IMPLEMENTATION OF INTELLIGENT RELAY USING LabVIEW FOR IDENTIFICATION AND CLASSIFICATION OF STATOR WINDING FAULTS IN THREE PHASE INDUCTION MOTOR

A Dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING

In

Power System

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DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "Implementation of intelligent relay using LabVIEW for identification and classification of stator winding faults in three phase induction motor", in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems and Electric Drives, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of Dr. Amrita Sinha. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part, nor in full to any other degree to any other university or institute except as reported in text and references.

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NOMENCLATURE

V_s	Three-phase stator voltage
i_s	Three-phase stator current
i_r	Three-phase rotor current
λ_s	Three-phase stator flux linkages
λ_r	Three-phase rotor flux linkages
L_{ss}	Stator winding self inductance matrix
L_{rr}	Rotor winding self inductance matrix
L_{sr}	Stator to rotor winding mutual inductance matrix
L_{rs}	Rotor to stator winding mutual inductance matrix
r_s	Stator resistance value
r_r	Rotor resistance value
L_{ls}	Per-phase self-inductance (leakage inductance) value of stator-winding
L_{lr}	Per-phase self-inductance value of rotor winding
L_{ms}	Mutual-inductance value between stator and rotor
L_{ss}	stator winding inductance matrix
L_{rr}	Rotor winding inductance matrix
L_{sr}	Stator and rotor mutual inductance matrix
μ	Fraction of shorted turns

ABBREVIATIONS

ANN	Artificial neural networks
NN	Neural networks
BP	Back propagation
GA	Genetic Algorithms
PSO	Particle Swarm Optimization
TS	Tabu Search
SA	Simulated Annealing
BFO	Bacterial Forging Optimization
ACO	Ant Colony Optimization

Abstract

The induction motor fault simulation has been done by making use of direct phase quantities. The continuous signals obtained from analysis have been sampled at 800 Hz i.e. 16 samples per cycle. Pattern generation, in order to identify between healthy and faulty condition of stator winding has been done using these samples. The patterns have been generated and ANN has been trained using these using MATLAB script file. The network has been trained using back propagation algorithm. The network has been able to successfully identify the stator winding faults in MATLAB and further classified. The trained intelligent network has been implemented in LabVIEW. The model has been tested for healthy condition and different stator winding faults. The designed intelligent relay detects and classifies the faults in stator winding as A-phase, B-phase or C-phase fault within a quarter of a cycle.

Chapter 1

Introduction

1.1 Overview

The three-phase induction motor form a major part of industrial load especially petroleum refineries, thermal power plants, chemical and nuclear plants where it is ought to run continuously. It is also used in general purpose applications because of its simple rugged construction, good operating characteristics, comparative low cost and easy maintenance. Various general purpose applications are like pumps, presses, conveyors, elevators, machine tools, centrifugal machines and packing equipments. Due to its wide usage, the studies of its behavior in abnormal conditions due to different type of faults, has been seeking a considerable attention. Induction motor subject to many types of faults although they are highly reliable and have relatively high efficiency. So, its protection is equally important. Mainly protection includes stator winding fault protection, thermal protection and broken rotor bar protection. Induction motor faults and failures include inter-turn short circuit faults in stator windings, bearing failures, broken rotor bars and end rings faults [1-2]. Approximately one-third of the total faults are stator winding faults, two – fifth bearing failure and ten percent are the broken rotor bars and end rings faults. These faults are summarized in Table 1.1. The data in the table represents the results of surveys conducted by the Motor Reliability Working Group of the IEEE-IAS and the Electric Power Research Institute (EPRI); however, latter surveyed 6321 motors [2] and former 1141 motors [1].

Table 1.1 Percentage of failure by component [1] [2]

Component failed	**Percentage of failure (%)**	
	EPRI	**IEEE-IAS**
Bearing Related	41	44
Winding Related	36	26
Rotor Related	9	8
Others	14	22

Although, Stator winding faults make one-third of total faults but its detection and protection has always been challenging as it is an internal fault. The simplest method of protection is the use of different protection relays, which operate to trip or disconnect the machine on sensing the serious disruptions of current in the winding once a fault like an over-current, over-voltage or an earth fault has occurred.

1.2 Literature Review

The literature review gives a detailed survey on different types of faults in an induction motor and their protection schemes implemented and diagnosed by different author in different ways.

Conventional methods of condition monitoring of induction motor usually involves sensors which are embedded in the machine itself and are very expensive. Conditional monitoring refers to the unceasing evaluation of the health of the equipment. Also, it includes a variety of techniques like current signature analysis, chemical monitoring and vibration monitoring. The sensors help to detect the developing faults by measuring the data like temperature and vibration as proposed by Tavner [3] and Sharifi [36].

Condition monitoring is applied for identification and detection of various electrical and mechanical faults and also the locations of the fault. The detection of faults when they are still developing is called inception failure detection. A fault may become catastrophic if not identified at initial stage and induction motor may be severely damaged. Thus, undetected induction motor faults may result in motor failure or complete shutdown of motor which turn to be overall very costly. A warning of imminent failure is possible by using condition monitoring and future preventive maintenance and repair work can be rescheduled resulting in optimum maintenance schedules and minimum down time. Therefore, knowledge of condition of motor helps the operator to review physical state of motor and carry out the maintenance required at appropriate time and prevent the motor damage by stopping the process. So, many techniques have been proposed by re-searchers including Muller [17], Pereira [18], Povinelli [19], Kersting [20], Siddique [21] and Nandi [22] for detection of faults in induction motor based on condition monitoring [33-35]. The fault in motor has been detected using the air-gap torque monitoring method also, but not directly by air-gap torque; although all faults in air gap produce sidebands at different and special frequencies. Hsu [6] proposed that instantaneous torque cannot be represented by Instantaneous power because it includes charging and discharging energy in windings. Also, in further studies, the position-varying load effects on the current harmonic spectrum have been discussed by Schoen [8] and it manage to separate the fault induced portion from load portion because effect of fault and load on current harmonic component is spatially dependent. For stator winding fault detection, spectral analysis of the stator current has also been featured by Benbouzid [10].

Additionally, for fault detection these conventional methods are not favorable for small-sized electric machines and are used in larger machines because of limitations specially the size of sensors and financial considerations as projected by Ghate [31]. Furthermost, detection of faults by sensors is limited.

Motor current signature analysis (MCSA) technique based on current spectrum and frequency spectrum of motor has also been used. The frequency spectrum in case of fault is different from the healthy condition which produces rotating frequency harmonics in the mutual and self winding and fault is modulated in air gap. The specific harmonic component in line current is detected in this. Also, Ventura presented that this technique is used for the detection of rotor broken bar detection [35]. Further, for rotor bar fault detection, stator current spectral analysis is done by Klima [4], Schoen [7] and Benbouzid [10] which mainly include the detection of broken rotor bar.

Then, for diagnosis of Induction Motor faults, advanced signal processing techniques like Fast Fourier Transform, Short-time Fourier transform, Wavelet Transform and Gabor transform have been provided by Benbouzid [10] [5]. Fast fourier technique is very easy to implement but not suitable for analysing transient signals which short time FFT can do using a time- frequency representation. Wavelet transform was used to analyse the signal with variable sized window which FFT and STFT could do with fixed sized window only as presented in [9]. Cruz [12] and Silva [23] has provided with the Park’s Vector approach which is used to detect the faults like stator winding turn short-circuit fault, open wound rotor, rotor cage fractures, air-gap eccentricity and rotor bearing damages. In Park’s vector representation, three-phase stator currents are transformed to an equivalent two-phase system and specified current patterns are specified. The healthy machine results in perfect circle representation and if motor is faulty elliptical pattern representation is seen.

A new method of condition monitoring based on global random optimizing methods for detection of induction motor fault has recently been developed by Zakaria [26]. This technique has benefit of identification of variety of faults without fault signatures knowledge. Also, Artificial intelligence based techniques have been introduced using the concepts of Fuzzy logic as proposed by Zidani [15], Genetic Algorithms by Siddique [21] and Bayesian Classifiers as presented by Haji [14] and Povinelli [19]. Artificial Neural Networks (ANN) is now widely used for protection as this can be considered as subclass of current waveforms pattern recognition; also used for data compression, load forecasting, image processing and power quality analysis. The ability to ‘learn’ and take decision intelligently is its main advantage.

In present work, ANN is used for pattern classification based on patterns obtained from analysis of direct phase quantities using stator current values. The network is trained i.e. make to ‘learn’ and distinguish between the healthy and stator faulty condition.

1.3 **Objective of the Thesis**

This thesis addresses faults that occur in the stator windings of induction motor and developing an intelligent relay using LabVIEW for stator winding fault protection by pattern identification and classification. The detection of fault has been done by using Artificial Intelligence Techniques using back propagation and generating patterns by making use of the direct phase equations. The back propagation algorithm has been used for fault identification in MATLAB software and further it is implemented using LabVIEW on the basis of which an intelligent relay has been designed.

1.4 **Organization of the work**

The thesis is organized in 6 chapters. The contents of chapters are as follows:

Chapter 2 discusses the fault diagnosis and its protection for three phase induction motor.
Chapter 3 emphasizes on Artificial Intelligence Techniques for pattern recognition
Chapter 4 covers the Induction Motor Fault Simulation using Direct Phase quantities
Chapter 5 employs the designing and implementation of intelligent relay in LabVIEW
Chapter 6 summarizes the conclusion and future scope of work.

Chapter 2

Induction Motor Fault Diagnosis and its Protection

As stated earlier, we can say Induction motor is the core of industrial world as it is rugged, versatile and has low manufacturing cost. But, at the same time, it is prone to faults also. So, proper study and analysis of various types of faults in three phase induction motor is desirable. Here, the various external troubles to motor are described and cause for failure of induction motor. [39]

2.1 Abnormal Operating Conditions which cause failures in Induction Motor

The abnormal conditions can be classified as below:

Mechanical Overloads: This includes the sustained overloads, stalling and prolonged or locked rotor. Prolonged loading is short time cyclic overloading. This results in rise in temperature of winding and insulation deterioration. Stalling occurs when motor draws a heavy current and does not start due to excessive load.

1. **Abnormal supply conditions:** This may occur due to sudden loss of supply voltage, unbalancing in the supply voltage, over-voltage, under-voltage, under frequency or the phase sequence reversal of the main supply voltage. Unbalancing supply enhances the negative sequence component in winding finally causing heating of rotor. Under-voltage supply results in increase in motor current for the same load.
2. **Faults in starting supply/circuit:** This may cause due to short-circuit in supply cable, some interruptions in the phase or due to single phasing. Single phasing means open circuit in one of the three phases of supply but the motor will continue to run on a single phase supply. In this condition, motor windings are over-heated and may be damaged because it will draw excessive current when motor is run at rated full load.
3. **Internal Faults in Motor itself:** These faults are the results of above mentioned three abnormal conditions. This includes phase to phase faults, phase to earth faults, phase-failure i.e. open circuit and mechanical failure. Stator earth fault are caused due to temperature rise in the windings finally causing the insulation failure.

2.1.1 Different kinds of faults

Induction motors are the workhorse for the industry because of its versatility, ruggedness and low manufacturing cost. Induction machines are the reliable machines but their failure rate is approximately 3% and it can be as high as 12% in pulp and paper industry. Downtime of the machine in industry may be expensive. The protection system may enhance the reliability, personal safety and protect the motor from over-heating.

The external motor troubles are described in four groups:

Single phasing effect: If the various condition of single phase arises during the running state of motor, then the winding of the motor will get heated due to the –ve sequence current which flows in the faulted phase. In single phasing condition, 2 phases will get the power supply and the negative sequence current is produced in the winding which is faulted. This is because the internal connections are connected with each other.

Unbalanced voltage and frequency

Overloading and starting effect.

Maintenance environmental and manufacturing effect

Other Faults:

Rotor Faults

The failures in the rotor are produced by a combination of various stresses like electromagnetic, dynamic, thermal, mechanical and environmental that affects the rotor. These faults includes faults such as a cracked rotor end-rings, broken rotor bar, short circuit of rotor laminations and open circuit represent 10% of the reported faults.

Eccentricity fault

The air gap refers to the space between the stator and the rotor in the induction motor. The damage may happen in the bearing which causes a degree of static or dynamic eccentricity. Incorrect positioning of the stator or the rotor is the main cause of static eccentricity. Dynamic eccentricity occurs when rotor centre is not at the centre of rotation and the minimum air gap also revolves with the rotor. Dynamic eccentricity is caused by a bent shaft, mechanical resonances, or bearings and movement. Mixed eccentricity occurs when combined static and dynamic take place. Bearing faults affects the resultant magnetic field and lead to air gap eccentricity.

Bearing Faults

In the induction motor, to allow the rotor to spin freely inside the stator, the bearings on both sides of the rotor shaft are provided. In order to protect the grease and the bearing itself the temperature of a bearing must not exceed a certain amount. Bearing faults account for around 40% of all machine breakdowns.

2.2 Requirement for Protection

Motor protection should be simple and economical. Ideally, the cost of protection scheme must be within about 5% of motor cost. Also, the motor protection should not operate during starting and permissible overloads. Following are the parameters on which choice of motor protection depends:

- Size of motor, rated voltage, Power Rating kW
- Type of motor: squirrel-cage or wound rotor
- Type of starter, switchgear and control gear
- Cost of motor and driven equipment
- Importance of process, whether the motor is essential service motor or not.
- Type of load, stating currents, possible abnormal conditions, etc.

Table 2.1 shows various protection schemes for induction motor

Table 2.1 Protection Chart for Induction Motors

Abnormal Condition	Alternate forms of protection from which choice is made	Remarks
Overloads	• Over load release • Thermal overload relays • Inverse over-current relays • Miniature circuit-breaker with built in trip coils	• Overload protection given for almost all motors • Should not trip during starting currents
Phase faults and Earth faults	• HRC fuses • High-set instantaneous over-current relays • Differential protection	• Differential protection becomes economical for motors above about 1000kW. Below this high-set instantaneous protection is preferred
Under-voltage	• Under voltage release • Under-voltage relays	• Under voltage release incorporated with every single starter • Under-voltage relay used in certain applications
Unbalanced voltage	• Negative phase sequence relays	• Only in special applications
Reverse	• Phase reversal protection	• Generally at supply point

phase sequence		• Prevents reversal of running
Single phasing	• Usual thermal overload relays • Special single phase preventers	• Recently developed static single phasing devices becoming popular • Unbalance protection
Stalling	• Thermal relays • Instantaneous O.C. Relays	• Instantaneous • Trip
Rotor faults	• Instantaneous over-current relays	• Only for wound rotor motors
Switching surges	• RC surge suppressor	• 100 ohm, 0.1 micro Farad connected between phase and ground

2.3 Protection scheme for low voltage Induction Motor (Below 1000V AC)

2.3.1 Starting Circuit Scheme

Starting current scheme is most widely used in industrial motors. Fig.2.1

Here, the main circuit consists of (1) Fuse, (2) Isolating Switch, (3) Thermal Relay and (4) Contactor. The motor is connected to three phase supply via the main circuit (shown dark). The auxiliary control circuit carries only control current consists of (5) control coil, (6) ON push button usually green and normally off and (7) OFF push button usually red and normally closed.

Operation of circuit:

When the push button (6) is pressed by the operator, control coil (5) gets voltage from the supply. As a result, the coil current flows through contact of (6) and (7). The energized coil lifts contactor (4) and close Main contact (RYB) and auxiliary contact (C). The motor starts as the ON push button (6) is shunted by auxiliary contact (C).

OFF button (7) is pressed when the motor is to be stopped. The motor stops as the control coil is de-energized and the contactor opens by spring action and gravity. If supply voltage fails, control coil is de-energized and contactor opens.

During overloads, the thermal relay (3) operates and thereby control circuit is internally disconnected. HRC fuses (1) provide very rapid short-circuit protection. Current is cut-off by HRC fuse even before it reaches the peak value.

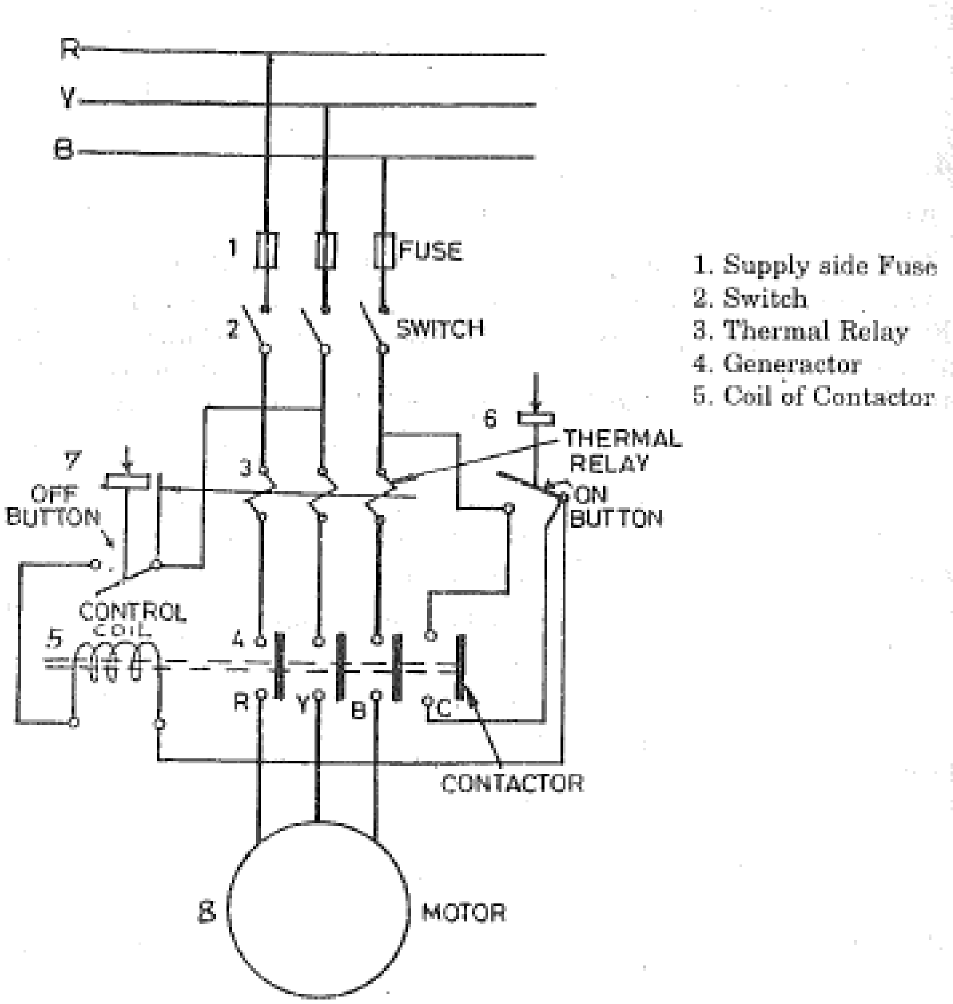


Fig. 2.1 Circuit of magnetic contactor starter for low voltage induction motor

The selection of thermal relay (3) is such that for normal starting condition, the relay does not operate. A setting range is provided for adjustment for different variations in load conditions. The starter should be selected properly and should not go on increasing the setting if motor trips during starting. Also, a simple protection scheme is given in Fig. 2.2.

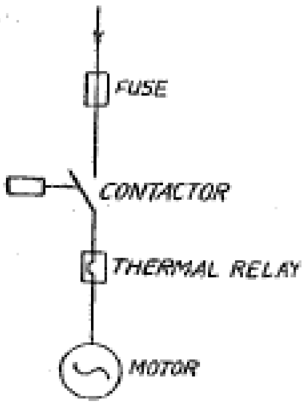


Fig. 2.2The fuse provide short-circuit Protection and thermal relay provides overload protection

2.3.2. Bimetal overload Devices

These are also used for the protection. Generally, for 3-phase motors, triple pole bimetal relays are employed. In case of overloading, bending of one or more bimetal strips cause movement of the common lever which in turn operates the trip contact. The bimetal strips can be heated directly by either current flowing through them or using special heater coil through which motor current flows. Alternate circuits of CT’s are attached in case of larger motors. Certain range can be set for bimetal relays. To enable ambient temperature compensation, they are provided with extra bimetal strip. Bimetal strips can be self-setting or hand resetting type. In operated state, the trip mechanism is locked until manual reset.

Characteristics for selecting bimetal-overload devices for protection of motors:-

- relay features, motor features
- loading type
- starting type, starting current
- overload protection
- phasing protection

2.3.3 Short circuit protection by HRC Fuses

Careful analysis must be done for short circuit protection of motor, connecting feeder and starter. Better coordination is required between overload protective device (OLPD) and short circuit protective devices for motor protection. Overload current ranges from 1.5 to 10 times rated current. The motor switching device for AC-3 duty can successfully make and break overload currents in this range. Fault currents more than 10 times the rated current can be considered ad short circuit currents and should be covered by short circuit protection device (SCPD).

Forms of SCPD:-

- HRC fuse
- Short circuit release opening the circuit breaker
- Instantaneous high set over-current relay which trips the circuit breaker.

In case of a short circuit, damage to the motor and starter can be prevented by selecting appropriate short circuit protective device. HRC fuse is recognized practice for back-up protection of circuit-breakers. It enables the use of economical circuit breakers of low breaking capacity.

For starting methods, and selection of relay on basis of starters including direct on-line delta starter and automatic star-delta starters is given in Table 2.2 and 2.3

Table 2.2 Relay selection Chart (Direct Online Delta Starters)

3 ph 50 c/s 440/440 V motors		Full load line current in Amperes	Relay range in Ampere	Back-up fuse rating in Ampere HRC fuses	
Hp	kW			Max	Min
10	7.5	13.6	13-20	50	25
12.5	9.4	17	13-20	50	25
15	11	20	20-30	80	35
15	11	20	20-30	80	35
20	15	28	20-30	80	60
25	18	35	30-45	100	60
30	22	40	30-45	100	60
35	26	47	45-63	125	80
40	30	55	45-63	125	80

Table 2.3 Relay Selection chart (Automatic Star Delta Starters)

3 ph 50 c/s 440/440 V motors		Full load line current	$Z_1/\sqrt{3}$	Relay range	Back-up fuse rating in Ampere HRC fuses	
Hp	kW	Amperes	ohm	Amperes	Max	Min
30	22	40	24	20-30	100	60
35	26	47	28	20-30	100	80
40	30	55	33	30-35	125	80
50	37.5	66	40	30-45	125	100
60	44	80	48	45-63	160	100
75	55	95	57	45-63	160	125

2.4 Protection of large motors:

Larger motors require protection against different faults or conditions.

Various kinds of protective relays are made to accommodate different uses. They can detect faults and trip the trip circuit of motor circuit breaker. Large 3-phase motor's protection includes short circuit, overloading and unbalanced loads protection.

Protections given to large motors are against following faults:-

- windings and connected circuit faults
- loss of supply voltage
- phase unbalance
- single phasing
- phase reversal
- inordinate overloads
- overvoltage switching

2.4.1 Types of relays for motor protection:

There are various type of protection required for the large motors. Relays provide simple way of protection. The relays are employed for different purposes as given below:

- Thermal protection only
- Thermal protection, instantaneous over-current protection
- Thermal instantaneous 3-phase over-current, instantaneous unbalance, single phasing
- Thermal, instantaneous 3-phase over-current, instantaneous unbalance, angle phasing and instantaneous earth fault.

If current is increased, the time decreases in these relays. Higher instantaneous over current and earth fault relays protects from short circuits. Sometimes, attraction armature type relays are used.

The typical settings of these relays are:

(1) 4-8 or 8-16 times full load current for instantaneous over-current elements.

(2) 0.2-0.4 times full load current for instantaneous earth fault current

2.5. Overload protection of induction motors:

Types of overload protection devices:

- Devices that react to motor current, for example: bimetal relays, electromagnetic relays, eutectic alloy relays and static relays. Circuit-breaker trip closure and opening the control circuit of main-contactor is handled by these relays.
- Devices that react to winding temperature, for example: thermistor, resistor devices embedded in slots, thermostats etc. Their work is to monitor winding temperature and trip the switching device.

Following conditions can be detected by the current detecting overload protection devices:

- Under-voltage, overloads
- Stalling, locked rotor
- Continuous overloads
- Single phasing
- Heavy starting
- Heavy breaking

Embedded thermal devices are the only means of detecting following conditions:

- Increase in temperature because of higher ambient temperature
- Increase in temperature because of cooling failure
- Increase in temperature because of other defects.

Overview of Thermal overload protection: Thermal overload protection is used to prevent motor from excessive stress. Motor winding temperature may rise to nearly maximum permissible unit which depends on type of insulation. The temperature surpasses the safe range in case of abnormal conditions and thus insulation durability decreases.

Stator winding temperature increases exponentially in certain overloads with passage of time. Thermal time constant and losses of the stator determines the temperature rise rate.

The blueprint of motor, ventilation and ambient temperature are responsible for the heat released into motor environment.

Load on motor determines the time taken to hit temperature rise limit and the time-current curve. The thermal holdup curves are also drawn for warm and cold situations for any machine. The thermal facsimile of the motor is handled by replica type thermal relay, that feature of these relay is very close replica of heating curve of motor.

To provide protection against cold and hot start situations, the relay is responsible for counterbalance of ambient temperature fluctuations.

The same time-current graph is used to show the features of replica relay and motor heating graph. When the motor heating curve cuts the relay characteristics at a point, the relay trips and circuit is open as shown in Fig. 2.3

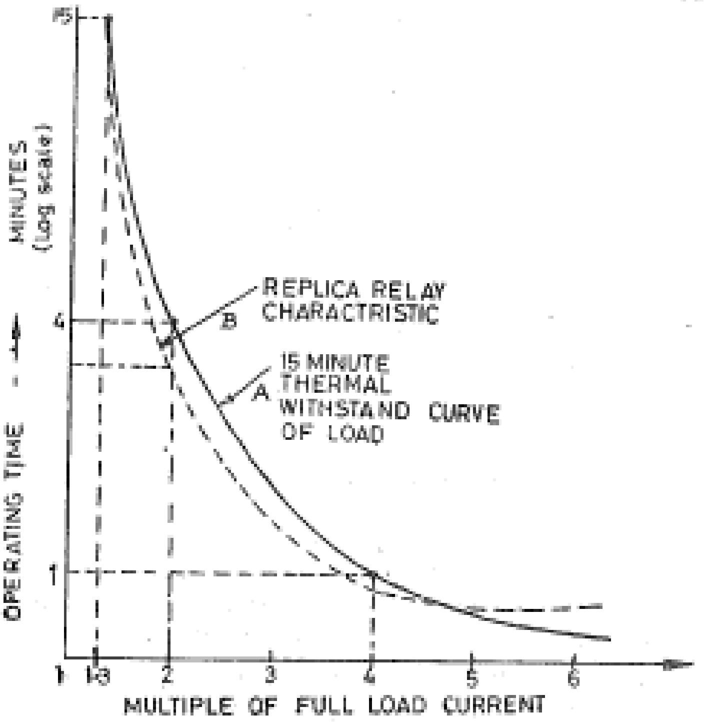


Fig. 2.3 Characteristics of induction motor heating and replica relay

The motor heating curves are not promptly available in practice. The thermal time constant of motor may alter to a great extent (from 15 minutes to 1 hour). So, the relay features must be chosen and set up to fit the proper protection requirements.

The operational conditions must be also kept in mind. The temperature of motor increases rapidly if regular starting is needed.

Fig. q shows the features of motor heating to rise highest permissible temperature in 15 minutes when overload is moderate (1.3 times full load current). The relay tripping depends on characteristics B. For example, 200% overload will trip the relay within 3-4 seconds. Overload of 200% can be hold up by motors for up-to 4 minutes.

2.6. Protection against unbalance

Causes for unbalance in voltage supply of 3-phase induction motor:

- single phase loads on distribution service line
- damaged fuses in power factor correcting plant
- short circuit inside or outside the motor
- single phasing

The unbalanced voltages produce -ve sequence currents which changes the direction of rotating magnetic field in reversed. This leads to the creation of double frequency induced current in rotor and conductors which in turn increases the temperature because of copper loss as given in Table 2.4.

This leads to unsafe rise in temperature of motor and its various parts. The unbalanced protection given to motor must stop extended unbalanced status but it must not unplug the motor for permissible unbalance of small time. The percentage of unbalance and ratio of +ve sequence impedance to -ve sequence impedance Table 2.5

The efficiency of motor will be 40-60% less of its total capability if unbalance protection is absent.

Table 2.4 De-rating factors if Induction Motor under Unbalanced Supply Voltage Conditions

Voltage unbalance $(\boldsymbol{V_2}/\boldsymbol{V_1})$x100	De-rating factor for full load current		
	$\frac{Z_1}{Z_2} = 4$	$\frac{Z_1}{Z_2} = 6$	$\frac{Z_1}{Z_2} = 8$
1	-	-	-
5	0.96	0.93	0.9
8	0.92	0.88	0.72
10	0.9	0.8	0.56
12	0.9	0.7	0.3
15	0.9	0.4	0

Table 2.5 Relation between voltage Unbalanced and Copper Losses in Motor

% Voltage unbalance	1	2	3	5
% Stator loss	101	102	106	115
% Rotor loss	105	112	130	175

2.6.1. Ways of providing protection from unbalanced voltages:

- Bimetallic relays set for faster tripping of unbalanced current.
- Single phase relays for detection of over-current in heavily loaded phases
- Phase unbalance relays

2.7. Protection against single phasing (phase failure)

If the various condition of single phase arises during the running state of motor, then the winding of the motor will get heated due to the –ve sequence current which flows in the faulted phase. In single phasing condition, 2 phases will get the power supply and the negative sequence current is produced in the winding which is faulted. This is because the internal connections are connected with each other.

If we unplug one of the supply lines, the three phase induction motors may still work but it will overheat as the entire power is given by the two windings. As a result of this, unbalanced currents are generated and its -ve sequence factor heats up the rotor. Since the thermal relays in small motors can detect rise in current in robust phases because of single phasing and hence offering enough protection to the motor. So, separate single phasing protections are not always required in smaller motors.

But in event of larger motors of about 50kW or more, a small unbalance may overheat the motor windings and motor can be damaged. Single phasing can also stall the motor and cause critical damage to the rotor when starting. Hence, separate protection from single phasing is required.

Damaged or blown fuses in power supplies or bad contacts in switch or contactor may lead to extensive unbalanced conditions in 3-phase induction motors.

Healthy phase current rises √3 times when single phasing happens and temperature of motor windings increases. The -ve sequence factor of unbalanced stator current leads to reverse rotation of magnetic field. Hence, the double frequency current is induced in rotor body and conductors and excessive heat is produced. The replica type thermal relays which protect the stator windings are not able to detect this overheating and rotor is severely damaged. The response time of phase over-current relays is high and are unable to accommodate instant protection in case of single phasing.

The motor must be unplugged instantly in an event of single phasing for example. In elevator motors, it is unsafe to remove plugging, inching and reversing. The phase unbalance relays are used to protect the larger motors with a drawback of high response time or lag which rely on unbalance magnitude.

For small motors, single phase preventers are attached to secondary line of CT's which incorporate -ve sequence filter. Level detector is connected to the output of this filter which handles the tripping of starter or circuit breaker in case -ve sequence current crosses the set up value Fig. 2.4

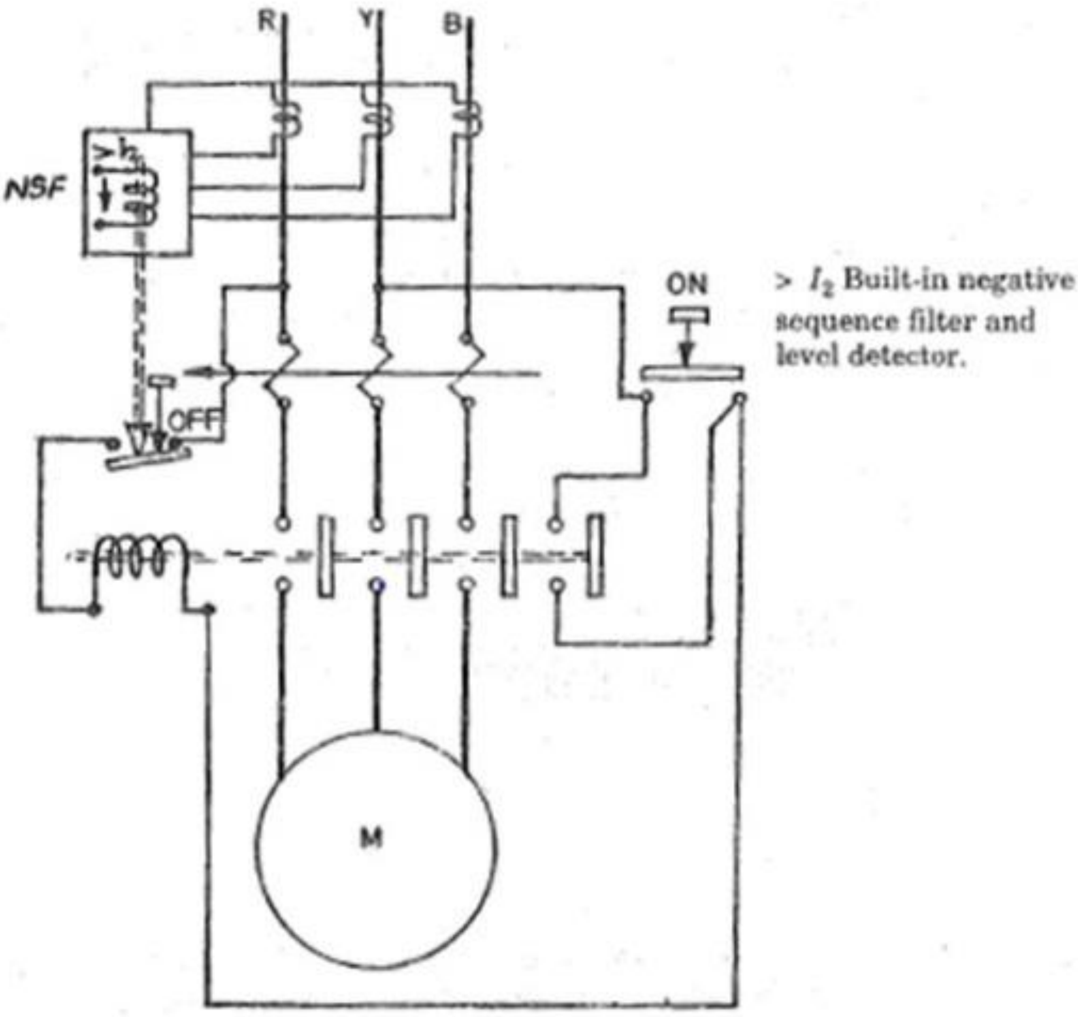


Fig. 2.4 Connections of single-phasing preventer

2.8 Phase Reversal Relay

Phase sequence of supply voltage determines the direction of rotation of the induction motors. During the repairs, supply connections may interchange causing phase reversal. This can alter the phase sequence of supply and the motor rotates in wrong direction. Phase reversal is very dangerous in some cases like in cranes, elevators and hoists etc. and require phase reversal relays for protection. Primary incoming substation of industrial works can provide these relays.

Working principle of these relays is based on electromagnetism. A disc motor is run by magnetic system triggered by secondaries of two line CT's or VT's. In order to get accurate phase sequence, the direction of torque exerted by this disc must be +ve so that auxiliary connections remain closed. In case of phase reversal, the direction of disc gets reversed which opens the contacts. Hence, we can de-energize the magnetic coil of starter or the circuit breaker can be tripped. The phase failure relays and the phase reversal relays of solid state can detect phase failures or phase reversals. In case the conditions are not normal, they can send tripping signal to output stage which may be a static device or auxiliary relay.

2.9 Phase to phase fault protection:

Stator windings and stampings will burn in case of phase to phase fault short circuit. So the power supply to the motor must be plugged out instantly. Protection of motor from these faults is done by using fast over-current relays.

When motor starts, this relay must be in inactive state. The value of over-current relay for phase faults must be higher than the starting conditions of the motor. Hence, the value of short-circuit protection relay must be set a little more than the maximum starting current of motor.

The starting current contains D.C. transient and A.C. component when motor is turned ON. The D.C. component hampers the proper functioning of over-current relay set for short circuit protection. Generally, a definite time lag of 2-4 cycles for over-current protection against phase faults in order to avoid high setting. So, the relay remains inactive during initial values D.C. transients. The D.C. transients start to decrease in 3-4 cycles and the relay does not pick-up due to the same (Fig. 2.5).

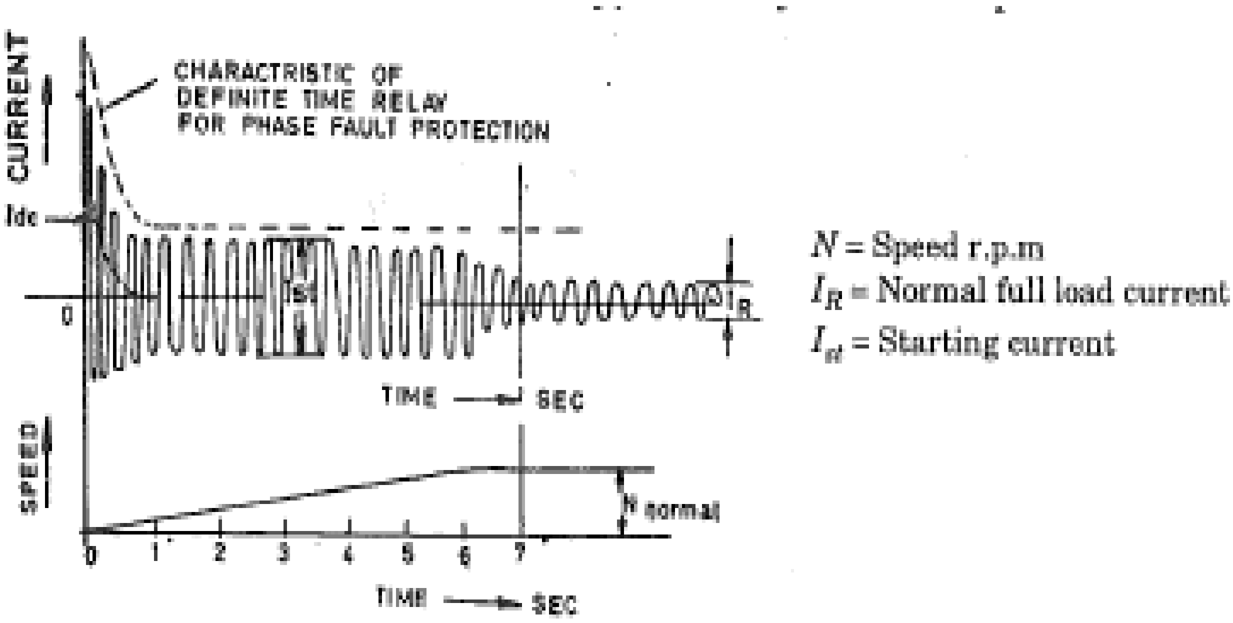


Fig.2.5. Starting characteristics of squirrel cage induction motor co-ordinated with over-current relay for phase faults

2.9.1. Limitations of over-current relays:

When the value of over-current relays is set higher than the starting characteristics (for example 5-7 times the full load current), the value of fault current may be lower than the relay's pick up value. It can occur near the neutral point of star connected motor for phase to phase faults. This may lead to severe damage to the motor as it cannot be removed quickly. Circulating current differential protection is very sensitive and can provide faster protection to all phase faults. The biased differential protection prevents mal-operation due to D.C. component and CT errors.

2.9.2. The slip-ring Induction Motors. Due to the resistance in rotor circuit, the slipping induction motors have limited starting current nearly 1.25 times the full load current. Hence, adequate phase faults protection can be provided by using over-current relays which can be set to around 1.4-1.6 times full load current.

2.9.3. Overload and phase fault protection of large motors: The heating curve of motor and the inverse definite minimum time (IDMT) characteristics must match (Fig.2.6). Thermal protections may provide enough protection for smaller overloads but cannot withstand heavy overloads. Protection provided by high set instantaneous overload relays for overloads is not enough.

Following combinations can be used in the schemes of over-current protection of large motors:-

1. Thermal over-current relay

2. Inverse long time relay

3. Instantaneous over-current relay

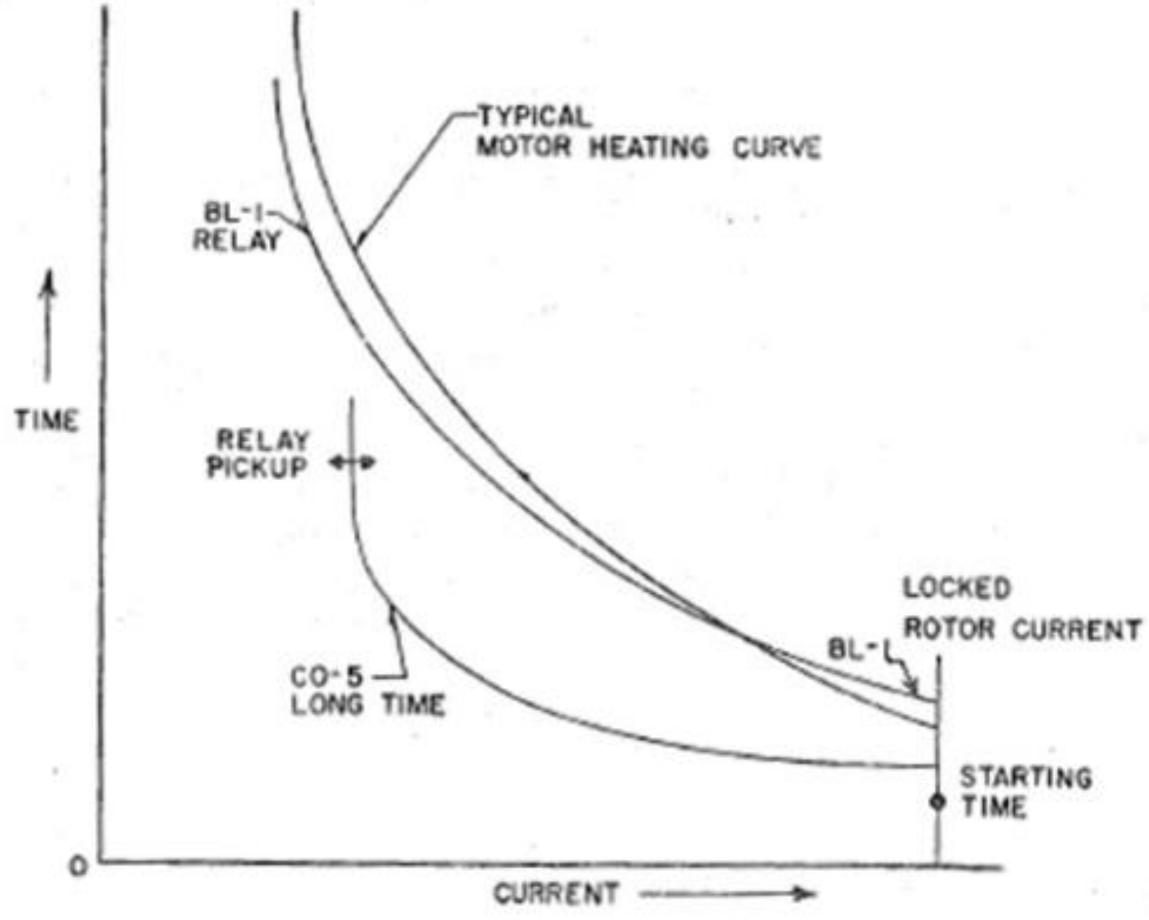


Fig. 2.6 Typical motor and relay characteristics

2.10. Stator earth fault protection

In order to lower the damage to windings and laminations, the earth-fault protection will disconnect the power supply from the motor as soon as possible.

The most suitable protection from earth faults can be given by zero sequence current transformer (ZSCT) or core balance type protection. This method particularly suited for system neutral earthed through resistance.

Due to resistance-earthing in these systems, earth fault currents are very less and as a result the phase over-current relays are unable to detect earth faults.

In case of earthed supply source, an inverse, very inverse or instantaneous induction type relay is attached to current transformer neutral. Normally, such sources have neutral impedance in order to limit the ground current so the sensitive ground relay settings are required. These settings are 1/5 of the minimum fault current for a solid fault at motor terminals.

Occasionally, the grounded relay may operate as soon as there is high in-rush current of direct on-line staring of large motors. This happens due to the false residual current generated by unequal saturation of the current transformers. The effect may be increased using two relays instead of three phase relays.

In 3.3kV - 11kV sub-stations and industrial power systems, the trend is towards appreciably less ground fault current and higher neutral impedance. This, make it tedious to obtain a very sensitive relay-setting with a capability not to operate on false residual current of the starting in-rush. For this, a window type current transformer with a single secondary winding surrounding all three phase conductors is used as shown in Fig. 2.7. This eliminates the false residual and permits applying a very sensitive instantaneous earth fault relay.

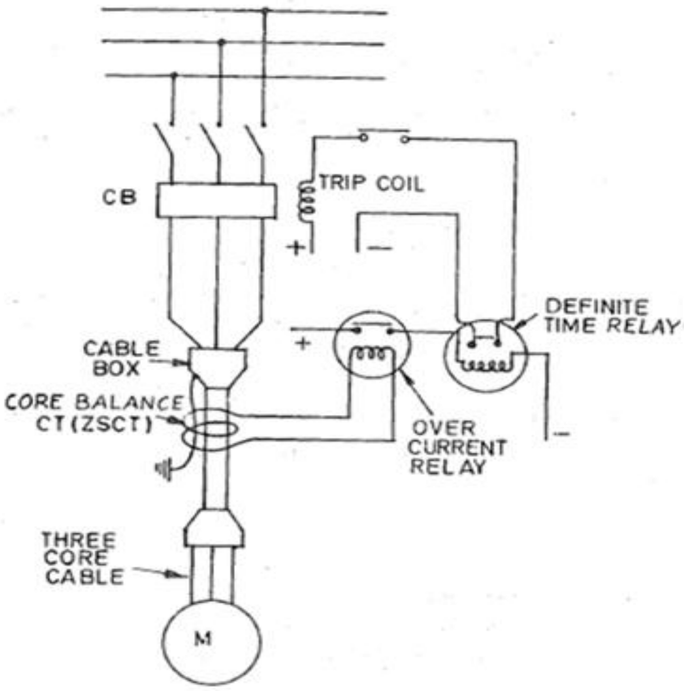


Fig. 2.7 Connections of core balance CT (Zero-sequence CT) for earth-fault Protection of Motor

2.11 Faults in Rotor winding

Rotor faults are possible in slip-ring induction motor. The stator over-current protection can act in this case because the increase in rotor current is reflected on the stator current. The setting of stator current relays is enough to detect the rotor fault which is generally of the order 1.6 times the full load current. Inter-turn Faults are difficult to detect as they are internal faults. Grounding or earthing can be done here. Neutral point of the supply should be earthed in low voltage circuits. Actually, single line to ground fault increases the voltage of healthy phase by $\sqrt{3}$ times which can damage the insulation of motor. Thus, the neutral should be earthed at every level otherwise cascade failure of motor may occur.

Chapter 3

Artificial Intelligence Techniques and pattern recognition

For induction motor fault detection, numerous methods have been developed in the last decades which include vibration analysis, motor current signature analysis, chemical analysis, temperature measurements, stochastic optimisation techniques and artificial intelligence methods. Recently, as AI techniques are emerging, they may involve several different fields to even new artificially intelligent technology. Here in this chapter, discussion is done on different AI techniques and Architecture of network is discussed which is used for fault detection.

3.1 Artificial Intelligence diagnoses

Artificial Intelligence system, as the name suggests is way forward to make any system intelligent like human brain and be able to function it accordingly with changing conditions and environment. The main idea is make a model which mimic natural human intelligence which may be in the form of a computer program to overcome the problems that are hard to solve and detect by traditional methods. Basically, to make a clone based on programming but work and take required action as we do, a human brain do. There are many methods used so far like Fuzzy logic, Neural Networks and stochastic approaches.

3.1.1 Fuzzy Logic

Fuzzy logic technique is to embody human knowledge by giving the fuzzy description or linguistic descriptions i.e. to control a system using human-like thinking. As a human deduces and take decisions on the basis of what he/she know, fuzzy controller is designed to emulate deductive thinking like humans. A block diagram of fuzzy control system is shown in Fig. 3.1. [27] To diagnose induction motor faults, fuzzy logic approach is used in [29] [32]. Fuzzy logic can make decision based on vague information like human thinking processes. It allows variable to be described which has a certain membership degree further in a set.

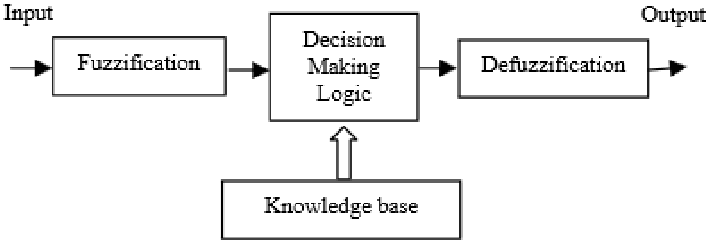


Fig. 3.1 Fuzzy control System [27]

3.1.2. Neural Networks

Artificial neural networks are based and modelled on the neural connections just like it is in the human brain. The input neuron which is actually an artificial neuron is given several inputs; it further applies preset biases and weights to each input and generates an output that is generally a non-linear output based on the constraints and results. All the neurons are connected in layers between the inputs and outputs neurons. This method is rather easy to develop and to perform [13] [37-38]. Neural networks can be applied when the information about the process is obtained by measurements, which later can be used in the training procedures of neural nets. This method is an on-line method. Using the data acquired from simulation or experimental tests, neural detectors can be designed [11].

3.1.3 Stochastic optimisation search methods

Stochastic optimisation techniques works on the idea of neighbourhood search and no mathematical model or data of the system is involved. Heuristic techniques do not give the guarantee of optimality and feasibility of solution however seeks near optimal solutions and their principles are easy to implement and use. [57]. A different search rule is used by every method to find the near to optimal solutions or the optimal one. The search space is the space for all feasible solutions. Each and every point in the search space represents one possible solution. Therefore, suitable solution is searched in solution space for the given time bound moving to a suitable solution towards the known solution. Every stochastic method has different way to escape from local minimum and reach global minima.

In recent years to address optimisation problems, so many stochastic algorithms have been proposed. The most popular algorithms are:

- Genetic Algorithms (GA) [60]
- Particle Swarm Optimisation (PSO) [58]
- Tabu Search (TS) [59]
- Simulated Annealing (SA) [16]
- Bacterial Forging Optimisation (BFO) [58]
- Ant Colony Optimisation (ACO)

3.2 Artificial Neural Network Architecture and Training (Learning)

The developed neural network is multi-layered consisting of one input layer, one hidden layer and one output layer. The network is feed forward back propagation network and fully connected. The number of neurons in the input and output layer depends upon the dimensions of patterns.

The parameters given in Table 1 are used to get the continuous signals by making use of equations based on direct phase quantities. The three phase stator current has been represented in discreet form which is obtained by sampling. The output of direct phase equation analysis will give the continuous waveforms of currents, voltages, torque, speed for different conditions in motor i.e. healthy condition and faulty condition. The continuous signal has been sampled at a sampling rate of 16 samples per cycles (over moving data window). These samples are used for training and testing which includes steady state condition samples with changing phase angle and different percentage of faulty turns of windings. The number of neurons for input layer and hidden layer are to be decided depending on the selected stator current samples. Input to NN is selected as 16 samples of each phase current of stator i.e. total 48 neurons at input layer. The NN generates 2 outputs for healthy and stator winding fault shown in Table 3.1. The output at neurons is computed by using a bias and also by a threshold function i.e. sigmoid with the activations determined by weights and the inputs [40].

Table 3.1 Input condition and output of NN

Condition	Meaning	Desired output (conditions) for 2 o/p neurons
Healthy condition	When there is no fault	1 0
Turn to Ground fault	Phase – A short circuited with ground	0 1

Again script file in MATLAB software has been used to develop the algorithm and further train and test the NN. The MATLAB result of Error calculation after training are further discussed in next chapter.

3.3 Back propagation training Algorithm

Back propagation training Algorithm or error back propagation algorithm is a training algorithm which is based on error signal propagated back from output to input layer after once signal is fed to input layer, then passes to hidden layer and finally reach the output layer.

It primarily adjusts the weight values internally and brings out a non-linear relationship between input and output. The weights are optimized till the error signal reaches the pre-described value. Solution of learning problem is given by the weight combinations which give minimum error value. The complete algorithm was used by Shenglin Zheng [] to implement Neural Networks using SAS and .NET.

Steps for training of back propagation algorithm:

1. Initialization of weights
2. Feed forward of input signal from input to output layer
3. Back propagation of errors
4. Weight updation if error not minimum

Chapter 4

Induction Motor Fault Simulation and Pattern Generation

Three-Phase Induction motor can be simulated by different methods i.e. by using different software like MATLAB, pSPICE, LabVIEW. Here, the simulation is done by using direct phase equations in MATLAB.

4.1 Analysis of Induction Motor in Healthy Condition

As it is well known, the primary components of induction motor are stator and rotor with three-phase windings on both 120 degrees apart. The analysis of motor can be done on the basis of resistance of windings and inductances of winding including self and mutual inductances. So, the motor analysis on basis of KVL and loop equations has been discussed in this section.

Assumptions:

The self inductances, mutual inductances, resistances of stator and rotor windings are considered as lumped parameters. The flux has been considered to be sinusoidally distributed.

Derivation:

In normal condition i.e. the healthy condition, the phase equations can be written as:

$$V_s = R_s i_s + d\lambda_s/dt \tag{4.1}$$

$$V_r = R_r i_r + d\lambda_r/dt \tag{4.2}$$

Where,

$V_s = [v_{as} \quad v_{bs} \quad v_{cs}]^T$, Three-phase stator voltage

$i_s = [i_{as} \quad i_{bs} \quad i_{cs}]^T$, Three-phase stator current

$i_r = [i_{ar} \quad i_{br} \quad i_{cr}]^T$, Three-phase rotor current

$\lambda_s = [\lambda_{as} \quad \lambda_{bs} \quad \lambda_{cs}]^T$, Three-phase stator flux linkages

$\lambda_r = [\lambda_{ar} \quad \lambda_{br} \quad \lambda_{cr}]^T$, Three-phase rotor flux linkages

Also, flux linkages can be written in terms of inductance and current as current in inductor multiplied by its inductance value gives the flux values.

$$\lambda_s = L_{ss} i_s + L_{sr} i_r \tag{4.3}$$

$$\lambda_r = L_{rs} i_s + L_{rr} i_r \tag{4.4}$$

Where,

L_{ss} is the stator winding self inductance matrix

L_{rr} is the rotor winding self inductance matrix

L_{sr} is the stator to rotor winding mutual inductance matrix

L_{rs} is the rotor to stator winding mutual inductance matrix

The resistance matrices for stator and rotor can be written as:

Stator resistance matrix:

$$R_s = r_s \,.\, I_{3\text{x}3} \tag{4.5}$$

$$R_r = r_r \,.\, I_{3\text{x}3} \tag{4.6}$$

Where,

r_s = stator resistance value

r_r = rotor resistance value

The self- inductance and mutual-inductance matrices for both stator and rotor can also be written in the similar way:

$$L_{ss} = \begin{bmatrix} L_{ls} + L_{ms} & -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & L_{ls} + L_{ms} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} & L_{ls} + L_{ms} \end{bmatrix} \tag{4.7}$$

$$L_{rr} = \begin{bmatrix} L_{lr} + L_{ms} & -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & L_{lr} + L_{ms} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} & L_{lr} + L_{ms} \end{bmatrix} \qquad (4.8)$$

$$L_{sr} = L_{ms} * \begin{bmatrix} cos(\theta r) & cos\left(\theta r + \frac{2\pi}{3}\right) & cos\left(\theta - \frac{2\pi}{3}\right) \\ cos\left(\theta r - \frac{2\pi}{3}\right) & cos(\theta r) & cos\left(\theta r + \frac{2\pi}{3}\right) \\ cos\left(\theta r + \frac{2\pi}{3}\right) & cos\left(\theta r - \frac{2\pi}{3}\right) & cos(\theta r) \end{bmatrix} \qquad (4.9)$$

$$L_{rs} = {L_{sr}}^{T} \qquad (4.10)$$

where,

L_{ls} = per-phase self-inductance (leakage inductance) value of stator-winding

L_{lr} = per-phase self-inductance value of rotor winding

L_{ms}= mutual-inductance value between stator and rotor

L_{ss} = stator winding inductance matrix

L_{rr} = rotor winding inductance matrix

L_{sr}= stator and rotor mutual inductance matrix

The electromagnetic torque can be expressed in machine variables as

$$T = \frac{P}{2} i_s^T \frac{\partial L_{sr}}{\partial \theta} i_r \qquad (4.11)$$

where,

P = number of poles

L_{sr}= stator and rotor mutual inductance matrix

$i_s = [i_{as} \quad i_{bs} \quad i_{cs}]^T$, Three-phase stator current

$i_r = [i_{ar} \quad i_{br} \quad i_{cr}]^T$, Three-phase rotor current

On basis of above equations, the results of the stator current (Fig. 4.1(a)), rotor current (Fig. 4.1(b)), stator voltage (Fig. 4.1(c)), rotor voltage (Fig. 4.1(d)) are obtained.

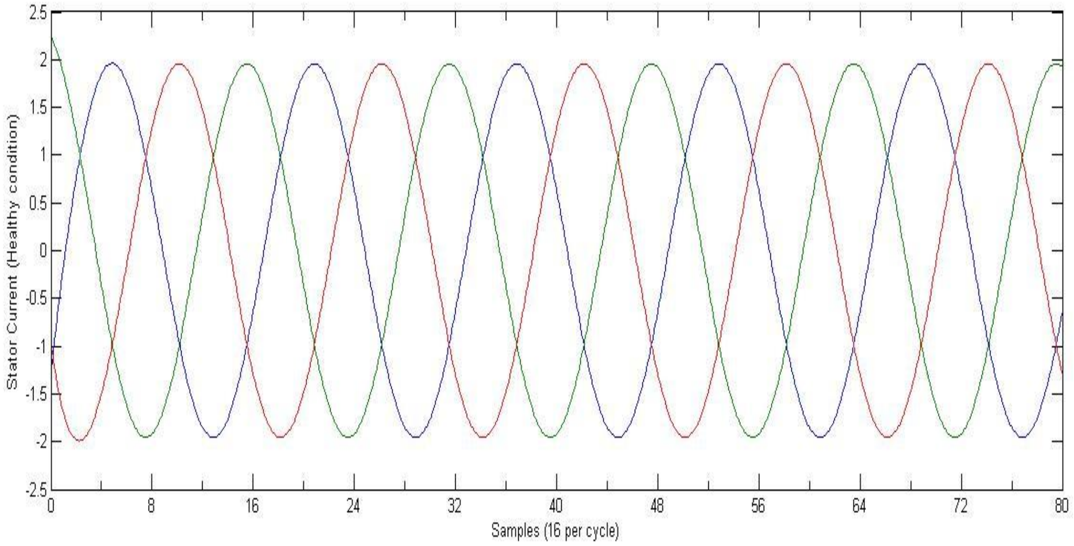


Fig. 4.1 (a) Healthy stator current

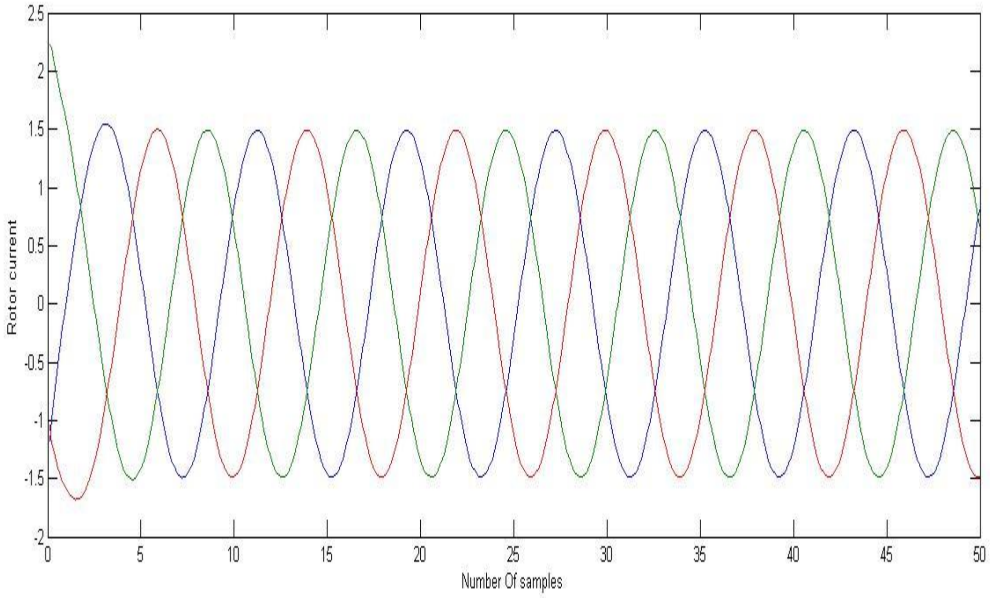


Fig. 4.1 (b) Healthy rotor current

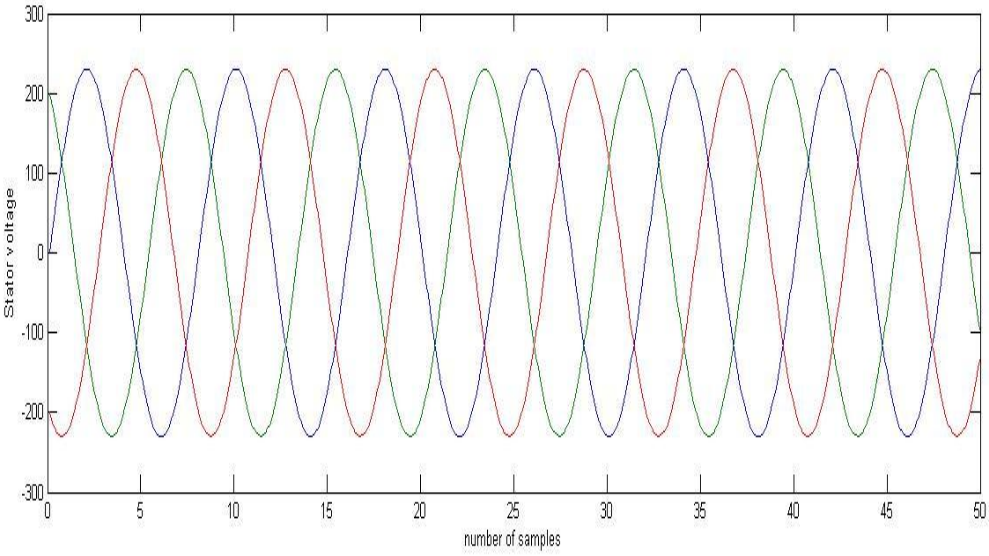


Fig. 4.1 (c) Healthy stator voltage

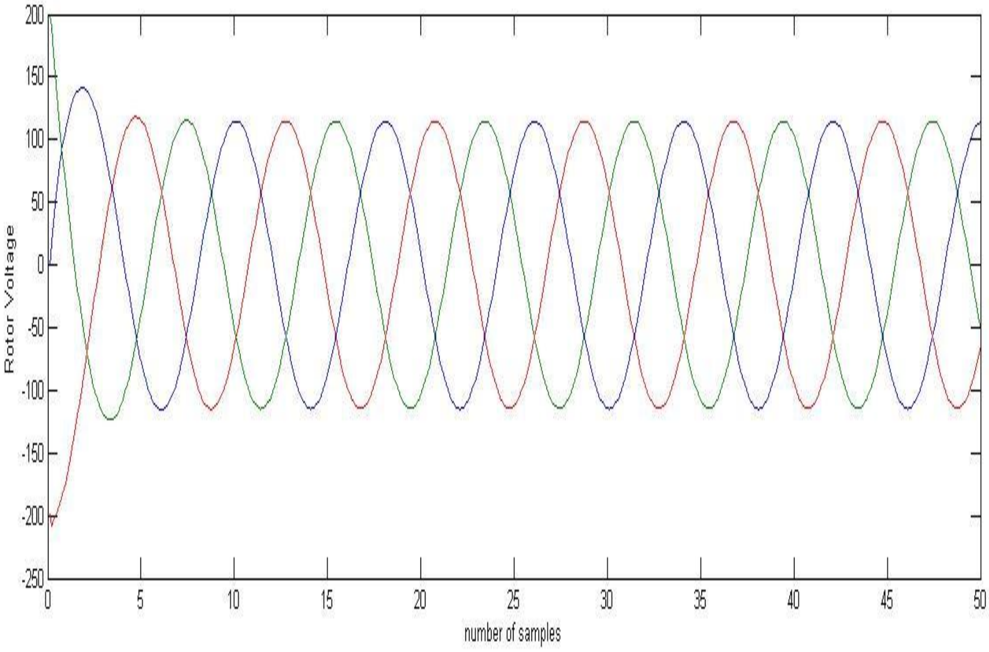


Fig. 4.1 (d) Healthy rotor voltage

Fig. 4.1 Simulation Results (Healthy Motor)

4.2 Analysis of Induction Motor with Turn Fault using Direct Phase Quantities

Assumptions:

Leakage inductance of shorted turns is μL_{ls}, where L_{ls} is per phase leakage reactance, and the fault impedance is resistive *(r_f).*

Furthermost, the self inductances, mutual inductances, resistances of stator and rotor windings are considered as lumped parameters and flux is considered to be sinusoidally distributed. The speed of motor has been considered to be constant at time when stator winding turn-ground fault occurs.

An induction motor with stator winding turn fault at phase A is shown in Fig. 4.2 where as_2 represents the shorted turns and *u* denotes the fraction of shorted turns.

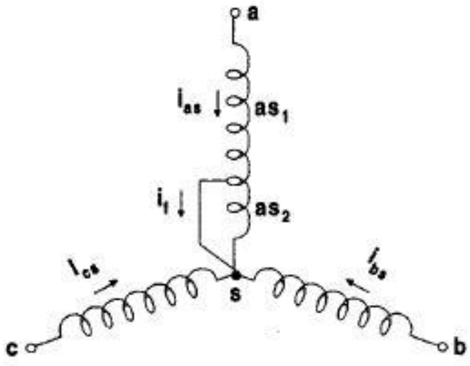


Fig.4.2 Stator winding turn fault

Derivation:

The stator and rotor equations for symmetrical induction machine with turn fault can be expressed as

$$V_s = R_s i_s + d\lambda_s/dt \tag{4.12}$$

$$0 = R_r i_r + d\lambda_r/dt \tag{4.13}$$

where,

$$V_s = [v_{as1} \quad v_{as2} \quad v_{bs} \quad v_{cs}]^T$$

$$i_s = \left[i_{as} \quad (i_{as-}i_f) \quad i_{bs} \quad i_{cs}\right]^T$$

$$i_r = [i_{ar} \quad i_{br} \quad i_{cr}]^T$$

$$\lambda_s = [\lambda_{as1} \quad \lambda_{as2} \quad \lambda_{bs} \quad \lambda_{cs}]^T = L_{ss}i_s + L_{sr}i_r$$

$$\lambda_r = [\lambda_{ar} \quad \lambda_{br} \quad \lambda_{cr}]^T = L_{rs}i_s + L_{rr}i_r$$

The resistance and inductance matrix are given by

$$R_s = r_s . diag[(1-\mu) \quad \mu \quad 0 \quad 0] \tag{4.14}$$

$$R_r = r_r . I_{3x3} \tag{4.15}$$

$$L_s = L_{ls} . diag[(1-\mu) \quad \mu \quad 0 \quad 0] + L_{ms} \begin{bmatrix} (1-\mu)^2 & \mu(1-\mu) & \frac{-(1-\mu)}{2} & \frac{-(1-\mu)}{2} \\ \mu(1-\mu) & \mu^2 & \frac{-\mu}{2} & \frac{-\mu}{2} \\ \frac{-(1-\mu)}{2} & \frac{-\mu}{2} & \frac{-1}{2} & 1 \\ \frac{-(1-\mu)}{2} & \frac{-\mu}{2} & 1 & \frac{-1}{2} \end{bmatrix} \tag{4.16}$$

$$L_{sr} = L_{ms} * \begin{bmatrix} (1-\mu)\cos(\theta_r) & (1-\mu)\cos(\theta_r + \frac{2\pi}{3}) & (1-\mu)\cos(\theta_r - \frac{2\pi}{3}) \\ \mu cos(\theta r) & \mu cos\left(\theta r + \frac{2\pi}{3}\right) & \mu cos(\theta r + \frac{2\pi}{3}) \\ cos\left(\theta r - \frac{2\pi}{3}\right) & cos(\theta r) & cos\left(\theta r + \frac{2\pi}{3}\right) \\ cos\left(\theta r + \frac{2\pi}{3}\right) & cos\left(\theta r - \frac{2\pi}{3}\right) & cos(\theta r) \end{bmatrix} \tag{4.17}$$

$$L_{rs} = {L_{sr}}^T \tag{4.16}$$

And

$$L_{rr} = \begin{bmatrix} L_{lr} + L_{ms} & -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & L_{lr} + L_{ms} & -\frac{L_{ms}}{2} \\ -\frac{L_{ms}}{2} & -\frac{L_{ms}}{2} & L_{lr} + L_{ms} \end{bmatrix} \tag{4.17}$$

The electromagnetic torque can be expressed in machine variables as

$$T = \frac{P}{2} i_s^T \frac{\partial L_{sr}}{\partial \theta} i_r \tag{4.18}$$

Similarly, turn fault equations for phases B and C and rotor open condition has been analysed. The various results of this simulation have been shown in Fig. 4.3

The three phase stator current values for healthy and faulty condition are used as pattern for input to input neurons of neural network. First, the training of neural network is done using the current values obtained from the equations used in above analysis then the network is tested for faulty values of current.

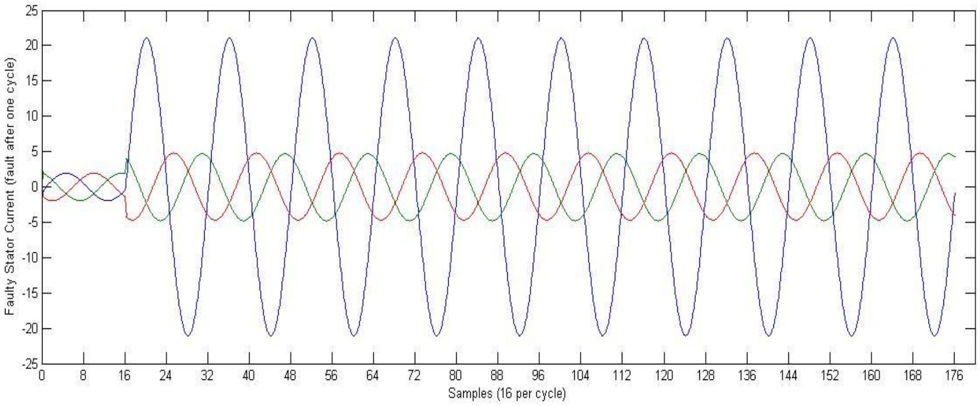


Fig. 4.3 (a) Faulty Stator Current after One Cycle of Healthy state

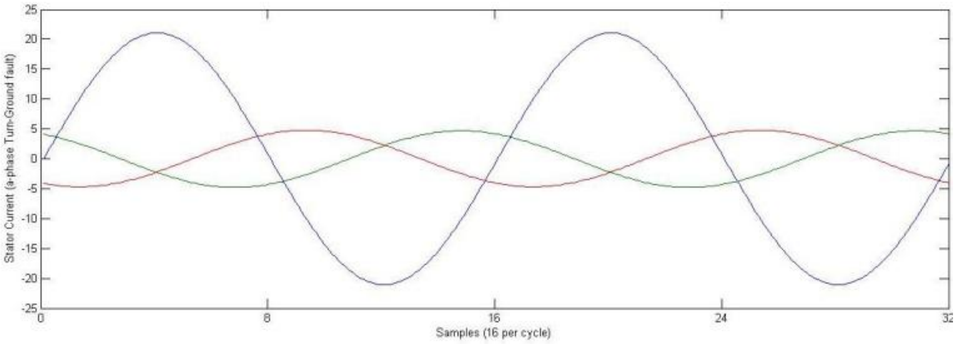


Fig. 4.3 (b) Faulty Stator Current

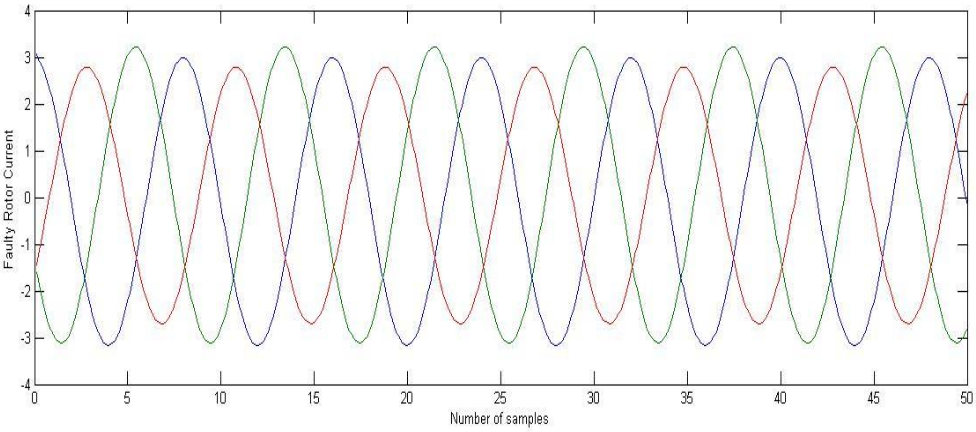


Fig. 4.3 (c) Faulty Rotor Current
Fig. 4.3 Simulation Results (Faulty Motor)

4.3 Induction Motor Simulation for Pattern Generation and Training of ANN

A three phase motor with parameters given in Appendix 1 has been used to get the patterns for training and testing. The analysis has been done by means of script file in MATLAB R2013a software. For pattern generation, the continuous signals of voltages and currents are sampled at a sampling rate of 16 samples per cycle over a data window of one cycle. So, all the parameters i.e. stator and rotor voltages and current, are sampled at same frequency. In order use ANN, the sampling rate in the analysis of direct phase quantities is set in such a way to get total 48 samples in one pattern i.e. 16 samples per cycle for each phase. This means signal is sampled at 800 Hz frequency. Stator current values are extracted and used as patterns. Induction motor simulation is run for iterations enough to compile the moving data window for training of ANN. This moving data window consists of 48 samples of steady-state condition with different phase angle and the turn to ground fault condition in stator winding with different percentage of faulty turns. Turn to ground fault in all the three phase of induction motor stator winding is considered for pattern generation. At the same time, the target window is set for both healthy and faulty conditions with neuron value high if true for both the cases. The moving data window with both healthy and faulty patterns must be shuffled also to get the better training of ANN. For training, extreme conditions must be considered; so, the faulty patterns considered are all above 50% shorted turns of stator winding. As the error of training approaches zero, the optimised weights and biases are saved. In short, the optimized network is saved and testing is done on the saved i.e. optimized NN. The testing window is also obtained from the simulation but other than the patterns selected for training. The testing window is made in such a way that fault propagate after one or two cycles of healthy condition. The trained NN must be able to detect the change in pattern and correspondingly show the results

Further, back propagation algorithm (BP) has been applied for fault identification in motor winding with 48 input neurons, 30 hidden neurons and 2 output neurons with desired output known or pre-set by us. In BP sigmoid function is used as an activation function. Learning rate of algorithm is also considered. It is set to a low value like 0.1 or so to make the convergence effective. Once identified, an attempt is made to classify the faults also using LabVIEW and employ an intelligent relay which will be discussed further. Different desired outputs (conditions) are used to train NN using BP that are quoted in Table 4.1 which includes Turn to ground fault with different percentage of shorted turns.

Table 4.1 Conditions for Training and Testing

Condition	Meaning	Desired output (conditions) for 2 o/p neurons
Healthy condition	When there is no fault	1 0
Turn to Ground fault	Phase – A short circuited with ground	0 1

4.4 ANN output results using MATLAB

The back propagation algorithm is implemented using MATLAB. The weights from input to hidden layer and from hidden to output layer are optimized using BP until the error signal approaches zero value. The error output after training of ANN with patterns generated using BP is shown in Fig. 4.4

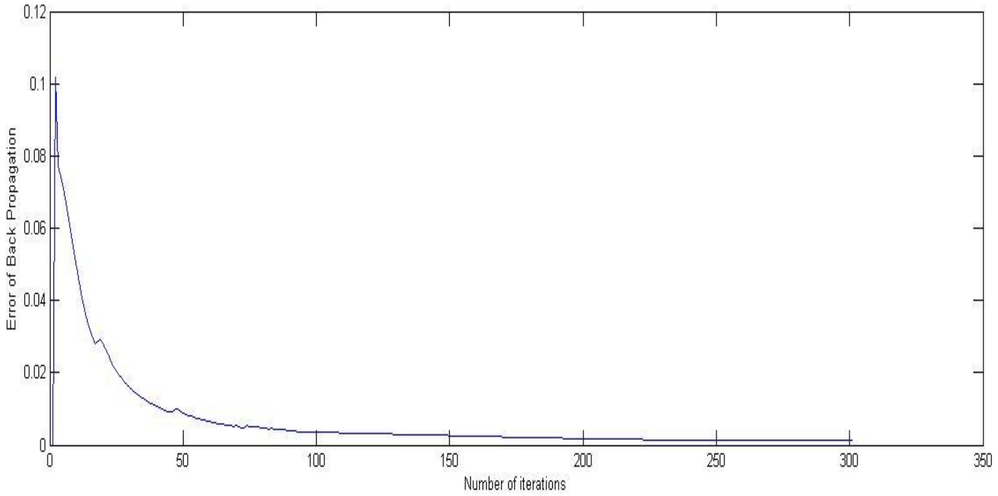


Fig. 4.4 Error after training of BP

Once the error signal approaches zero, implies the network is now trained also called learning. The network giving the above error value was saved and testing is done on the same network with a testing window of 40 samples comprising 20 healthy and 20 faulty stator current patterns. The network was able to identify the healthy and faulty pattern quite successfully. It was also tested for only healthy and only faulty patterns. The results of all these cases are shown in figures below.

Fig.4.5 Shows the MATLAB test result for healthy current patterns

Fig.4.6 Shows the MATLAB test result for healthy and A-phase faulty current patterns

Fig.4.7 Shows the MATLAB test result for healthy and B-phase faulty current patterns

Fig.4.8 Shows the MATLAB test result for healthy and C-phase faulty current patterns

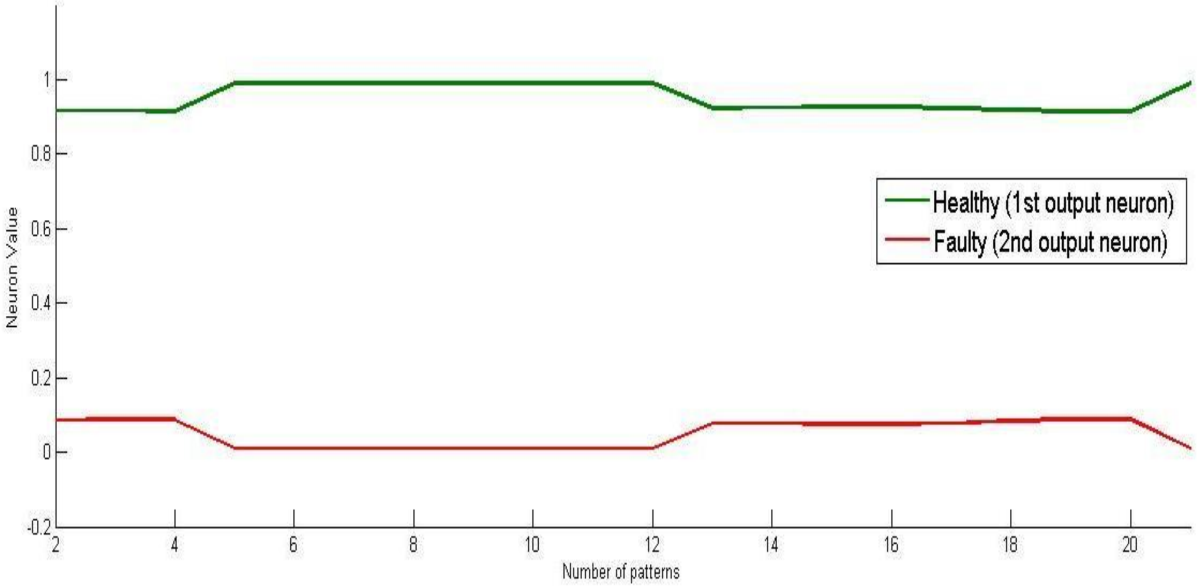


Fig. 4.5 Result of testing (Healthy Condition)

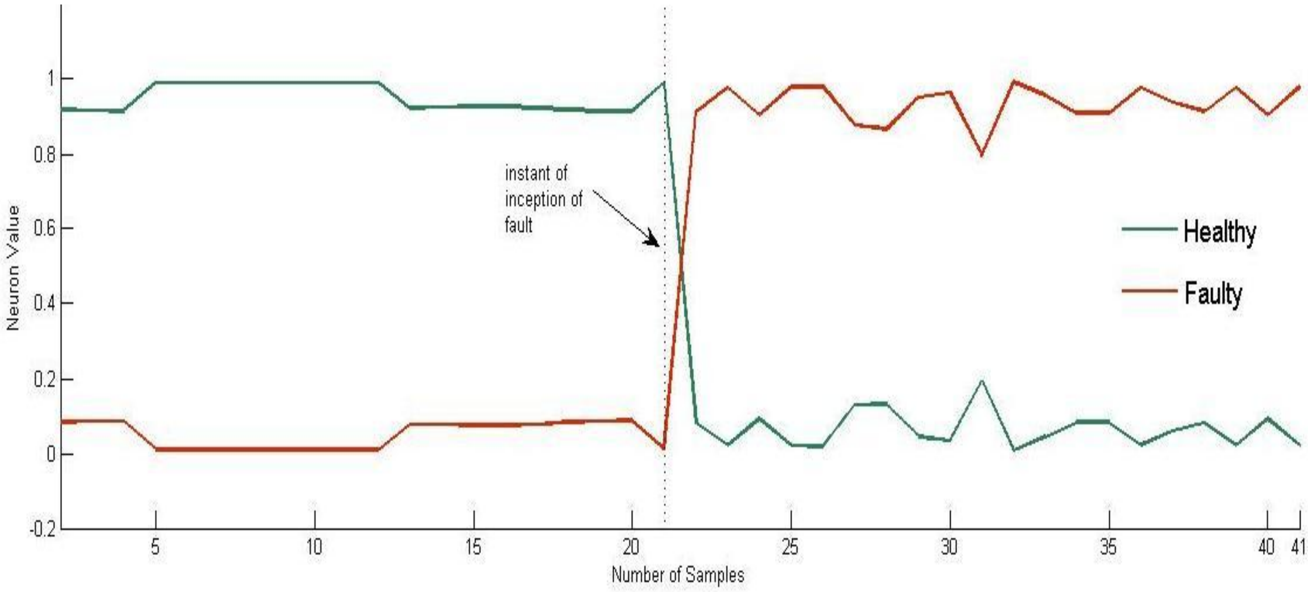


Fig. 4.6 Result of Test (Fault in A phase)

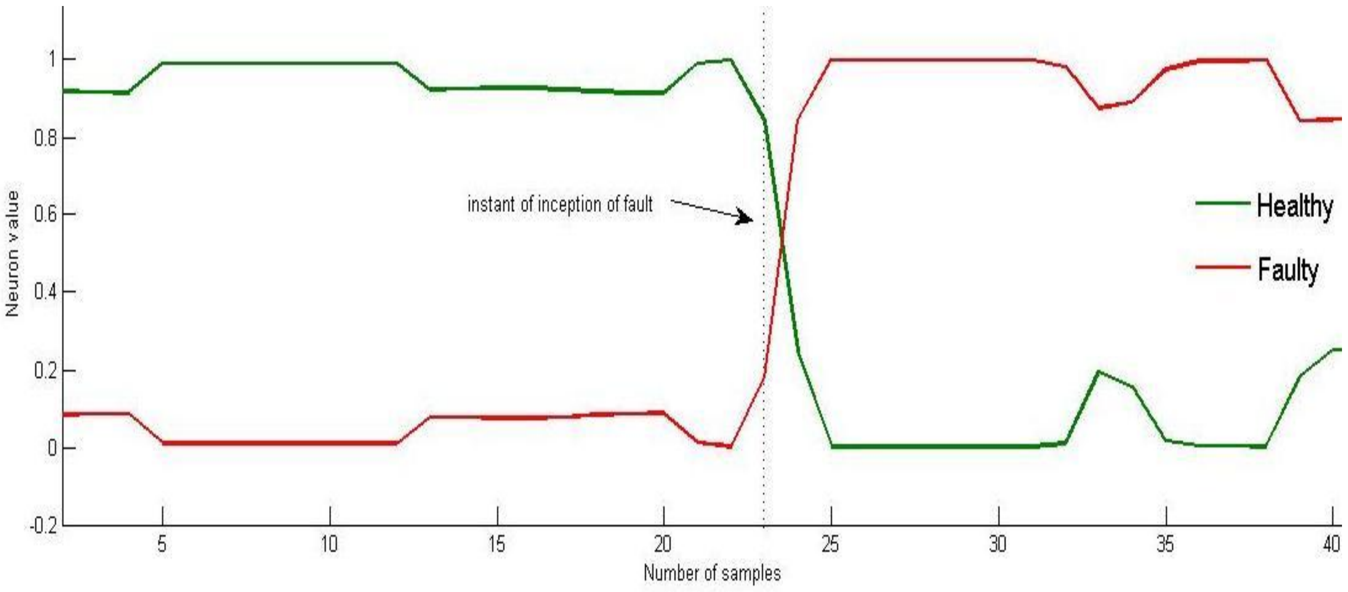


Fig. 4.7 Result of Test (Fault in B phase)

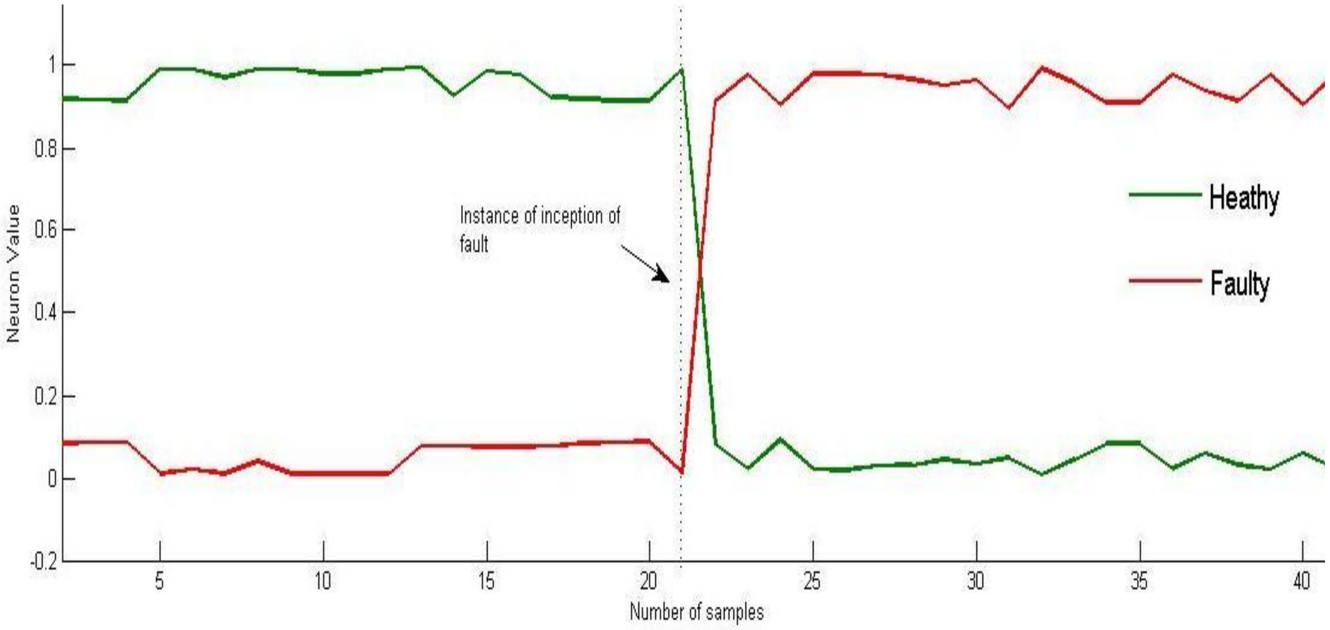


Fig. 4.8 Fault in C phase

Once the faulty or healthy condition is identified using ANN and by its coding in MATLAB, the classification can be done using the LabVIEW software.

Chapter 5

Designing and Implementation of intelligent relay using LabVIEW

LabVIEW, Laboratory Virtual Instrument Engineering Workbench is a graphical programming language used as instrument control software and data acquisition. Here block diagram method is used to compile the machine codes.

ANN using BP is implemented in LabVIEW and classification is done here. This classification can be used further to design an intelligent relay which trip the circuit as soon as it detect a faulty pattern and also give us the indication that the fault has occurred in which phase of the stator winding. LabVIEW application is used for testing here. After training and obtaining the optimized weights from results, testing is done in LabVIEW environment. The block diagram is shown in Fig. 5.1 and the front panel outputs are shown in figures below:
Fig.5.2 shows the test result of faulty condition and it further classify it as A phase faulty condition.
Fig. 5.3 shows the test result of faulty condition and it further classify it as B phase faulty condition.
Fig. 5.4 shows the test result of faulty condition and it further classify it as C phase faulty condition.
An intelligent relay design primarily depends upon its decision taking capability for tripping the circuit whenever is detects a fault and also to classify it correctly. It is clear from the results that the fault is detected within a quarter of cycle i.e. less than 5ms and also it classifies the fault in the stator winding of induction motor. The patterns are sampled at 800Hz frequency. For 16 samples per cycle, it takes 20ms. This means, for one sample it takes 1.25ms. So, at the time of testing, if 100 samples are considered, we can calculate the time taken for classification of one sample. If the time value is less than 1.25ms, the design of intelligent is quite successful. But, if the time is more than 1.25ms, this means the sampling frequency must be increased so that the intelligent relay could work fast and successfully.

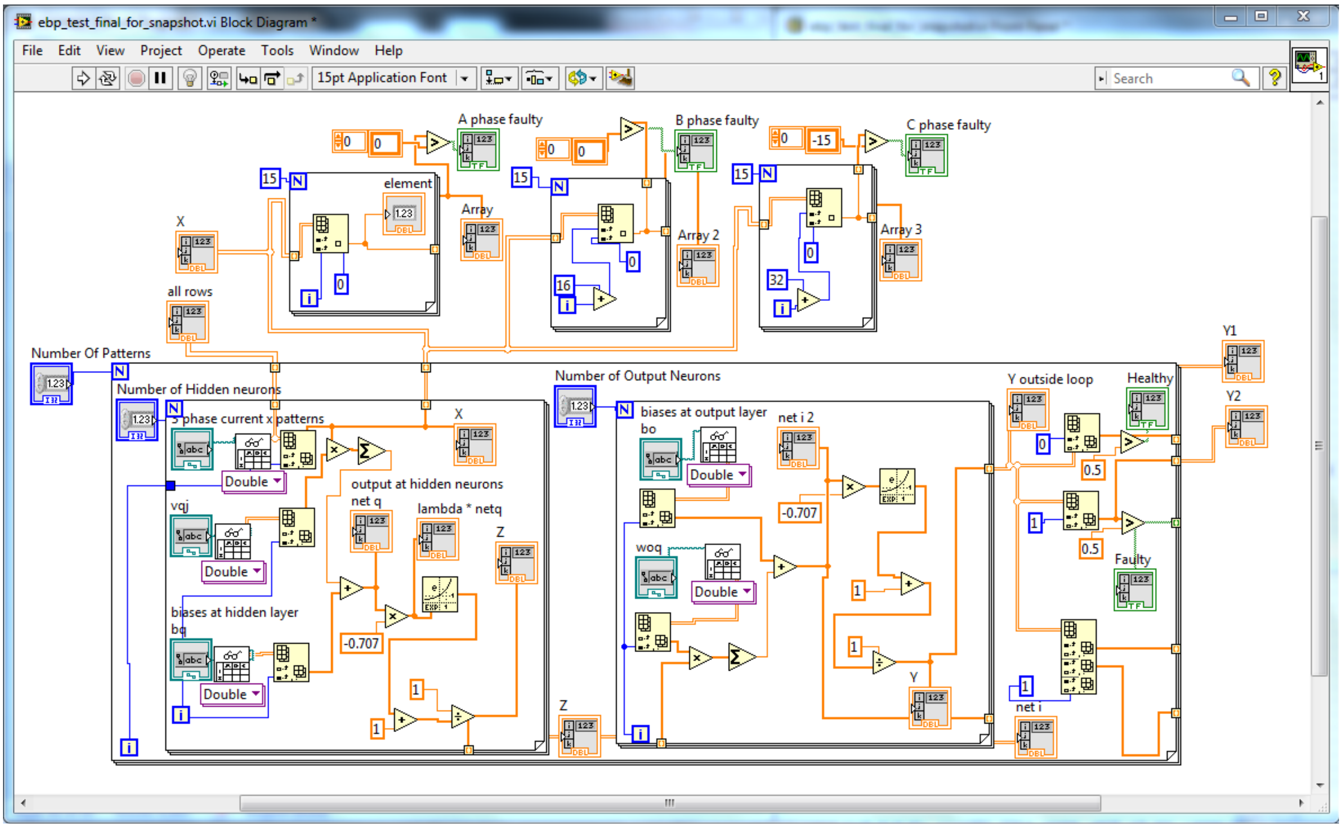
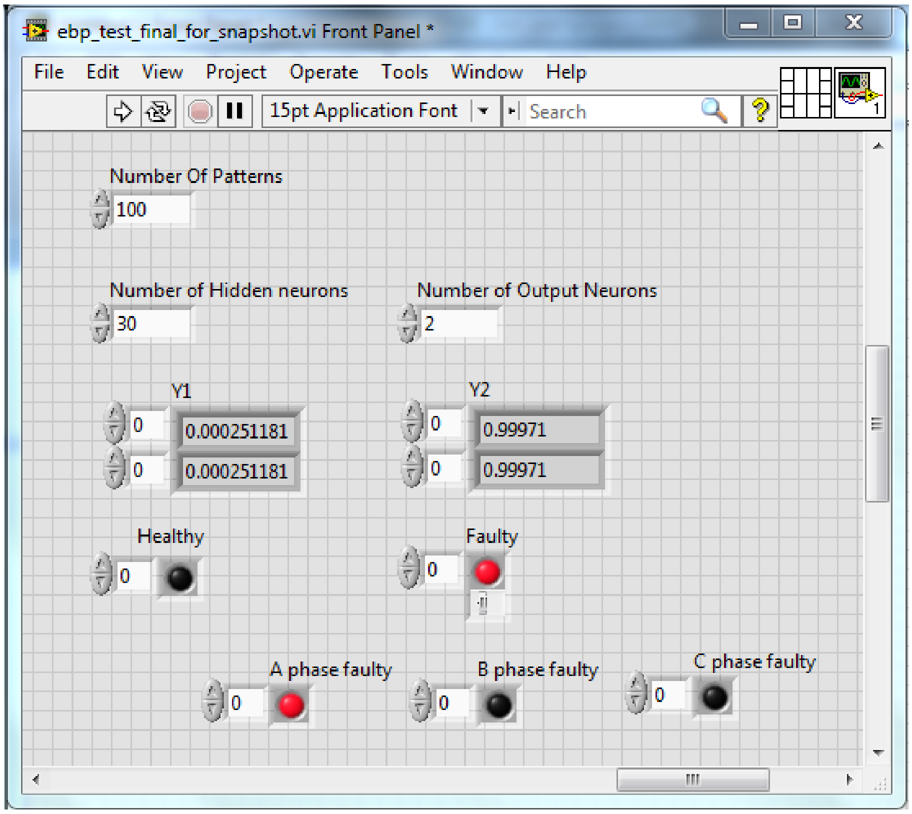


Fig. 5.1 VI Block Diagram



Number Of Patterns 100

Number of Hidden neurons 30

Number of Output Neurons 2

Y1
0 0.000251181
0 0.000251181

Y2
0 0.99971
0 0.99971

Healthy 0

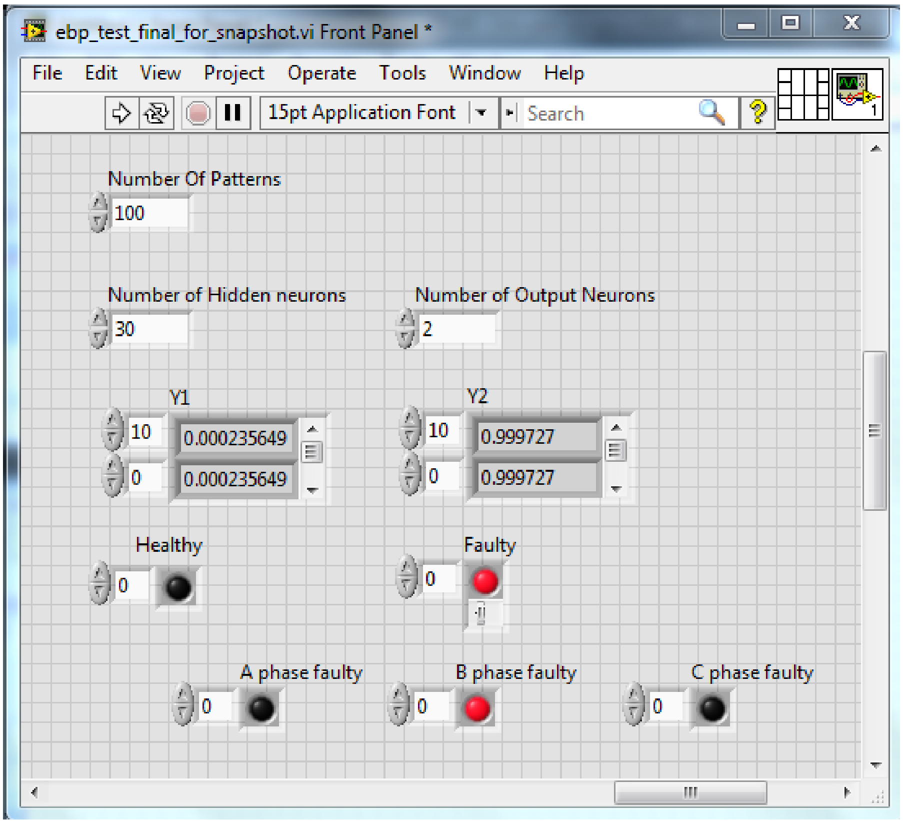
Faulty 0

A phase faulty 0

B phase faulty 0

C phase faulty 0

Figure 5.2 VI Front panel showing faulty condition with fault in A phase



Number Of Patterns
100

Number of Hidden neurons
30

Number of Output Neurons
2

Y1
10 0.000235649
0 0.000235649

Y2
10 0.999727
0 0.999727

Healthy
0

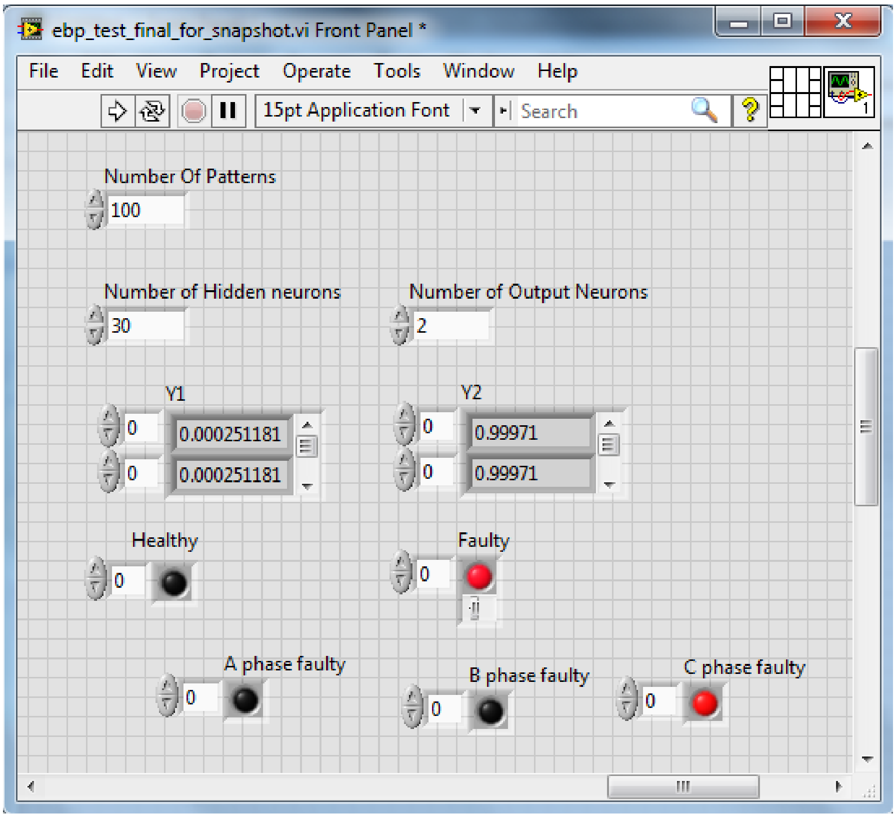
Faulty
0

A phase faulty
0

B phase faulty
0

C phase faulty
0

Figure 5.3 VI Front panel showing faulty condition with fault in B phase



Number Of Patterns
100

Number of Hidden neurons
30

Number of Output Neurons
2

Y1
0 0.000251181
0 0.000251181

Y2
0 0.99971
0 0.99971

Healthy
0

Faulty
0

A phase faulty
0

B phase faulty
0

C phase faulty
0

Figure 5.4 VI Front panel showing faulty condition with fault in C phase

Chapter 6

Conclusion and Future Scope

Conclusion:

The stator winding fault simulation of induction motor has been obtained by making use of direct phase quantities in MATLAB. The simulated stator current has been used to discriminate between healthy condition and stator winding fault. The various voltages and current signals obtained are sampled at 800 Hz (16 samples per cycle) to get the training and testing patterns. The three phase stator currents (16 samples per phase) have been used to train the ANN using back propagation algorithm. Once identified as healthy or faulty condition the faults classification of stator winding fault has been done. The classification has been further implemented using LabVIEW and on the basis of result of the same. Therefore, an intelligent relay has been designed which is able to identify and classify the stator winding faults within a quarter of a cycle. The implemented circuitry in LabVIEW can be further realized in hardware.

Future Scope:

The implementation of fault identification and classification can be further expanded to identify and detect other faults like all rotor faults, Turn to turn faults of winding and fault related to flux. So, the future work may be on basis of other considerations like:

- Including winding details and implementing modified winding function theory.
- Flux distortion effects due to misalignment of rotor.
- Temperature distribution at the two ends of the induction motor.
- Rotor fault detection in motor.

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Appendix

Table 1 Three Phase Induction Motor Parameters

Input Voltage And Frequency	230 V, 50 Hz
Power, no. of poles	5.5 kW, 2
Stator Resistance	1.5 ohm
Rotor Resistance	2 ohm
Stator self inductance	3.5
Rotor self inductance	3.5
Mutual Inductance	55
Inertia	0.296