons (Nodes) that tries to simulate the working of the human nervous system or the brain .Neural network are inspired from the biological brain. ANN is the result of efforts made by many scientists in order to make a system that can act like human brain and neural network have successfully simulated the Brain up to an extent. Let us understand the Biological neural network in order to understand the artificial neural network. Biological neural network consist of a large collection of biological neurons. Each neuron have four mains parts namely.

- Nucleus : Centre of the neuron
- Dendrites: Thread like structure act as receiving ends of signal.
- Soma : Body of neuron
- Axon: Transmitter of signal between neurons.

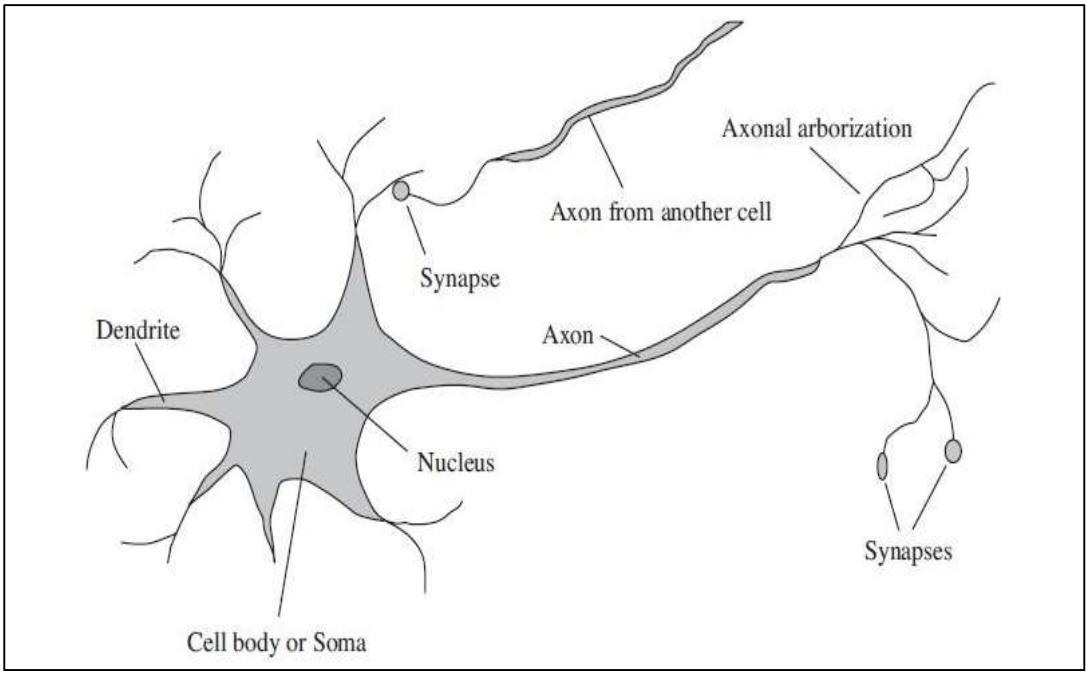


*Figure 11 : Biological Neuron Cell*

Biological neuron make connection with other neurons approximately up to million neurons at junctions called synapsis. Synapsis are connected to dendrites which receives signal from other neuron in form of electrochemical reactions. All the signals are added up and if the sum exceed the amount required for firing (process of transmission of signal from one neuron to other neuron) then the neuron fires through the axon connected of other neuron .There is a synaptic junction between the axon and dendrites of other neuron so the signal is passed from synaptic junction to dendrites as shown in figure7. Based on the biological neuron many scientist try to come up with a mathematical model that could act like neuron.

## 1.1. PERCEPTRON

In 1943 two scientists McCulloch and Pitts come up with the mathematical model that represents a neuron. It fires when the submission exceed particular threshold value .This was the starting of Artificial Neural Network. This model was able to sum up all the inputs and then uses an activation function in order to make decision whether to fire i.e. transfer signal further or not. The model was a linear model and there were two type of activation functions, one is threshold function and other one is sigmoidal function.

Perceptron have following components:

- Input
- Weights
- Summing unit
- Activation unit
- Output

Inputs represents the data input given to the neuron same as the input received by the dendrites of neuron. Then with multiple inputs there are associated weight with each

input. The summing unit give the summation of the product of input to corresponding weight associated with input and then this some is pass on to the activation function which decides whether to pass on the output or not activation function are further discussed in brief in coming topics of same chapter .The collection of neuron in layers form the artificial neural network .

The equation governing the model are

- The sum of weights for all input:

$$s_i = \sum_{i=0}^{n} a_i w_i$$

- Then after this activation function is applied to get the final output y :

$$y = \emptyset\left(\sum_{i=0}^{n} a_i w_i\right)$$

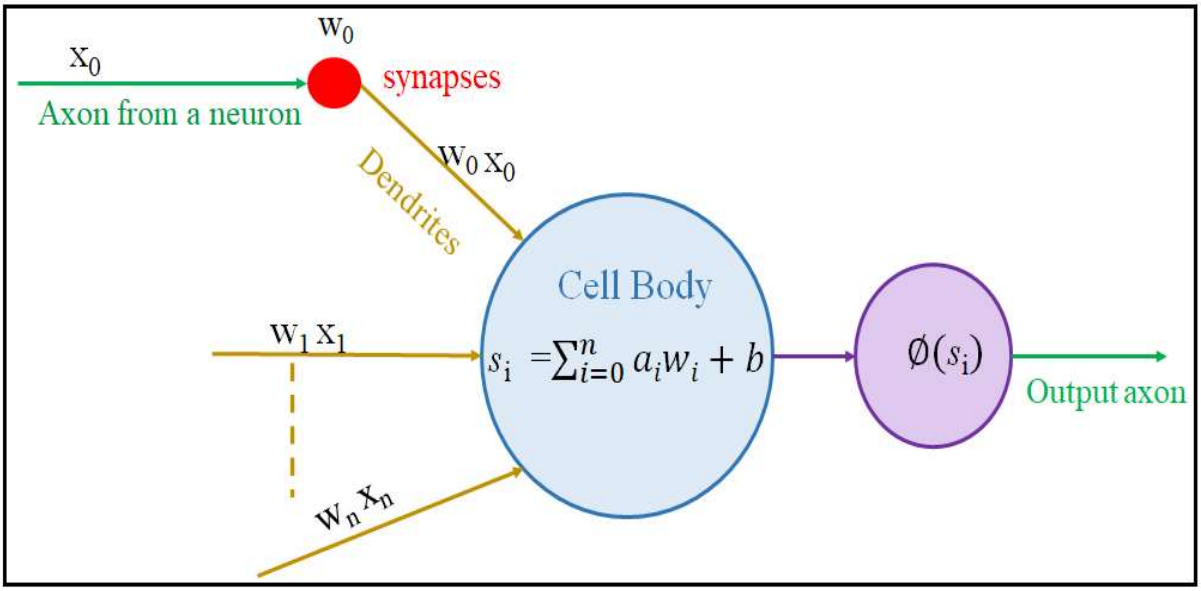


*Figure 8: Perceptron (neuron)*

Drawback of perceptron model:

- Perceptron model is very simple model
- Perceptron model can only work with linearly separable data.

- Perceptron model can't be used with complex problems
- Perceptron model can't be used for unbalanced data.

Because of these failures of the perceptron there was a need of much more stable and powerful model, this give rise to the artificial neural network. We will now discuss an important type of ANN called the Multilayer ANN.

## 1.2 ARTIFICIAL-NEURAL-NETWORK

The collection of neurons (nodes) in form of layers and layers put together form the different notation of neural network some of them are:

- Feed-forward Artificial neural network
- Multilayer neural network

All these networks are classified based on the arrangement of neuron layers, let's discuss them one by one.

A. Feed-forward Neural network :

i. Feed-forward neural network are the Multilayer perceptron but larger in size

ii. In these information moves from input to output direction.

iii. There is no back injection of error

iv. These are less competent in comparison with their other family members.

v. There are further classified into two types :

1. Single-layer Perceptron.
2. Multilayer Perceptron.

1. Single-Layer perceptron:

i. Basic computational unit

ii. Basic model that acts like biological neuron

iii. Can only work with linearly separable data.

2. Multilayer Perceptron :

i. Contain more than one layer

ii. More than one hidden layer

iii. Good for non-linear data as well

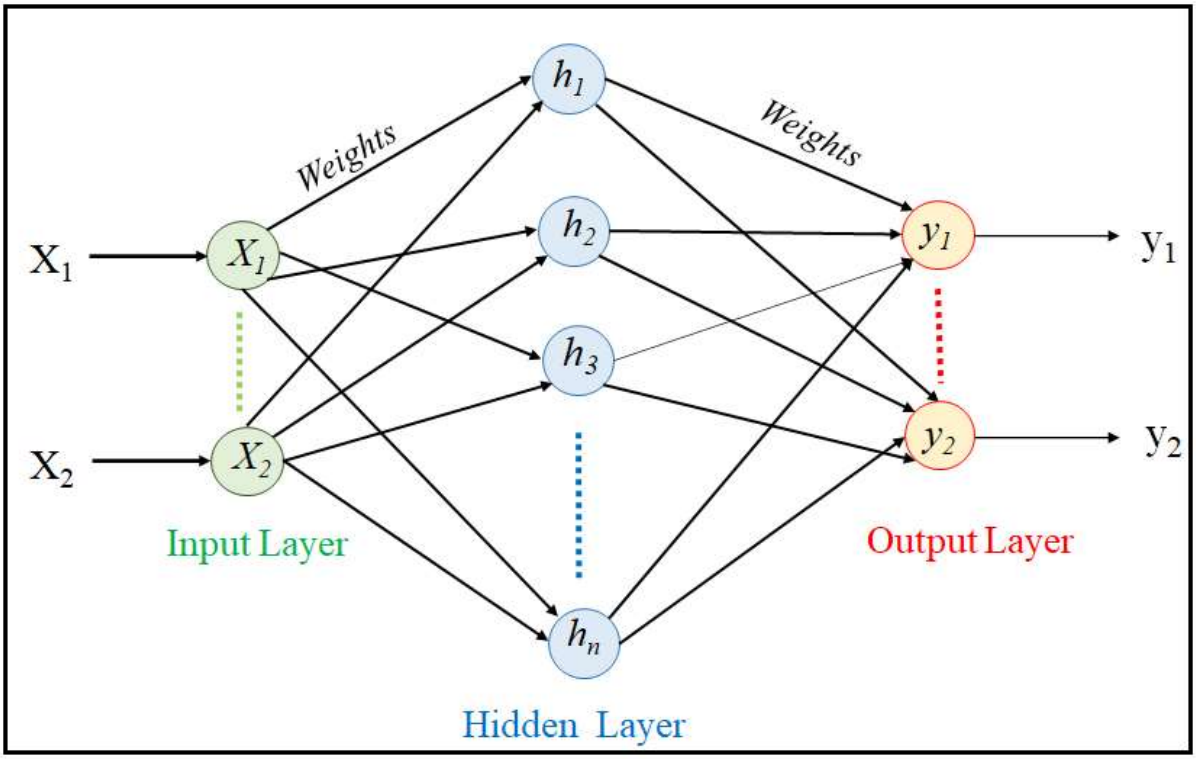


*Figure 12 : Multilayer Perceptron.*

B. Multilayer artificial neural network :

A collection of neuron made a layer and when many layers are connected in such a way that first layer is connected to second layer and second layer is connected to third layer and so on until we have a last layer. This collection of layers interconnected to each other with the help of an activation function is called Multilayer Artificial Neural

Network. Multi-Layer Artificial Neural Network have a non-linear activation function between each connection of layers. The first layer is defined as input layer and the last one is output layer whereas the layer in-between input and output layer are called hidden layers.

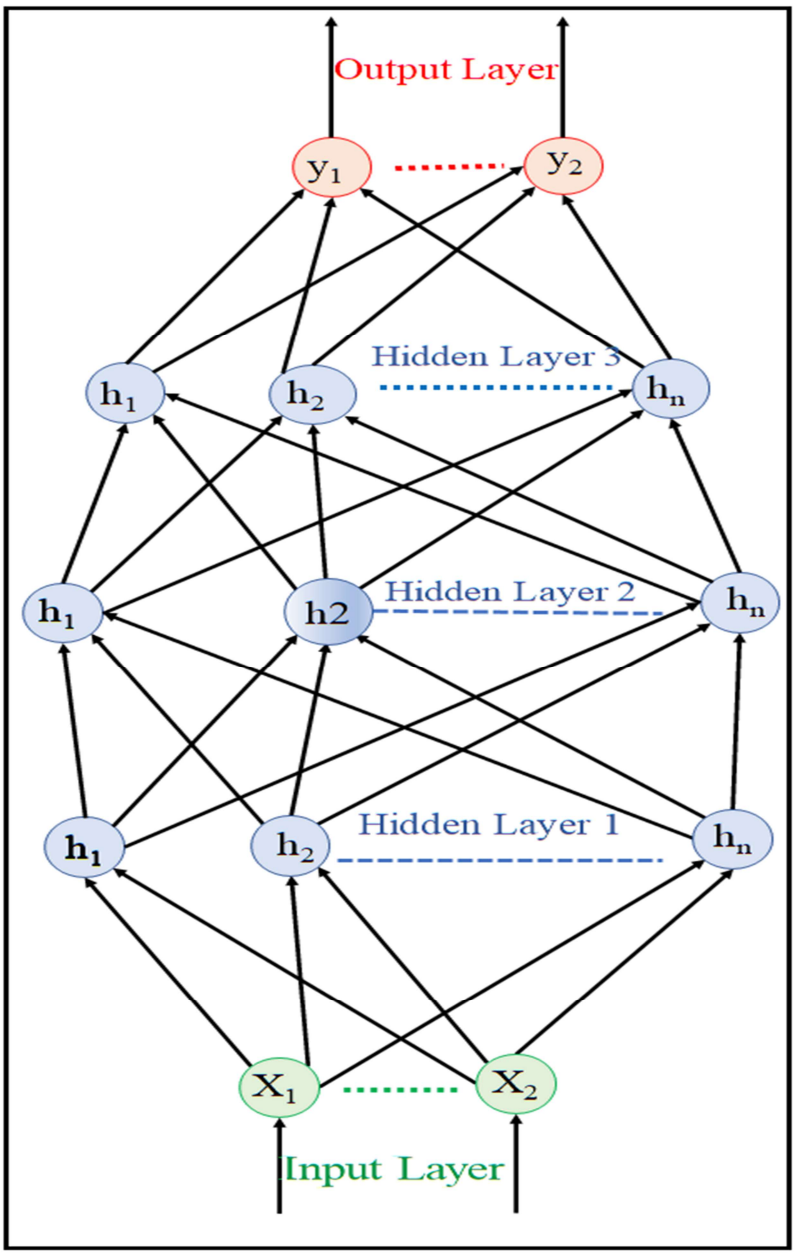


*Figure 13 : Basic Structure of MLANN*

## 2. MLANN TRAINING

The Model is fed with the pre-processed training data .The Model will take the data and tries to learn it and as a result will come up with a function that actually relates the mapping between the input data and the output corresponding to data.

MLANN will start with input and random weight then it will be passed on through layers until we have the predicted output. Once Model has the predicted output it is then calculate the error by comparing the actual output and predicted output. If there is any error then error is propagated back to the input layer and weights are updated in such a way that we can minimize the error this is called back propagation training. So BP has four steps

- Step 1 : Initializing weight
- Step 2 : Feed-forward the signal
- Step 3 : Back-propagation of error
- Step 4: Updating weight to reduce error.

## 3. MODEL EVALUATION:

MLANN Model was successfully trained on training data and then it is evaluated over testing data. The testing data is 20 % of the total dataset which was taken out in starting before training of the model. This was done in order to evaluate model effectively because if the model is trained and evaluated over the same data then it may have shown amazing results but there is a certainty that the model might have crammed the data and had not actually learned anything and when the same model will be used on new data it would had collapsed .So it is important to evaluate model on data other than the data it has seen in training.

## 3. MODEL 2: SUPPORT-VECTOR-MACHINE CLASSIFIER:

### 1. INTRODUCTION

SVM classifier is a classifier which is based on the support vectors and was basically developed for the binary classification. It was developed in order to find the most optimal hyper-plane separating the two classes with maximum margin .Support vector machine works on the principle of vectors. It tries out all the different available separation line possible in order to separate two classes and choose one with the maximum margin.

Let us consider an example where we have two classes shown in figure.

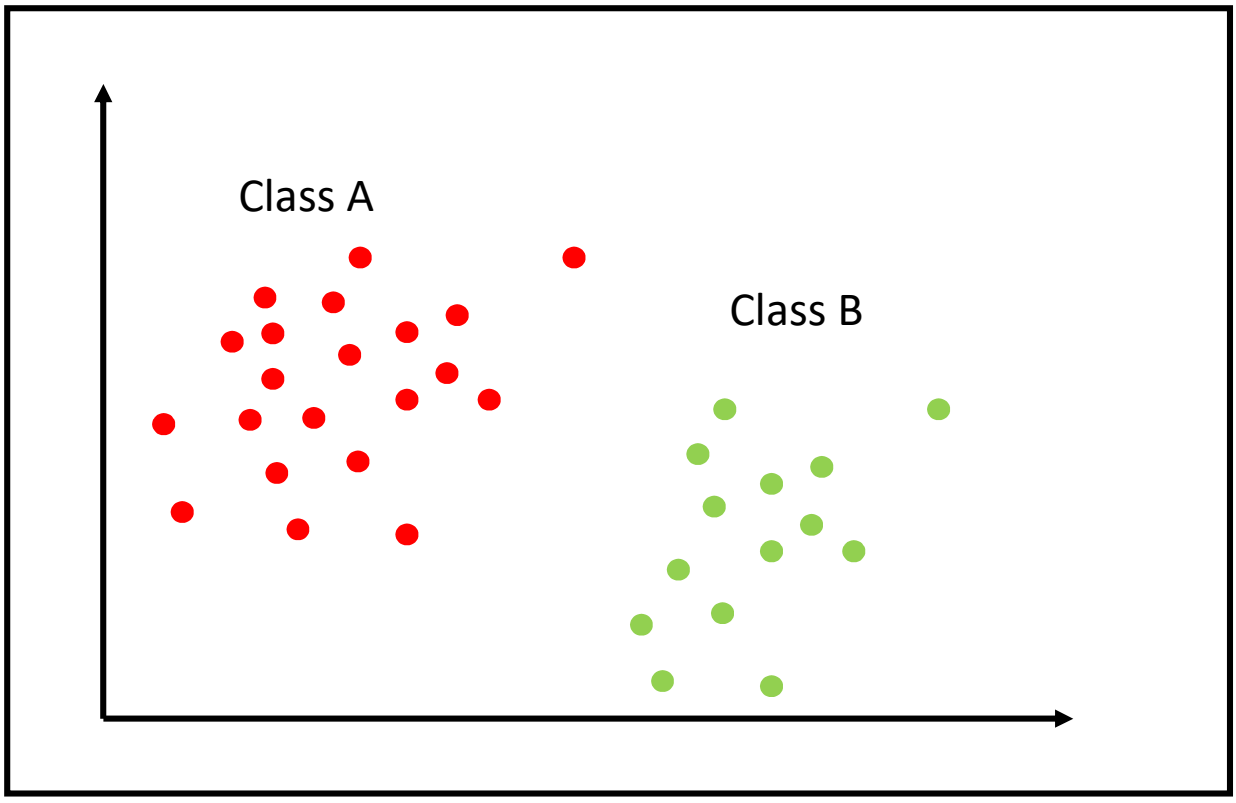


*Figure 14 : Two classes*

- In order to separate these two classes we come up with many separates like L1,L2 , L3

- Through intuition we can say that L2 is best separator as it has the maximum margin.

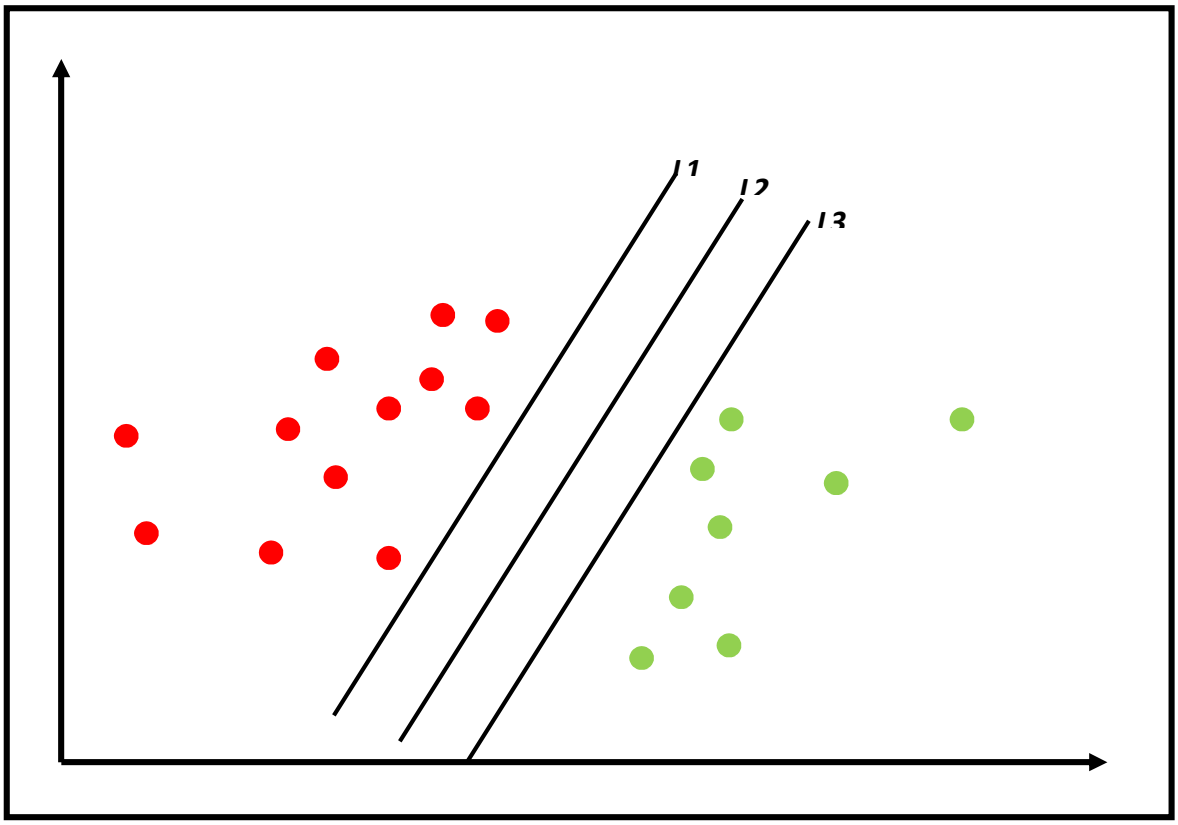


*Figure 15: Some of the possible separators.*

So the maximum hyper-plane is represented in figure 14.

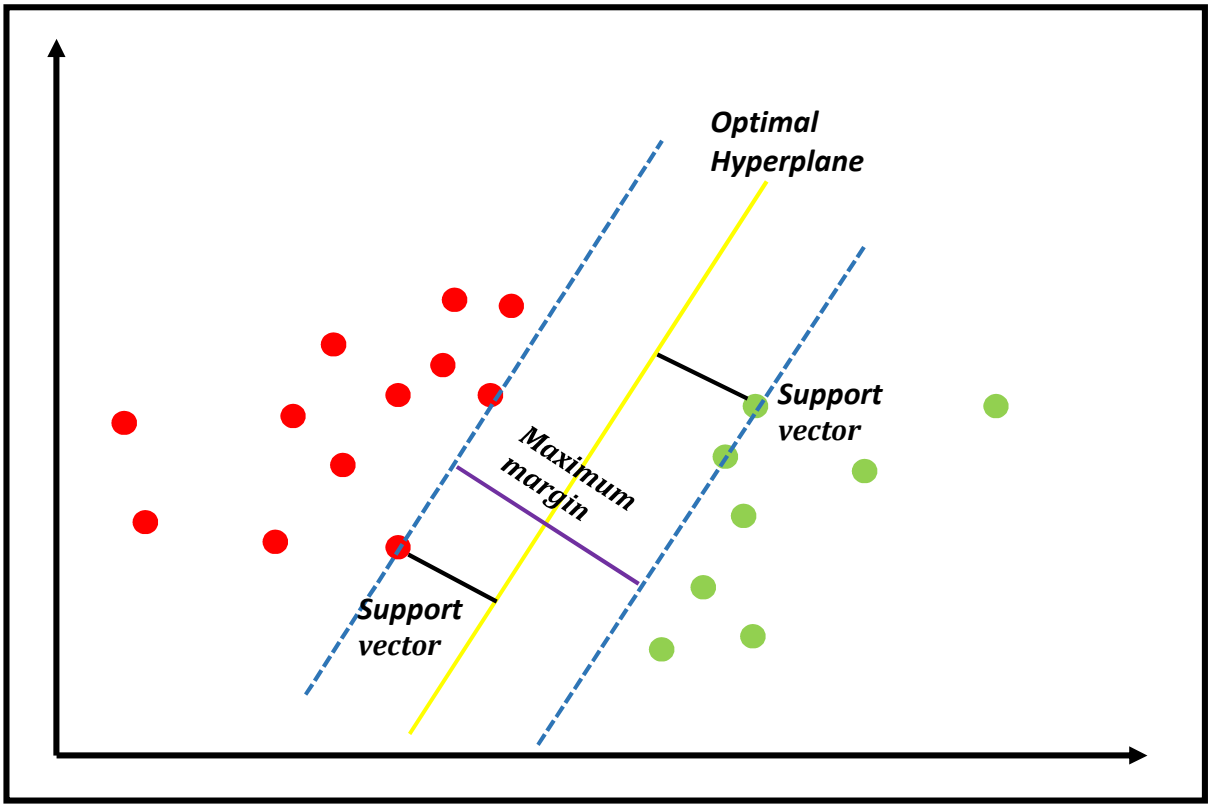


*Figure 16: Final Optimal Hyper-plane*

The equation governing the linear classifier in case of binary classification are given as:

- Equation of the separating line (L2) :

$$\boldsymbol{w^T x} + b = 0$$

Where $w^T$ denotes the vector of weights**.**

**x** denotes the vectors of input.

b denotes the bias.

- There can be many separating linear classifier such as L1, L2, and L3 etc. So the equation for this is given by the

$$f(x) = \boldsymbol{w^T x} + b$$

For multiclass classification we use C -SVM which follows the approach of one versus all .This id developed by the Boser et al., 1992; Cortes and Vapnik , 1995 and is then using the sklearn library and LIBSVM this can be implemented in python.

## 2. SVM CLASSIFIER TRAINING

The classifier Model is fed with the pre-processed training data .The Model will take the data and tries to learn it and as a result will come up with a function that actually relates the mapping between the input data and the output corresponding to data.

## 3. MODEL EVALUATION:

SVM Classifier Model was successfully trained on training data and then it is evaluated over testing data. The testing data is 20 % of the total dataset which was taken out in starting before training of the model. This was done in order to evaluate model effectively because if the model is trained and evaluated over the same data then it may have shown amazing results but there is a certainty that the model might have crammed the data and had not actually learned anything and when the same model will be used on new data it would had collapsed .So it is important to evaluate model on data other than the data it has seen in training.

# Chapter 6: DATA & DATA PRE-PROCESSING

Overview:

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Present chapter gives a brief introduction the dataset that is used in the simulation and pre-processing of data.

## 1. DATA

Data is the most important tool required for any simulation. Without it is impossible to think about any training or simulation .Getting data for the simulation of this project was one of the biggest challenges as data is private and no company or organization be it government or private is ready to share the data with anyone .

This project uses the dissolved gas analysis data in order to train the models and to get the results out of it. The accuracy of model depends upon the authenticity of data .All the data has been collected from the research paper by Michel Duval [24] and Enwen Li [25].

The DGA data consist of concentration of gases along with the actual fault related to transformers .The Gases present are Acetylene, Ethylene, Hydrogen, Methane and Ethane. The gases is show in figures where X-axis represent the sample i.e. transformer and Y-Axis represents the concentration of gas in ppm.

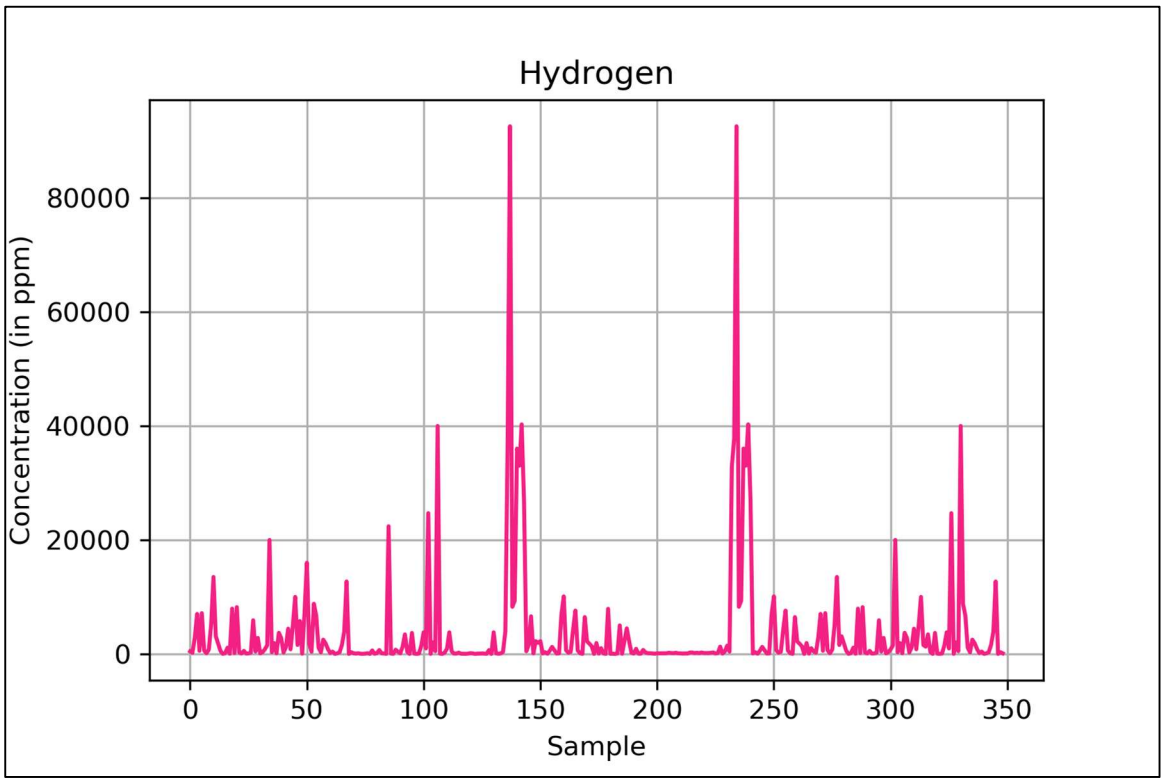


*Figure 17 : Concentration of $H_2$ gas per sample*

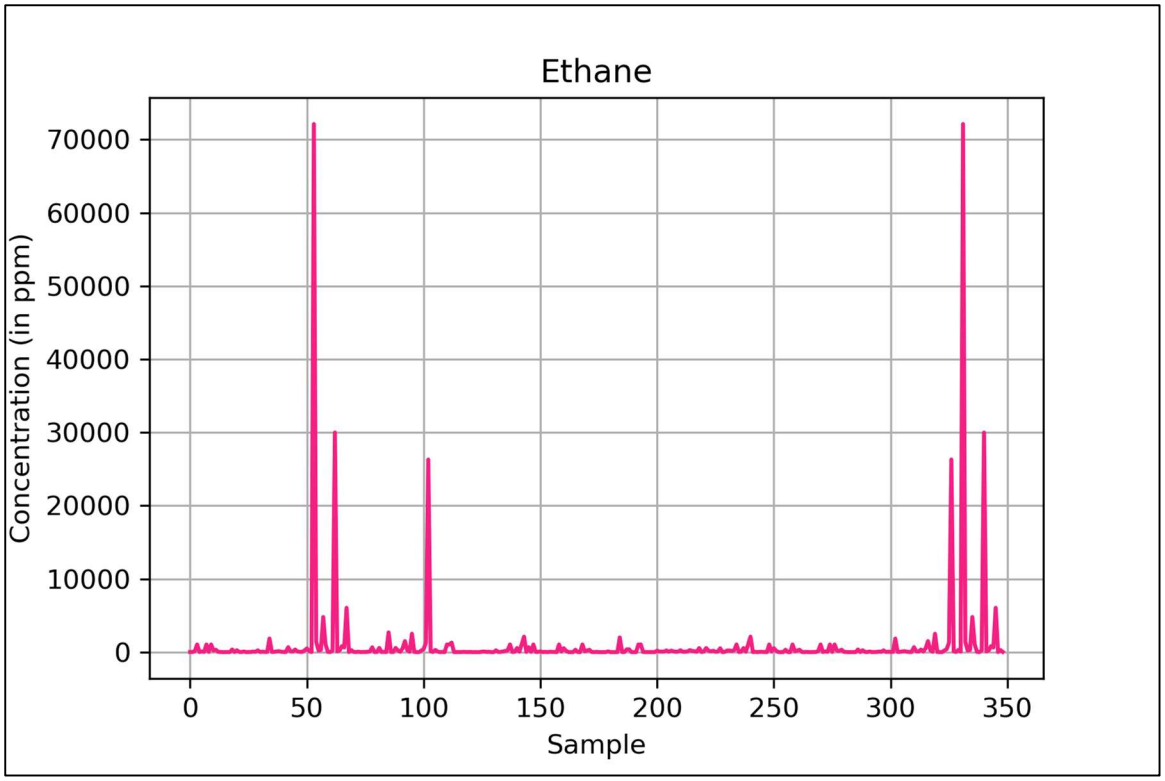


*Figure 18: Concentration of $C_2H_6$ per sample*

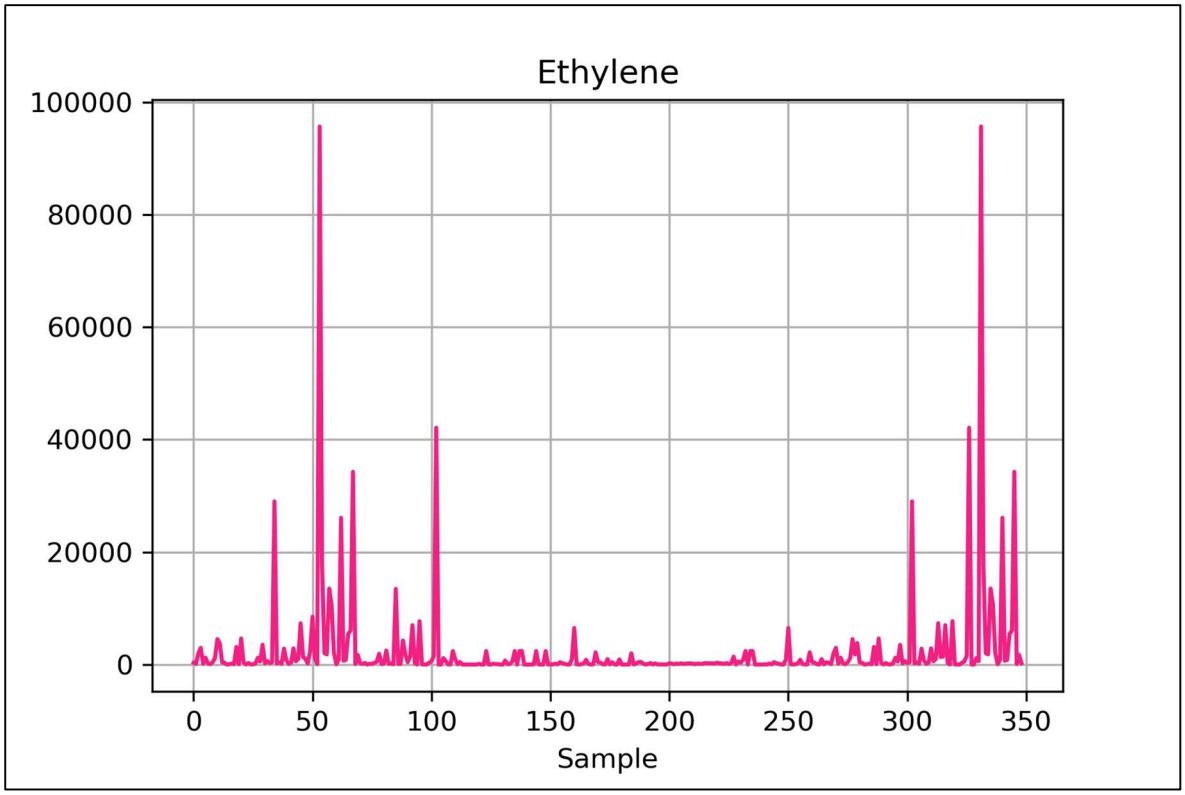


*Figure 19: concentration of ethylene per sample*

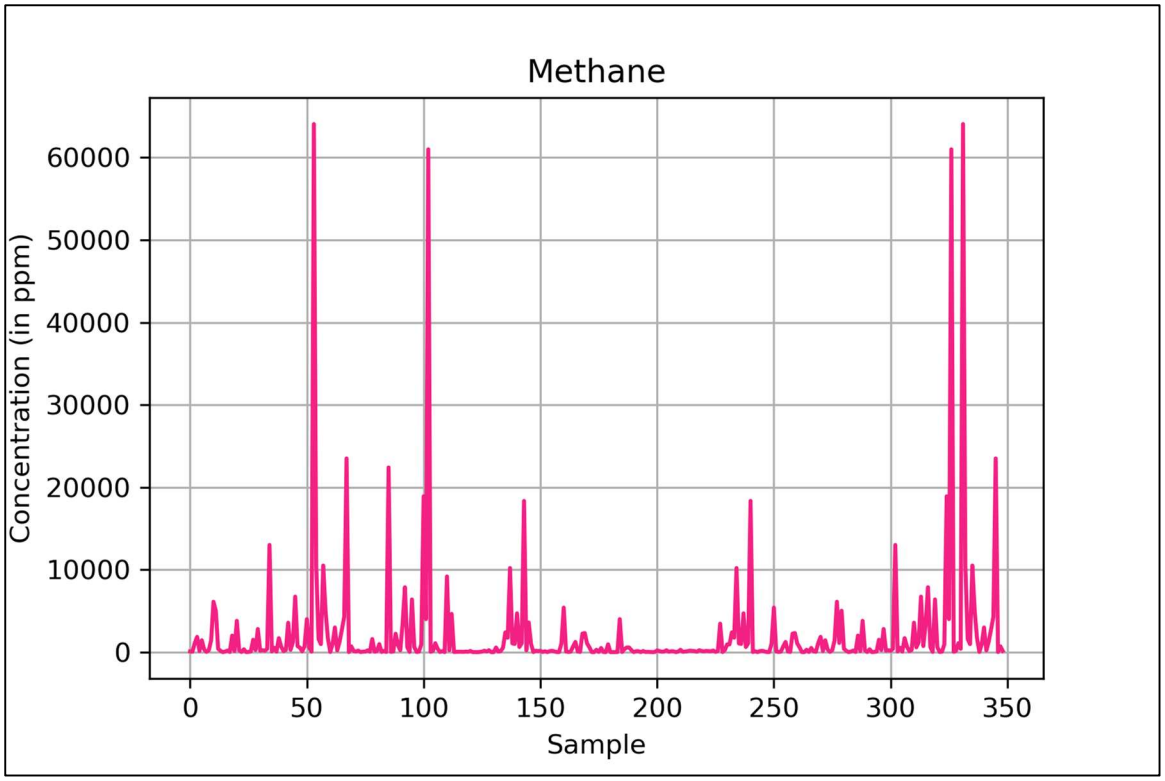


*Figure 20 : Concentration of $CH_4$ per sample*

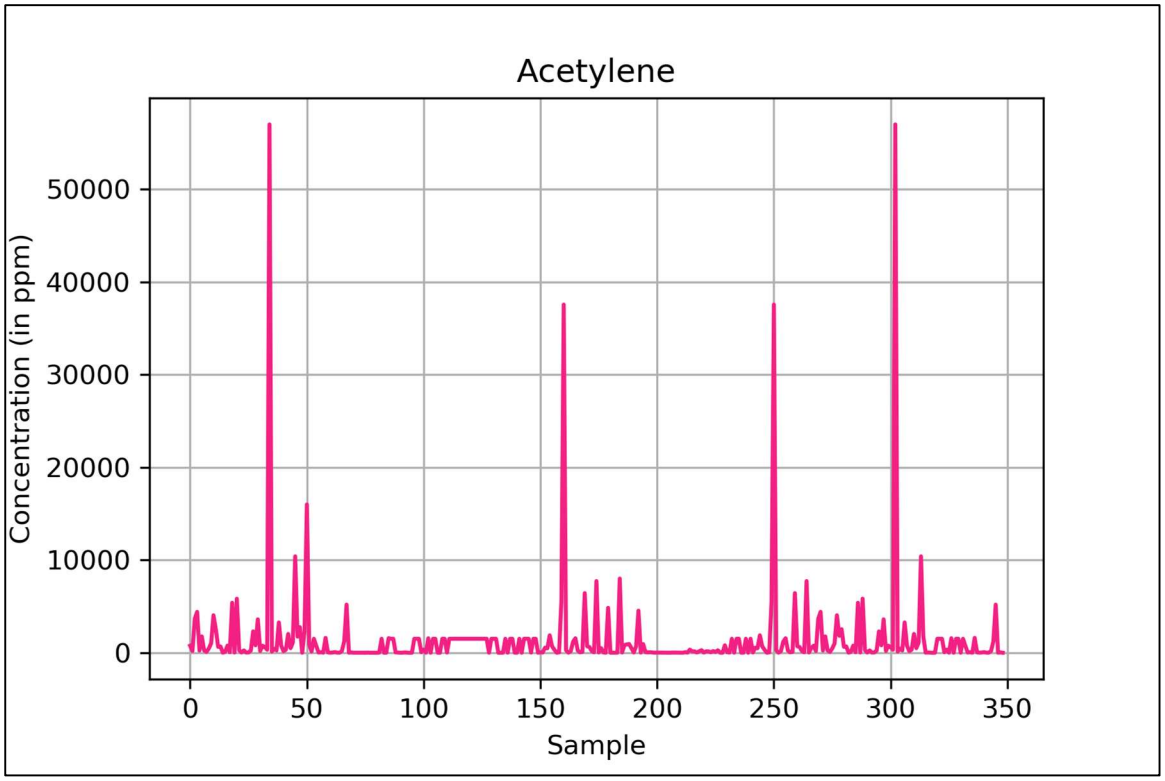


*Figure 21: Concentration of $C_2H_2$ per sample*

## 2. DATA-PREPROCESSING

Data preprocessing is a vital part of training a machine learning model as the state of data can directly affect the learning. Mostly data is in drawn from various sources which makes it non uniform and ambiguous. So it is important to preprocess data before feeding it to a machine leaning model.

If the data that we are using is having some inadequate or irrelevant information, then the model may presents less accurate results, or may fail to discover anything of use at all. Thus, data pre-processing is an important step machine learning. The pre-processing step is used to resolve several types of problems such as noise in data, redundancy data, missing values in data etc. All the Machine learning algorithms rely heavily on the product of data-prepossessing, which is the final training set [19].

Data pre-processing includes:

- Loading DGA Dataset.
- Handling missing data.
- Handling text labels.
- Separating dependent and independent variables.
- Handling data with categories.
- Normalizing the data.
- Splitting training and testing data

Dataset is loaded and is divided into the input features(X) and output features(y).the input features are gases (acetylene ($C_2H_2$), Ethylene ($C_2H_4$), Hydrogen($H_2$), methane($CH_4$ ),Ethane($C_2H_6$)) concentration in ppm and output features are faults type as given in Table 1 .These two tasks are done with the help of pandas library[11]. Our dataset has output features as categories represented in form of text like PD,D1,D2,TH,TL,NF these are converted into numerical label using the Scikit-learn library [12].Then categorical variables are handles using

keras library[21].After this data is normalized and split into training and testing data using Scikit-learn library[21].Spitting is very important for validating the performance of the machine leaning model After splitting the dataset train data is feed to classifier model and model is trained over it. After training is over model is evaluated over testing data.

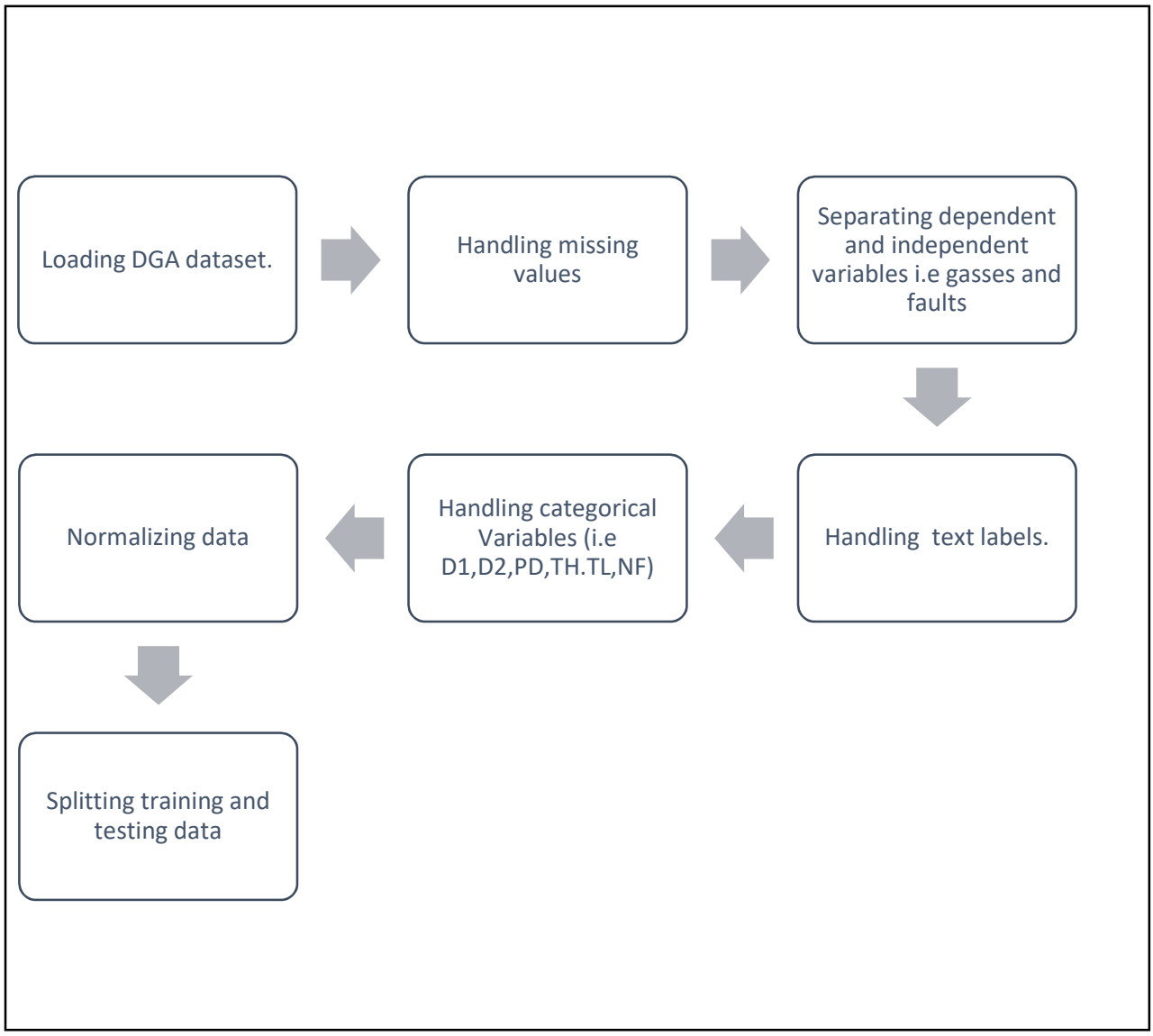


*Figure 22: Data Pre-processing*

# Chapter 7: SIMULATION & RESULTS:

Overview:

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Present chapter gives the simulation details.

## 1. GENERAL INTRODUCTION:

Before beginning with simulation it is very important to understand some basic concepts and components that has been used for simulation so that we have no doubt while seeing the results and interpreting them

- Tools used for simulation :
    - Python 3.7 ,Spyder (Integrated development environment )
- Data fed to the models have six types of fault but ML models will not understand these so in order to feed them to the model we have already pre-processed them into variable as shown in table 8 :

| **Serial Number** | **FAULT TYPE** | **ACRONYMS USED** | **FAULT CODE** |
|---|---|---|---|
| 1. | Partial discharge Fault | PD | 3 |
| 2. | Low Energy Discharge | D1 | 0 |
| 3. | High Energy Discharge | D2 | 1 |
| 4. | Thermal fault low and medium temp(temp<700°C ) | TL | 5 |
| 5. | Thermal fault high temperature (Temp>700°C) | TH | 4 |
| 6. | No Fault | NF | 2 |

*Table 8: Fault types and assigned code*

## COMPLETE OVERFLOW OF SIMULATION:

- Step 1 : Getting data
- Step 2 : Data pre- processing
    - The process deals with of using raw data and making it ready for machine learning model
- Step 3. MODEL Formation
    - A particular machine learning model is selected from all the available models (like MLANN, SVM, KNN, etc.)
    - Optimal hyper-parameters are selected for the model.
- Step 4 : Training the model
    - Selected model is trained over the training data which a part of the overall data and is approximately seventy percent of it.
- Step 5 : Evaluating the model
    - Model is evaluated over the test data i.e. prediction are made over this data and a

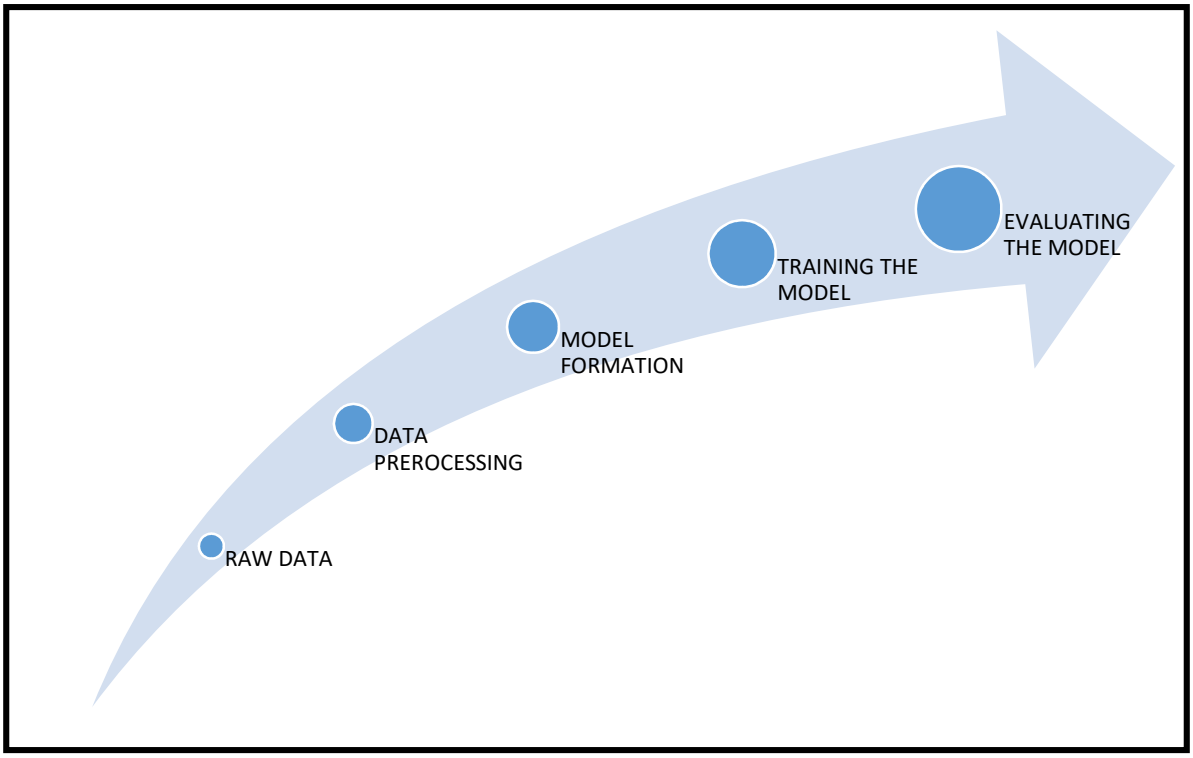


*Figure 23 : Overview of Simulation*

## 2. SIMULATION USING MULTILAYER ARTIFICIAL NEURAL NETWORK.

MLANN are the multilayer perceptron with more than one hidden layers and activation function at each hidden layer so in order to pass on the output to next layer input has to go through the activation function first.

### 1. MODEL FORMATION:

Multilayer Artificial Neural Network classifier model is build using the keras API [22]. Model have one input layer, two hidden layers and one output layer. The input layer has no activation function while first hidden layer uses softplus as activation function, second hidden layer uses Rectifier linear function as activation function and the output layer uses the softmax as activation function .The input layer has five nodes (neurons) first hidden layer has twenty nodes (neurons), second hidden layer has fifteen nodes (neurons) and output layer has six nodes. The Model is trained using back-propagation algorithm along with the stochastic Gradient descent optimizer Adam [26].The number of layers and optimal activation functions per layer are selected through the GridsearchCV [21].

| **Component** | **Value** |
|---|---|
| Optimizer | Adam |
| Layers | 4 |
| Neurons | 46 |
| Epochs | 1500 |
| Batch size | 40 |

*Table 9 : Important component related to model*

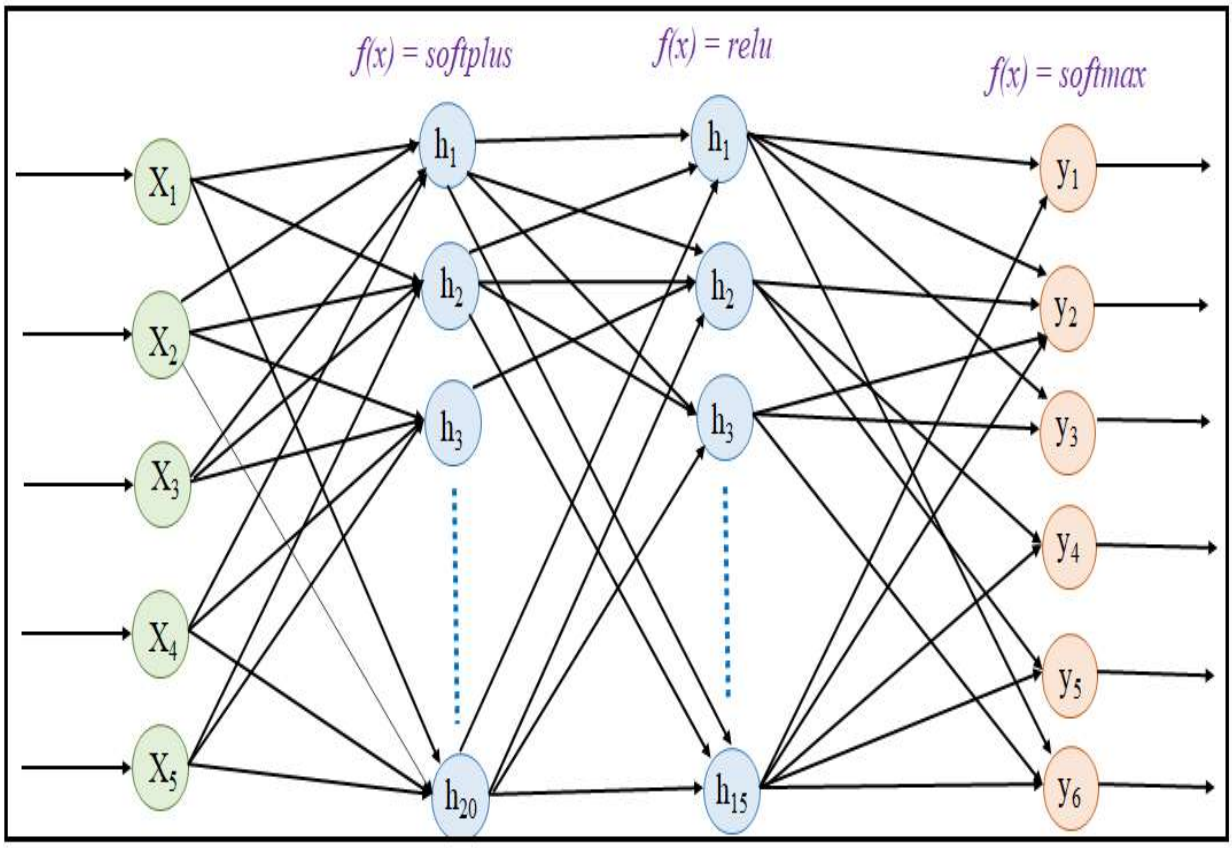


*Figure 24 : MLANN model used*

The GridsearchCV is a tool of the sklearn library that uses all the possible hyper-parameters to train the model and find out accuracy per parameter then it gives out the optimal parameters based on the accuracies. Some of the important components of the model are given in the table given below.

## 2. RESULTS:

Model has successfully classified the faults into respective categories and gives an accuracy 75.71% .Three plots have been given in fig 26, 27, 28 which depicts the actual output, predicted output by model and comparison.

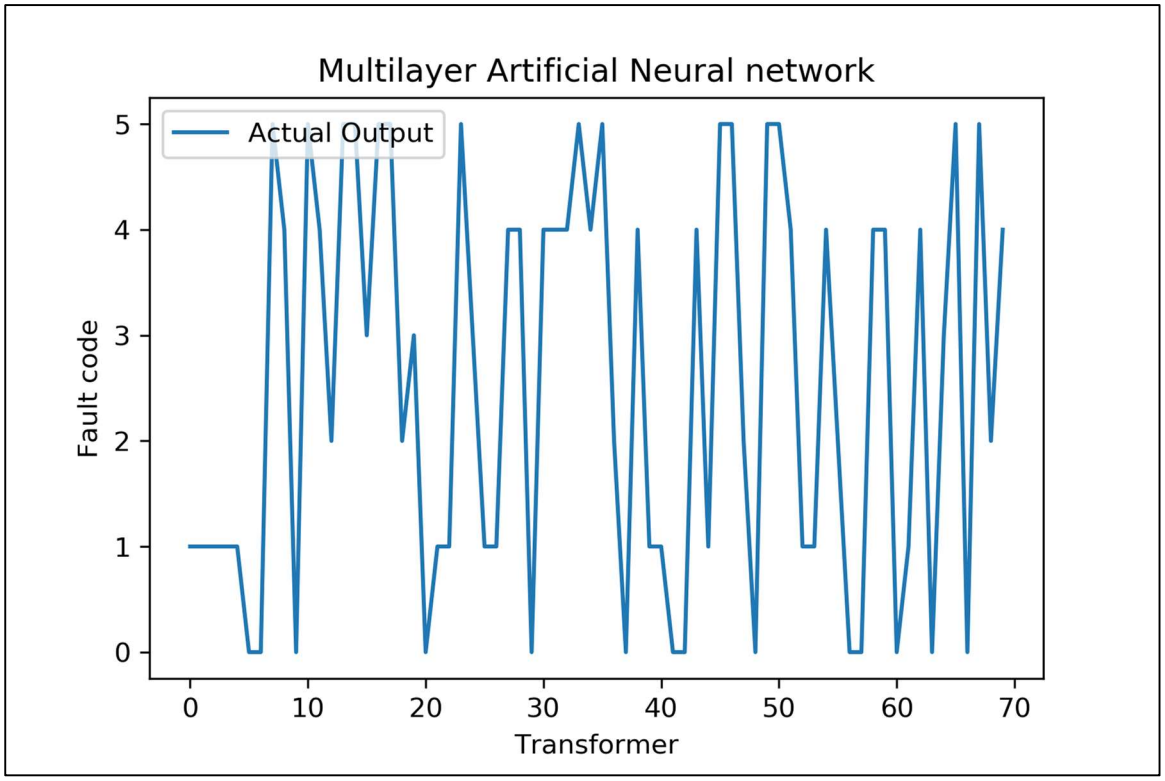


*Figure 25 : Actual output*

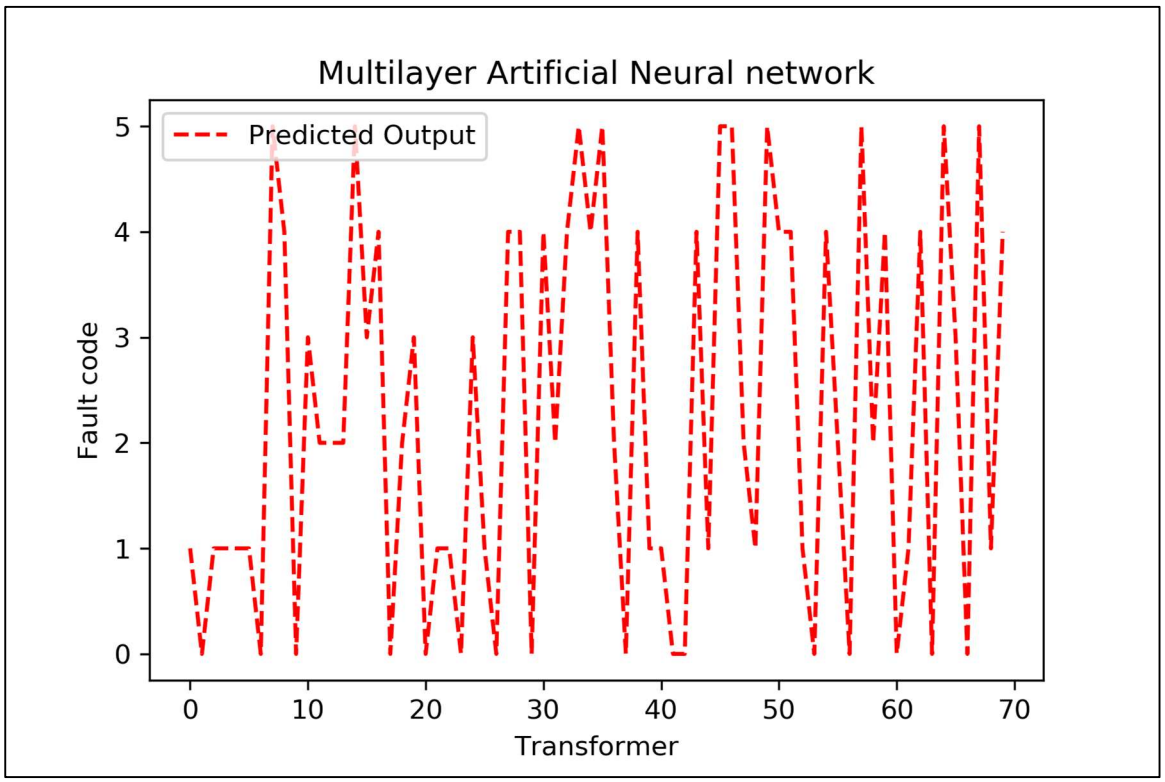


*Figure 26: predicted output by model.*

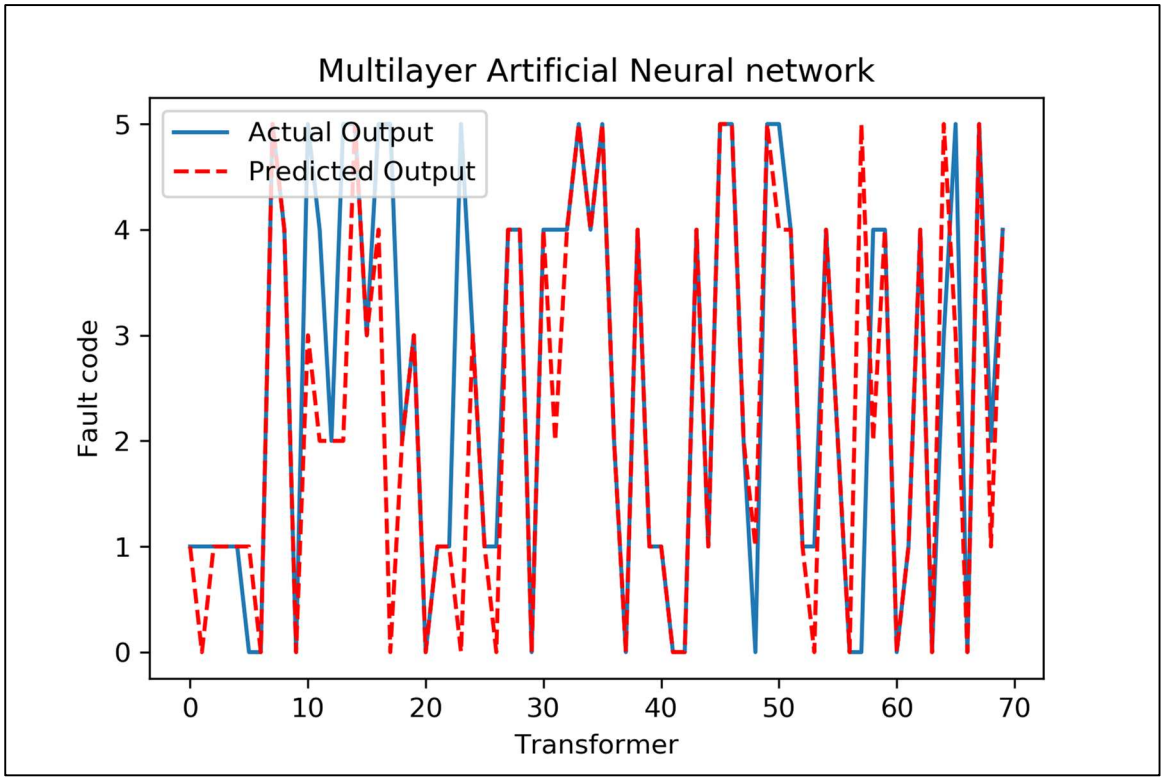


*Figure 27: Comparison between Actual and predicted output*

## 3. SIMULATION WITH HELP OF SVM (SUPPORT VECTOR MACHINE) CLASSIFIER:

### 1. MODEL FORMATION:

SVM classifier model is formed using the LIBSVM and Scikit-learn libraries [12] [18]. The model is formed in python 3.7 in spyder (IDE).The important parameters of Support Vector Machine Classifier model are:

- Penalty parameter C
- Kernel function
- Value of Gamma

All the parameters are selected using the GridSearchCV tool [12]. The GridsearchCV is a tool of the Scikit-learn library that uses all the possible values of given parameters to train the model and find out accuracy per set of parameters and then it gives out the optimal parameters based on the accuracies , the parameter used in the model are given in table

| SERIAL NUMBER | PARAMETER | VALUE |
|---|---|---|
| 1. | C | 100 |
| 2. | Kernel function | RBF |
| 3. | gamma | 0.5 |

*Table 10: SVM model parameters*

The support vector machine classifier uses the kernel function RBF which stands for Radial Basic function and in governed by the equation:

$$k(x, y) = e^{-\gamma||x-y||^2}$$

## 2. RESULTS:

Model has successfully classified the faults into respective categories and gives an accuracy 81.42% .Three plots have been given in fig 29, 30, 31 which depicts comparison of predicted versus actual output, predicted output and actual output respectively .

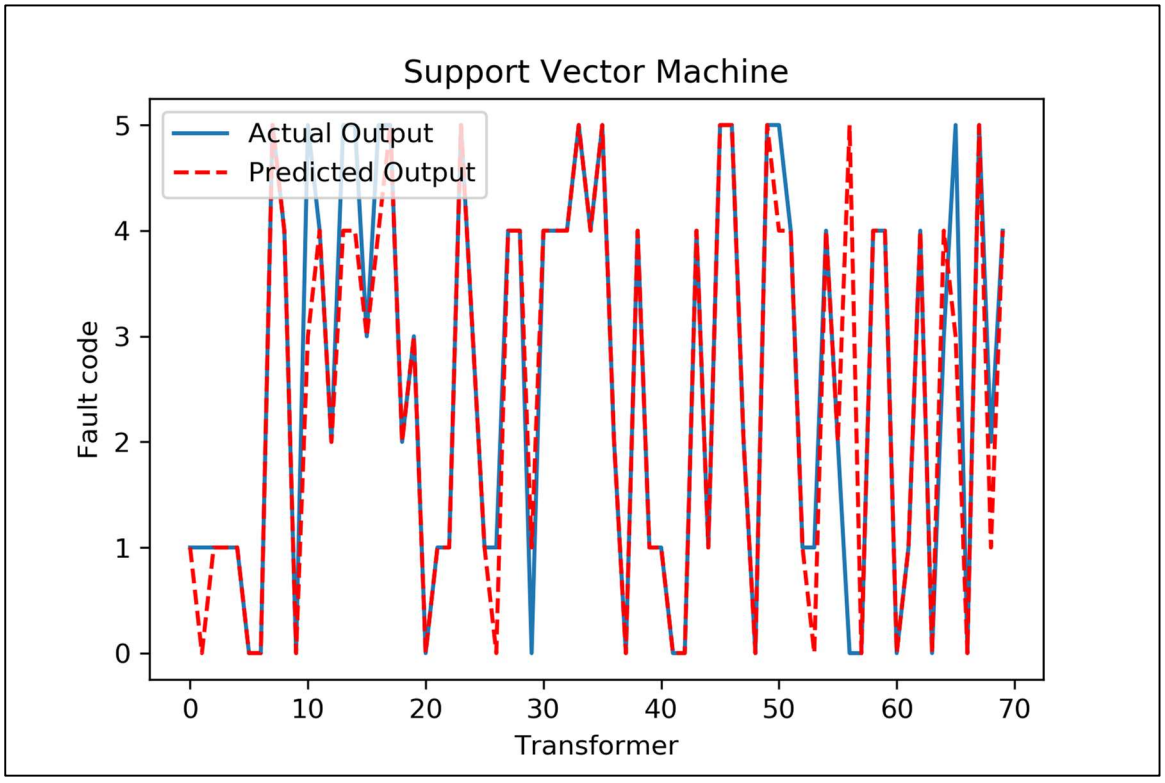


*Figure 28 Comparison of Actual versus Predicted output for SVM Model*

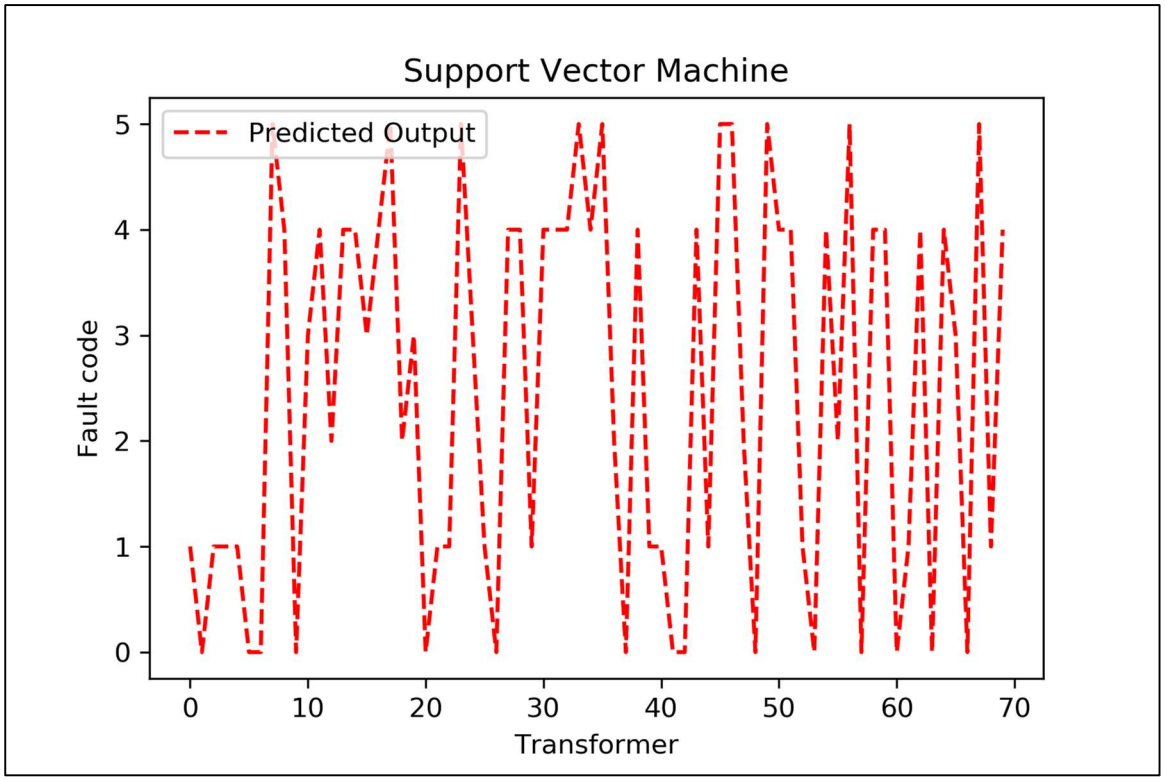


*Figure 29 : Predicted Output by SVM model*

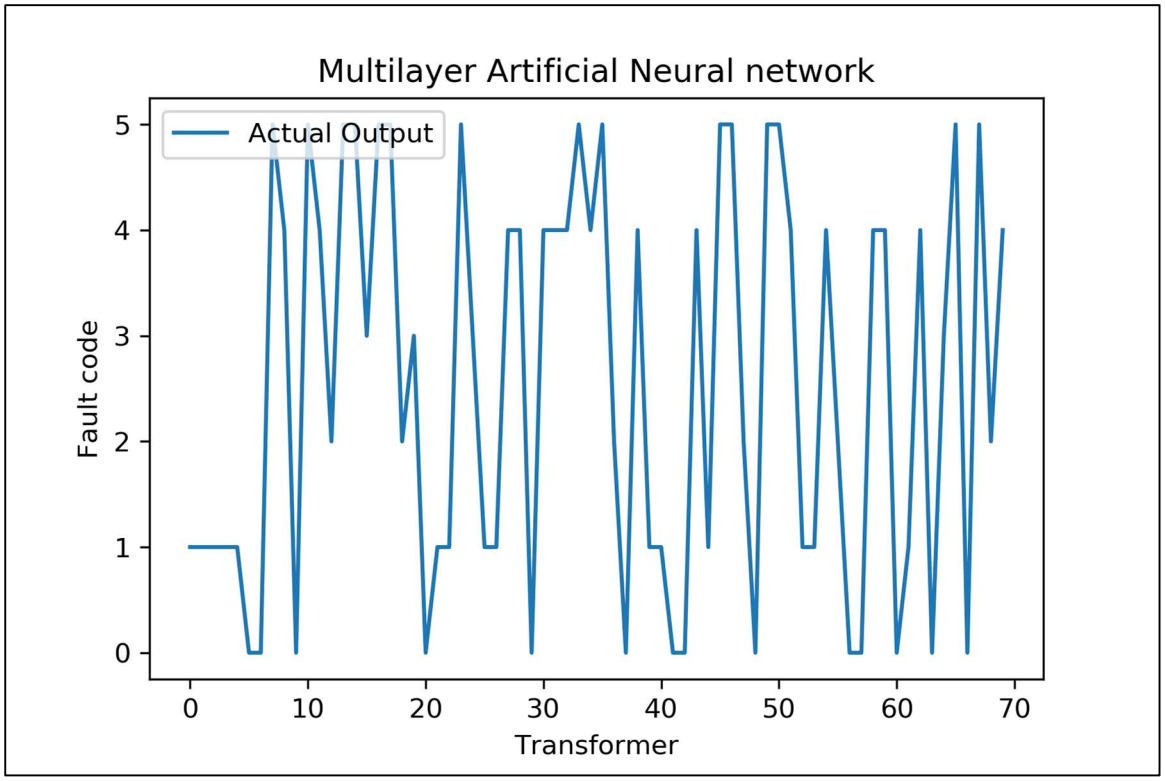


*Figure 30: Actual output*

# Chapter 8: CONCLUSION AND FUTURE SCOPE:

Overview:

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Present chapter gives the conclusion statement and future work.

## CONCLUSION:

The Transformers fault prediction was done using the DGA dataset. Machine learning Algorithm models like Multilayer Artificial Neural Network and Support vector machine classifier were used.

Both models were successful in predicting the fault of transformers using DGA data. The SVM classifier gives an accuracy of 81 % percent while the MLANN gives an accuracy of around 75.71% .Hence it is seen that for fault prediction of transformer using machine learning SVM is a better option.

## FUTURE SCOPE:

- Some other machine learning models can be used for prediction.
- The result of prediction may vary with change in data so if a large dataset is available with more number of dependent feature then models may give better results.
- Some techniques like cross-validation can be used in future work to improve the results.

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