Design, On-line Condition Monitoring And Fault Diagnosis Of Toroidal Transformers

A Project Report

Submitted by

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in partial fulfillment for the award of the degree

of

Master of Engineering

in

POWER ELECTRONICS AND DRIVES

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

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JUNE - 2006

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TO WHOM SO EVER IT MAY CONCERN

This is to certify that **Miss. R.Bharathi** student of **Kumaraguru College of Technology,** Coimbatore – 641 006 affiliated to **Anna University,** studying in II year M.E (Power Electronics & Drives) has done her project work in our company, for the specialized project title of **"Design, On-Line Condition Monitoring & Fault Diagnosis of Toroidal Transformers "** for the period from June – 05 to April – 06.

During this period her conduct and character were found to be good and we wish her all success in the future.

For **Salzer Electronics Limited – Unit – II**

M.Lakshminarayana
Manager Works

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ABSTRACT

Transformers are subjected to incipient faults, which if undetected, can lead to eventual destruction of the winding insulation in a transformer. The insulation failure is caused mainly due to the inter-turn fault in a transformer.

Due to the rapidly propagating nature of insulation failure, it is critical to detect inter-turn fault in an early stage to prevent further damage to the transformer. This project focuses on the three elements related to toroidal transformers: Investigation of design methodology, on-line condition monitoring and fault diagnosis. The design of 1 KVA toroidal transformer is investigated. The electrical and mechanical parameters for the transformer are listed. They can be used for further analysis in the fault diagnosis process. The transformer parameters such as voltage, current, power factor, temperature, tap changer position of the transformer are continuously monitored in a practical system and displayed. An effective transformer monitoring system with a modern data communication strategy has high reliability for long time operation of transformers.

Artificial neural network and fuzzy logic tools have been used for the inter- turn fault diagnosis of toroidal transformers because of their superior learning and generalization capabilities and built-in fault tolerance in practical applications respectively. The performance of the neural network for the inter-turn fault diagnosis is compared with the performance of fuzzy logic technique. The fuzzy logic technique proves to have less percentage error as compared to the neural network technique. The fault diagnosis system developed for the toroidal transformers can be extended to other types of transformers with different ratings.

தொகுப்புரை

டிரான்ஸ்பாமர்களில் ஏற்படும் சில பழுதுகளை ஆரம்ப காலத்திலேயே கவனிக்காமல் விடுவதால் அது டிரான்ஸ்பாமரின் வைண்டிங் இன்சுலேசனையே பழுதாக்கி விடுகின்றன. இதற்கான முக்கிய காரணம் டிரான்ஸ்பாமர்களில் உண்டாகும் இன்டர் - டேர்ன் பழுது.

இந்த இன்டர் - டேர்ன் பழுதானது விரைவில் பரவக்கூடியதால் இதை உடனே கவனித்து, தடுப்பது டிரான்ஸ்பாமர் மேலும் பழுதாகாமல் பாதுகாக்க உதவுகிறது. இந்த பிராஜக்டின் முக்கிய நோக்கம் ஒரு டொராய்டல் டிரான்ஸ்பாமரின் டிசைனை வடிவமைத்து, அதை நேரடியாக கண்காணித்து, ஏதேனும் பழுது உண்டானால் அதை தெரிவிப்பதே ஆகும். ஒரு 1 கே.வி. ஏ ரொடாய்டல் டிரான்ஸ்பாமரின் மாதிரி வடிவம் பற்றி ஆராயந்துள்ளது. டிரான்ஸ்பாமரின் வோல்டேஜ், கரண்ட், பவர்வேக்டர், டெம்பெரேச்சர், டேப் சேஞ்சரின் அமைப்பு ஆகியவை தொடர்ச்சியாக கண்காணித்து, அவை பார்வையிடப்பட்டு ஒரு நல்ல கண்காணிப்பு முறை உருவாக்கப்பட்டுள்ளது.

செயற்கை நியூரல் நெட்வர்க்கும், வஸ்ஸி லாஜிக்கும் டிராண்ஸ்பாமரில் உண்டாகும் இன்டர்டேர்ன் பழுதை கவனிக்க தேர்ந்தெடுத்துள்ள இரண்டு முறைகள் இதற்குக் காரணம் இந்த முறைகளில் உள்ள நியுராண்கள் ஒரு நெட்வர்க்கை எளிதில் வகுத்து, அதை உபயோகிக்கும் தகுதியும், மேலும் நடைமுறையின் உபயோகத்திற்கேற்ப பழுதை வகுக்குத் கூறும் முறைகளை உள்ளடக்கியது. நியூரல் நெட்வர்கின் பழுதை வகுத்துச் சொல்லும் திறனை வஸ்ஸி லாஜிக் முறையுடன் ஒப்பிடப்பட்டுள்ளது. இதில் வஸ்ஸி லாஜிச் முறை நியூரல் நெட்வர்கை விட குறைவான விழுக்காடு குறைபாட்டைக் கொண்டு இன்டர்டேர்ன் பழுதை துள்ளியமாக சொல்லும் திறன் கண்டுபிடிக்கப்பட்டுள்ளது.

இந்த இண்டர் - டேர்ன் பழுது டொராய்டல் டிரான்ஸ்பாமரில் வகுத்துள்ளது. இதை ஒரு முன் மாதிரியாக வைத்துக் கொண்டு மேலும் பல டிரான்ஸ்பாமரில் உள்ள பழுதுகளை வகுக்க இந்த முறை உதவியாக இருக்கும்.

ACKNOWLEDGEMENT

I thank the almighty god without whose grace this work would not have come true. I consider it a privilege to extend a few words of gratitude and respect to all those who guided and inspired me in successful completion of this project.

I wish to express my heartfelt gratitude to our beloved Principal **Dr.K.K.Padmanabhan** for providing necessary facilities to carry out this Project.

I take this opportunity to express my sincere thanks to my course tutor and project guide **Prof.K.Regupathy Subramanian** Dean and Head of the Department of Electrical and Electronics Engineering, Kumaraguru College of Technology for his moral support and encouragement during the entire course. I am highly indebted to him for having helped me a great extent by providing fruitful suggestions for improvement.

I also extend my sincere thanks to **Prof.V.Duraisamy** Assistant Professor, and **Mrs. D.Somasundareswari** Senior Lecturer, Department of Electrical and Electronics Engineering, Kumaraguru College of Technology, who both gave invaluable guidance, moral support and encouragement for successful completion of the project.

I express my sincere thanks to **Mr. R.Veerasamy** Sr. Engineer, R&D Salzer Electronics II who guided me a lot with regard to the project.

My thanks are due to all faculty members in Electrical and Electronics Engineering Department, my family members and friends who provided immense encouragement and support for the completion of this project.

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LIST OF SYMBOLS

Bm - Flux density in Tesla

Ag - Gross core area in Sq.cm

k - Resistivity of copper in $\mu\Omega$/Cm

A - Gross core area in Sq.cm

f - Activation function

T - Number of turns

T - Temperature in degrees

γ - Momentum co-efficient

μ - Membership function.

CHAPTER 1

INTRODUCTION

1.1 NEED FOR THE PROJECT

The large number of transformers installed in a complex power distribution system increasingly requires accurate diagnostics, which can be conveniently performed in a monitoring center where the information on the actual state of the machine is received, processed and interpreted. The technology advancement in electronic equipments resulted in an explosion of information that is available locally or most times it is communicated to the control center, It is possible to utilize available real time data for extracting more details about the condition of the transformer which is monitored. Fault diagnosis power transformers is an important measure to prevent serious system outage causing deterioration of transformers. Consequently transformers must be periodically tested to find faults and to predict the transformer from further deterioration as early as possible.

1.2 PROJECT OBJECTIVES

The main objective of the project are

i) To investigate the design of torodial transformer

ii) To on-line monitor the transformer parameters such as voltage, current, temperature, Power factor, tap changer position.

iii) To diagnose the effects of inter-turn fault in a transformer using neural network and fuzzy logic technique.

1.3 ORGANIZATION OF THE REPORT

The first chapter describes the need for the project, objectives of the project, and organization of the report.

The second chapter gives the general introduction to the torodial transformers and their applications with the online condition monitoring system and the need for fault diagnosis.

The third chapter gives the design procedure of a toroidal transformer , with the components used for construction of transformer and their fabrication steps.

The fourth chapter gives complete description of online condition monitoring circuit, parameters to be monitored with both hardware and software description and their operation.

The fifth and sixth chapter provide a basic introduction of neural network and fuzzy logic systems adopted for fault diagnosis of the transformer in the project.

The seventh chapter gives the brief overview of the fault to be diagnosed using neural network and fuzzy logic with the test data and their comparison with the diagnosis results.

The conclusions from test and simulation results and suggestions for future work are identified in chapter eight.

CHAPTER 2

DESCRIPITION OF TOROIDAL TRANSFORMERS

2.1 TOROIDAL TRANSFORMERS

Toroidal transformers are high performers among transformers. They offer the smallest size (by volume and weight), less leakage inductance, and lower electromagnetic Interference (EMI). At the heart of the toroidal is a highly efficient donut shaped core. To construct the core, grain-oriented silicon-iron is slit to form a ribbon of steel which is then wound, like a very tight clock spring. The result is a core in which all of the molecules are aligned with the direction of flux. Molecules not aligned with the flux direction increase a core's reluctance, degrading performance to the level of common steel when the molecules are 90 degrees out of phase. EI laminated cores, which are stamped from grain-orinted Si-Fe, may have as much as 40% of the total core area perpendicular to the ideal grain direction, with another 40% acting only as a return flux path. This more efficient use of the core material in a toroidal can result in a size and weight reduction of up to 50% depending on power rating.

The windings of toroids cool better because of the proportionally larger surface area. A 360 degree wound toroidal transformer has a high degree of symmetry. Its geometry leads to near complete magnetic field cancellation outside of its coil, hence the toroidal transformer has less leakage inductance and less EMI when compared against other transformers of equal power rating. The magnetic field cancellation is more complete for the round cross section. The round cross section also gives a shorter turn length per unit of cross sectional area, hence lower winding resistances. The toroidal transformer also has better winding to winding magnetic coupling because of its toroidal shape. Toroidal transformers can be used in any transformer application that can accommodate its shape.

2.2 ADVANTAGES OF TOROIDS

Toroidal transformers offer several advantages over standard laminated power transformers.

1) Toroids have less leakage inductance.
2) Less EMI.
3) Low air gap
4) High efficiency
5) Smallest size (by volume and weight)
6) Reduced transformer hum.
7) Less temperature rise
8) Toroids provide quiet, efficient operation with very low stray magnetic fields
9) Easy to mount
10) Flexible dimensions.

2.3 APPLICATIONS OF TOROIDS

Toroidal transformers can be used in any transformer application that can accommodate its shape. Following are some of many transformer applications. Toroidal transformers are used in electrical measurements

1) In construction of switch board
2) In Audio equipments
3) In Robotics and automation
4) In the construction of household appliances and office appliances
5) For welding appliances like metal welding, ultrasonic welding, plastic welding
6) In Textile technology
7) For Lighting and Illumination technique
8) For Traffic control of traffic lights or signalers.
9) In medicine technique for defibrallation, dental technique, Kidney machine.

2.4 ON-LINE CONDITION MONITORING

Monitoring means mainly data acquisition, sensor development, data collection and development of methods for condition measurement of power transformers. Diagnostics is the step after monitoring .Problems pertaining to the design of the monitoring system and tapping of data at every instant accurately for the 0.5 KVA transformer are the problem considered. The monitoring system in this project is designed in such a way so as to monitor the voltage ,current, temperature, power factor, tap changer position of the transformer at various operating conditions .

The monitoring system must be designed for long-time operation and a high reliability with respect to the lifetime of power transformers. There must be reasonable relationship between installation and operation costs and the benefit of a transformer monitoring system. The monitoring system should provide information for a more reliable estimation of the transformers remaining lifetime. It should support the introduction of codition-based maintenance and help to avoid unexpected outages. One of the most important features of an effective transformer monitoring system is a modern data communication strategy. There is a distinction between offline and online monitoring. Offline monitoring means that the transformer must be switched off in order to measure relevant data for technical reasons. Online monitoring means data is acquired while the transformer is in operation.

2.5 NEED FOR FAULT DIAGNOSIS

Fault diagnosis of power transformers is an important measure to prevent serious system outage causing deterioration of transformers. Consequently, transformers must be periodically tested to find faults and to predict the transformer from further deterioration as early as possible. In this project the problem under study for fault diagnosis is the effects of inter fault in a 50 VA and 5 KVA toroidal transformer under various operating conditions. The main effect of inter turn fault in a transformer is the failure of insulation.

The windings of a transformer are insulated to prevent shorting of the winding turns. This insulation is categorized into several classes, which are rated for different maximum operating temperatures. Often, however ,these maximum temperatures are violated due to the operating environment, load requirements, etc. This violation leads to cracks, thinning and eventual loss of insulation at some points on the stator windings. This effectively decreases the number of transformer turns causing inter-turn shorting of the windings. A decrease in the winding equivalent turns will increase the transformer winding current, thus causing increased heating in the stator due to additional I2R losses. The increased heating will cause a corresponding temperature rise in the winding thereby decreasing the life expectancy of the transformer winding insulation. The insulation failure will cause additional shorted turns, further increase in temperature, and a further increase in rate of deterioration of the transformer insulation. To study this problem Neural Networks and Fuzzy Logic has been used for fault diagnosis and a comparison is made between these two techniques in terms of performance which can be used as an example for further detailed study in future with different ratings of transformer.

CHAPTER 3

DESIGN AND FABRICATION OF TOROIDAL TRANSFORMERS

Transformers used nowadays are extremely various in their purpose, arrangement and sizes. This chapter discusses the design and fabrication of a Toroidal transformer. Toroidal transformers are high performers among transformers. They can be used in any transformer application that can accommodate its shape. Toroidal transformers offer many advantages over standard laminated transformers. Low air gap, low weight, high induction, high efficiency, less temperature rise, easy to mount and flexible dimensions are the advantages of toroidal transformers.

3.1 SYSTEM REQUIREMENTS

The system requirements of a transformer vary depending on the type of application where the transformer is employed. The necessary initial data for designing the transformer are :

1. The type of the transformer
2. Rated KVA
3. The number of phases
4. The rated voltages of all the windings with the indication of regulation steps (if any)
5. The frequency
6. The connection of transformer windings
7. The cooling system
8. Operation duty (constant continuous load, varying load, cyclic load)
9. Short circuit impedance
10. No-load losses (core losses)
11. Load losses (short circuit losses).

3.2 DESIGN STEPS

The following are the recommended steps in the transformer design.

(a) Prelimnary calculation

Here steel grade and design value of core flux density are chosen and by using an empricial formula, e.m.f. per turn is calculated. Then the arrangement of the core is chosen and the diameter of the circle enclosing the cross-section is determined.

(b) Design of transformer windings

(c) Design of transformer core

(d) Calculation of short cicuit impedance

(e) Calculation of losses

(f) Calculation of Efficiency.

Design steps may differ depending on the rating, type of transformer, Maximum temperature rise, operation duty etc.

3.3 AN EXAMPLE DESIGN

The design of 1 KVA Toroidal transformer is undertaken as an example. The various design specifications are:

1. Rated KVA=1
2. Number of phases=1
3. Type of transformer=natural cooled,Toroidal core,Isolation type
4. Primary voltage=230 V
5. Secondary voltage=230 V
6. Operating duty=constant continuous load
7. Short circuit impedance=(5-7)%
8. No load current=3%
9. Frequency=50 Hz
10. Core dimensions=150*60*65 mm.
11. Type of Insulation= Class B
12. Allowable temperature rise= 50 degree.

STEP 1:Prelimnary calculations

1. Input Voltage = 230 V

2.Current, I = KVA/V

= 4.4 A

3.Current density, Cd = 3.0 A/Sq. mm(max)

4.Conductor area = I/Cd

= 1.467 Sqmm

5.Area of proposed conductor= (3.141*d^2)/4

= 1.54 Sqmm (where d= 1.4 mm)

6.Working current density = 4.4/1.54

= 2.857 A/Sqmm.

7.Cross sectional area of core(Ac) = (OD-ID)/2* height*0.95(Sq cm)

= 24.22 Sq cm.

8.Mean length of conductor (Lm) = (OD+ID)/2*(22/7) cm.

= 33.78 cm.

9.Core weight = (Ac*Lm*7.65)/1000 (Kgs)

= 6.25 Kg.

10 Transformer weight = 9.5 Kg (core weight+ copper weight)

note: Since the type of transformer to be designed is of isolation type the above calculations are the same for primary and secondary side.

STEP 2:Winding calculations

1.Voltage per turn,Et = K*sqrt(Q)

where,Q = rated KVA

K = (0.37-0.45)[For copper conductor]

Et = 0.45

2.Number of secondary turns (T) = Sec voltage/Et

= 575 T

3.Number of primary turns at normal = (Py voltage/Sec voltage)*Sec turns

= 575 T

STEP 3:Input Voltage

Input Voltage (Vin) =4.44*f*Bm*Ac*T*10 power minus 4
Vin = 20.16 V.
where,f = frequency in Hz
Bm = flux density in Tesla(1.5 Tesla)
Ac = gross core area in Sq cm
T = No of turns

STEP 4:Winding details

1.Conductor material = copper
2.Wire gauge = 16 AWG
3.Number of layers = 4
4.Number of turns = 575 T
5.Turns per layer = 143 T
6.Magnetising current @1.5T = (1.21*core weight)/Vin
= 0.375 A
7.Magnetising current @ 1.7T = (2.55*core weight)/Vin
= 0.791 A.

STEP 5:Winding resistance and load loss

1.Resistivity of copper(K) = 1.71 micro ohm/cm
2.Winding resistance,R = (L*K*10 power minus 3)/A
where,L = 194189 mm(L=L1*T)
= 2 micro ohm/cm
3.current = 4.4 A
4.I^2*R loss = 0.968 w
5.Total I^2*R(LV+HV) = 1.93 w
6.Approx stray loss = 10 w
7.Load loss at rated load = 1.93 +10 w
= 11.93 w

STEP 6:

1.Percentage resistance,R(%) = (core loss in Kw/Rated KVA)*100

= (0.015/1)*100

= 1.5%

2.Percentage impedance,Z(%) = sqrt(X(%)^2+R(%)^2)

= 6.08 %

wher,X(%) = Percentage reactance.

STEP 7: Calculation of efficiency

1.Eficiency at rated load and at UPF = Output/(output+losses)*100

= 100/(100+0.03+2.036)*100

= 97.97 %

2.Efficiency at 75 % load &UPF = 98.45 %

3.Efficiency at 50 % load &UPF = 98.93 %

4.Maximum efficiency=(KVA*K)/((KVA*K)+No load loss Kw+(K^2*load loss Kw))*100

Where K = load at maximum efficiency

K = sqrt(0.03/2.036)

= 0.1213.

5.Maximum efficiency = 97.82%

STEP 8: Regulation

(%) Regulation = (No-Load voltage - Full load Voltage) / Full load voltage

= (237-230)/230

= 3 %

3.4 MATERIALS PROPOSED FOR THE CONSTRUCTION OF TRANSFORMER

The following are the various materials used in the construction of transformer. They are,

3.4.1 Conducting materials

The conducting materials may be copper or aluminium,but copper is the widely used electrical conductor due to high electrical conductivity and excellent mechanical properties. It is predicted that at present rate of consumption of copper existing deposits will be exhausted within a period of about 40 years. Therefore , aluminium which is the conductor material next to copper is used.

3.4.2 Magnetic materials

All magnetic materials possess magnetic properties to a greater or a lesser degree. The magnetic properties of materials are characterized by their relative permeability. Materials may divided as ferromagnetic material,paramagnetic material and diamagnetic material. Solid core materials may be iron,low carbon and silicon steel, sheet steel. Sheet steel possessing higher silicon content(4-5% silicon) called "transformer grade steels"are mainly used in transformers.Cold rolled grain oriented steels(CRGO), though costly give much reduced iron loss and much better magnetization curve that hot rolled steels. Due to this fact CRGO cores are commonly used as a core material in the construction of transformer.

3.4.3 Insulating materials

Insulating materials or insulants are extremely diverse in origin and properties.They are essentially nonmetallic,organic or inorganic,uniform or heterogeneous in composition,natural or synthetic. Many of them are of natural origin like paper,cloth,paraffin wax and natural resins. Wide use is made of many inorganic insulating materials such as glass,ceramics and mica. The recognised classes of insulating materials and the temperature assigned to them are as follows:

Class	**Temperature**
Y(formerly 0)	90c
A	105c
E	120c
B	130c
F	155c
H	180c
C	7above 180c

Synthetic-resin-bonded paper,treated pressboard or similar material is used for the insulation between core and coils and also between the primary and secondary windings.

3.5 FABRICATION

The following are the various steps in the fabrication of a transformer from the bare core to the dispatch of a transformer. They are,

1. Core slitting
2. Core deburring
3. Annealing
4. Core assembly
5. Coil assembly
6. Processing
7. Box up
8. Testing
9. Fault detection
10. Fault clearing
11. Despatch

The bare core is slitted into thin sheets of thickness 0.25mm to 0.5mm. The core deburring is done to make the surface of core smooth. Then annealing is done to make the magnetic properties of core within the specified limits. Then a layer of insulating material called Mylar(Polyester material) is wound on the core. The primary winding is wound around the followed by a layer of insulation and finally secondary winding is wound around the core. Finally a layer of insulation is done and the pour potting is done followed by a layer of taping and lead work for both primary and secondary winding is done. Then a series of tests is conducted on the transformer like IG test,Noload and Short circuit test. If the transformer passes the following tests the transformer is dispatched else the transformer is dismantled and rework is done to check for the number of turns,thermal switch continuity ,IG test and finally tested after reassembly.

CHAPTER 4

ON-LINE CONDITION MONITORING SYSTEM

4.1 PROBLEM DEFINITION

Problems pertaining to the design of a monitoring system and tapping of data at every instant accurately for the 0.5 KVA toroidal power transformer are the issues addressed. The monitoring system is designed in such a way so as to monitor the voltage, current, temperature, power factor and tap changer position of the transformer at various operating conditions. In the monitoring phase, the on-line values of various transformer parameters are monitored. The tapped analog signals are converted to digital values using an analog to digital converter. The monitored values are interfaced to the computer by means of a 25 pin female parallel port connector. The computer then processes the data and displays the output.

The analog to digital converter requires a power supply of +5volts. The operational –amplifier used requires a dual power supply of +12 volts and –12 volts. With suitable voltage regulators ,the power supply unit is designed. For the measurement of the electrical parameters such as voltage and current, potential transformers and current transformers are required respectively. The applied voltage is first stepped down using potential transformer. The output of the potential transformer is then given to the inverting amplifier, which acts as the precision rectifier. The output is the dc voltage, which is the equivalent of the ac voltage fed to transformer. Again by the use of an inverting amplifier the negative output is converted into the positive value, which is an ac voltage equivalent of the dc voltage. The measurement of current is similar to the measurement of voltage except that the output of the current transformer is converted into ac voltage by connecting a shunt resistor across the current transformer.

The temperature is measured using thermistor and converted to equivalent voltage which is fed as input to the operational amplifier. The power factor measurement circuit consists of a current to voltage converter circuit, a zero crossing detector circuit and an XOR logic gate circuit. Triacs can be used as static switches for on-load tap changing of transformer. From the secondary voltage measured, the tap position of the secondary winding can be found and displayed.

4.2 HARDWARE DESCRIPTION

The overall block diagram of the monitoring system from the stage of data tapping to the output display stage is shown for the single phase toroidal transformer in Figure 4.1. A non-intrusive approach of monitoring the toroidal transformer using the existing instrumentation infrastructure systems is shown below.

The following are the various parameters of the transformer to be monitored.

1. Primary voltage
2. Primary current
3. Secondary voltage
4. Secondary current
5. Power factor
6. Temperature
7. Tap changer position.

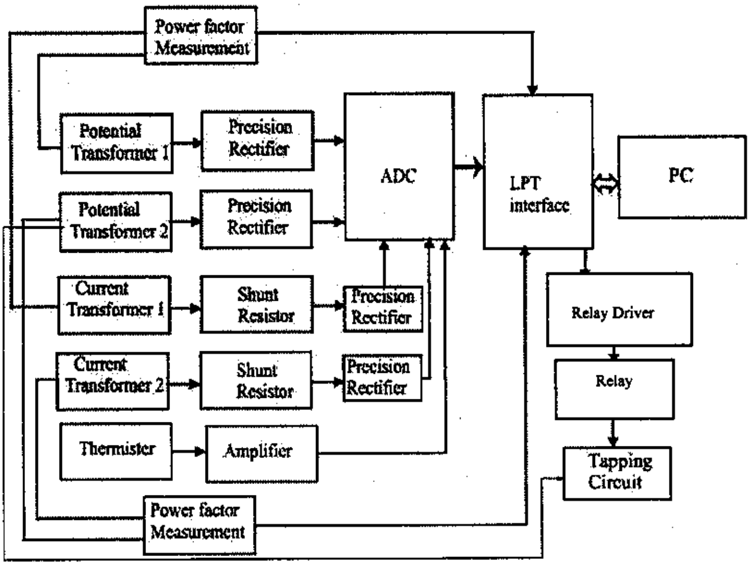


Figure 4.1 Overall block diagram of the monitoring transformer.

4.2.1 Power supply unit

Power supply is the basic building block for the entire hardware unit.

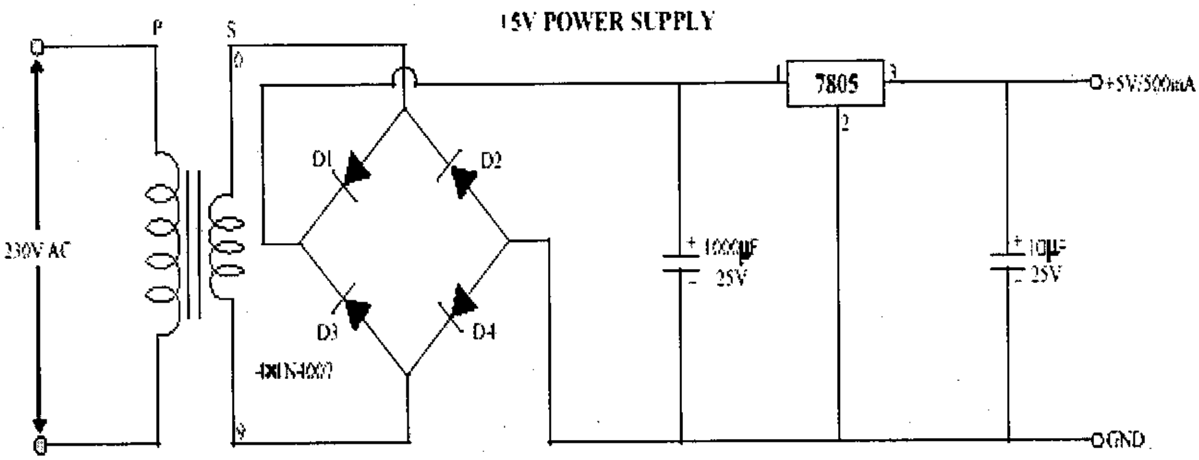


Figure 4.2 +5v Power supply

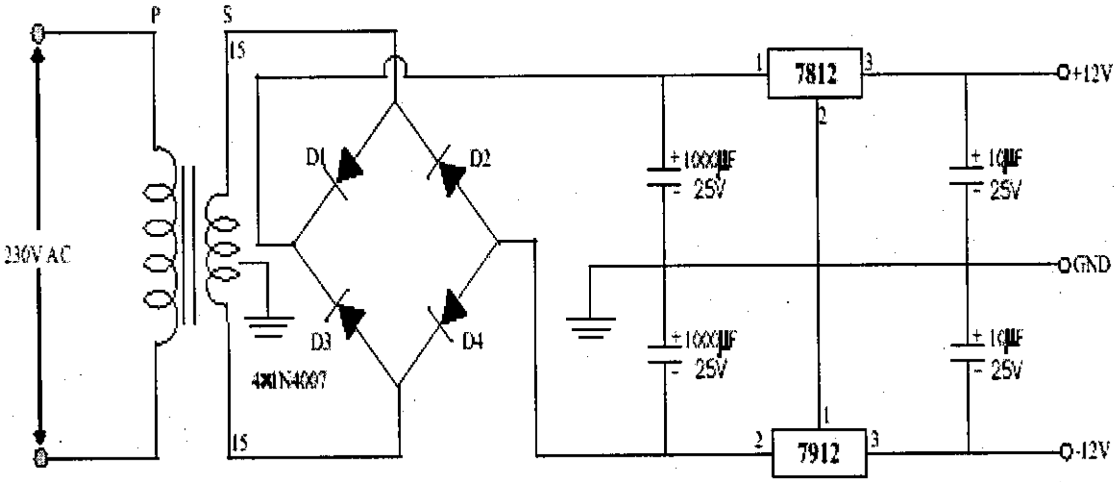


Figure 4.3 +12v Dual power supply

Figure 4.2 shows a +5V power supply and Figure 4.3 shows the 12V dual power supply. Power supply unit consists of a step down transformer,230V/15-0-15V and 230V/0-9V used to perform the step down operation. In the power supply unit, rectification is normally achieved using a solid-state diode. A commonly used circuit for supplying large amounts of dc power is the bridge rectifier. In the bridge rectifier ,four diodes (IN 4007)are used to achieve full wave rectification. Two diodes will conduct during the positive cycle and the other two will conduct during the negative half cycle. The dc voltage appearing across the output terminals of the bridge rectifier will be somewhat less than 90% of the applied RMS value. The output from the rectifier is not a pure dc and hence filtering circuit is required. Filtering unit consists of capacitor of 1000micro farad/25V to reduce ripples and a capacitor of 10 micro farad / 25V for maintaining the stability of the voltage at load side.

Regulator is required to regulate the dc voltage at the required levels.ic7805 used in this project provides +5V dc supply. IC7812 and 7912 is used for providing +12 V and –12V dc supply.

4.2.2 Measurement of voltage

The voltage measurement circuit of this project is shown as in the Figure 4.4. In case of voltage measurement, the two PT's are connected across the input supply, which is to be monitored. The PT is rated at 230V/6V. The ac output voltage of the PT is rectified, filtered and converted into pure dc by using precision rectifier.

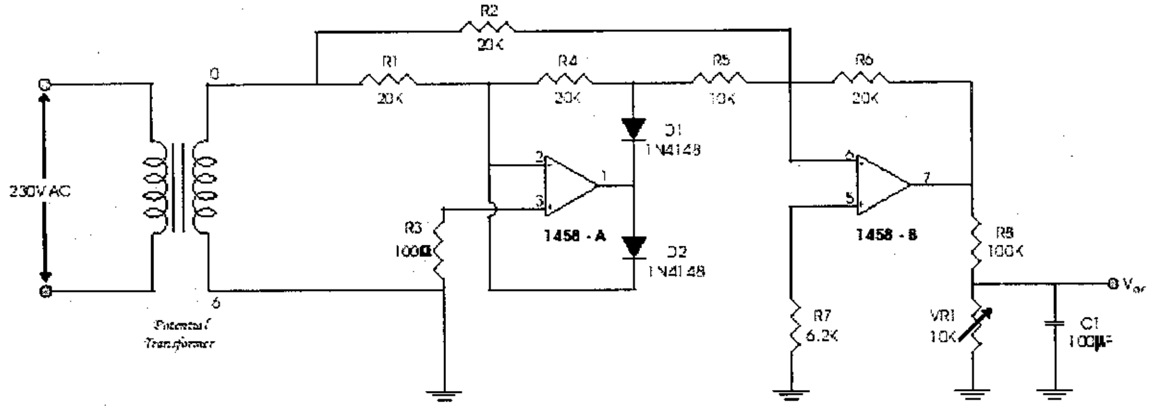


Figure 4.4 Voltage measuring circuit

In the precision rectifier circuit, A is an inverting rectifier. The output from A is added to the original input signal in B(summing mixer). Negative alterations of Ein results in no output at E1 due to the rectification. E_{in} feeds B through a 20K ohms resistor and E1feeds B through a 10K ohms resistor.

The net effect of this scaling is that, for equal amplitudes of E_{in} and E1,E1 will produce twice as much current flow into the summing point. This fact is used as an advantage here, as the negative alteration of E1 produces twice the input current of precisely half the amplitude, which E1alone would generate due to the subtraction of $E_{in.}$ It is the equivalent of having E1 feed through a 20K ohms input resistor and having E_{in} non-existing during this half cycle and it results in a positive going output at B.

4.2.3 Measurement of current

The current measuring circuit of this project is shown as in the Figure 4.5.The CT's are connected in series with the transformer under test. The CT is rated at 5A/150mA. The shunt resistor of value 56 ohm is connected across the CT. Hence we can have ac voltage proportional to the current flowing through the primary of the CT given as the input to the rectifier unit.

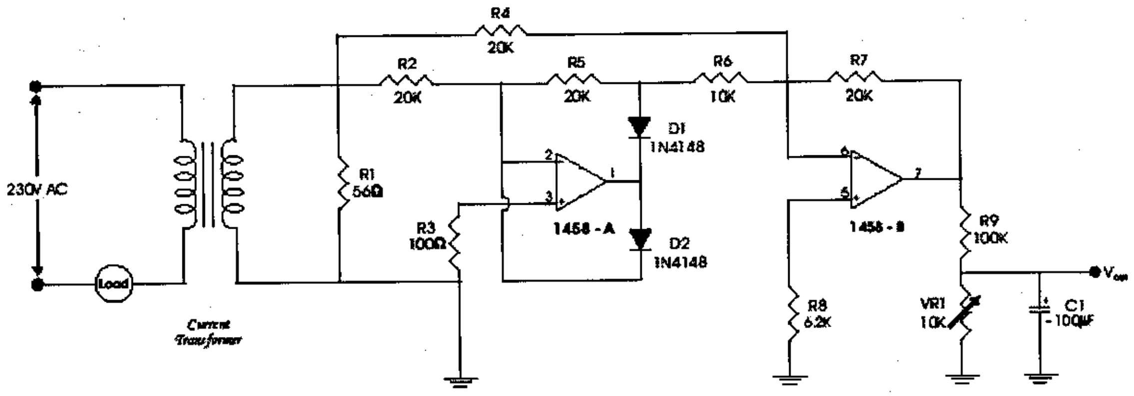


Figure 4.5 Current measuring circuit

4.2.4 Measurement of temperature

The temperature measuring circuit is shown in the Figure 4.6. Using Temperature sensor like Thermistor, the temperature of the transformer is converted into equivalent voltage and after stepping it down to a suitable value, it is given as one of the inputs to an operational amplifier. To another input a reference voltage is given. Whenever the temperature goes above the permissible value, the opamp gives a high pulse to computer port and in turn the transformer is tripped immediately.

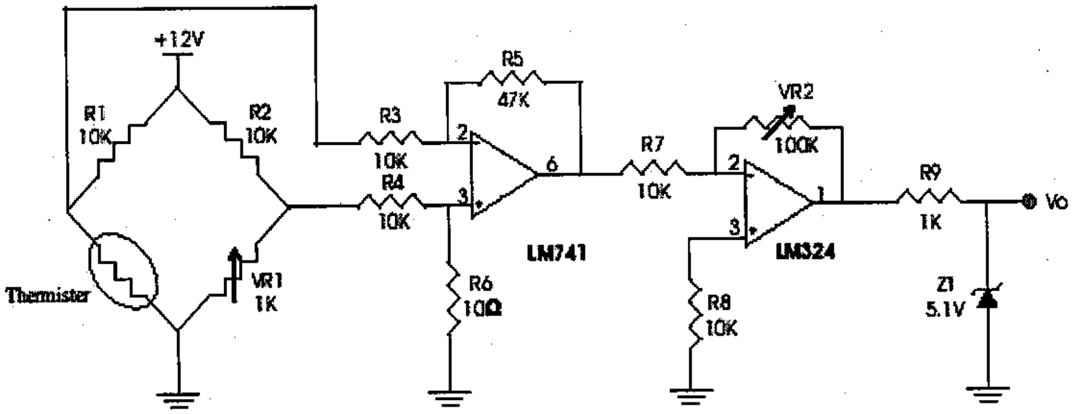


Figure 4.6 Temperature measuring circuit

4.2.5 Power factor measurement

The power factor measurement circuit is shown in Figure 4.7. The measurement circuit consists of a current to voltage converter circuit, a zero crossing detector circuit, a rectifying diode and an XOR logic gate circuit. The output from current to voltage converter is given to the zero crossing detector circuit. The heart of this circuit is an operational amplifier. To one of its inputs a voltage source will be given and another input is connected to ground. Whenever the input sinusoidal voltage signal crosses natural zero, the output square wave voltage signal also crosses the natural zero. A logic which gives a high output when the logic levels of both of its inputs are unequal is called an XOR gate. When both inputs are equal, it gives a low output. In the above circuit two NOR gates and one NAND gate is used to realize the XOR logic function.

The voltage is given as one of the inputs to zero crossing detector and the other input is connected to the zero reference voltage. The output is a square wave. Similarly the square wave for the current equivalent voltage is also obtained by passing it through another zero crossing detector. These are then passed through a diode and the negative portion is clipped and the output of the diode is fed to one input of XOR gate. To its other input the negative clipped current equivalent voltage is fed. So as per XOR logic, the will give an output pulse for a period for which the two inputs are in opposite logic levels. The duration of the output is equivalent to the phase difference between the two inputs. This value is fed as input to a cosine function which directly gives the value of power factor.

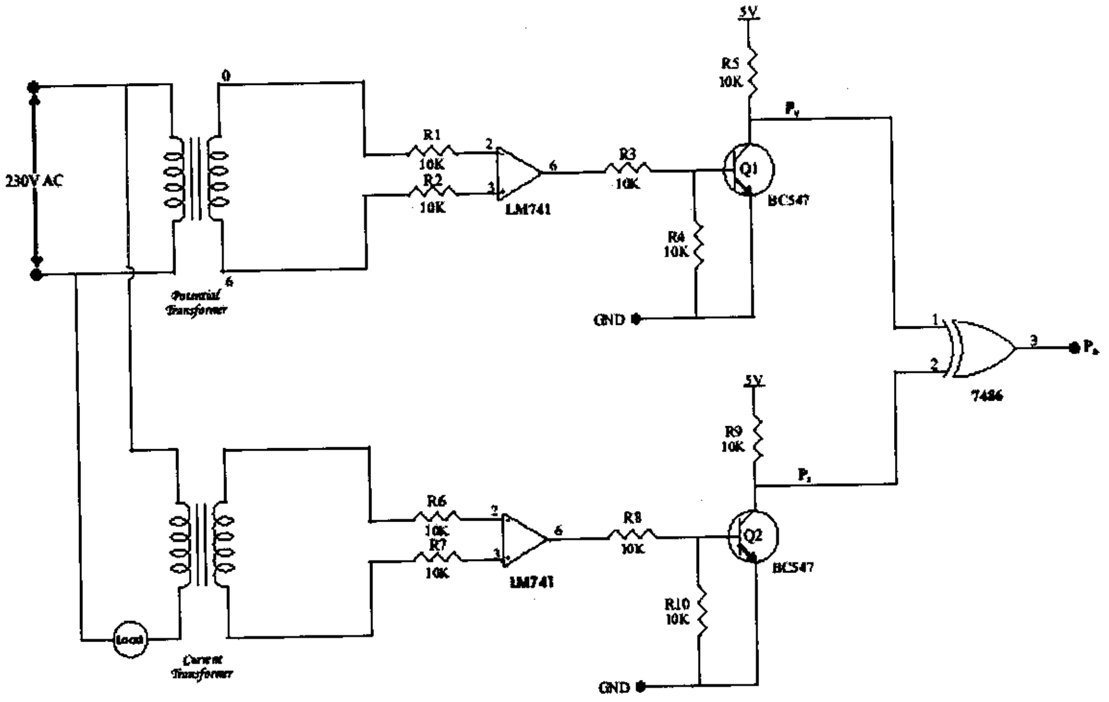


Figure 4.7 Power factor measuring circuit

4.2.6 Tap sensing circuit

The tap sensing circuit is shown in the Figure 4.8. From the secondary voltage measured, the tap position of the secondary winding can be found and displayed. A relay can be used for this purpose.The tappings are provided at 115 V, 230 V, 345 V at the secondary of the toroidal transformer.

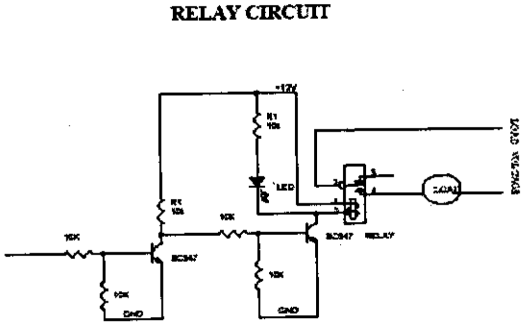


Figure 4.8 Tapsensing Circuit

4.2.7 Analog to digital converter

The ADC used here is of successive approximation type. The IC used is ADC0809. Here it uses an efficient code search strategy for the purpose of accuracy in conversion. Here the purpose of this IC is that it will receive the analog voltage signals from the transformer and get it converted into corresponding digital signals to feed it into the computer.

4.3 Software description

The output signals from the ADC is interfaced to the PC using a 25 pin female parallel port connector, which enables the user to know the values of various parameters of that device at that inatant.

4.3.1 Introduction to parallel ports

A port is a set of signal lines that the microprocessor, or CPU uses to exchange data with other components. Typical uses for ports are communicating with printers, modems, Keyboards and displays or just about any component or device except system memory. Most computer ports are digital, where each signal or bit is 0 or1. A parallel port transfers multiple bits at once, while a serial port transfers a bit at a time.

The Parallel Port is the most commonly used port for interfacing home made projects. This port will allow the input of up to 9 bits or the output of 12 bits at any one given time, thus requiring minimal external circuitry to implement many simpler tasks. The port is composed of 4 control lines, 5 status lines and 8 data lines. It's found commonly on the back of your PC as a D-Type 25 Pin female connector. There may also be a D-Type 25 pin male connector. This will be a serial RS-232 port and thus, is a totally incompatible port.

Newer Parallel Port's are standardized under the IEEE 1284 standard first released in 1994.

This standard defines 5 modes of operation which are as follows,

1. Compatibility Mode.
2. Nibble Mode.
3. Byte Mode.
4. EPP Mode *(Enhanced Parallel Port).*
5. ECP Mode *(Extended Capabilities Port).*

For a detailed information on parallel ports refer the website, http://www.senet.com.au/~cpeacock

4.3.2 System Interface

Either GUI or MATLAB programming can be used for the display of various parameters. In this project MATLAB programming is used for online condition monitoring of transformer parameters. A graphical user interface(GUI) is a pictorial interface to a program. A good GUI can make programs easier to use by providing them with a consistent appearance, and intuitive controls such as pushbuttons, edit boxes, list boxes, sliders and menus. A graphical user interface provides the user with a familiar environment in which to work. It contains pushbuttons, toggle buttons so that the user can concentrate on the purpose of the application instead of the mechanics involved in doing things. The input to the GUI is called as events and a program that responds to events is said to be an *event driven*. The three principal elements required to create a MATLAB Graphical User Interface are Components, Containers and Callbacks.

Each item on a MATLAB GUI is a graphical component. The types of components include graphical controls, static elements, menus, toolbars and axes. The components of a GUI must be arranged within a container, which is a window on the computer screen. The most common container is a *figure*. The other types of containers are *panels* and *button groups*. Finally there must be some way to perform an action if a user clicks a mouse on a button o types information on a keyboard. A mouse klicks or a key press is an *event*. The code executed in response to an event is known as a *callback*.

The standard GUI components created by *uicontrol* include text fields, edit boxes, pushbuttons, toggle buttons, checkboxes, radio buttons, popup menus, list boxes, and sliders. The standard GUI components created by *uimenu* and *uicontextmenu* are standard menus and context menus. MATLAB containers consist of figures, panels and button groups. Figures are created by the *figure* function. They are separate windows, complete with title bars, menu, and toolbars. Panels are created by the *uipanel* function. They are containers that reside within figures or other containers and do not have title bars, menu, or toolbars. Panels can contain *uicontrol* components and other panels or button groups, and those items will be laid out with respect to the panel itself. If the panel is moved, all of its contents move with it. Button groups are created by the *uibuttongroup* function. They are special types of panels that control any radio buttons or toggle buttons contained within them to ensure that at most one of them can be on at any time. Any of these components and containers can be placed on a figure using *guide* (the GUI Development Environment tool). Once the GUI layout has been completed, the user must edit the object properties with the Property Inspector and then write a callback function to implement the actions associated with each GUI object.

4.3.3 Algorithm for programming in MATLAB

Step 1 : Start the program.

Step 2 : Assign the parallel ports as input or output depending on the requirement.

Step 3 : Initialize the parallel port registers.

Step 4 : The measured values of voltage, current, power factor, temperature and tapchanger position of the toroidal transformer are given as input to the parallel port of PC.

Step 5 : The PC takes the data and the GUI displays the various parameters of the Toroidal transformer based on the time delay in the program.

Step 6 : The PC then transports the displayed values to the parallel port if needed else the program is terminated.

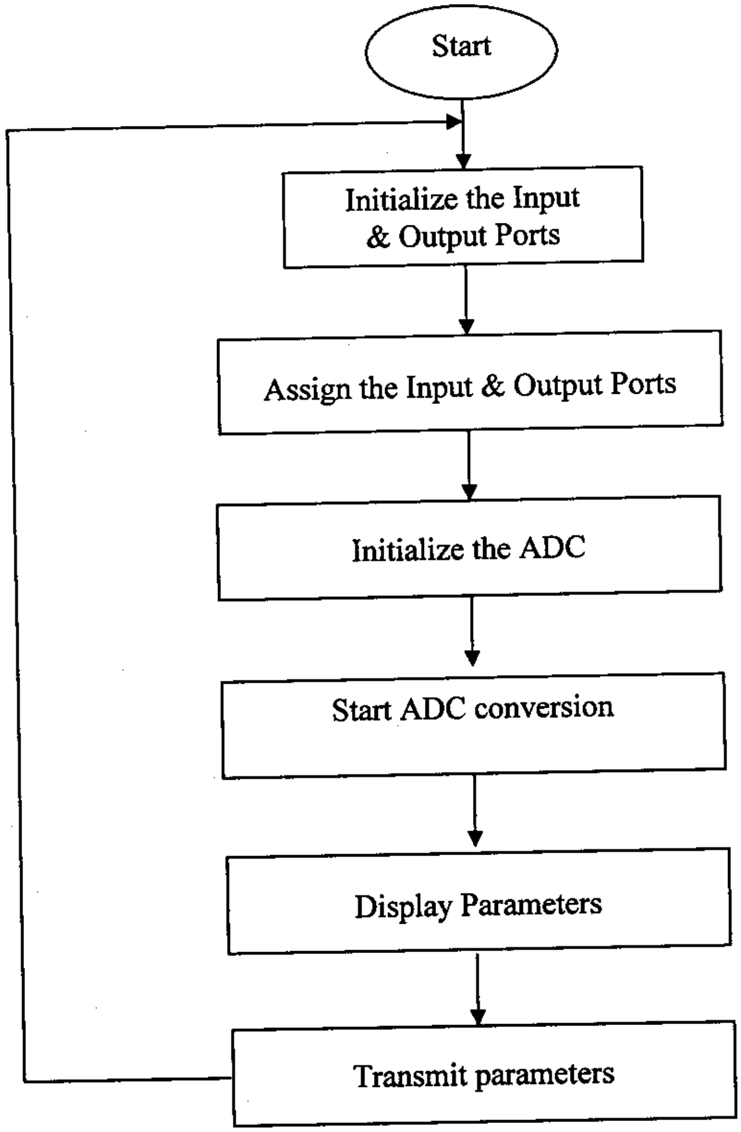


Figure 4.9. Flowchart for MATLAB programming.

CHAPTER 5

NEURAL NETWORK

Neural Networks ,which are simplified models of the biological neuron system, is a massively parallel distributed system made up of highly interconnected neural computing elements that have the ability to learn and thereby acquire knowledge and make it available for use. An artificial neural network is an information processing system that has certain performance characteristics in common with biological neural networks. Laurene Fausett explains that the artificial neural networks have been developed as generalization of mathematical models of human cognition or neural biology, based on assumption that:

1. Information processing occurs at many simple elements called neuron.
2. Signals are passed between neurons over connection links.
3. Each connection link has an associated weight, which, in a typical neural net, multiplies the signal transmitted.
4. Each neuron applies an activation function(usually nonlinear) to its net input(sum of weighted input signals) to determine the output signal.

A biological neuron has three types of components that are of particular interest in understanding an artificial neuron: its dendrites, soma and axon. Dendrites receive signal from other neurons. The signals are electrical impulses that are transmitted across a synaptic gap by means of a chemical process. When sufficient input is received, the cell fires, that is, it transmits a signal over its axon to other cells.

An Artificial Neural Network is characterized by,

(1) Its pattern of connections between the neurons (called its *architecture)*

(2) Its method of determining the weights on the connections (called its *training* or *learning, algorithm*),and

(3) Its *activation function*

A neural net consists of a large number of simple processing elements called neurons, units, cells or nodes. Each neuron is connected to other neurons by means of directed communication links, each with an associated weight. The weights represent information being used by the net to solve a problem. Neural nets can be applied to a wide variety of problems, such as storing and recalling data or patterns, classifying patterns, performing general mappings from input patterns to output patterns, grouping similar patterns or finding solutions to constrained optimization problems.

5.1 INTRODUCTION

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. The network function is determined largely by the connections between elements. Therefore, a neural network can be trained to perform a particular function by adjusting the values of the connections (weight) between the elements. Commonly neural networks are adjusted, or trained, so that a particular input leads to a specific target output. Figure 5.1 Shows the basic operation of a neural network.

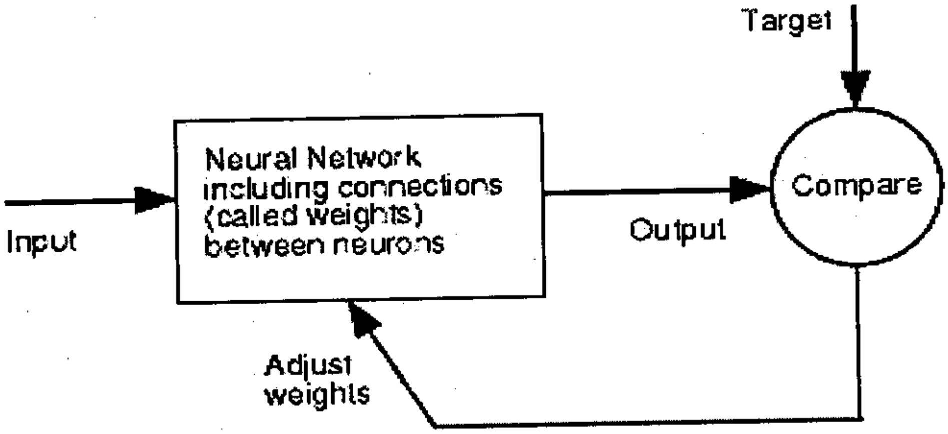
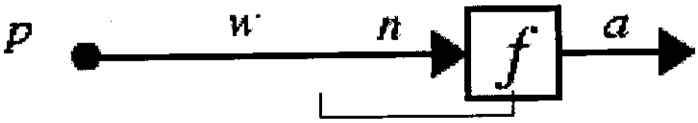


Figure 5.1 Basic operation of neural network

There ,the network weight is adjusted, based on a comparison of the output and the target, until the network output matches the target.

5.2 NEURON MODEL

Figure 5.2 shows a neuron with a single scalar input with no bias. The scalar input p, is transmitted through a connection that multiplies its strength by the scalar weight w, to form the product wp, again a scalar. Here the weighted input wp is the only argument of the activation function *f*, which produces the scalar output a.

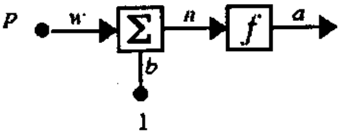


Neuron without bias

$a=f(wp)$

Figure 5.2 Single –input neuron without bias

Figure 5.3 shows a neuron with a scalar input, with scalar bias. The bias is much like a weight, except that it has a constant input of 1. The activation function net input n, again a scalar, is a sum of the weighted input wp and the bias b. This sum is the argument of the activation function *f*. *f* is an activation function, typically a step function or a sigmoid function, that takes the argument a and produces the output a. w and b both adjustable parameters of the neuron.



$a=f(wp+b)$

Figure 5.3 Single-input neuron with bias

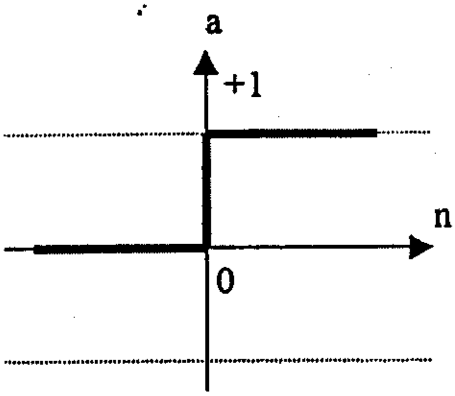
The central idea of neural networks is that such parameters can be adjusted so that the network exhibits some desired or interesting behavior. Thus, we can train the network to do a particular job by adjusting the weight or bias parameters, or perhaps the network itself will adjust these parameters to achieve some desired end.

5.2.1 Activation functions

An activation function may be linear or a non-linear function of n. A particular activation function is chosen to satisfy some specifications of a problem that the neuron is attempting to solve. There are three most commonly used activation function. They are

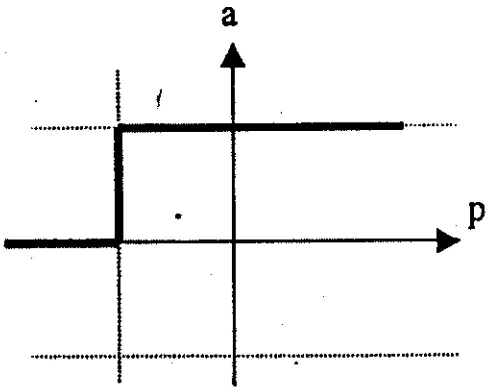
(a) Hard limit activation function
(b) Linear activation function
(c) Log-sigmoid activation function

(a) Hard limit activation function:



a = hardlim (n)

Figure 5.4 Hard limit activation function



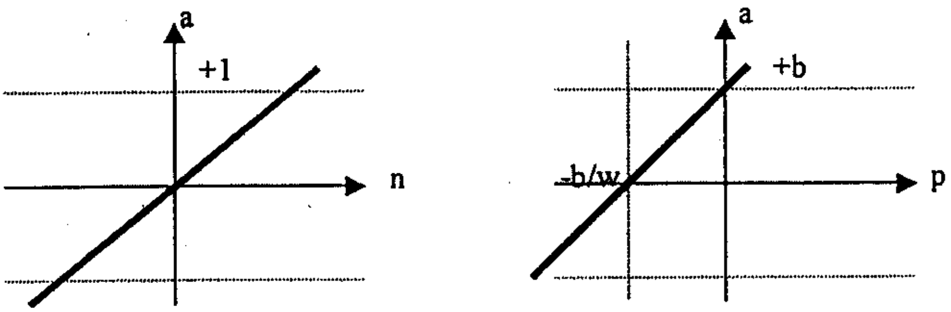
a = hardlim (wp + b)

Single – input hardlim neuron

Figure 5.4 shows the graphical representation of the hard limit activation function. The hard limit activation function sets the output of the neuron to 0 if the function argument is less than 0, or 1 if its argument is greater than or equal to 0.

(b) Linear activation function:

The output of a linear activation function is equal to its input. The output (a) versus input (p) characteristics of a single-input linear neuron is shown in Figure 5.5



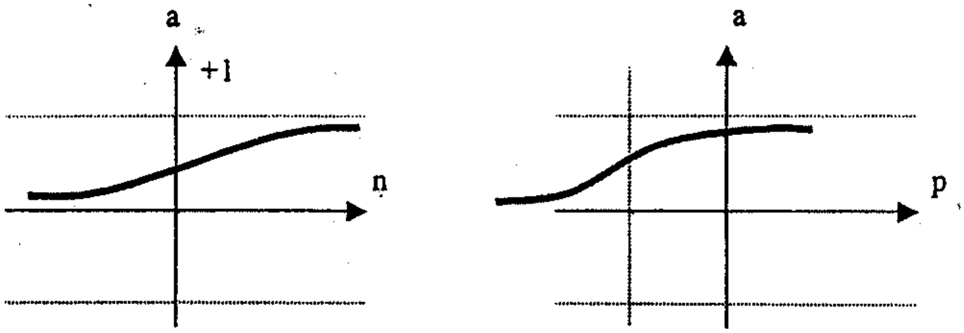
a = purelin (n)

a = purelin (wp + b)

Figure 5.5 Linear activation function

Single-input purelin neuron

(c). Log-sigmoid activation function:



a = logsig(n)

a = logsig (wp + b)

Figure 5.6 Log-sigmoid activation function

Single-input logsig neuron

Figure 5.6 shows the log-sigmoid activation function. This activation function takes the input (Which may have any value between plus and minus infinity) and squashes the output into the range 0 to 1, according to expression

$$a = \frac{1}{1+e^{-n}}$$

This activation function is commonly used in multilayer networks that are trained using the back-propagation algorithm, in part because this function is differentiable.

5.3 LEARNING RULES

The weights and biases of the network can be modified by means of *'learning rule'*. This procedure may also be referred to as a *training algorithm*. The purpose of the learning rule is to train the network to perform some task. Neural networks can be trained to solve problem that are difficult for conventional computers or human beings. There are many types of neural network learning rules. They fall into three broad categories: supervised learning, unsupervised learning and reinforcement(or graded) learning.

(a) Supervised learning: In supervised learning, the network is provided with inputs and the corresponding correct output. As the inputs are applied to the network, the network outputs are compared to the targets. The learning rule is then used to adjust the weights and biases of the network in order to move the network outputs closer to the targets. An example for the supervised learning is the perceptron-learning rule.

(b) Reinforcement learning: This is similar to supervised learning, except that, instead of being provided with the correct output for each network input, the algorithm is only given a grade. The grade is a measure of the network performance over some sequence of inputs. This type of learning is currently much less common than supervised learning.

(b) Unsupervised learning: In unsupervised learning, the weights and biases are modified in response to network inputs only. There are no target outputs available. The network learns to categorize the input patterns into a finite number of classes. An example for unsupervised learning algorithm is Adaptive Resonance Theory.

5.4 BACK-PROPAGATION NEURAL NETWORK

In supervised learning,the first learning rule is the perceptron-learning rule,in which the learning rule is provided with a set of examples of proper network behavior. As each input is applied to the network,the learning rule adjusts the network parameters so that the network output will move closer to the target. The perceptron learning rule is very simple,but it is also quite powerful. This rule will always converge to a correct solution,if such a solution exists. The perceptron-learning rule,the LMS (Least Mean Square) algorithm is an example of supervised training. The LMS algorithm will adjust the weights and biases to minimize the mean square error, where the error is the difference between the target output and the netwok output. The perceptron-net is incapable of implementing certain elementary functions.

Performance learning is another important class of learning law, in which the network parameters are adjusted to optimize the performance of the network.
Backpropagation can be used to trin multilayer networks. As with the LMS algoritmm and backpropagation is only in the way in which the derivatives are calculated. The single-layer perceptron like networks are only able to solve linearly separable classification problems. Multilayer perceptron, trained by backpropagation algorithm were developed to overcome these limitations and is currently the most widely used neural network. In addition, multilayer networks can be used as universal function approximators. A two-layer network, with sigmoid-type activations in the hidden layer,can approximate any practical function, with enough neurons in the hidden layer.

The back-propagation algorithm uses the chain rule in order to compute the derivatives of the squared error with respect to the weights and biases in the hidden layers. It is called *backpropagation* because the derivatives are computed first at the last layer of the network,and then propagated backward through the network,using the chain rule,to compute the derivatives in the hidden layers.

The back-propagation training algorithm is an iterative algorithm designed to minimize the mean square error between the actual output of a feedforward net and the desired output .

5.5 CHOICE OF PARAMETERS FOR NETWORK TRAINING

When the basic back-propagation algorithm is applied to a practical problem the training may take days or weeks of computer time. This has encouraged considerable research on methods to accelerate the convergence of the algorithm. The research on faster algorithms falls roughly into two categories; the first category involves the development of heuristic techniques, which arises out of a study of the distinctive performance of the standard back-propagation algorithm. These heuristic techniques include such ideas as varying the learning rate,using momentum and rescaling variables. Another category of research has focused on standard numerical optimization techniques.

5.5.1 Learning rate

The speed of training the back-propagation network is improved by changing the learning rate during training. Increasing the learning rate on flat surfaces and then decreasing the learning rate when slope increases can increase the process of convergence. If the learning rate is too large, it leads to unstable learning. And if it is too small, it leads to incredibly long training times. Hence care has to be taken while deciding learning rate. There are many different approaches for varying the learning rate. The learning rate is varied according to the performance of the algorithm. The rules of the variable learning rate back-propagation algorithm are:

1. If the squared error increases by more than some set percentage (typically one to five percent) after weight update, then the weight update is discarded,the learning

rate is multiplied by some factor 0< μ <1, and the momentum coefficiency is set to zero.

2. If the squared error decreases after a weight update, then the weight update is accepted and the learning rate is multiplied by some factor > 1. If has been previously set to zero, it is reset to its original value.
3. If the squared error increases by less than , then the weight update is accepted but the learning rate is unchanged . If has been previously set to zero,it is reset to its original value.

5.5.2 Momentum:

In back-propagation with momentum, the weight change is in a direction that is a combination of the current gradient and the previous gradient. This is a modification of gradient descent whose advantage arises chiefly when some training data are very different from the majority of the data. By the use of momentum larger training rate can be used, while maintaining the stability the stability of the algorithm. Another feature of momentum is that it tends to accelerate convergence when the trajectory is moving in a consistent direction. The larger the value of, the more the momentum the trajectory has. The momentum coefficient is maintained with the range [0 , 1].

The application of the Neural Network technique for fault diagnosis is described in chapter 7.

CHAPTER 6

FUZZY LOGIC

Logic is the science of reasoning. Symbolic or mathematical logic has turned out to be a powerful computational paradigm. Not only does symbolic logic help in the description of events in the real world but has turned out to be an effective tool for inferring or deducing information from a given set of facts. Just as mathematical sets have been classified into crisp sets and fuzzy sets, logic can also be broadly viewed as crisp logic and fuzzy logic. Just as crisp sets survive on a 2-state membership(0/1) and fuzzy sets on a multistate membership [0-1], crisp logic is built on a 2-state truth value (True/False) and fuzzy logic on a multistate truth value (True/False/very True/Partly False and so on.)

6.1 INTRODUCTION

In crisp logic, the truth values acquired by propositions or predicates are 2-valued, namely True, False which may be treated numerically equivalent to (0,1). However, in fuzzy logic, truth values are multivalued such as absolutely true, partly true, absolutely false, very true, and so on and are numerically equivalent to (0-1). Fuzzy logic is all about relative importance of precision. It is a convenient way to map an input space to an output space. The general observations about fuzzy logic are:

1. Fuzzy logic is conceptually easy to understand.
2. Fuzzy logic is flexible
3. Fuzzy logic is tolerant of imprecise data
4. Fuzzy logic can model nonlinear functions of arbitrary complexity
5. Fuzzy logic can be built on top of the experience of experts
6. Fuzzy logic can be blended with conventional control techniques
7. Fuzzy logic is based on natural language.

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership. In fuzzy logic ,the truth of any statement becomes a matter of degree.

6.2 BASIC MODEL OF A FUZZY SYSTEM

A fuzzy logic system in general has the following components namely numerical input or crisp input, Fuzzification, Inference engine (Rule base) Defuzzification and finally the numerical output or crisp output. The basic model of a fuzzy system is shown in Figure 6.1.

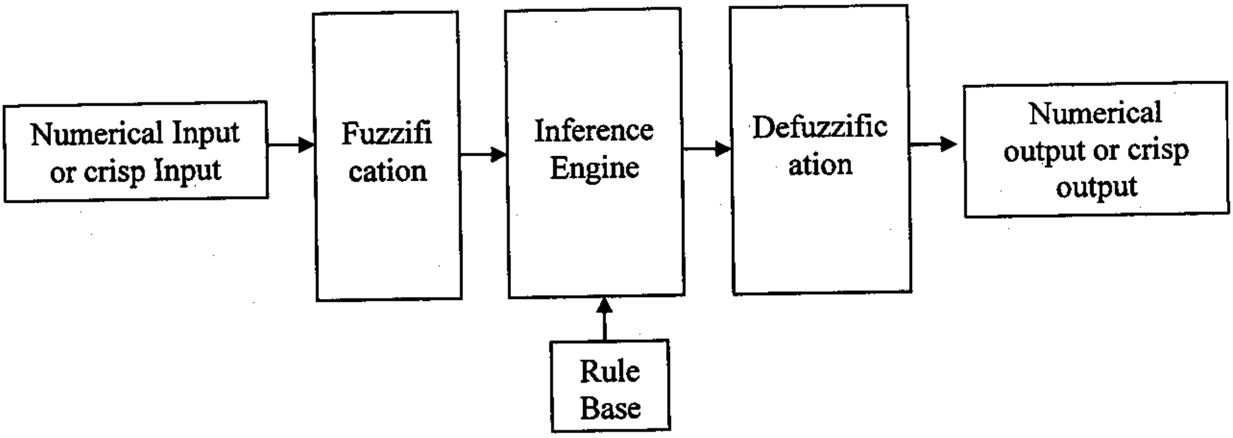


Figure. 6.1. Basic model of a fuzzy system

At first the numerical input or crisp input is given to the fuzzification block. Fuzzification is the process of converting the numerical input or crisp input to a fuzzy set. The output of fuzzification is given to the fuzzy inference block. A fuzzy inference also referred to as approximate reasoning refers to computational procedures used for evaluating linguistic descriptions. Fuzzy liguistic descriptions are formal representations of systems made through fuzzy IF-THEN rules. They encode knowledge about a system in statements of the form – IF (a set of conditions) are satisfied THEN (a set of consequents) can be inferred. Fuzzy IF-THEN rules are coded in the form-

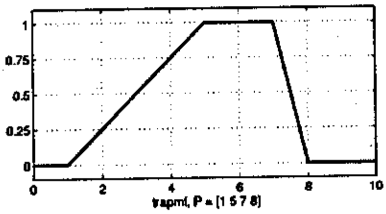
IF (x_1 is A_1, x_2 is A_2,,..... ,x_n is A_n) THEN (y_1 is B_1, y_2 is B_2,........, y_n is B_n).

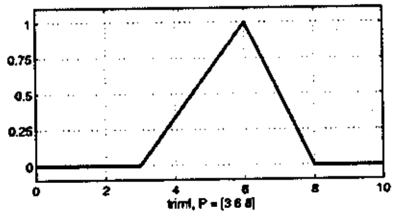
where linguistic variables x_i , y_i , take the values of fuzzy sets A_i, and B_j respectively. Defuzzification is the process of converting a fuzzy set to single crisp value. The defuzzification methods are centroid method, center of sums, and mean of maxima. The centroid method also known as the center of area method which obtains the centre of area occupied by the fuzzy set. In the centroid method, the overlapping area is counted once whereas in centre of sums, the overlapping area is counted twice. One simple way of defuzzifying the output is to take the crisp value with the highest degree of membership. In cases with more than one element having the maximum value,the mean value if the maxima is taken.

6.3 MEMBERSHIP FUNCTIONS

A membership function (MF) is a curve that defines how each point in the input space is mapped to membership value between 0 and 1. The input space is sometimes referred to as the universe of discourse. The only condition a membership function must really satisfy is that it must vary between 0 and 1. The function itself can be an arbitrary curve whose shape we can define as a function that suits from the point of view of simplicity, convenience, speed, and efficiency. There are 11 types of membership functions namely , piecewise linear functions, the Gaussian distribution function, the sigmoid curve, quadratic and cubic polynomial curves. The simplest membership functions are formed using straight lines.

The output verses input curve of the triangular and trapezoidal membership function is shown in Figure 6.2





Two membership functions are built on the Gaussian distribution curve: a simple Gaussian curve and a two-sided composite of two different Gaussian curves. The two functions are *gaussmf* and *gauss2mf*. The *generalized bell* membership function is specified by the name *gbellmf*. The Gaussian membership function is shown in Figure 6.3.

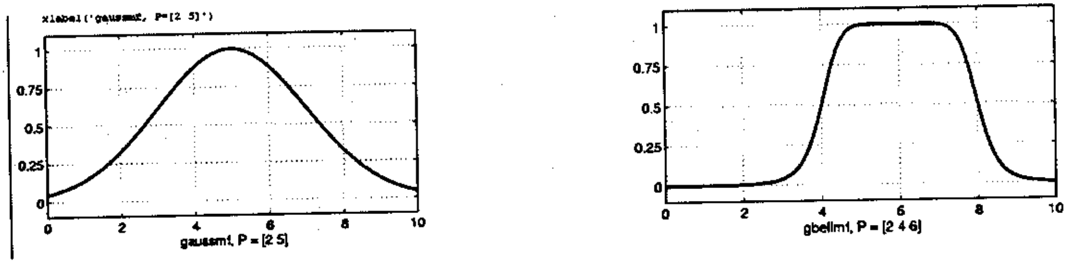


Figure 6.3 Gaussian membership function

The sigmoidal membership function function, which is either open left or right and also a closed one. In addition to basic sigmoidal function *sigmf* the two functions difference between two sigmoidal functions *sigmf* and the product of two sigmoidal functions *psigmf* is shown in Figure 6.4.

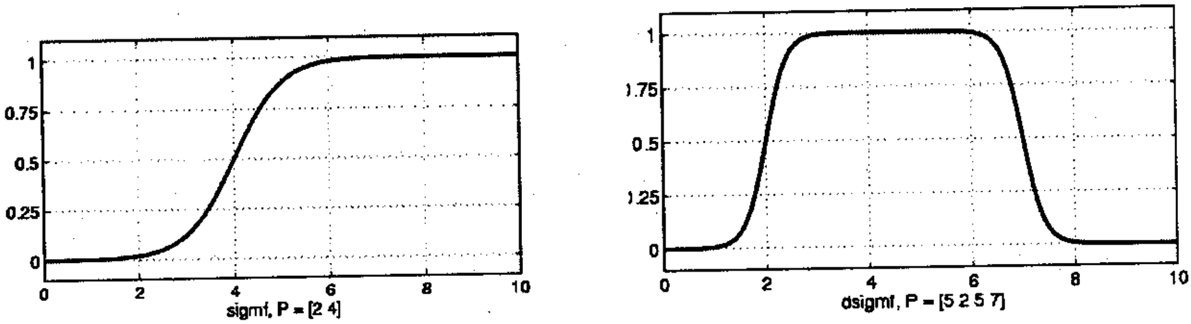


Figure 6.4 Sigmoidal membership function

6.4 FUZZY INFERENCE SYSTEMS

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. There are two types of fuzzy inference systems namely Mamdani – type and Sugeno – type. Fuzzy inference systems have been successfully applied in many fields such as automatic control, data classification, decision analysis, expert systems, and computer vision.

Mamdani's method was the first control system built using fuzzy set theory. In Mamdani- type the inference system expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. In many cases it is much more efficient, to use a single spike as the distributed fuzzy set. This is sometimes known as a singleton output membership function, and it can be thought of as a pre- defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general Mamdani method, which finds the centroid of a two-dimensional function by weighted average of a few data points.

The Sugeno-type of system can be used to model any inference systems in which the output membership functions are either linear or constant. This system integrates the two-dimensional function to find the centroid. In this project Mamdani's type of inference system is used as the defuzzification can be done only by this method.

In the Fuzzy logic there are five parts of the fuzzy inference process: Fzzification of the input variables, application of the fuzzy operator (AND or OR) in the antecedent, implication from the antecent to the consequent, aggregation of the consequents across the rules, and defuzzification.

1) Fuzzify Inputs:

The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. The input is always a crisp numerical value limited to the universe of discourse of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set. The fuzzification of the input amounts to either a table lookup or a function evaluation.

2) Apply Fuzzy Operator:

Once the inputs have been fuzzified, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. The input to the fuzzy operator is two or more membership values from fuzzified input variables.

3) Apply Implication Method:

Before applying the implication method, weight is applied to the number given by the antecedent. Once proper weighting has been assigned to each rule, the implication method is implemented. There are two implication methods, they are *min* (minimum), which truncates the output fuzzy set, and *prod* (product),which scales the output fuzzy set.

4) Aggregate All Outputs:

Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable. Three methods of aggregation are, *max* (maximum), *probor* (probabilistic or) , and *sum* (simply the sum of each rule's output set).

5) Defuzzify:

The input for the defuzzification process is a fuzzy set and the output is a single number. The aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set.

The application of the Fuzzy logic technique for fault diagnosis is described in chapter 7.

CHAPTER 7

NEURAL NETWORK AND FUZZY LOGIC BASED FAULT DIAGNOSIS OF TOROIDAL TRANSFORMERS

7.1 INTRODUCTION

As an important component in modern power systems, the transformer is responsible for the stable and reliable power transmission and distribution. Fault diagnosis of power transformers is an important measure to prevent serious system outage due to such faults as the deterioration of electrical insulation in transformers. Consequently, transformers must strictly periodically examined to find faults and to protect them from further deterioration as early as possible. Some of the internal faults that occur in a transformer are short circuit of transformer winding and inter-turn short circuit. Among these two faults the impact of the second fault on the insulation of transformer is high. A further aggregation of this fault in a transformer is insulation failure which cause considerable decrease in the life of transformers installed in large power systems.

To study the effect of inter-turn short- circuit fault, Toroidal transformers are tested with different loading conditions and the failure of insulation is assessed taking voltage and current as input with temperature being the output and are trained using Neural Networks and Fuzzy Logic techniques. Artificial neural networks (ANNs) have been proposed to tackle the transformer fault diagnosis, because of their superior learning and generalization capabilities, and built-in fault tolerance in practical applications. The ANNs can acquire new experiences by incremental training from newly obtained samples. Moreover, the ANNs can interpolate and extrapolate from their experiences, providing at least a best guess of the fault. The ANNs trained by an error back-propagation algorithm have good diagnostic capabilities.

Fuzzy logic technique has been proposed to diagnose inter-turn fault of toroidal transformers. The crisp boundaries of the gas attributes for classifying the fault types were fuzzified in the fuzzy logic system. The diagnosis results obtained using fuzzy logic system is compared with the results obtained from Neural Networks. The performance of the two techniques used for fault diagnosis is compared based on the percentage error obtained from training the system.

7.2 PROBLEM DEFINITION

One of the most important faults in transformrs is inter-turn short-circuit of transformers. The effect of this fault on transformers is insulation failure. The windings of transformers are insulated to prevent shorting of the winding turns. This insulation is categorized into several classes, which are rated for different maximum operating temperatures. Often, however, these maximum temperatures are violated due to the operating environment, load requirements, etc. This violation leads to cracks, thinning and eventual loss of insulation at some points on the windings . This effectively decreases the number of transformer turns by causing inter-turn shorting of the windings. A decrease in the winding equivalent turns will increase the winding current, thus causing increased heating in the stator due to additional $I^2 R$ losses. The increased heating will cause a corresponding temperature rise in the winding of transformer thereby decreasing the life expectancy of the winding insulation. Insulation failure will cause additional shorted turns, further increase in temperature, and a further increase in rate of deterioration of the winding insulation.

To, study the effect of inter-turn fault, Toroidal transformers of 50 VA and 5 KVA have been tested at various voltage levels and at different loading conditions. The effect of inter-turn fault is tested on primary side, secondary side and combined primary-secondary side. The 50 VA transformer is tested at 230 V, 200 V, 180 V at full load and half load and the variation in temperature is noted with change in voltage and current. The above transformer was shorted for a 20 % (1058 /106 turns) on the secondary side where inter- turn short was increased from first turn to the tenth turn. It was noted that with increase of shorted turns the temperature rise was high. Since the temperature developed was only 50 degrees there was no considerable effect on the insulation of windings but cracks was developed due the prolonged temperature rise.

To have a detailed study of inter-turn fault on the insulation of transformer a 5 KVA transformer is tested at primary side, secondary side and on primary-secondary side. At 115 V, 100 V, 230 V at 2 A load. The temperature rise was 128 degree at 230 V particularly when turn fault is on the secondary side. At this voltage level the current rise was also high. Table 7.1 shows the ratings of the test transformer.

Table 7.1 Parameters and ratings of the test transformer.

Rated KVA	50 VA	5 KVA
Type of transformer	Stepdown,230 V/20 V	Stepdown,230 V/200V
V, rated	230 V	230 V
I, rated	2.5 A	22 A
Class of Insulation	CLASS A	CLASS B
Pry- Sec turns	1058/106 turns	232 / 200 turns
Winding thickness	25/18 AWG	12/ 11 AWG

7.3 METHODOLOGY

Neural Network and Fuzzy logic based fault diagnosis scheme for Toroidal transformer requires various sets of test data which are collected by noting the temperature change with corresponding variation in voltage and current. The transformer is said to have insulation failure if the temperature rise was above the class of insulation used. It is 110 degrees in 50 VA transformer and 130 degrees in 5 KVA transformer.A detailed description of each process carried to diagnose the fault in a toroidal transformer follows.

7.3.1 STRUCTURE OF FAULT DIAGNOSIS SYSTEM USING NEURAL NETWORK

An artificial neural network is composed of neurons with a deterministic activation function. The neural network is trained by adjusting the numerical value of the weights between each unit. Once the neuron is properly trained, the network weights will contain the non-linearity of the desired mapping, so that difficulties in the mathematical modeling can be avoided. The back- propagation training algorithm is used to adjust the numerical values of the weights and the internal threshold of each neuron.The network is trined by, initially selecting small random weights and internal threshold and then presenting the test data. Weights and thresholds are until the error is adjusted to acceptable value.

Figure.7.1 Shows the structure of the conventional fault diagnosis system using neural network.

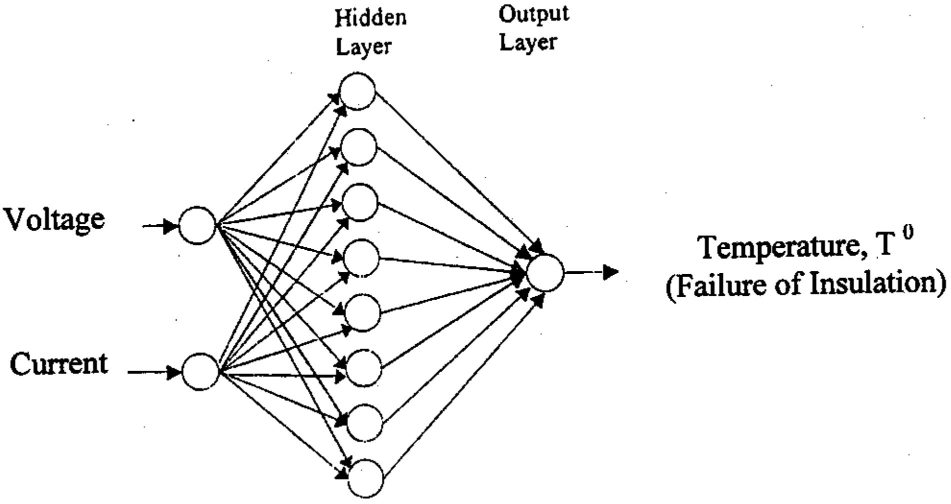


Figure 7.1 Conventional fault diagnosis system

The Neural Network consists of two layers, hidden layer and the output layer. The nodes in each layer receive input signals from the previous layer and pass the output to the subsequent layer. The nodes of the input layer receive a set of input signals from outside system and directly deliver the input data to the input of the hidden layer by the weighted links. The condition of insulation is decided based on the temperature rise of shorted windings with the criteria being the voltage and current.

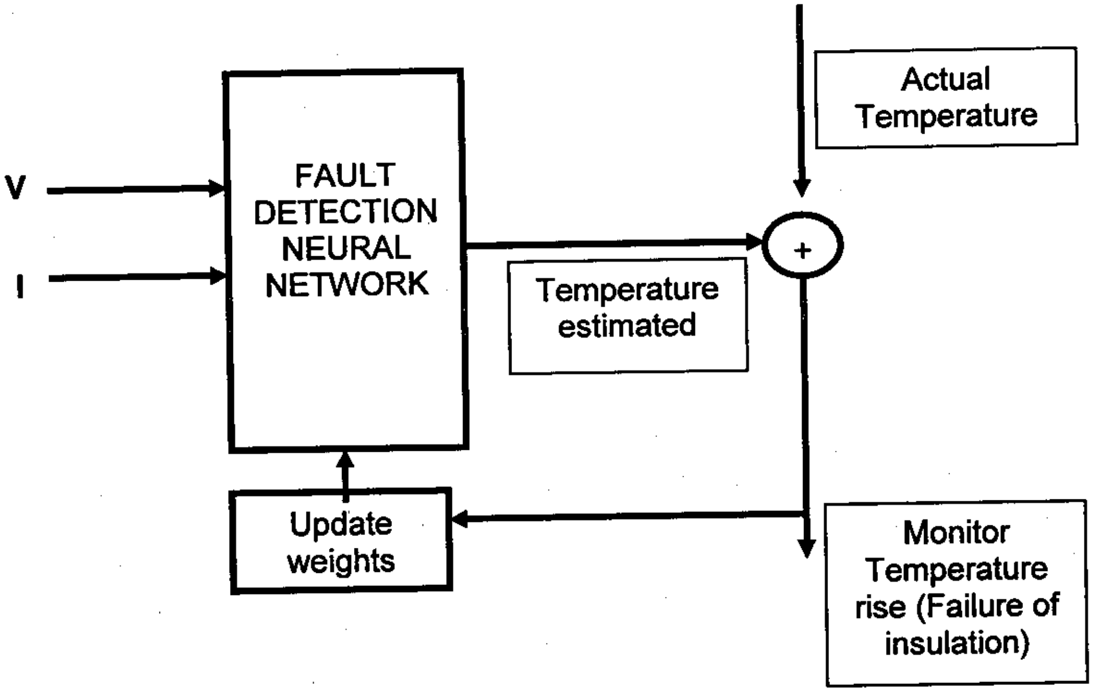


Figure.7.2. Proposed neural network based turn fault diagnosis in a transformer.

The voltage and current are fed as input to the neural network with temperature as the target. Suitable hidden layer neurons are selected based on minimum mean square error. Back-propagation neural network is used with training function used is *trainlm*. The learning rate and number of epochs are decided to obtain minimum error. As the epochs reaches the maximum value set for different voltage levels the error reaches the minimum thereby reducing the difference between the network output and the target specified.

Performance 0.0042

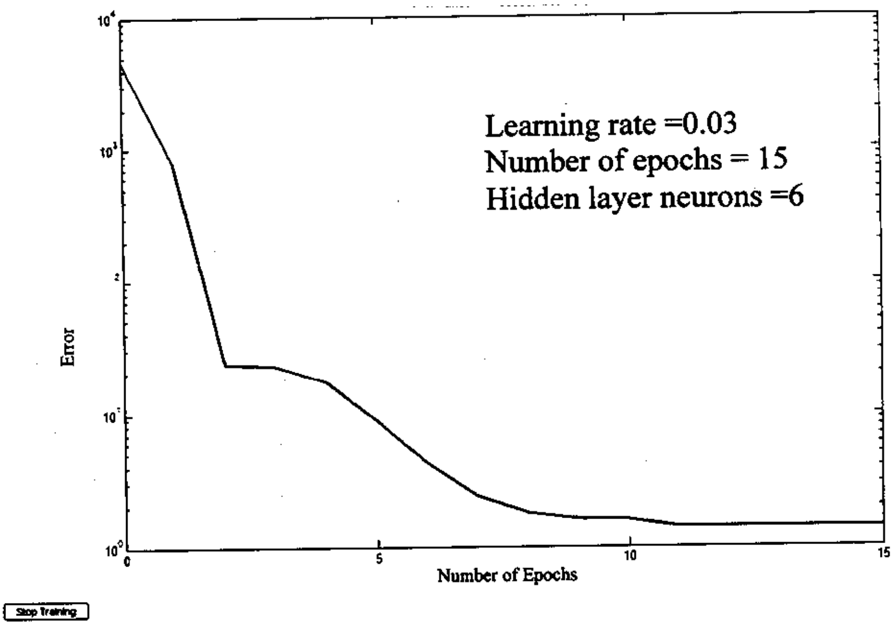


Figure 7.3 Epoch V_s Error characteristic for 50VA transformer at 200 V.

Performance 0.028

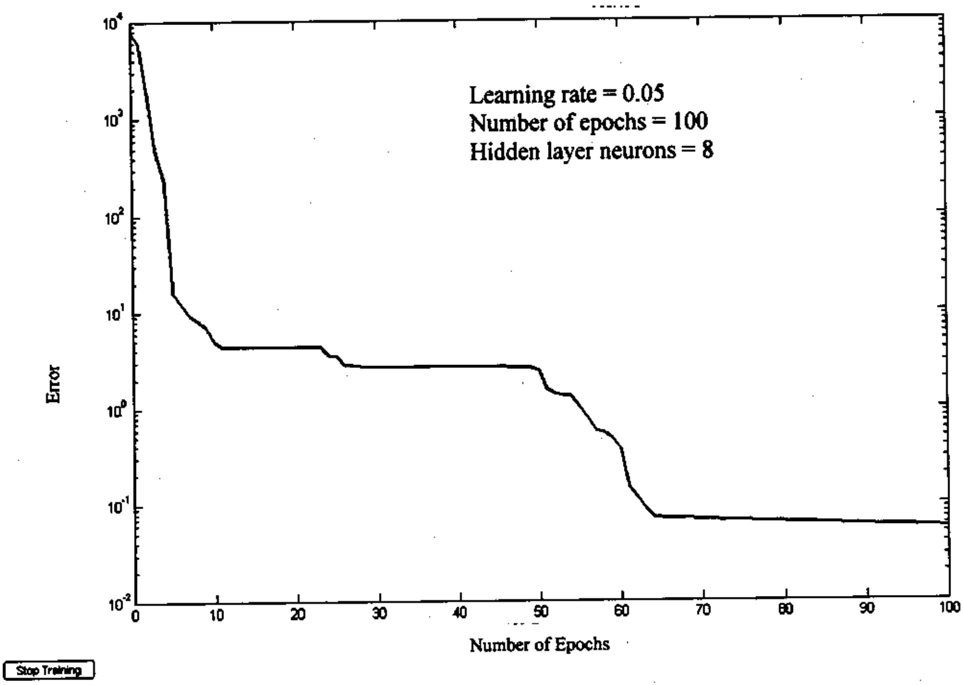


Figure 7.4 Epoch V_s Error characteristic for 50VA transformer at 230 V.

Performance 0.0106

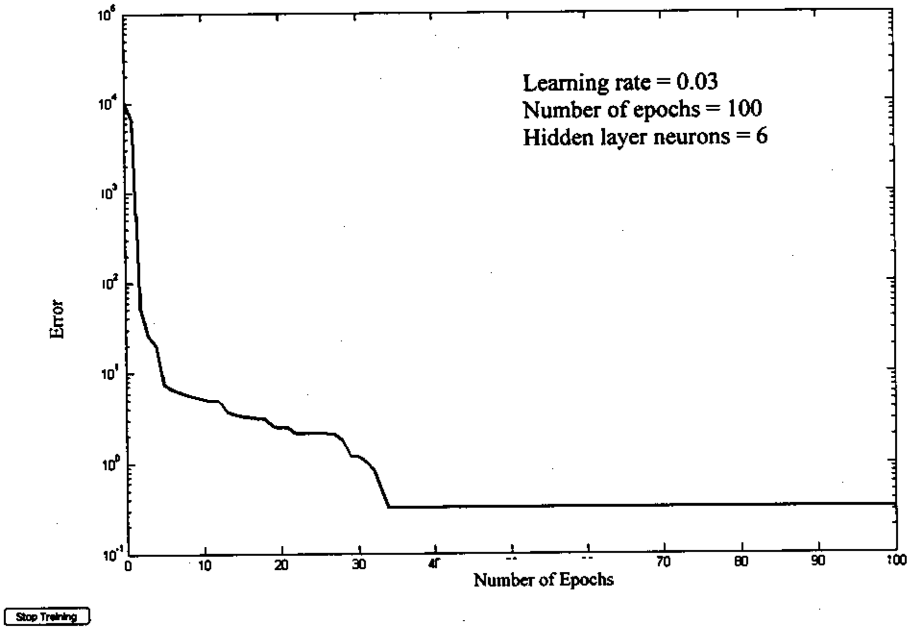


Figure 7.5 Epoch V_s Error characteristic for 50VA transformer at 180 V.

Performance 0.0685

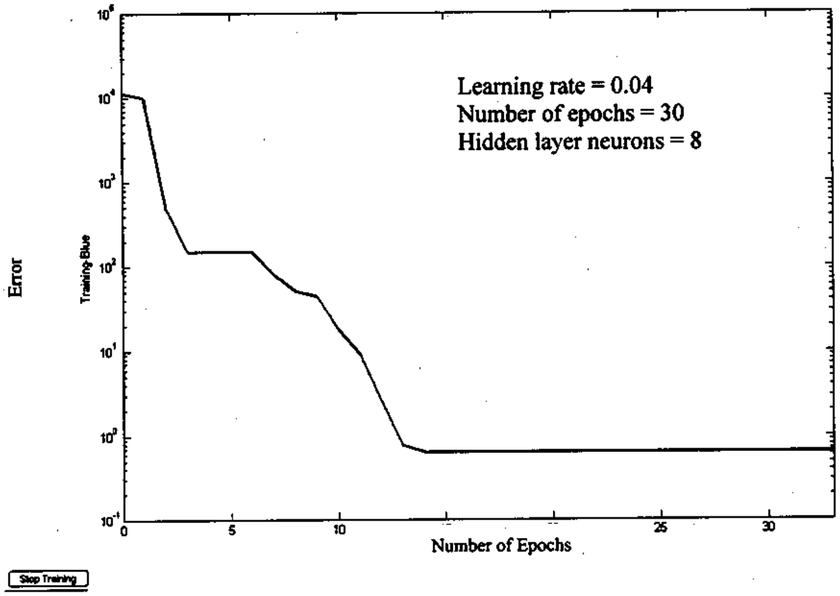


Figure 7.6 Epoch V_s Error characteristic for 5 KVA transformer at 230 V.

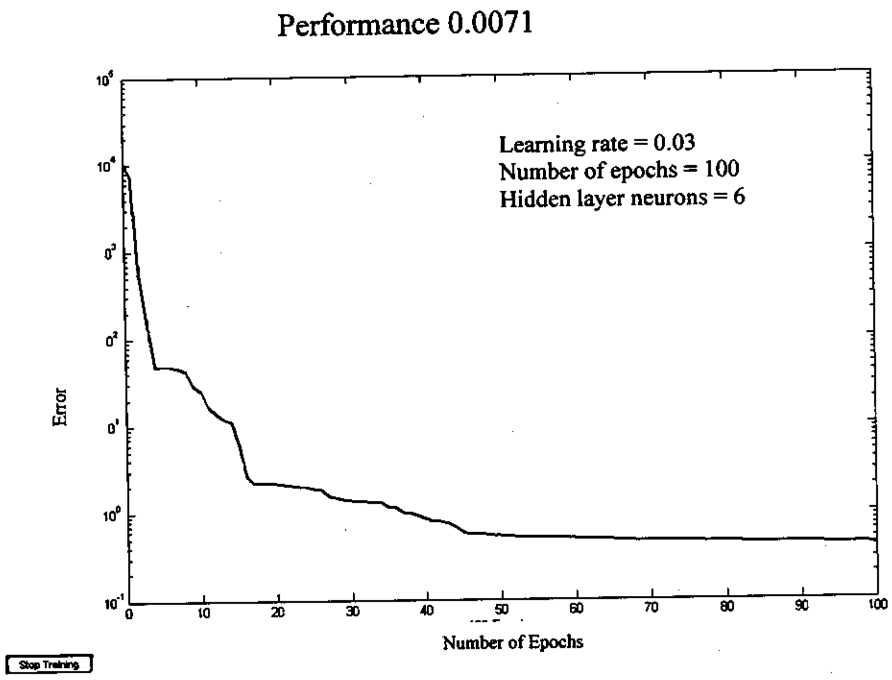


Figure 7.7 Epoch V_s Error characteristic for 5 KVA transformer at 115 V.

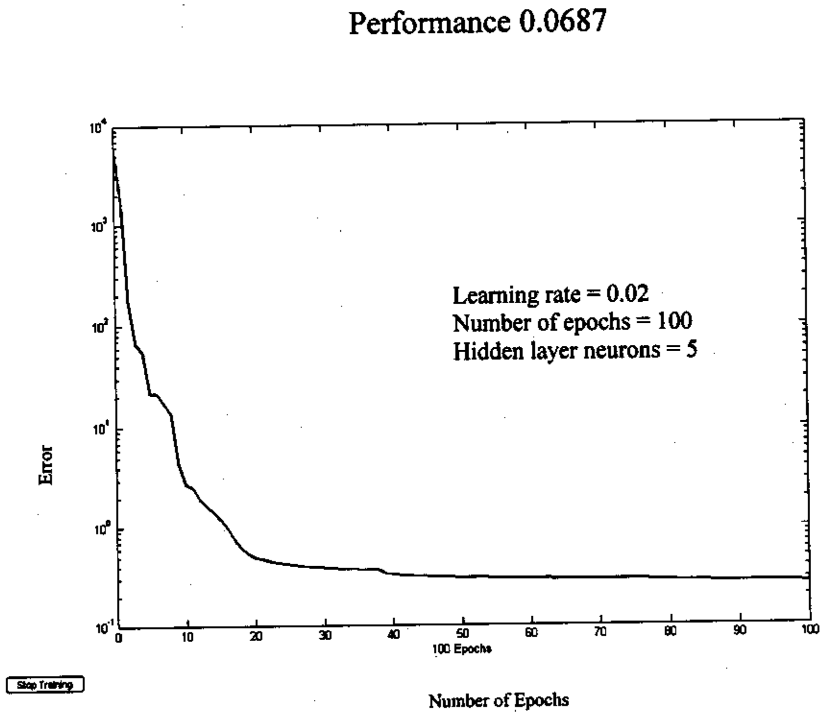


Figure 7.8 Epoch V_s Error characteristic for 5 KVA transformer at 100 V.

Figure 7.3 to Figure 7.8 show the Epoch Vs Error characteristics for a 50 VA and 5 KVA toroidal transformer. From figure 7.3 , 7.4 and 7.5 it is inferred that the error surface is more at 230 V compared to 200 V and 180 V. Also the number of epochs is high compared to 200 V and 180 V. These two points make clear that the effect of inter –turn fault is more at 230 V than at 200 V and 180 V for 50 VA transformer. Similarly from figure 7.6 to 7.8 the error surface in figure 7.6 is more and learning rate is also high comparing to figure 7.7 and 7.8, which concludes that the effect of inter-turn fault is severe when it occurs at 230V.

The main objective of this neural network training is that it can be used as a reference for future fault diagnosis with different test conditions. The activation function in the first layer is log-Sigmoid, and the output layer transfer function is linear. The training function used is *trainlm.* From the above training it is seen that the effect of inter- turn fault is high at 230 V in a 5 KVA transformer and it is severe when it occurs at secondary side of a 5 KVA transformer. The test data used for training the neural network is shown in the section 7.5.

7.3.3 STRUCTURE OF FAULT DIAGNOSIS SYSTEM USING FUZZY LOGIC TECHNIQUE.

Fuzzy logic technique has been proposed to diagnose the inter-fault of transformers. The crisp boundaries of the temperature rise attributes for classifying the insulation failure of a transformer from a healthy transformer. The condition of insulation is decided based on the temperature rise of windings with the criteria being the voltage and current. The test data which is used as the input of the fuzzy logic system is shown in section. 7.5. Figure.7.9. shows the proposed structure of fault diagnosis system using Fuzzy logic technique.

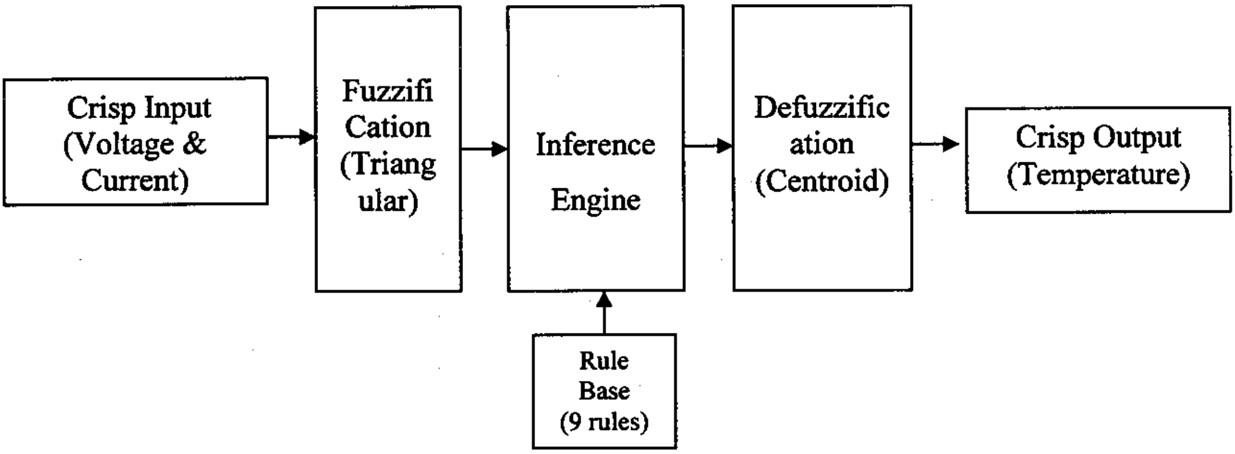


Figure 7.9 Proposed fuzzy based turn fault diagnosis system

In a fuzzy logic system there are five parts of fuzzy inference process: fuzzification of the input variables, application of the fuzzy operator (AND or OR) in the antecedent, implication from the antecedent to the consequent, aggregation of the consequents across the rules, and defuzzification.

Fuzzification is done by taking crisp values of voltage and current of the Toroidal transformer at various test conditions and crisp input is converted to a fuzzy value using *triangular* membership function. In this project Mamdani's fuzzy inference method is used for training. Once the inputs have been fuzzified, AND or OR logical operator is used for converting two or more membership values to a single truth value. The two AND methods are *min* (minimum) and *prod* (product),whereas *max* (maximum) and the probabilistic OR method *probor* are two OR methods used.

After obtaining the fuzzy values using fuzzy operators the rules are applied. The rules for this project are developed with output as temperature and inputs as voltage and current. The outputs are classified either as Low, Medium and High based on the value of Voltage and current on the trial- and -error basis. The fuzzy rule table is shown in Table.7.1

Table 7.1 Fuzzy rule table

Voltage \ Current	L	M	H
L	L	M	H
M	M	M	H
H	H	M	H

L – Low, M – Medium, H – High

The outputs of each rule are combined into a single fuzzy set using an aggregation process. Three methods used for aggregation are, *max* (maximum), *probor*(probabilistic OR), and *sum* (sum of each rule's output set). To convert the fuzzy output to a single output value, defuzzification process is used. In this project the defuzzification method used is *centroid.*

The voltage and current are fed as crisp input to the fuzzy logic system with temperature as the crisp output. Then using triangular membership function, fuzzy rule table, centroid defuzzification function a crisp output (Temperature) is obtained. The output of fuzzy logic system may be in the form of Rule viewer and Surface viewer. The rule viewer displays a roadmap of the whole fuzzy inference process. In a Surface viewer we get a three dimensional plot of two input to single output value.

Figure.7.10. to Figure.7.12 show the rule view and surface view of the fuzzy inference process. These outputs show that the effect of inter-turn fault is predominant at 230 V and when the fault is on secondary side.

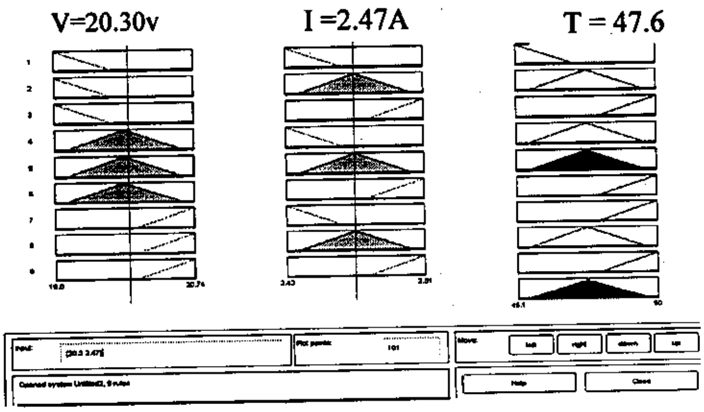
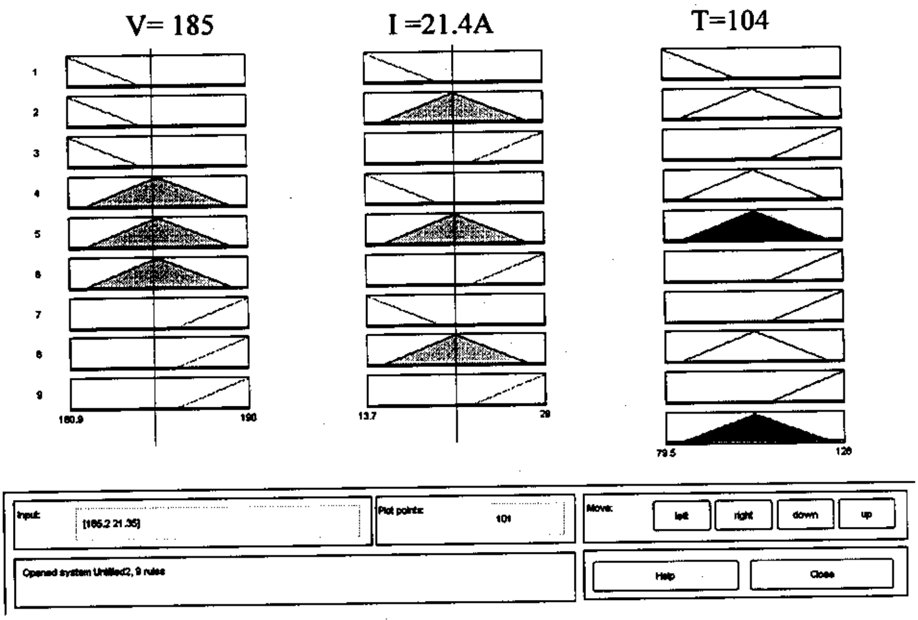


Figure 7.10 Rule view of 50VA transformer at 230V



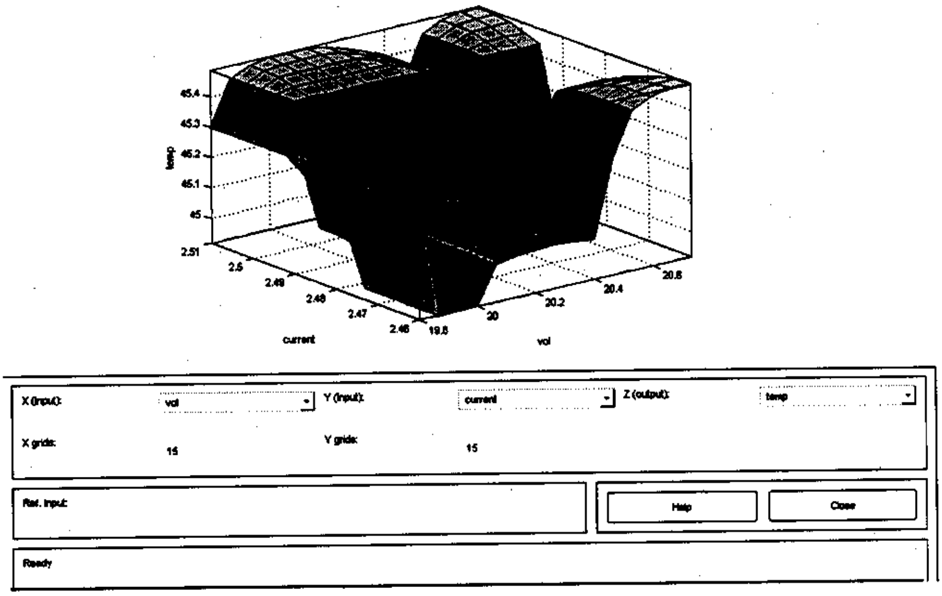
Input: [185.2 21.35]

Plot points: 101

Move:

Opened system Untitled2, 9 rules

Figure 7.11 Rule view of 5KVA transformer at 230V



X (input): vol

Y (input): current

Z (output): temp

X grids: 15

Y grids: 15

Ref. input:

Ready

Figure 7.12 Surface view of 50 VA Transformer at 230 V

Figure 7.10 and 7.11 are the aggregate of the fuzzy inference process providing the rule view with inter – turn fault is predominant at 230 V and when the secondary side is shorted. The figure 7.12 shows the surface view of a 50 VA transformer which is a three dimensional view of the input and output surface which is plotted for different turn fault positions. The error surface is more when the inter-turn fault is on the secondary side.

7.4 SOFTWARE DESCRIPTION

7.4.1 Simulation of artificial neural network using MATLAB.

MATLAB is a software package, which performs numeric computation and visualization. MATLAB is widely available and, because of its matrix/vector notation and graphics,is a convenient environment to experiment with neural networks. Many of the important features of neural networks become apparent only for large-scale problems, which are computationally intensive and not feasible for hand calculations. With MATLAB, neural network algorithms can be quickly implemented, and largesale problems can be tested conveniently.

The algorithm and flowchart for simulation in MATLAB is as follows.

Step 1 : Define the structure of the Neural Network.
Step 2 : Initialize the weight and biases of the network.
Step 3 : Provide the network with the inputs and targets.
Step 4 : State the number of epochs, learning rate and the error rate.
Step 5 : Train the network for the input and the corresponding targets.

Step 6 : Check for the error convergence else repeat step 4 till the error converges to the required value.
Step 7 : Check whether number of epochs is reached. Stop training if the specified number of epochs is reached else continue step 4 to step 6.

Step 8 : Compute and display the desired target.

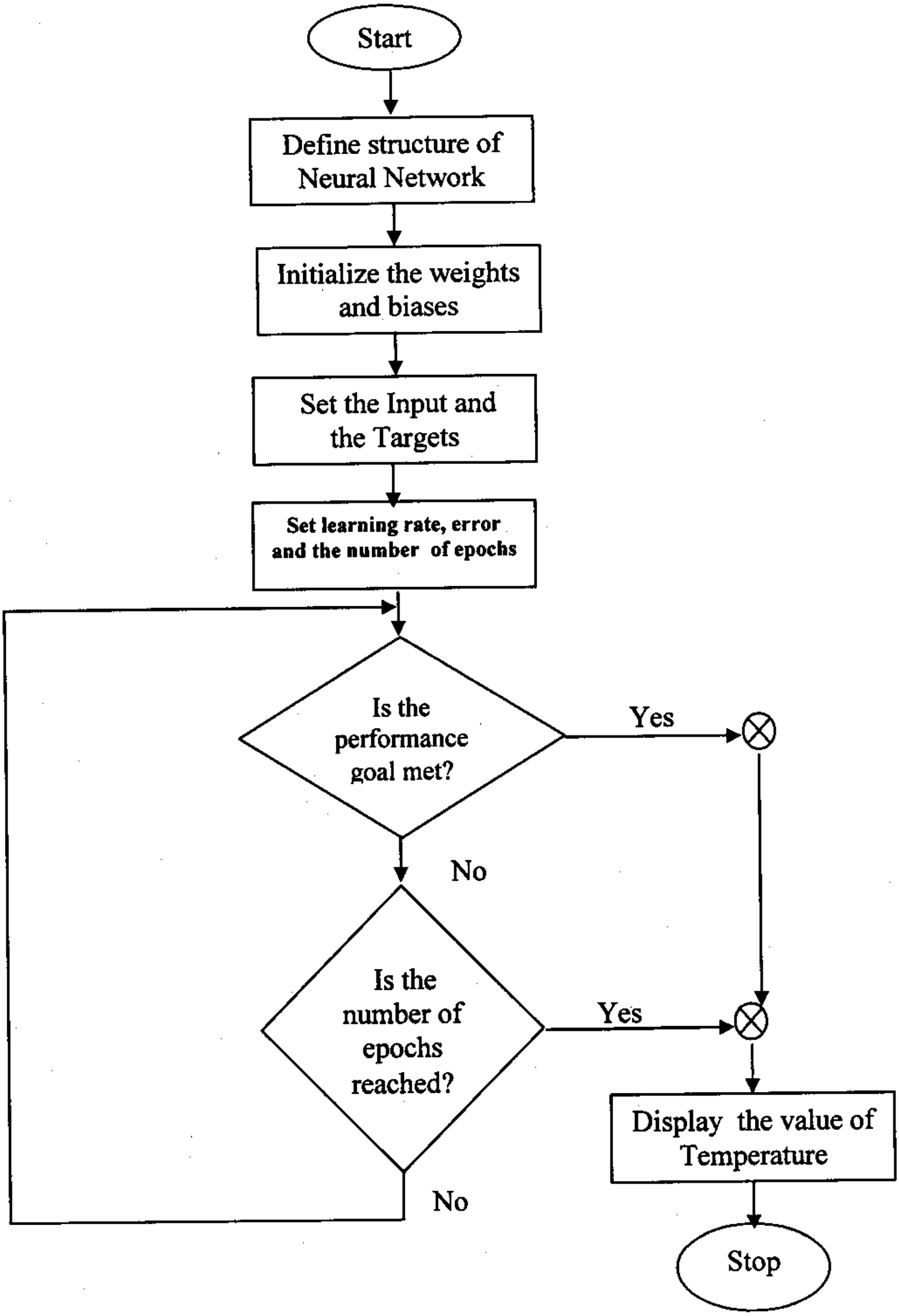


Figure 7.13. Flowchart for MATLAB simulation using Neural Network

7.4.2 Simulation of fuzzy logic using MATLAB

The algorithm and flowchart for simulation in MATLAB is as follows:

Step 1 : Define the structure of fuzzy logic system.

Step 2 : Select the type of fuzzy inference system to be used.

Step 3 : Apply the inputs to the fuzzy system

Step 4 : Fuzzify the input values by selecting appropriate membership function.

Step 5 : Choose the fuzzy operator

Step 6 : Apply the implication method based on the framed rules.

Step 7 : Aggregate the output of step 6 to get the single fuzzy set as implication method gives the output for each rule.

Step 8 : Defuzzify the output values to get a crisp output value.

Step 9 : If the defuzzified output is not the desired output value then by trial and error basis train the fuzzy system to get the desired output by repeating the step 4.

Step10 : Display the output value

Step 11 : Stop.

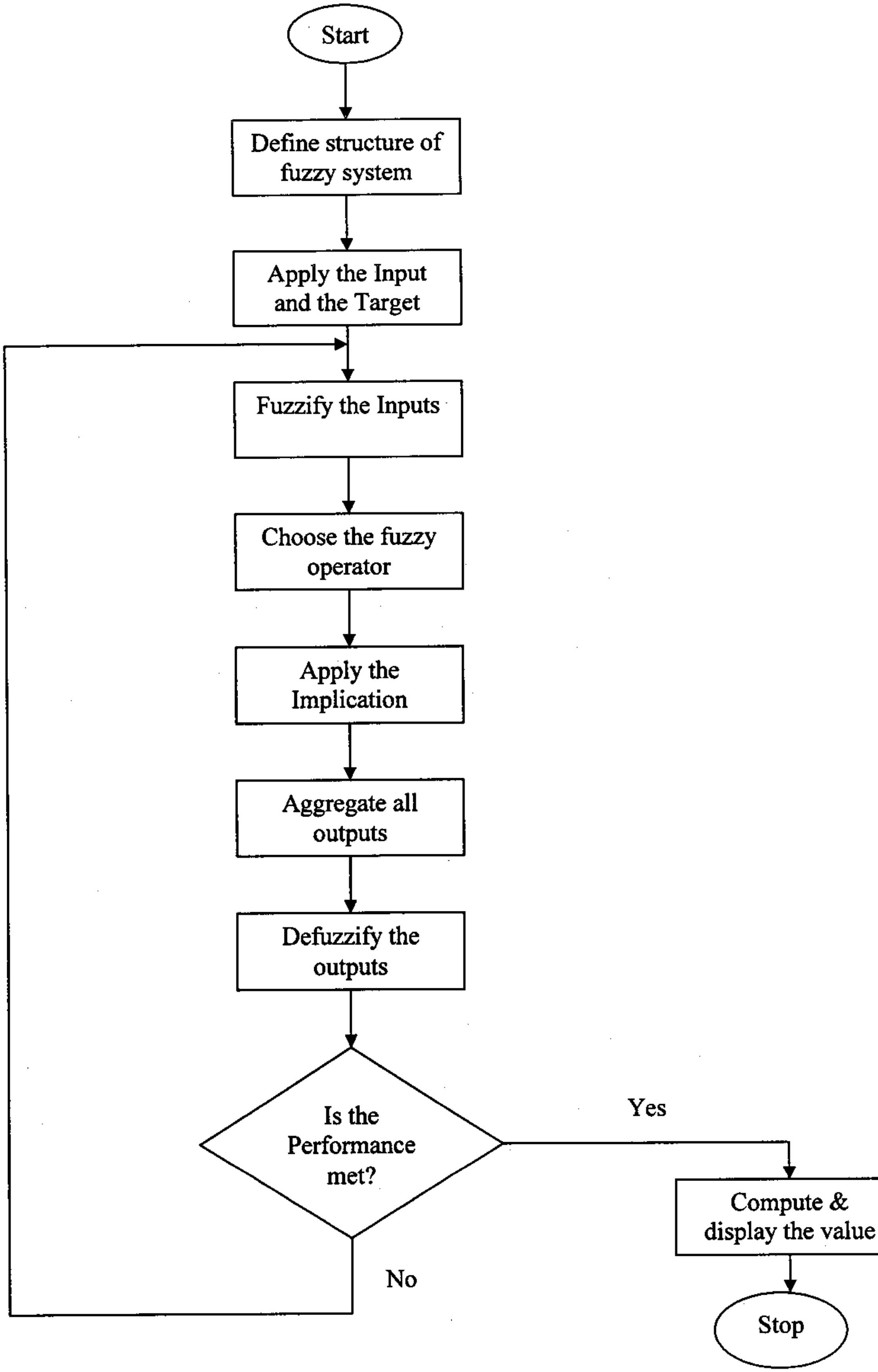


Figure 7.14 Flow Chart for MATLAB simulation Using Fuzzy Logic

Table 7.2 Diagnosis results of 50VA Transformer (% Error)

Technique Used	**Neural Network**			**Fuzzy logic**		
Load	230V	200V	180V	230V	200V	180V
Full Load	2.822	0.42	1.06	0.34	0.22	0.13
Half Load	0.49	0.14	0.98	0.27	0.34	0.38

Table 7.3. Diagnosis results of 5 KVA Transformer (% Error)

Technique Used	**Neural Network**			**Fuzzy logic**		
Load	115V	100V	230V	115V	100V	230V
Secondary Short	1.8	0.81	6.9	0.73	0.48	0.23
Primary Short	0.71	3.54	3.2	0.43	3.18	1.08
Pri-Sec Short	1.03	6.9	6.2	0.42	1.18	2

Table 7.2 and 7.3 show the diagnosis results of a 50 VA and 5 KVA transformers where neural network and fuzzy logic techniques are compared based on the percentage error in training.

In table 7.2 at 230 V full load condition the percentage error for neural network is 2.822 but for fuzzy logic it is only 0.34%. This difference in percentage error shows that the fault diagnosis usig fuzzy logic is more advantageous comparing to neural network which has high % error. Similarly from table 7.3 ,at 230 V when the secondary side is shorted the % error in neural network is 6.9 which is high compared to fuzzy logic which has only 0.23%.

So it infers that the effect of inter-turn fault in a Toroidal transformer is severe when it occurs on the secondary side particularlyat 230 V. It can be concluded from table 7.2 and 7.3 that fuzzy logic technique is the best simulation method compared to neural network for inter-turn fault diagnosis of toroidal transformers.

EXPERIMENTAL RESULTS

The input parameters for the two techniques namely neural network and fuzzy logic used for fault diagnosis are shown for two test transformers of 50 VA and 5 KVA which is tested at various load conditions. Table.7.4 shows the temperature rise of a 50 VA toroidal transformer at 230 V at full load and half load. The voltages are measured with respect to secondary side for the various test conditions shown in the table below.

Table.7.4. Temperature rise of a 50 VA transformer at 230 V full load and half Load.

Sl. No	**Shorted Turns**	**Voltage (V_{sec})**		**Current (A)**		**Temperature(^{o}c)**	
		Full Load	**Half Load**	**Full Load**	**Half Load**	**Full Load**	**Half Load**
1.	1&2	19.80	20.33	2.43	1.19	45.7	42.4
2.	1&3	20.12	20.69	2.44	1.20	46.4	42.6
3.	1&4	20.28	20.79	2.46	1.23	47.2	42.7
4.	1&5	20.30	21.05	2.47	1.25	47.6	42.8
5.	1&6	20.48	21.07	2.47	1.26	47.8	42.9
6.	1&7	20.54	21.30	2.48	1.27	48.0	43.0
7.	1&8	20.66	21.33	2.49	1.28	48.9	43.6
8.	1&9	20.69	21.36	2.50	1.29	49.3	43.8
9.	1&10	20.74	21.7	2.51	1.3	50	43.9

Table.7 .5 Temperature rise of a 50 VA transformer at 200 V full load and half Load.

Sl. No	**Shorted Turns**	**Voltage (V_{sec})**		**Current (A)**		**Temperature**	
		Full Load	**Half Load**	**Full Load**	**Half Load**	**Full Load**	**Half Load**
1.	1&2	17.23	17.66	2.10	1.01	42.4	4139
2.	1&3	17.44	17.20	2.11	1.06	42.6	41.5
3.	1&4	17.50	18.15	2.53	1.07	42.7	41.6
4.	1&5	17.61	18.21	2.65	1.09	42.9	41.7
5.	1&6	17.72	18.24	2.70	1.14	43.0	41.8
6.	1&7	17.74	18.31	2.73	1.16	43.2	41.9
7.	1&8	17.77	18.41	2.77	1.18	43.7	41.95
8.	1&9	17.99	18.56	2.91	1.19	44	41.99
9.	1&10	18	18.62	3.0	1.2	44.6	42.3

Table.7 .6 Temperature rise of a 50 VA transformer at 180 V full load and half Load.

Sl. No	Shorted Turns	Voltage(V_{sec})		Current(A)		Temperature(° c)	
		Full Load	Half Load	Full Load	Half Load	Full Load	Half Load
1.	1&2	15.63	14.5	1.92	0.93	39	37.5
2.	1&3	15.69	14.8	1.93	0.94	39.1	37.8
3.	1&4	15.73	14.9	1.94	0.95	39.3	37.9
4.	1&5	15.85	15	1.95	0.96	39.5	38.2
5.	1&6	16.09	15.3	1.96	0.97	39.6	38.3
6.	1&7	16.11	15.9	1.97	0.97	39.7	38.4
7.	1&8	16.15	16.0	1.98	0.98	39.8	38.7
8.	1&9	16.63	16.03	1.99	0.99	39.8	38.8
9.	1&10	17	16.20	2	1	39.9	38.9

Table.7.7 Temperature rise of a 5KVA transformer when secondary is shorted

Sl no	Shorted Turns (T)	Voltage(V_{sec})			Current(A)			Temperature(° c)		
		115V	100V	230V	115V	100V	230V	115V	100V	230V
1.	5	84.3	74.7	180.9	5.53	5.10	13.7	65	60	79.5
2.	8	85.6	75.4	181.0	7.72	7.40	18.7	75	66	89
3.	10	86.7	76.3	184	9.10	8.36	19.5	82	70	98
4.	12	89.7	78	185.2	9.29	4.16	21.3	85	72	106
5.	15	91	78.3	186.9	11.09	9.9	24	100	78	115
6.	18	93.7	79.4	187.5	12.30	11	27	101	85	120
7.	20	95.1	82.3	190	13.06	12.3	29	103	95	128

Table.7.8 Temperature rise of a 5KVA transformer when Primary is shorted

Sl no	Shorted Turns (T)	Voltage(V_{sec})			Current(A)			Temperature(° c)		
		115V	100V	230V	115V	100V	230V	115V	100V	230V
1.	5	103.47	90.12	200	4.78	4.22	19.8	75	70	90
2.	8	105.30	90.88	190	5.10	6.29	32.5	80	73	92
3.	10	106.62	91.50	192	6.88	7.35	34.8	93	87	94
4.	12	107.12	92.73	193.9	7.44	8.51	36.9	101	91	97
5.	15	109.33	93.20	194	9.18	10.88	30.7	115	95	102
6.	18	110.50	94.62	194.8	12.43	11.25	42.2	118	109	104
7.	20	111.21	95.35	195	14.72	12.35	43	120	110	129

Table.7.9 Temperature rise of a 5KVA transformer when Pry-Sec is shorted

Sl no	Shorted Turns (T)	Voltage(V_{sec})			Current(A)			Temperature(° c)		
		115V	100V	230V	115V	100V	230V	115V	100V	230V
1.	5	198	170.2	215.3	9.5	8.5	30	70	69	89
2.	8	198.6	172.8	217.5	12.7	12.3	31.9	75	70	92
3.	10	199.4	174.3	218.2	15.3	13.9	32.7	83	81	99
4.	12	199.8	176.5	219.4	19.8	16.9	34.5	89	86	103
5.	15	200.3	180.7	220.3	21.4	20.4	35.3	95	90	109
6.	18	200.9	182.4	222.6	24.6	23.3	38.9	101	97	117
7.	20	201.7	183.6	224.9	29	25.8	40	110	103	128.7

RESULTS AND DISCUSSION

Two techniques neural network and fuzzy logic were adopted for analyzing the fault conditions. The test parameters were used as reference and the results were presented and analysed. But by the comparison of the diagnosis results it is seen that the fuzzy logic technique has less percentage error as compared to neural network. It is also observed that the effect of inter-fault is predominant on the secondary side of the 5 KVA transformer particularly at 230 V. So fuzzy logic technique can be used for fault diagnosis of toroidal transformers with different power ratings and specifications.

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

Toroidal transformer design parameters were investigated and outlined for a 1 KVA transformer. The transformer parameters such as voltage, current, power factor, temperature and tap changer position are continuously monitored and displayed providing an effective transformer monitoring system.

Two techniques Neural Network and Fuzzy Logic were adopted for analyzing the fault conditions. The test parameters were used as reference and the results were presented and analyzed.

Fuzzy logic technique proves to have less percentage error as compared to the neural network. It has been observed from the actual test data that the effect of inter-turn fault is predominant on the secondary side of the transformer at 230 V.

Some suggestions for future work :

- The fault diagnosis scheme can be carried out using combined neural- fuzzy techniques.
- A further development of this project would be to find the exact location of inter-turn fault in a transformer through the measurement of resistance, thus eliminating the need for entire dismantle of the winding to find the location of fault.

COMPANY PROFILE

SALZER ELECTRONICS LIMITED

Salzer Electronics Limited was established in 1985 to design and manufacture world class Cam operated Rotary Switches in Technical Collaboration with M/S. Salzer Schalgerate Fabric, Germany. The company has a consistent track record for the last fifteen years in profit making and declaring dividends.

The company has entered into technical and financial collaboration with M/S. Plitron Manufacturing Inc., Canada, in 1995 for manufacturing Toroidal Transformers. The company has a strong R&D facility with full fledged laboratory to upgrade the products and set new market trends.

Distinctions:

- Formed in 1985, we have a 20 year track record of success.
- 7 factories with international connections.
- International product approvals like CSA,UL,VDE & CE.
- Worldwide availability of our products.
- Full fledged R& D facilities.
- ISO 9000 series accreditation for all factories are at various levels.
- Self sufficient captive tool room.

APPENDIX 1

ON-LINE CONDITION MONITORING SYSTEM OF TOROIDAL TRANSFORMER

APPENDIX 2

```
// MATLAB Program

PortIO(2,888,1); %Write LPT1 Port 2
pause(0.1);
PortIO(2,890,1);
PortIO(2,890,0);
PortIO(2,890,2);
PortIO(2,890,0);
pause(0.01);
PortIO(2,890,35);
ct1=portIO(1,888,1)/10
PortIO(2,890,0);
pause(0.01);
%b(loop)=PortIO(1,888,0);
%fprintf('%d \n',b);
% PortIO(2,890,0);
%TOP CHANGER LED

PortIO(2,888,2); %Write LPT1, Port 3
pause(0.1); %delay
PortIO(2,890,1);
PortIO(2,890,0);
PortIO(2,890,2);
PortIO(2,890,0);
pause(0.01);
PortIO(2,890,35);
ct2=portIO(0,888,0)/10
PortIO(2,890,0);

%ANALOG INPUTS

   PortIO(2,890,32);
   pause(0.1);
   PortIO(2,888,0);
   PortIO(2,890,5);
   pause(0.1);
   PortIO(2,890,0);

for j=1:100


PortIO(2,888,0); %Write LPT1, Port 1
pause(0.1); %delay
PortIO(2,890,1);
```

```
PortIO(2,890,0);
PortIO(2,890,2);
PortIO(2,890,0);
pause(0.01);
PortIO(2,890,35);
vol1=portIO(0,888,0)
PortIO(2,890,0);

PortIO(2,888,3); %Write LPT1 Port 4
pause(0.1);
PortIO(2,890,1);
PortIO(2,890,0);
PortIO(2,890,2);
PortIO(2,890,0);
pause(0.01);
PortIO(2,890,35);
vol2=portIO(1,888,1)
PortIO(2,890,0);
pause(0.01);

if vol2>=0&vol2<=115
   %ss1=0;
   PortIO(2,890,32);
   pause(0.1);
   PortIO(2,888,0);
   PortIO(2,890,5);
   pause(0.1);
   PortIO(2,890,0);
end

if vol2>=115&vol2<=230
   %ss2=3;
   PortIO(2,890,32);
   pause(0.1);
   PortIO(2,888,3);
   PortIO(2,890,5);
   pause(0.1);
   PortIO(2,890,0);
end

if vol2>=230&vol2<=345
   %ss3=2;
   PortIO(2,890,32);
   pause(0.1);
   PortIO(2,888,2);
   PortIO(2,890,5);
```

```
   pause(0.1);
   PortIO(2,890,0);
end


if vol1>=0&vol1<=115
   %ss1=0;
   PortIO(2,890,32);
   pause(0.1);
   PortIO(2,888,0);
   PortIO(2,890,5);
   pause(0.1);
   PortIO(2,890,0);
end

if vol1>=115&vol1<=230
   %ss2=3;
   PortIO(2,890,32);
   pause(0.1);
   PortIO(2,888,3);
   PortIO(2,890,5);
   pause(0.1);
   PortIO(2,890,0);
end

if vol1>=230&vol1<=345
   %ss3=2;
   PortIO(2,890,32);
   pause(0.1);
   PortIO(2,888,2);
   PortIO(2,890,5);
   pause(0.1);
   PortIO(2,890,0);
end
end
PortIO(2,888,4); %Write LPT1, Port 5
pause(0.1); %delay
PortIO(2,890,1);
PortIO(2,890,0);
PortIO(2,890,2);
PortIO(2,890,0);
pause(0.01);
PortIO(2,890,35);
temp=portIO(0,888,0)
PortIO(2,890,0);
```

```
%POWER fACTOR

for i=1:10000
PortIO(2,890,36);
pp=PortIO(1,888,0);
pp1=bitand(pp,1);
if(pp1==0)
 tic
  PortIO(2,890,36);
  pp1=PortIO(1,888,0);
  pp1=bitand(pp1,1);
if(pp1==1)
x=cos(toc)
end
end
end

for k=1:10000
PortIO(2,890,36);
pp=PortIO(1,888,0);
pp1=bitand(pp,2);
if(pp1==0)
    tic
 %y=cos(toc)
  PortIO(2,890,36);
  pp1=PortIO(1,888,0);
  pp1=bitand(pp1,2);
if(pp1==2)
 %tic
 y=cos(toc)
end
end
end
```

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