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Design of Data Aquistion interface circuit used in Detection Inter-turn Faultin Motorbased onMotor Current Signature Analysis (MCSA)Technique

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ABSTRACT
A commitment to condition monitoring involves the operators of plant in the conduct of a range of activities. These activities may be complicated in nature and indeed may often be performed automatically under computer control. They can, however, always be down into a relatively small number of easily identifiable functional tasks. This makes it much easier to identify the common elements of machine condition monitoring schemes .The Motor Current Signature Analysis (MCSA) is considered the most popular fault detection method now a day because it can easily detect the common machine fault such as turn to turn short circuit . The present paper discusses the fundamentals of Motor Current Signature Analysis (MCSA) plus condition monitoring of the induction motor using MCSA. A proposed interface circuit design and application will be further explain in this paper, the implemented monitoring unit circuit also illustrated, see appendix A. Artificial neural networks are extensively used for speed, torque estimation, and solid state drive control in both DC and AC machines. Two scenarios presented in this paper, first ten turns assume to be shorted, and in the second thirty turns shorted to show the difference in the amplitude of frequencies at each case. Finally artificial intelligent techniques are increasingly used for condition monitoring and fault detection of machines. This paper present. An improvement in three-phase squirrel-cage induction motor stator inter-turn fault detection and diagnosis based on a neural network approach is presented.
Keywords: Faults Diagnose, Three Phase Induction Motor, ArtificialNeuralNetwork (ANN**)**

I. INTRODUCTION

Three phase squirrel cage motor is normally use for industrial purposes. Various techniques are used to control the speed such as DTC (Direct Torque Control), Vector Control, Close Loop Feedback Control etc. Small single phase Induction machine are used for home appliances hence the machine monitoring plays an important role for industrial as well as domestic appliances growth. Various fault detection method has been used in past two decades.

Special attention is given to non-invasive methods which are capable to detect fault using major data without disassembly the machine. The Motor Current Signature Analysis (MCSA) is considered the most popular fault detection method now a day because it can easily detect the common machine fault such as turn to turn short circuit, cracked /broken rotor bars, bearing deterioration etc. The present paper discusses the fundamentals of Motor Current Signature Analysis (MCSA) plus condition monitoring of the induction motor using MCSA.Stator Faults are usually related to insulation failure. In common parlance they are generally known as Phase-to-ground or phase-to-phase faults. It is believed that these faults start as undetected turn-to-turn faults that finally grow and culminate into major ones [3]. Almost 30-40 % of all reported induction motor failures falls in this category.

Stator insulation can fail due to several reasons. Primary among these are :

a) High stator core or winding temperatures.
b) Slack core lamination, slot wedges and joints.
c) Loose bracing for end winding.
d) Contamination due to oil, moisture and dirt.
e) Short circuit or starting stresses.
f) Electrical discharges.
g) Leakage in cooling systems.

There are a number of techniques to detect these faults. Penman et. al. [1] were able to detect turn to turn faults by analyzing the axial flux component of the machine using a large coil wound concentrically around the shaft of the machine. Even the fault position could be detected by mounting four coils symmetrically in the four quadrants of the motor at a radius of about half the distance from the shaft to the stator end winding.

This is the result of negative sequence currents flowing in the line as also have been shown in [3]. However, negative sequence currents can also be caused by voltage unbalance, machine saturation etc.

The aim of this Paper is to:

1- Motor curent Signature Analysis applied in order to monitor and detec the Inter-turn fault Motor.
2- This paper presents the design and realization of data acquisition, as monitoring system for the interference between the PC lab and the motor.
3- Training the neural network to simulate the effects of three types of 3-phase induction machine faults.The required training data which will be used to train the ANN are obtained pratically by the designed monitoring system.

The rest of this paper is structured as follows. Section II Illustrates stator short circuit and its math expression. Section III present the fundamental of MCSA. Section IV presents elements used in monitoring system, section V illustratesthe basic steps for monitoring, while section VI presents the experimental results. Section VII presents the proposed interface circuit operation used in monitoring unit, software implementation illustrated in section VIII, section IX illustrates the process for Data Acquisition systems,

II. SHORT CIRCUIT IN STATOR WINDING

In large generators and motors in power plants,the stator and rotor winding insulation is exposed to a combination of thermal,electrical,vibration,thermo-mechanical,and environmental stresses during operation.In the log term,the multiple stresses cause ageing,which finally leads to insulation breakdown.For this reason ,it is important to estimate the remaining insulation integrity of the winding after a period of operating time.[5]

Deterioration of the winding insulation usually beings as an inter-turn fault involving a few turns of the winding.A turn fault in the stator winding of an electrical machine causes a large circulating current to flow in the shorted turns.Such a circulating current is of the magnitude of twice the locked rotor current;it causes severe localised heating and sustains favourable conditions for the fault to rapidly spread to a larger section of the winding[4].Another fault associated with the stator winding is called"single-phasing".In this case,one supply line or phase winding becomes open-circuited.The resulting motor connection has a line voltage directly across two phases(assuming a"star"connected machine) which is equivalent to a single-phase circuit.The effect of an insulation fault between turns is to eliminate a turn or group of turns from the stator winding.This will be of little consequence but it will be quantifiable in the flux distribution in the air-gab **.[6]**

The frequency components to be detected in the axial flux component is given by,

$$(k \pm n(1-s)/p)\, f \qquad (1)$$

where **p**is the number of pole pairs, ***f***is the mains frequency, **k=1,3** and **n= 1,2,3**,….,(**2p-1**) and **s** isthe slip.

Toliyat and Lipo [2] have shown both through modeling and experimentation that these faults result in asymmetry in the machine impedance causing the machine to draw unbalance phase currents.

Fig.1 shows an inter-turn short circuit between two points,a and b,of a complete stator winding .The path to the circulating current between these points is closed and the path A-A' can be expanded into two independent circuits.Fig.1 shows that the two currents,the phase current and the current which flows in the short circuited part,produce opposite MMFs.Therefore,inter-turn short circuits have a cumulative effect in decreasing the MMF in the vicinity of the short –circuited turn(s).Firstly,when a short circuit occurs,the phase widing has less turns and,therefore,less MMF.Secondly,the short-circuit current MMF is opposite the MMF of the phase winding.The circulating current *Ic* is a result of the galvanic contact between points a and b but also due to the contribution brought by the transformer effect or mutual induction.

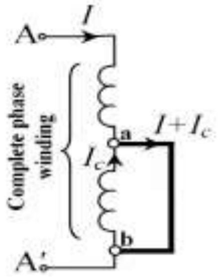


Fig.(1) Iner-turn short circuit

III. FUNDAMENTALS OF MONITORING SYSTEMSUSING (MCSA)

A commitment to condition monitoring involves the operators of plant in the conduct of a range of activities. These activities may be complicated in nature and indeed may often be performed automatically under computer control. They can, however, always be down into a relatively small number of easily identifiable functional tasks. This makes it much easier to identify the common elements of machine condition monitoring schemes . With the industrial growth, it has become necessary to monitor the condition of the machine/system. Electrical machine being the most sensitive part has great importance for the researcher to monitor the faults diagnosis. Three phase squirrel cage motor is normally use for industrial purposes. Various techniques are used to control the speed such as DTC (Direct Torque Control), Vector Control, Close Loop Feedback Control etc. Small single phase Induction machine are used for home appliances hence the machine monitoring plays an important role for industrial as well as domestic appliances growth. Various fault detection method has been used in past two decades. Special attention is given to non-invasive methods which are capable to detect fault using major data without disassembly the machine. The Motor Current Signature Analysis (MCSA) is considered the most popular fault detection method now a day because it can easily detect the common machine fault such as turn to turn short circuit, cracked /broken rotor bars, bearing deterioration etc. The present paper discusses the fundamentals of Motor Current Signature Analysis (MCSA) plus condition monitoring of the induction motor using MCSA [7].

IV. ELEMENTS OF A MONITORING SYSTEM

A sophisticated monitoring system can read the entrances of hundreds of sensors and execute mathematical operations and process a diagnosis. Currently, the diagnosis is gotten, most of the time, using artificial intelligence techniques, a monitoring system can be divided in four main stages [8]:

- Transduction of the interest signals;
- Acquisition of the data;
- Processing of the acquired data;
- Diagnosis.

Figure (2) presents a pictorial form of this process.

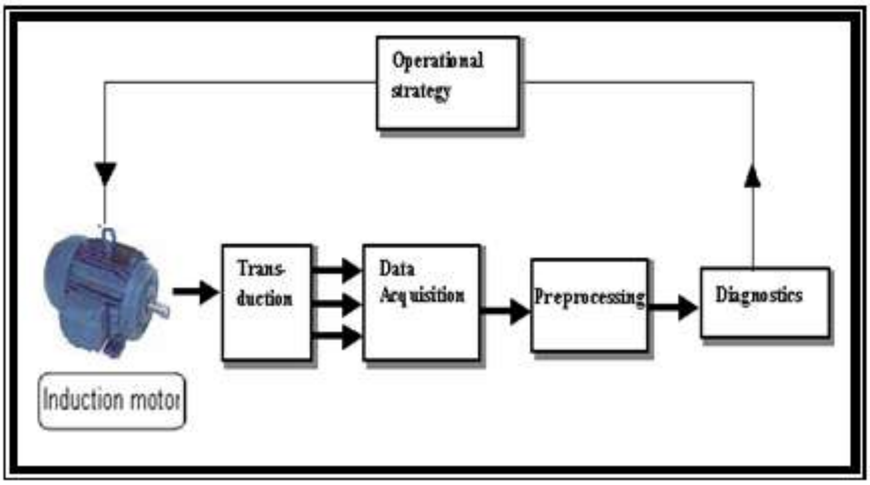


Fig. (2) Condition Monitoring System

A full mathematical analysis (with experimental verification) of a three-phase induction motor operating with broken rotor bars was published by Williamson and Smith (1982)—this gives an excellent in-depth analysis. A conceptual explanation is now presented to assist the reader in gaining a physical understanding of what happens in an induction motor with broken rotor bars. It is well known that a three-phase symmetrical stator winding fed from asymmetrical supply will produce a resultant forward rotating magnetic field at synchronous speed, and, if exact symmetry exists, there will be no resultant backward rotating field. Any asymmetry of the supply or stator winding impedances will cause a resultant backward rotating field from the stator winding.

Now apply the same rotating magnetic field fundamentals to the rotor winding, the first difference compared to the stator winding is that the frequency of the induced voltage and current in the rotor winding is at slip frequency and not at the supply frequency: s = per unit slip, f1=supply frequency Hz, f2= sf1 Hz, f2= slip frequency of rotor currents Hz. The rotor currents in a cage winding produce an effective three- phase magnetic field, which has the same number of poles as the stator field but it is rotating at slip frequency (*f2*) with respect to the rotating rotor. When the cage winding is symmetrical, there is only a forward rotating field at slip frequency with respect to the rotor. If rotor asymmetry occurs, then there will be a resultant backward rotating field at slip frequency with respect to the forward rotating rotor. The result of this is that, with respect to the stationary stator winding, this backward rotating field at slip frequency with respect to the rotor induces avoltage and current in the stator winding at [9]

$$f_{sb}=f_1(1-2s)Hz \quad (1)$$

This is referred to as a twice slip frequency sideband due to broken rotor bars. There is therefore a cyclic variation of current that causes a torque pulsation at twice slip frequency (*2sf1*) and a corresponding speed oscillation that is also a function of the drive inertia. This speed oscillation can reduce the magnitude (amps) of the *f1 (1- 2s)* sideband, but an upper sideband current component at *f1(1+2s)* is induced in the stator winding due to the rotor oscillation. This upper sideband is also enhanced by the third time harmonic flux. Broken rotor bars therefore result in current components being induced in the stator winding at frequencies given by[13]:

$$fsb=f1(1\pm 2s)Hz \quad (2)$$

This gives ±2sf1sidebands around the supply frequency component *f1*. These are the classical twice slip frequency sidebands due to broken rotor bars. These are sometimes referred to as the pole pass frequencies by condition monitoring practitioners, but this is not really an appropriate terminology and can cause confusion. The publications by electrical machine designers, researchers, and manufacturers always refer to the twice slip frequency sidebands due to broken bars, Due to the variables that affect the frequency of these sidebands and their magnitude in amps (normally in dB in a MCSA system), the diagnostic strategy has to consider the following:

- Different rotor designs (effect of pole number and number of rotor slots, etc.).
- A wide range of power ratings.
- Different load conditions.
- Mechanical load characteristics.
- Mechanical components in the drive train.

These factors can significantly affect the diagnosis and need to be considered in the development of reliable MCSA instrumentation systems for three-phase induction motors.From the supply frequency line. The left-side component is caused directly by the fault, while the right-side component is caused by the consequent speed ripple. The sum of the amplitudes of these two components was proven to be a very good diagnostic index, suitably correlated to the fault severity for fabricated rotors. A drawback of this diagnostic procedure is the possible confusion with the motor current modulation produced by other events. As an example, pulsating load and particular rotor design also cause sideband current components. If the load variation frequency is near, the resulting current spectrum is similar to that of a faulted rotor, but the two causes can still be distinguished. A more difficult issue is that of the particular design of the rotor structure [14].

V. BASIC STEPS FOR ANALYSIS

There are a number of simple steps that can be used for analysis using MCSA. The steps are as follow:

1. Map out an overview of the system being analyzed.
2. Determine the complaints related to the system in question. For instance, is the reason for analysis due to improper operation of the equipment, etc. and is there other data that can be used in an analysis.
3. Take data.
4. Review data and analyze:
5. Review low frequency demodulated current to view the condition of the rotor and identify any load-related issues.
6. Review high frequency demodulated current and voltage in order to determine other faults including electrical and mechanical health. In addition, there are several rules that should be considered:

1. Sidebands around the line frequency indicate rotor bar faults. The higher the peaks, the greater the faults.
2. Harmonic frequencies often relate to casting voids or loose rotor bars.
3. Non-pp. sidebands that cause a 'raised noise floor' around the line frequency peak normally relate to driven load looseness or other driven problems.

4. Peaks that show in current and voltage relate to electrical issues, such as incoming power. Peaks that show in current only relate to winding and mechanical faults.
5. Peak pairs that do not relate to running speed or line frequency are most often bearing related problems [11].

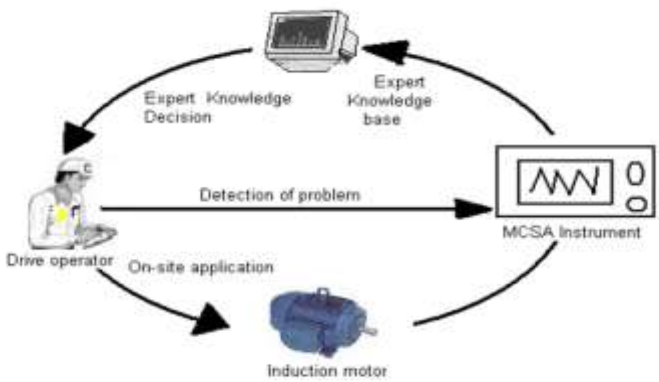


Fig. (3) Overall MCSA Strategy

VI. EXPERIMENTAL WORK AND RESULTS

erimental study of fault detection usually requires operating a physical system under some fault conditions, which may be dangerous, destructive, and costly. Efforts have been made in the laborattory to perform fault detection,

Fig .(4) and Fig. (5) illustrate the testbed used in this work. The system consists of 2.2KWMotor , 50 Hz, 2 pole, 3000 rpm induction motors, pulleys, belt, computer with Data Acquisition, Oscilloscope and spectrum analyzer used to create the data needed under no-load conditions. A dc Generator of 3KW is coupled with the motor by the pulley and belt as shown in Fig.(5). The fundamental operation of the Data Acquisition system, including detailed descriptions of the measurment system and control systems will be disccussed in this paper.

Fig.(4) Close Up Of Laboratory Equipments Set-Up

Inter -turn performed by two different numbers of short-circuited stator turns to achieve two different degrees of faults as can be seen in Fig.(6).Three taps were made in stator turns (10 turns) between the first and the second tap. (20 turns) between the seond tap and the third tap. There are 67turns in

Fig.(5) Flexible Coupling

each coils . The FFT analyses were performed on the acquired data. The side bands frequencies and their amplitudes was calculated as shown in tables by applying equation (2.3) in two cases both these cases at no load.

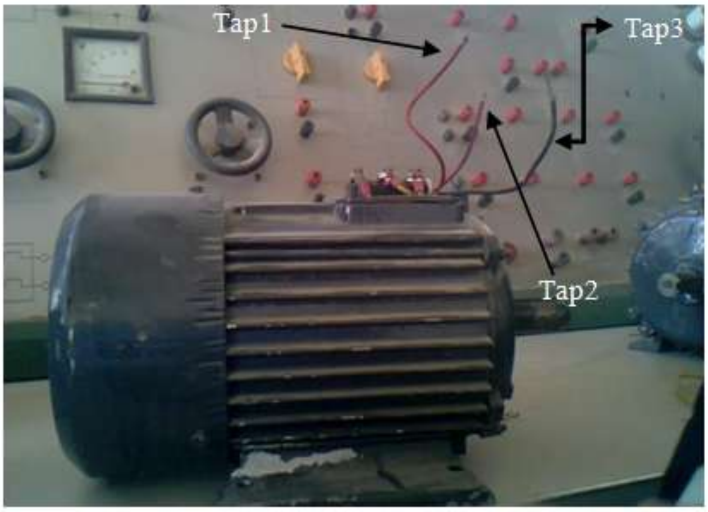
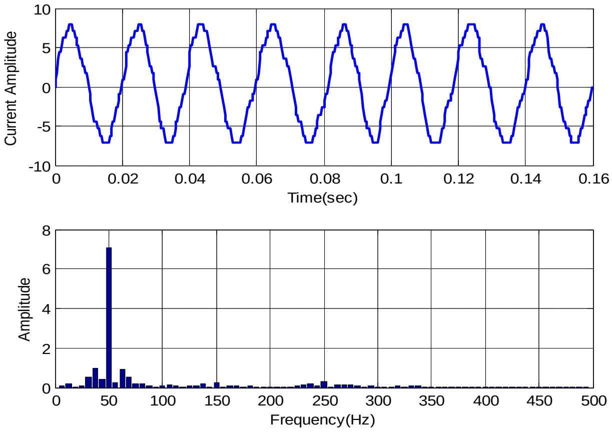


Fig.(6) Modeled stator inter-turn fault

VI.A. (10 Turns Shorted At No-Load Test)
In this case the shorte was between the tap1 and tap 2 , the number of shorted turns was ten.The stator line current and it's FFT as shown in Fig.(7) the current and the speed was 8 A.2650rpm respectively.



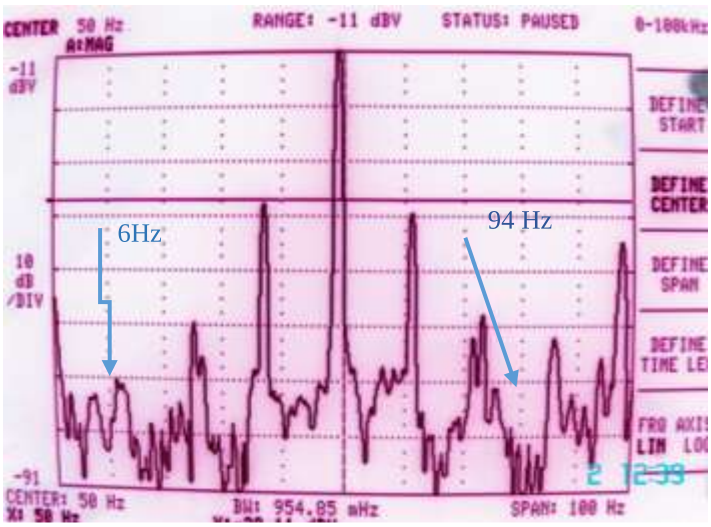


Fig. (7) Current waveform of stator inter-turn fault at no-load
a)Line current wavefom b) FFT

Table 4.10 Illustrates the positive negative harmonics sequence and their amplitudes for different values of ***k*** at no-load,the data of the motor is:

Case 1.when the shorted turn from (10-20).

S=ns-nr/ns= 0.133 ,nr=2650

$f_s=(k\pm n(1-s)/p)f$

Where p is the number of pole pairs, f is the mains frequency , n=1

k	Neg.Harmonic	Amplitude	Pos.Harmonic	Amplitude
1	6	0.323	94	0.01288
3	106	0.1119	194	0.0126
5	206	0.0176	294	0.018
7	306	0.0078	394	0.0156
9	406	0.0126	494	0.0139
11	506	0.0151	594	0.0056
13	606	0.0103	694	0.0119
15	706	0.0033	794	0.0082
17	806	0.0147	894	0.01
19	906	0.015	994	0.0013

Inupt Frequency	Motor Speed	Slip(s)	KW Rating	pole pairs	current
50Hz	2650rpm	0.133	2.2kw	1	8A

Fig. (8) Frequency spectrum at (Center = 50Hz and span =100Hz)no-load

VI.B. (30 Turns Shorted At No-Load Test)

In this case the shorte was between the tap1and tap 3 that means the number of shorted turns was thirty.The stator line current and it's FFT as shown in Fig.(4-34). The current speed was 9 A.2500 rpm

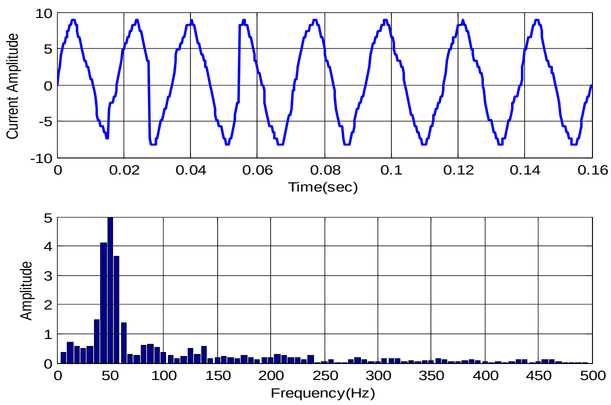


Fig.(9) Current waveform of stator inter-turn fault at no-load
a)Line current wavefom b) FFT

T**able 4.11** Illustrates the positive negative harmonics sequence and their amplitudes for different values of ***k*** at no load,the data of the motor is:

k	Pos.Harmonic	Amplitude	Neg.Harmonic	Amplitude
1	92	0.1312	8	0.396
3	194	0.071	67	0.395
5	292	0.037	125	0.23
7	392	0.011	183	0.05
9	492	0.029	242	0.062
11	592	0.005	300	0.05
13	692	0.013	385	0.041
15	792	0.014	416	0.004
17	892	0.0184	475	0.053
19	992	0.01	533	0.027
21	1092	0.03	591	0.028

Case 2.when the shorted turn from (10-40).
S=ns-nr/ns=0.166,nr=2500

$f_s=(k \pm n(1-s)/p)f$

Where p is the number of pole pairs, f is the mains frequency ,n=1

Inupt Frequency Motor Speed Slip (s) KW Rating pole pairs 50 H 2500rpm 0.166 2.2kw 1

VII. THE PROPOSED CIRCUIT OPERATION

The four test signals are applied to the four inputs (in1- in4) of the IC7, which is dual (4-1) line analog switch multiplexer IC, the four inputs of this IC are at pins (1,5,2,4). The selection of the input lines is controlled by the control pins (10,9) which are (A,B) control lines, these lines are controlled by the LPT bus of the microcomputer. The signal are required to be made in a suitable form before providing them to analog multiplexer ; this can be done using the following simple circuits:

1. Speed signal Voltage circuit, this circuit reduce the voltage (speed) by factor (1/18) uses the resistors (R13 & R14), shown in Fig. (4-4) , this circuit used the range of analog voltage signal coming from Tachometer from range (0-90V) to range (0-5V).
2. Motor current circuit, by using the circuit shown in Fig. (4-4) to invert of signal polarity .This circuit used to invert the current signal coming from CT to the voltage signal before providing it to the multiplexer circuit.
3. Voltage follower (buffer) circuit, the circuit shown in Fig. (4-4) is used because its input resistance is high . Therefore, it draws negligible current from signal source, and then the loading effect will be removed. This circuit is used in different place of the system hardware, such as using it between the output of the multiplexer circuit and the input of analog to digital converter. Pin (3) of the IC7 is the output pin that accessed to the input of the sample and hold IC1, this IC converts the analog signal to the sampled signal , where, the hold time depends on capacitance value of the capacitor C1.The sampling signal comes from the invertion of the STS output pin of the Analog-to-digital convertor IC2, its frequency value is choosed by the software user’s.The output of the sampler IC1 is accessed to the input of the Analog-to-Digital convertor IC2. This IC has two convertion modes these are: (8bits, 12bits) conversions, the first one was selected.

In this mode the control pins (12/8, A_o, CE) or (2,4,6) connected to the +Vcc, and (Analog com, CE) or (pins 9, 3) connected to the ground (GND) pin. The output data bits of IC2 are (D4-D11) at pins(20-27).The AD574 type was chosen for IC2 in this design, where this IC converts the sampled analog signal to digital numbers, the lowest level of the analog is converted to $(00)_H$ number,while the highest level is converted to $(FF)_H$ number. The output data bits (D4-D11) are connected to the 8-bits input lines of the Latch circuit(IC3 type 74HC374), this IC saves the output digital number of the A/D convertor for a period of time while the microcomputer read this data from the LPT bus (pins 10,11,12,13).The loading (saving) signal came from the invertion of the STS output control pin of the A/D convertor IC2. The output data from the Latch ciruit (IC3) goes to to the buffer drive circuit(IC4) type 74LS241, which it acts as a nibble (4-Bits) selector. The control pins (OEA, OEB) are shorted and connected to the pin(5) [D3] of the LPT bus, if this line goes to High state then the higher state nibble (D4-D7) is selected, and if this line goes to Low state then the Lower nibble (D0-D3) is selected. The output pins of this IC are shorted by this manner, Q0 to Q4, Q1 to Q5, Q2 to Q6, Q3 to Q7.

The output pins (Q0-Q2) or (Q4-Q6) of IC4 are connected to iput pins (Q4-Q6) of the LPT bus, while Q3 of IC4 is inverted then connected to Q7 of LPT bus. The combinational circuit of ¼ IC6, 1/6 IC5 and C2 is used as a monostable circuit (one-shot to), it converts the clock signal that came from pin(4) (D2) of the LPT bus to series of narrow Low pulses that goes to the (R/C) control pin of A/D convertor IC. The resistors (R3-R10) are used for isolation and protection of the LPT bus of the microcomputer from the proposed circuit.See Appendix B

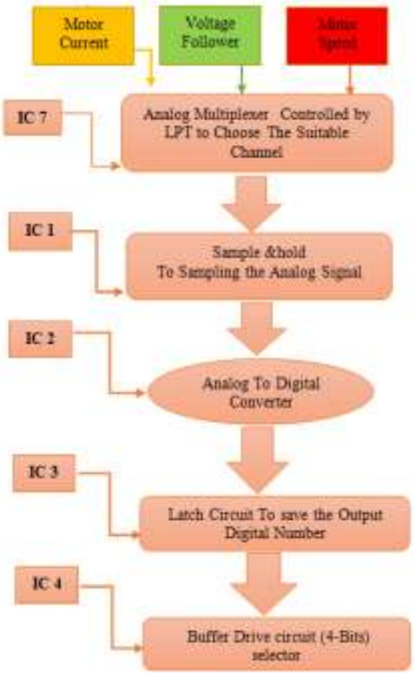


Fig.(10) Block diagrame of the main sections of the data acquisition system

VIII. SOFTWARE IMPLEMENTATION

The implementation of the software programe included five steps in the first stage the data of the current and the speed given to the data acquisition circuit, the line current measured by using current transformer (10/4) A passing through a resistance of 1Ω which given 4 volt to the data acquisition circuit, this circuit will convert these analogue current signal to 3250 digtal numbers, in the stage two these numbers will loaded to the FFT programe to abtain the sampling frequency and sampling time of the waveform (see appendix c-4).

The speed of the motor measured by using the tachometer the value of the speed will convert to the voltage value, it's found that the tachometer used in the laboratory give 0.06 volt for each rotation, for example if the motor speed is 2800 rpm the tachometer give 168 volt this value will reduce to about 4 volt before used in data acqusition circuit. Stage three include the calculation of the frequencies of the positive, negative side bands by applying the equeations which are realated to the five faults, this stage also included extraction of the amplitudes of these frequencies see appendix c-2. Stage four refer to the rule of the neural network in faults detection , the amplitudes of the side bands used as inputs as mentioned before in this chapter , see the training of the neural programe in appendix c-3. Fig.(11) illustrates the flowchart of the system operations. The basic following steps illustrates the Fast Fourier Transform (FFT) which are :

1- all line currents of the healthy and faulty motors should be given to the programe (see appendix c-4).
2- Choose the number of the cycle (six cycles have been chosen in this work) as shown from line current for all type of faults .
3- Calculate the length of the six waves.
4- Calculate the sampling time and sampling frequency.

The four steps mentioned above done using the programe in (appendix c-4).

5- Applying the FFT package (yy1=fft(b,s)) see appendix c-5, where b is the values of the numbers by which the six cycles were drawn, s is the total number of these values it was equal to 390 for the six cyles (65 values for each cycle over 0.02 (sec)). Therefore the sampling time can be calculated by divided the 65 values on 0.02(sec) and the result is the sampling time it was equal to 3.076923e-4sec, then the sampling frequency is: 1/sampling time =3250 Hz

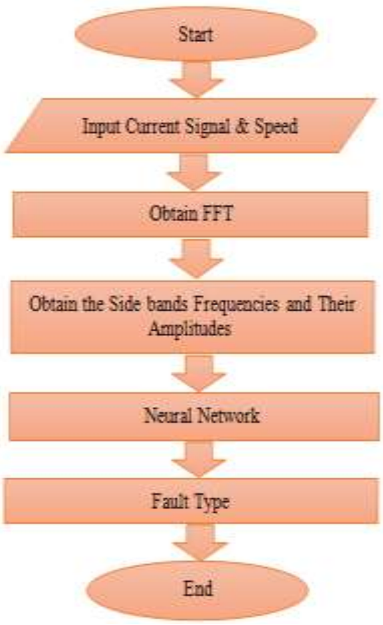


Fig. (11) Flowchart of system operations

Fig.(12) illustrates the flowchart of the quick basic programe used in the interface circuit, the acquisition circuit channel have been controlled by using the programe of the interfac (see appendix d).

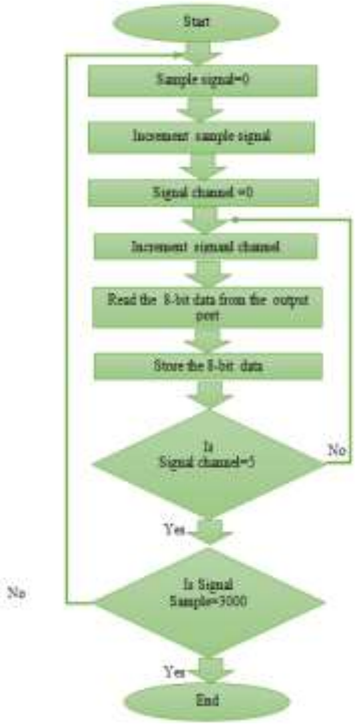


Fig.(12) Flow chart of interface programe

IX. CONCLUSION AND FUTURE WORK

The work reported in this paper has involved designing and building a motor monitoring system using an Aritificial neural network for fault detction of three phase induction motor .To accomplish this, a hardware system was designed and built to acquire three-phase stator current and speed from a (2.2kw) squirrel-cage induction motor. The ability of the phase current to detect specific fault was tested, sincemonitoring this parameter is the most convenient and cheapest way to sense a fault. it was clear that The sideband frequencies are function of the slip, so they are changing with the speed (that change with the load) .

From the sideband frequencies calculated in the tables(1 and 2) it's found that the distance of the positive and negative from the fundamental increased with increasing of the load, and the same for different values of k/p and for all types of faults. From the reported work,the disadvantage of most ANN's are their inability to respond to previously unseen conditions. Therefore , if there is an occurance of a new fault that the network doesn't been train to recognize ,and the fault may be misdiagnosed which produce weak output results. The number of selected input channels of data acquisition circuit used in this work was two (one for current and the other for tachometer), these slected chanals may increase to four depend on the types of data needed to investigated.

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Appendix A: Structure of Data Acquisition Circuit.