DETECTION AND CLASSIFICATION OF FAULTS IN INDUCTION MOTOR USING WAVELET AND FUZZY CONTROLLER

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ABSTRACT

Computer simulation of electric motor operation is particularly useful for gaining an insight into their dynamic behavior and electro-mechanical interaction. A suitable model enables motor faults to be simulated and the change in corresponding parameters to be predicted without physical experimentation. This proposed approach presents both a theoretical and experimental analysis of asymmetric stator winding and rotor faults in induction machines. A three-phase induction motor was simulated and operated under normal healthy operation, with phase to phase winding fault, phase to ground winding fault and short circuit winding fault and with voltage imbalances between phases of supply. The results illustrate good agreement between both simulated and experimental results.
For analysis of fault condition conventional method of Fast Fourier transform are first employ and test for different winding fault conditions. Then fuzzy logic controller based on fuzzy rule base design for analysis of stator winding faults. From both the conditions it clear that the FFT analysis only calibrate total harmonics distortion (THD) of faulted voltage and current signal of three phase induction motor input side (stator side). While fuzzy logic controller directly analyzed the type of the fault on induction motor stator winding. Then finally, the results of fuzzy logic controller compare with signal process method as wavelet transform and Fast fourier transform analysis method. Motor model and fault analysis system design in MATLAB 2015 Simulink software. Using this software, motor parameter analysis, fault cases analyzed.

Keyword: - *Three phase induction motor, fault analysis, fuzzy logic, wavelet transform.*

1. INTRODUCTION

Induction motors are complex electro-mechanical devices utilized in most industrial applications for the conversion of power from electrical to mechanical form. Induction motors are used worldwide as the workhorse in industrial applications. Such motors are robust machines used not only for general purposes, but also in hazardous locations and severe environments. General purpose applications of induction motors include pumps, conveyors, machine tools, centrifugal machines, presses, elevators, and packaging equipment. On the other hand, applications in hazardous locations include petrochemical and natural gas plants, while severe environment applications for induction motors include grain elevators, shredders, and equipment for coal plants. Additionally, induction motors are highly reliable, require low maintenance, and have relatively high efficiency. Moreover, the wide range of power of induction motors, which is from hundreds of watts to megawatts, satisfies the production needs of most industrial processes.
However, induction motors are susceptible to many types of fault in industrial applications. A motor failure that is not identified in an initial stage may become catastrophic and the induction motor may suffer severe damage. Thus, undetected motor faults may cascade into motor failure, which in turn may cause production shutdowns. Such shutdowns are costly in terms of lost production time, maintenance costs, and wasted raw materials.
The motor faults are due to mechanical and electrical stresses. Mechanical stresses are caused by overloads and abrupt load changes, which can produce bearing faults and rotor bar breakage. On the other hand, electrical stresses

are usually associated with the power supply. Induction motors can be energized from constant frequency sinusoidal power supplies or from adjustable speed ac drives. However, induction motors are more susceptible to fault when supplied by ac drives. This is due to the extra voltage stress on the stator windings, the high frequency stator current components, and the induced bearing currents, caused by ac drives. In addition, motor over voltages can occur because of the length of cable connections between a motor and an ac drive. This last effect is caused by reflected wave transient voltages [1]. Such electrical stresses may produce stator winding short circuits and result in a complete motor failure.

According to published surveys [2, 3], induction motor failures include bearing failures, inter-turn short circuits in stator windings, and broken rotor bars and end ring faults. Bearing failures are responsible for approximately two-fifths of all faults. Inter-turn short circuits in stator windings represent approximately one-third of the reported faults. Broken rotor bars and end ring faults represent around ten percent of the induction.

This table presents the surveys conducted by the Electric Power Research Institute (EPRI), which surveyed 6312 motors [3], and the survey conducted by the Motor Reliability Working Group of the IEEE-IAS, which surveyed 1141 motors [2]. motor faults. These faults are summarized in Table 1.

Table-1: Percentage of failure by component

Failed components	Percentage of failure (%)	
	IEEE-IAS	EPRI
Bearings Related	44	41
Winding related	26	36
Rotor Related	8	9
Others	22	14

Several alternatives have been used in industry to prevent severe damage to induction motors from the above mentioned faults and to avoid unexpected production shutdowns. Schedule of frequent maintenance is implemented to verify the integrity of the motors, as well as to verify abnormal vibration, lubrication problems, bearings conditions, and stator windings and rotor cage integrity. Most maintenance must be performed with the induction motor turned off, which also implies production shutdown. Usually, large companies prefer yearly maintenance in which the production is stopped for full maintenance procedures. Redundancy is another way to prevent production shutdowns, but not induction motor failure. Employing redundancy requires two sets of equipment, including induction motors. The first set of equipment operates unless there is a failure, in which case the second set takes over. This solution is not feasible in many industrial applications due to high equipment cost and physical space limitations.

2. THEROTICAL STUDY

2.1 Fuzzy Logic Controller

Fuzzy logic is a logic which deals with uncertainty by modelling the events.
It deals with three entities:
i. Degree of accuracy /precision
ii. Uncertainty
iii. Vagueness (approximately equal)

In a narrow sense, fuzzy logic is a logical system, which is an extension of multi – valued logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In fuzzy logic, the truth of any statement becomes a matter of degree. Any statement can be fuzzy. The major advantage that fuzzy reasoning offers is the ability to reply to a yes-no question with a not-quite-yes-or-no answer. Humans do this kind of thing all the time (think how rarely you get a straight answer to a seemingly simple question), but it is a rather new trick for computers.

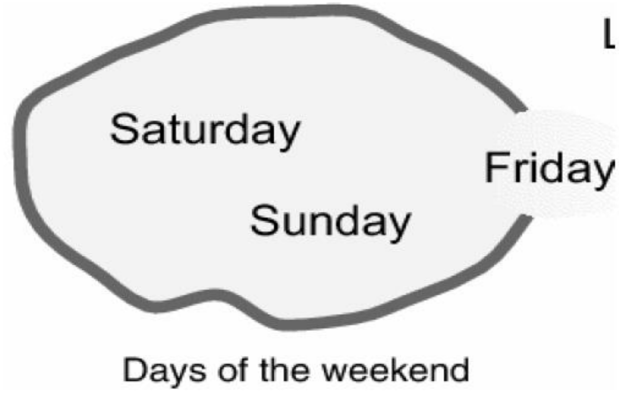

Figure-1: Representation of days of the weekend using fuzzy set

There are three days which comes in our mind when we talk about weekends. So, if we define these using two valued function we can either give 1 0r 0 to every day. But if we use fuzzy logic we can give different membership value to each day. Almost all will say that
Saturday and Sunday are weekend. But if we see more precisely Friday is also somewhat weekend. This can be understood through the below graphs in figure 2. So, using fuzzy we need not to give exact responses or absolute answers. We can somewhat skip from the question or in a broader way can give somewhat varying answer.

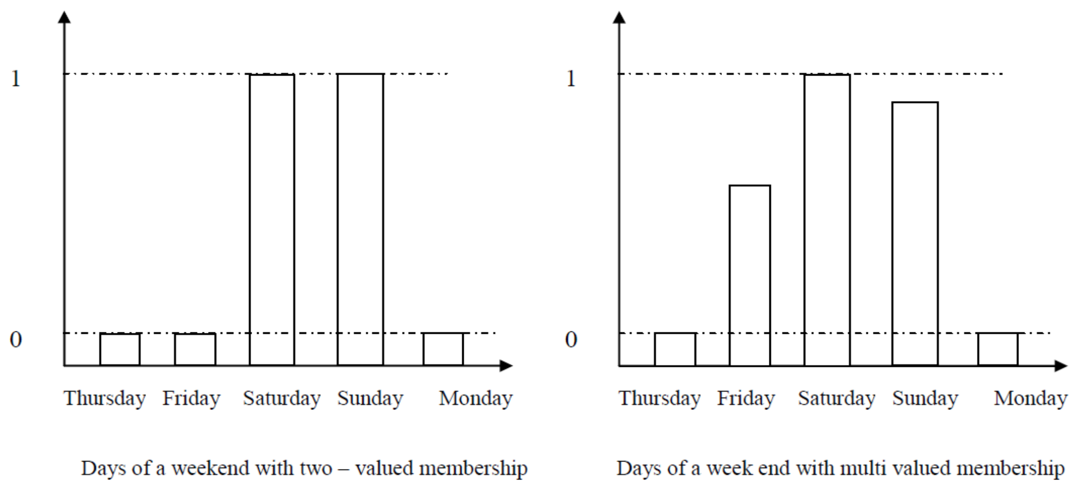

Figure-2: Bar graph of classical set and fuzzy set

Foundation of fuzzy logic: Fuzzy logic starts with the concept of a fuzzy set. We have a set defined as binary set because it can assign only binary values, means either 1 (full membership) or 0 (no membership). It cannot have values in between 0 and 1. On the other hand a fuzzy set is a set without a crisp, clearly defined boundary. So by using fuzzy logic we can assign values in between 0 and 1 or we can say that we can give answer of a yes/no question in partial yes/no. It gives the users a wide range of variation or choices.

Membership function: A membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. With the help of membership function we can assign values in between 0 and 1 to a set, which gives us a degree of unprecisioness. There are different types of membership functions which we can use such as
i. Triangular
ii. Trapezoidal
iii. Gaussian or Singleton
iv. Sigmoid

v. Piecewise linear

The choice of the membership function clearly depends upon the problem we have chosen. There is no boundation on choosing a membership function. But for most of the problems triangular and trapezoidal membership functions are used because these two M.F gives the best result because of their simple formulas and as they can be easily computed. These two membership functions produce the optimum results.

Fuzzy inference system: Fuzzy inferencing method is basically an inferencing process for a given input so as to provide an output using knowledge base / rule base which consist of number of rules. This system helps the fuzzy controller to understand different parameters and to make the rules in accordance to it. The different blocks used in fuzzy inferencing are as follows:

i. Fuzzification

ii. Fuzzy Inference Engine

iii. Defuzzification

Fuzzification: It is a process of transforming a classical set into fuzzy set or it is a process of translating an uncertain event into fuzzy set by assigning a proper membership function or it is a process of transforming a scalar value into a fuzzy value. This is achieved with different types of fuzzifiers. There are generally three types of fuzzifiers, which are used for fuzzification process; they are Singleton fuzzifier, Gaussian fuzzifier and Trapezoidal or Triangular fuzzifier.

Fuzzy inference engine: These are the types of the method with the rule base so as to obtain the fuzzy values. There are basically two types of methods which we are using in this:

i. Mamdani method

ii. Sugeno method

Mamdani Method: It is a graphical technique of inference. It is a simple rule system which comprises of two hypotheses and one conclusion. This method is the most common, easy to understand and hence in use in most of the cases. Mamdani's logic gets its basics from the Loft's Zade's 1973 paper. In this paper Lofti suggested fuzzy method or algorithm for decision making of complex systems. Mamdani using the method suggested by Lofti and using the linguistic control rules given by plant operators tried to control a steam engine and thus framed a rule base, now known as Mamdani"s rule base.

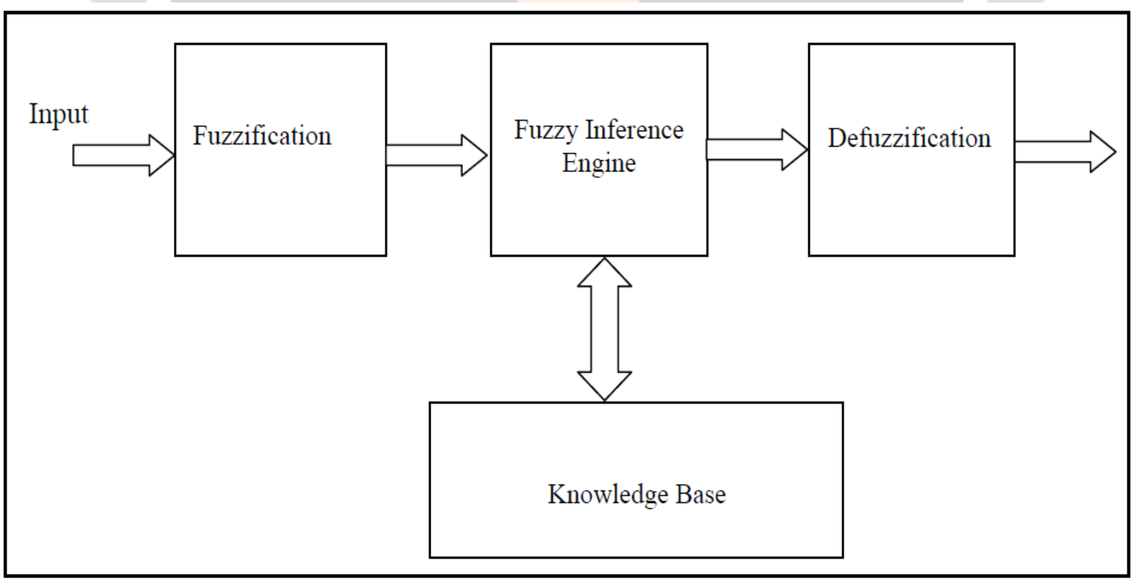

Figure 4.3: Fuzzy Inference System

Advantages of Mamdani Method:

a) It is intuitive.

b) It can be implemented in most of the problems.

c) It can easily be understood by humans as it contains language rules.

Sugeno Method: A type of fuzzy inference in which the consequent of each rule is a linear combination of the inputs. The output is a weighted linear combination of the consequents. It is suited to mathematical analysis.
Advantages of Sugeno Method:
a) It is computationally efficient.
b) It works well with linear techniques (e.g., PID control).
c) It has guaranteed continuity of the output surface.
d) It is well suited to mathematical analysis.

Defuzzification: It is the reverse process of fuzzification. In defuzzification we convert the fuzzy set or fuzzy value into real set or real scalar. There are five methods for defuzzification:
i. Centroid method
ii. Bisector method
iii. Middle of Maximum
iv. Smallest of Maximum
v. Largest of Maximum
The most commonly used method among all is the centroid method

2.2 Wavelet Transform
Wavelet transform is a methodology or transform to deal with the signals which cannot be processed using FFT transform and other available transforms. Its average value is zero and it is not like the other sinusoids which extends from minus to plus infinity. There range is limited. Wavelets are irregular in nature, they are also non – symmetrical and are very useful for the analysis of constant frequency signals. The signals containing unwanted oscillations and harmonics can also be operated by using wavelets. The below figure 4, shows the wavelet transform of a cosine wave at level 20.

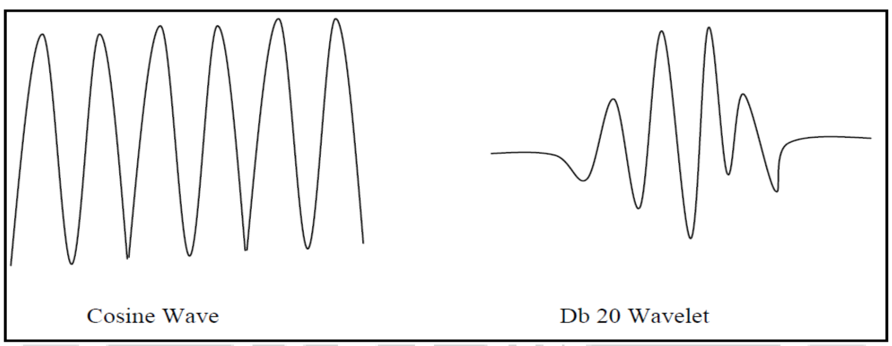

Figure-4: Wavelet Transform of Cosine wave

The other transforms such as FFT, DFT are useful tool for analysis of frequency components of signal but with these transforms we cannot comment on the time instants.
On the other hand wavelet transform focuses on high frequency components for short time interval and on low frequency components for long time interval. Due to this the analysis of the signals with localized impulses and oscillations increases manifolds.
Need of wavelet transform: In our analysis of the inrush and the fault currents what we have observed is that the inrushes current as well as the fault current signals are non – periodic in nature. It is also observed that these signals are oscillating in nature contains localized impulses superimposed on power frequency and its harmonics.
Discrete wavelet transform: Discrete Wavelet Transform is used to separate the data in various frequency components, as does the FFT. As FFT is used to separate unwanted signal such as noise from the original signal in the same sense DWT is also used for analysis of the signals and avoiding unwanted outages.
In FFT we cannot comment on specific time interval but in DWT we can remove the noise or frequency computed at some particular instant. This gives us a way to operate the signal in a different way as we can remove some unwanted signals at some particular interval as well as keep some useful data at some other point of interval. By using IDWT we can easily reconstruct the signal after removing the unwanted signals. Now through a block diagram we will see how DWT works:

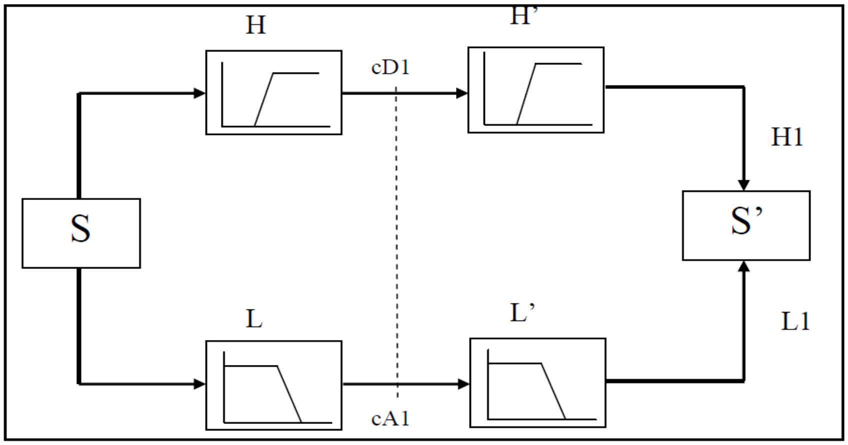

Figure-5: Single level Discrete Wavelet Transform

The discrete wavelet transform can be divided into two parts the left half which is known as decomposition and consists of the forward transform and the right half which consists of forward transform and is known as the reconstruction portion. In the middle is a line which is used to separate the two halves and is also used to add the complexity in the system. In figure 4.6 the input signal is passed through the high pass filter 'H' and coefficientcD1 is generated. This signal is further passed through a high pass reconstruction filter 'H' to produce the detail coefficient H1. The signal S is also passed through a low pass decomposition filter L to produce the coefficient cA1, which is further passed through a low pass reconstruction filter L" to produce the approximation L1. The upper filters H and H" are the high pass filters and the lower filters L and L" and the low pass filters. Figure 5 showed a single level WT, while the below figure 6 shows a multi level WT. In each step we down sampled the signal by 2 or we can say that decimation by 2.

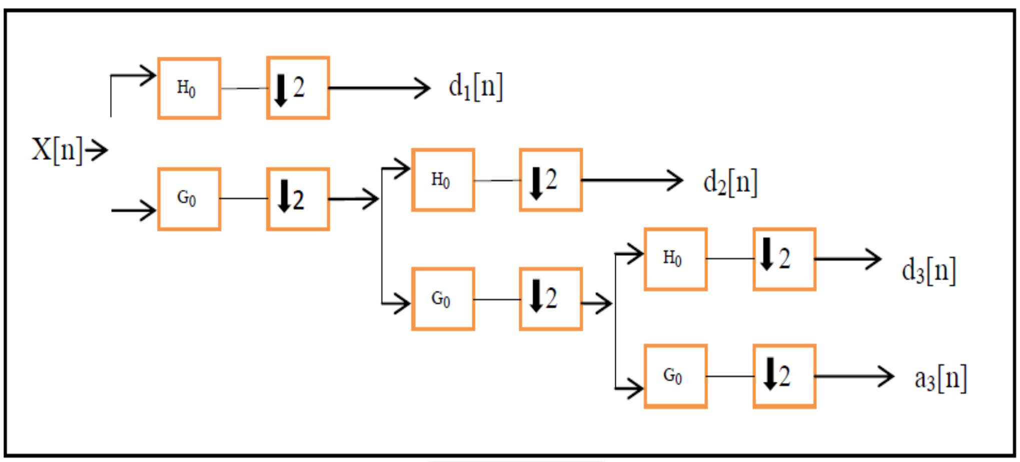

Figure-6: Implementation of Multi Level DWT

Where, Ho = High Pass Filter
Go = Low Pass Filter
d1[n] = Level one decomposition
d2[n] = Level two decomposition and so on
a3[n] = Level three approximation

Comparison of DWT with others: From here we can see that in case of DWT we can assign different time intervals for different frequency components. In the top block we have assigned a lower time interval and hence a higher frequency while in the bottom one we have assigned longer time interval and a low frequency

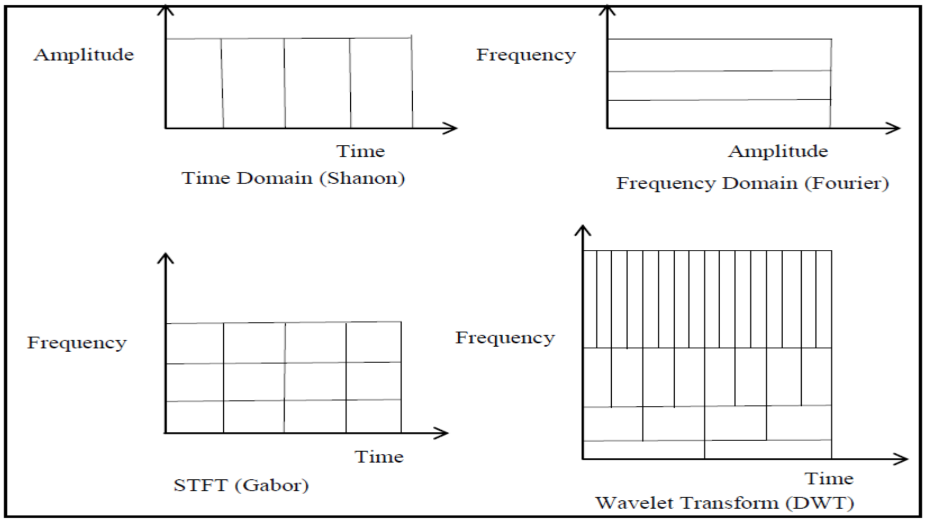

Figure-7: Different Transforms Methods

3. PROPOSED METHODOLOGY

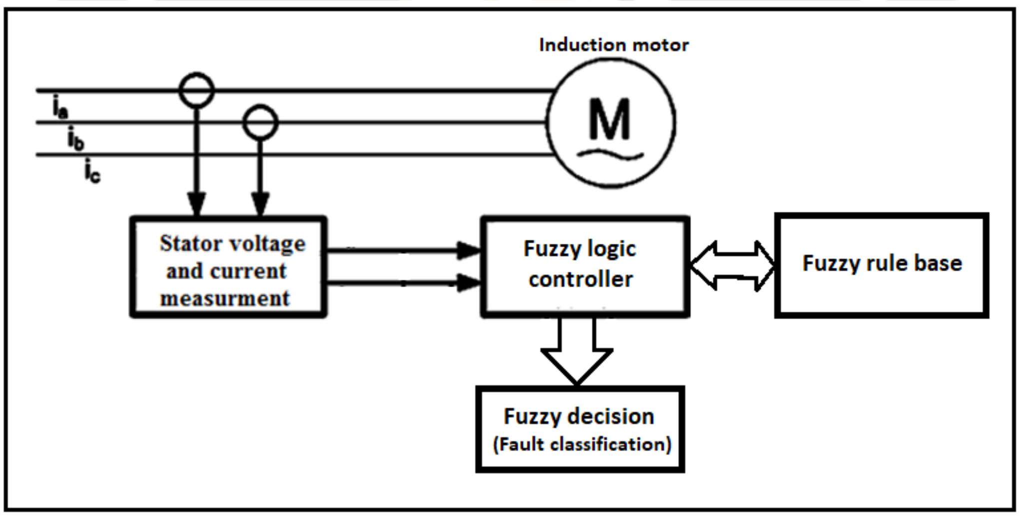

Figure-8: Generalized block diagram of fuzzy logic controller based approach

Figure 8 shows the fuzzy logic controller based three phase induction motor fault classification. In these approach first three phase induction motor input voltage and input current are measured using CTs and PTs. Fuzzy rule base design for fuzzy logic controller system, for that purpose three phase induction motor operate on normal condition and different fault conditions. Based on reading of three phase voltage and current, rules are design for normal, phase to phase winding fault, phase to ground winding fault and short circuit fault. Then after fuzzy logic controller places after three phase voltage and current measurement system. The detail of fuzzy logic controller and Fast Fourier transform explain on chapter 4.

3.1 Wavelet Transform Approach

In figure 8 shows the block diagram of proposed approach in which input three phase voltage and current of three phase induction motor send to the wavelet transform toolbox in MATLAB simulink software. The wavelet transform calibrates the details and approximate coefficients for all three phase currents and all three phase voltages. Then after we have to calibrate the spectral energy of each details and approximate signal for analysis of different fault conditions at induction motor stator side.

3.2 Project Implementation

This project implementation will be done using MATLAB Simulink software. The major blocks will be design in MATLAB simulink as follows:

- Simulation of power system using simpower system toolbox.
- Simulation of three phase induction motor using sim power system toolbox.
- Simulation of fault analysis system for induction motor using simpower system toolbox.
- Simulation of FFT for frequency component analysis of voltage and current waveform of stator input supply.
- Simulation of frequency analysis system for fault analysis using DSP (Digital Signal Processing) toolbox.
- Simulation of different fault in three phase induction motor.

4. SIMULATION RESULTS

4.1 FFT Analysis

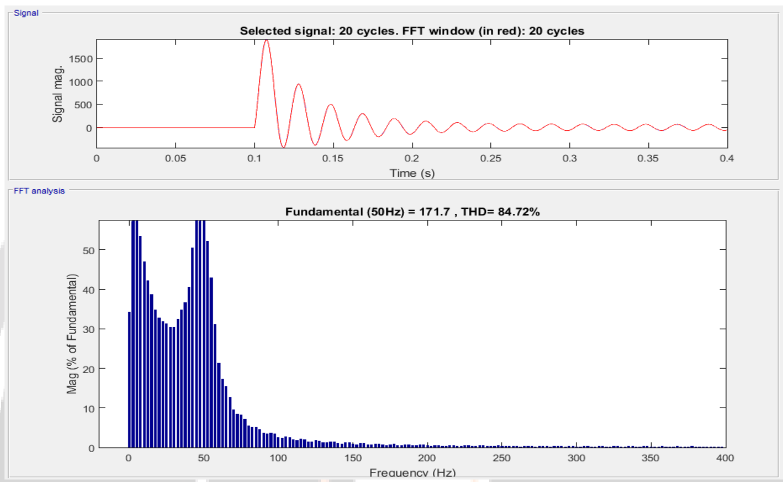

Figure-9: FFT Analysis on phase A current signal during normal condition

The FFT analysis of all three phase voltages and currents are done using FFT analysis toolbox in MATLAB simulink software. FFT analysis is done for normal conditions as well as faults conditions at stator of induction motor. The fault conditions are phase to ground, winding phase to phase fault and three phase short circuit winding faults. The FFT analysis of three phase voltages and three phase currents for each phase are calibrated for normal and fault condition shown in figure 6.1 to 6.21. Also table 6.1 shows the total harmonics distortion calibrated at each three phase voltages and current during normal condition and stator faults conditions.

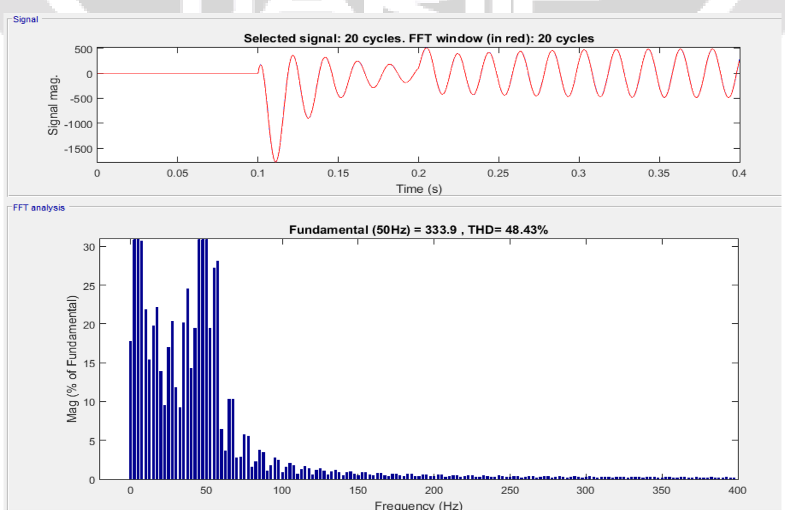

Figure-10: FFT Analysis on phase A current of induction motor during phase to ground fault in phase A winding to Ground

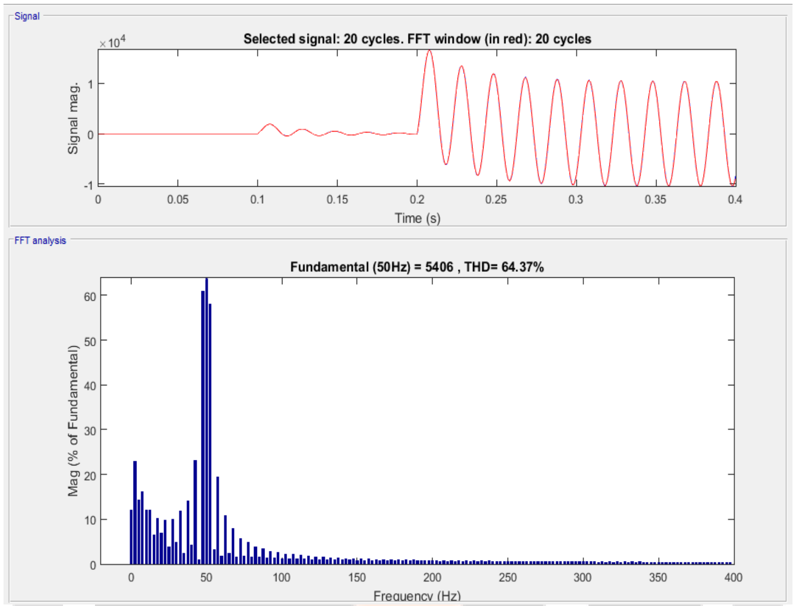

Figure-11: FFT Analysis on phase A Current of induction motor during three phase short circuit in stator winding

Table-2: FFT Analysis result for calibration of Total Harmonics Distortion (THD)

Sr No	Fault type	Total Harmonics Distortion (THD) %					
		Va	**Vb**	**Vc**	**Ia**	**Ib**	**Ic**
1	Normal	1.7	1.93	1.55	84.72	93.91	84.81
2	Ph-Gnd (A-G)	53.21	2.06	2.17	64.02	101..97	48.43
3	Ph-Gnd (B-G)	2.37	55.47	1.7	51.29	66.43	90.55
4	Ph-Gnd (C-G)	1.78	2.51	50.75	91.9	51.08	68.02
5	Ph-Ph (A-B)	46.68	49.31	2.14	63.81	63.56	48.99
6	Ph-Ph (B-C)	2.23	46.69	48.95	46.57	66.06	66.28
7	Ph-Ph (A-C)	45.34	2.445	43.1	65.59	48.02	66.15
8	Three phase short circuit	68.32	73.65	68.17	64.38	64.55	66.8

Table 2 shows the Total harmonics distortion calibration using FFT analysis. From above table it is clear that during normal condition of three phase induction motor THD for three phase voltage is below 2% and three phase current THD is in between 80 to 95%. For abnormal condition total harmonics distortion for faulted phases was increases that means harmonics content increases in faulted phase.

4.2 Fuzzy logic controller designing

Figure 12 shows the fuzzy logic controller designer window in matlab simulink software in which there are total six inputs and one output for design fuzzy logic controller. The six inputs are three phases measured input voltage and three phase currents of induction motor. Also single output of fuzzy logic controller is the shows the status of different types of fault condition as well as normal condition.

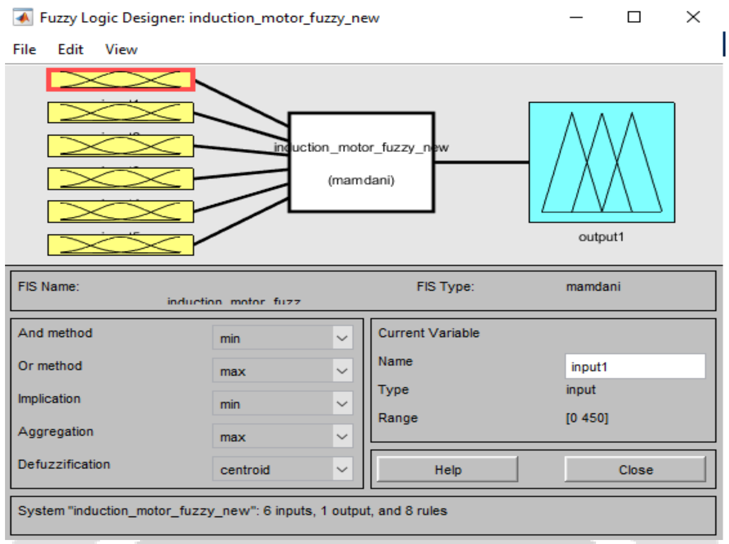

Figure-12: Fuzzy logic controller designing toolbox in MATLAB simulink for induction motor fault analysis

Table-3: Details of membership functions for three phase input voltages

Name of linguistic variable	Type of membership function	Range of Membership function
Low	Triangular	0 to 50 to 100
Medium	Triangular	100 to 150 to 200
High	Triangular	200 to 325 to 450

Figure 13 shows the phase A voltage membership functions designer window in which phase A voltage divided into three linguistic variables like Low, Medium and High and details of each linguistic variable shown in table 4. Similarly, Phase B and Phase C voltage membership function design as Phase A variables with same membership function selections and values.

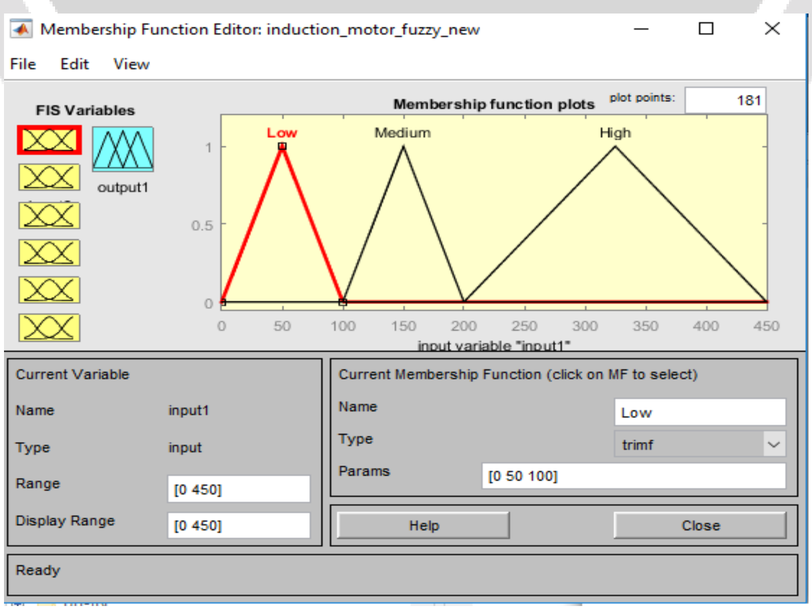

Figure -14: Membership function for three phase stator input voltage (Va, Vb and Vc)

Table-4: Details of membership functions for three phase input currents

Name of linguistic variable	Type of membership function	Range of Membership function
Low	Triangular	0 to 25 to 50
Medium	Triangular	50 to 1838 to 3725
High	Triangular	3725 to 5615 to 7500

Table-5: Details of Membership functions for fuzzy logic controller

Name of linguistic variable	Type of membership function	Range of Membership function
Normal	Triangular	0 to 0.5 to 1
Phase to phase fault	Triangular	1 to 1.5 to 2
Phase to ground fault	Triangular	2 to 2.5 to 3
Short circuit fault	Triangular	3 to 3.5 to 4

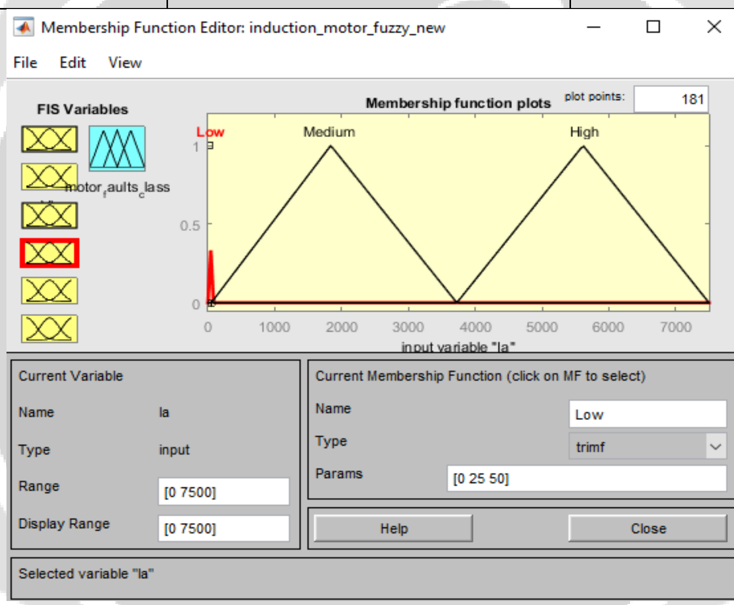

Figure-15: Membership function for three phase stator input current (Ia, Ib and Ic)

Figure 15 shows the phase A current membership functions designer window in which phase A current divided into three linguistic variables like Low, Medium and High and details of each linguistic variable shown in table 5. Similarly, Phase B and Phase C current membership function design as Phase A variables with same membership function selections and values.

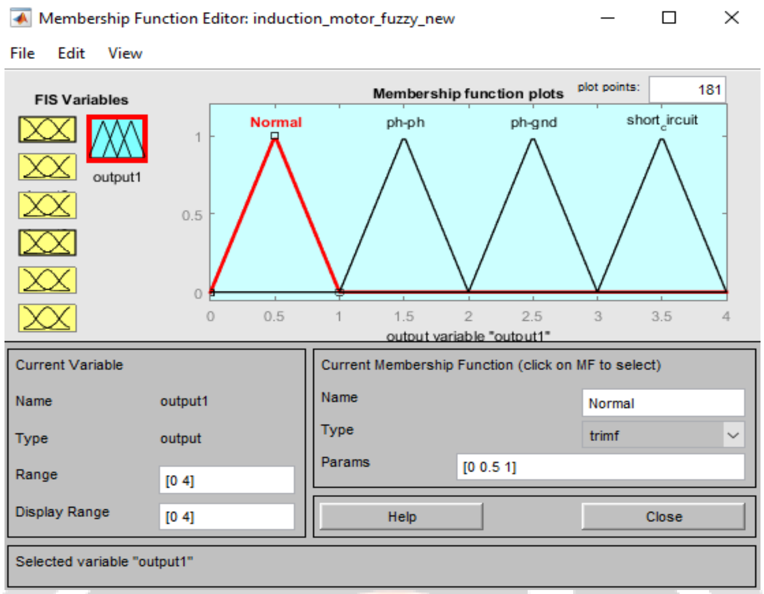

Figure-16: Membership function for fuzzy decision for three phase induction motor fault classification

Figure 16 shows the output membership function designer window for fuzzy logic controller which classifies the normal condition and fault conditions like winding phase to ground fault, Winding phase to phase faults and three phase short circuit fault. The output is divided into three linguistic variables like normal. Phase to ground, phase to phase and short circuit and details of each membership function shown in table 5.

Figure 17 shows the fuzzy rule base editor window in which we have to edit different types of fuzzy rule bases by selecting the six inputs and corresponding output. There are total eight rules design which are "IF-THEN-AND" rules for classify the different fault conditions and normal conditions.

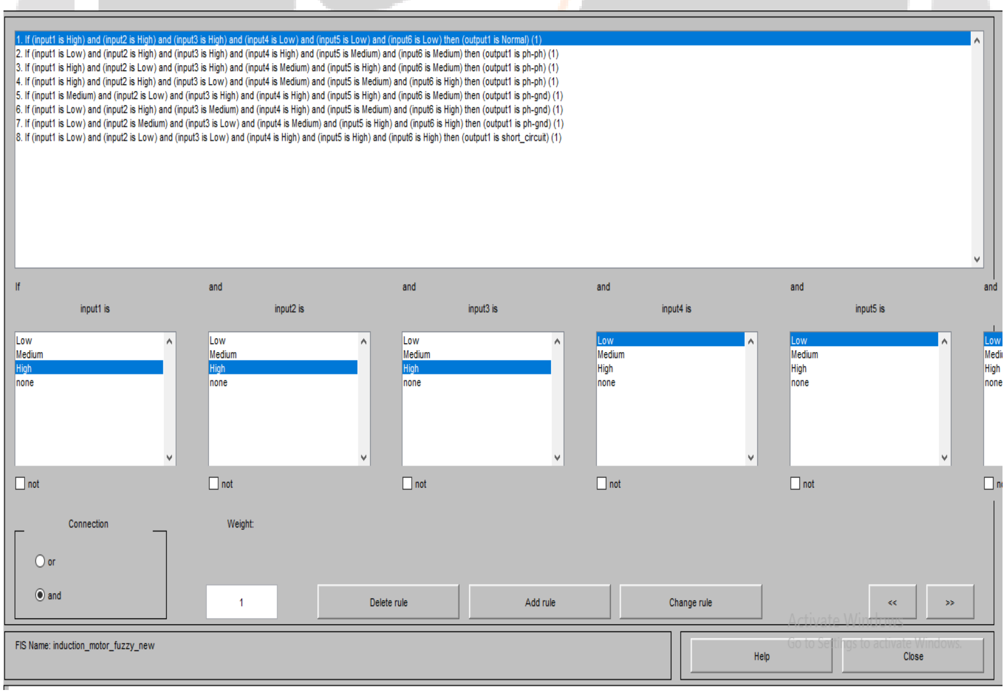

Figure-17: Fuzzy rule base for fuzzy logic controller

Table-6: Three phase stator current and voltage for different fault condition and normal condition

Sr No	Faults	Fault Type	Va	Vb	Vc	Ia	Ib	Ic
1	Normal	Normal	229.4	229.4	229.4	47.51	47.48	47.52
2	AG	Wgd ph-Gn	89.24	220	218.7	7174	313.3	345.1
3	BG	Wgd ph-Gn	218.8	89.24	220	345.2	7174	313.3
4	CG	Wgd ph-Gn	220	218.7	89.24	313.5	345.1	7174
5	AB	Wdg ph-ph	120.8	94.51	215.3	6459	6396	521.8
6	BC	Wdg ph-ph	215.2	120.8	94.5	522	6457	6393
7	AC	Wdg ph-ph	94.47	215.2	120.7	6395	522.1	6458
8	ABC	Wdg ph-ph	14.83	14.81	14.79	7410	7403	7399
9	ABCG	Wgd ph-Gn	14.83	14.8	14.8	7412	7402	7397

Table 6 shows the three phase voltage and current of three phase induction motor measured during normal conditions and faults conditions at different winding phases of motor. That data are useful for design the fuzzy rule base and fuzzy input membership functions for design fuzzy logic controller.

Table-7: Fuzzy logic controller results for different fault condition

Sr No	Fault type	Range of fuzzy decision	Actual decision by fuzzy controller
1	Normal	0 to 1	0.5
2	Ph-Gnd (A-G)	1 to 2	1.5
3	Ph-Gnd (B-G)	1 to 2	1.5
4	Ph-Gnd (C-G)	1 to 2	1.5
5	Ph-Ph (A-B)	2 to 3	2
6	Ph-Ph (B-C)	2 to 3	2
7	Ph-Ph (A-C)	2 to 3	2.5
8	Three phase short circuit	3 to 4	3.5

Table 7 shows the fuzzy logic controller outputs for different conditions like normal and faults conditions. It is observed that fuzzy logic controller is providing the outputs for all normal and fault cases in decided membership function ranges. And fuzzy controller provides the output for classification of all normal and faults conditions 100%.

4.3 Three Phase induction motor parameters for normal condition

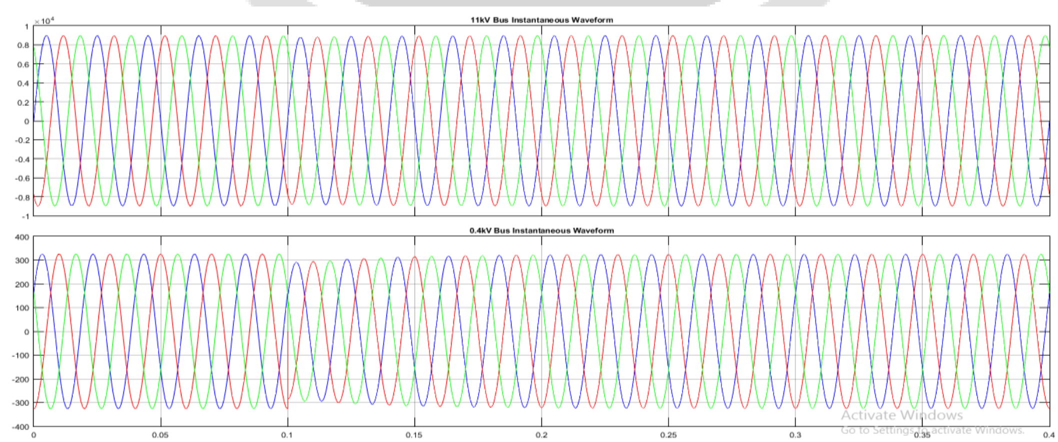

Figure-18: Three phase 11 KV bus bar voltage and 0.4 KV bus bar voltage measurement during normal condition

Figure 18 shows the three phase voltage and current measured at input or stator side of three phase induction motor during normal condition. Here observed that, three phase voltage and current becomes normal throughout the operation. But at 0.1 second time when motor starts then currents becomes decreases while small fluctuations in three phase voltages during motor starting only.

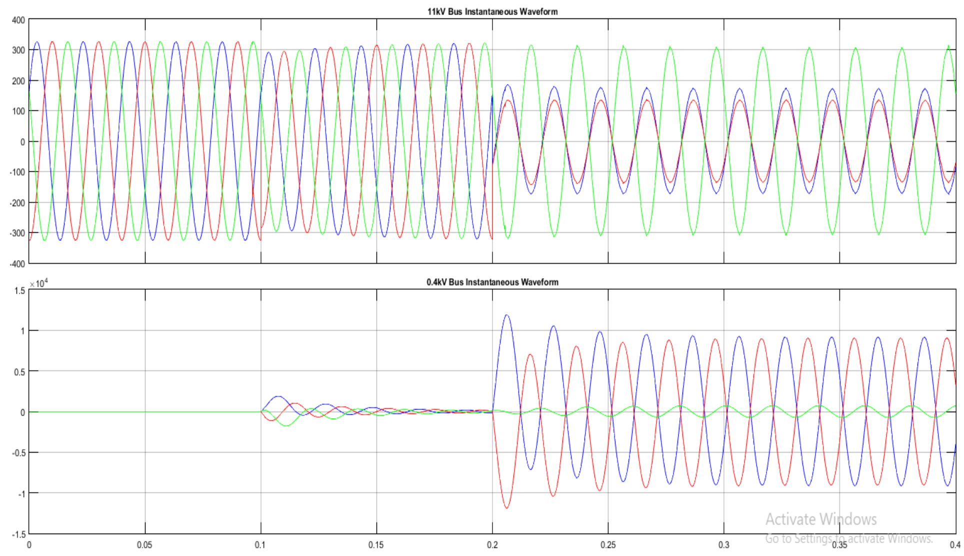

Figure-19: Three phase 11 KV bus bar voltage and 0.4 KV bus bar voltage measurements during Phase to phase winding fault in phase A and B winding operation

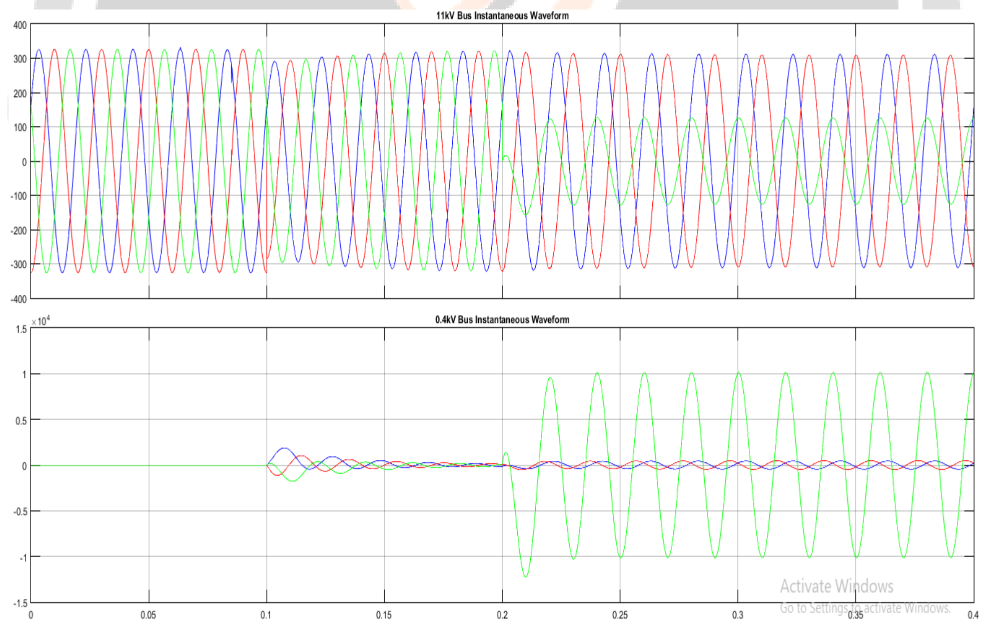

Figure-20: Three phase 11 KV bus bar voltage and 0.4 KV bus bar voltage measurements during Phase to ground winding fault in phase C to gnd winding operation

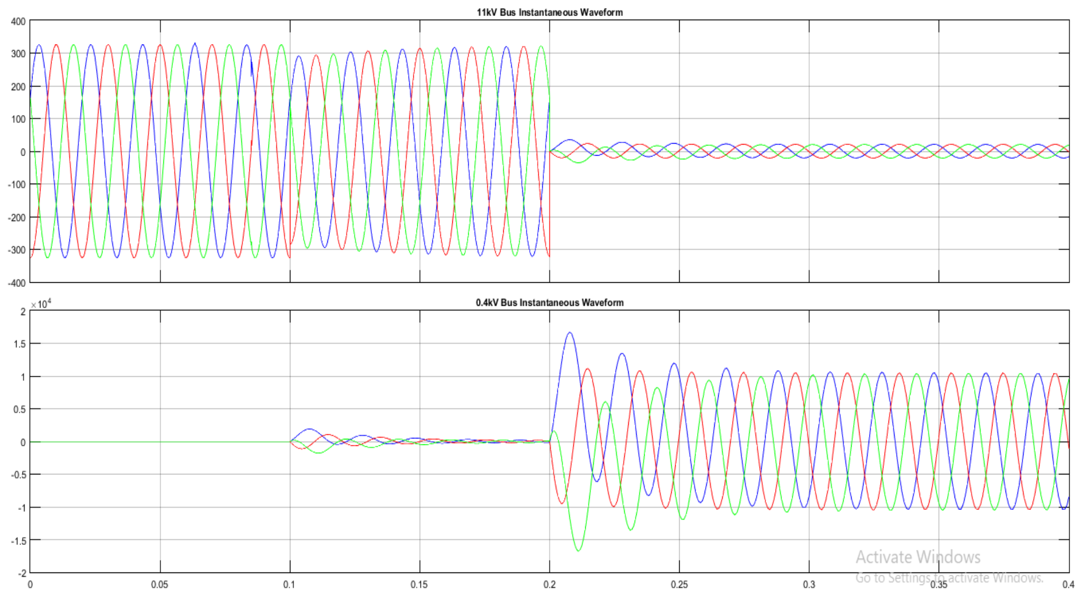

Figure-21: Three phase 11 KV bus bar voltage and 0.4 KV bus bar voltage measurement during short circuit faults operation

4.4. Wavelet transforms results

Figure 22 shows the wavelet multi-resolution analysis window for analysis of input phase A current of motor in which we have to use Db3 motor wavelet with 3 level of multi-resolution analysis. Similarly, for phase B and phase C, wavelet multi-resolution analysis results shown in figures 6.35 and 6.36 respectively.

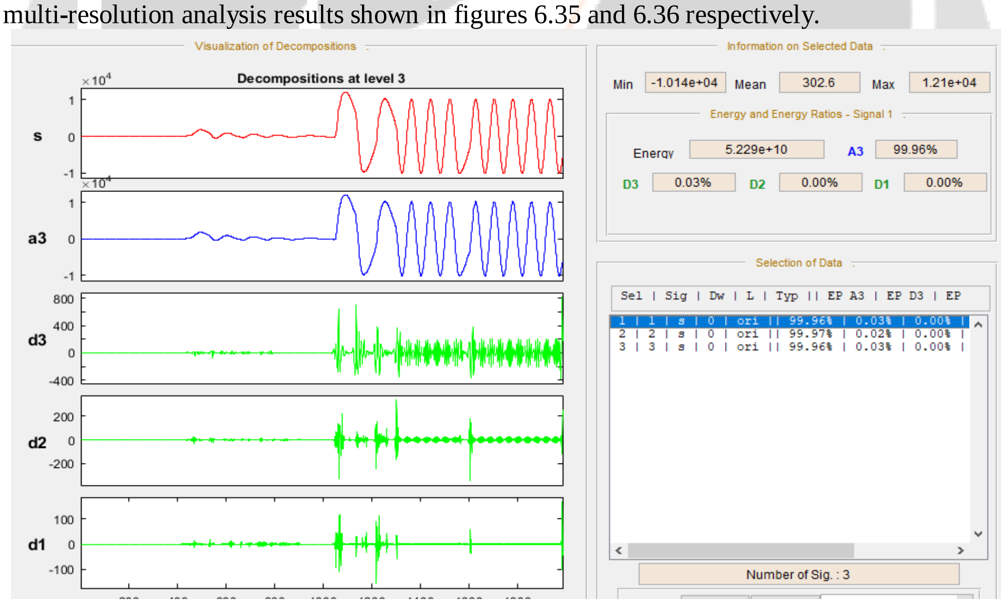

Figure-22: Wavelet multi-resolution analysis of current of phase A during Phase to ground fault in phase A to ground using DB3 Mother wavelet

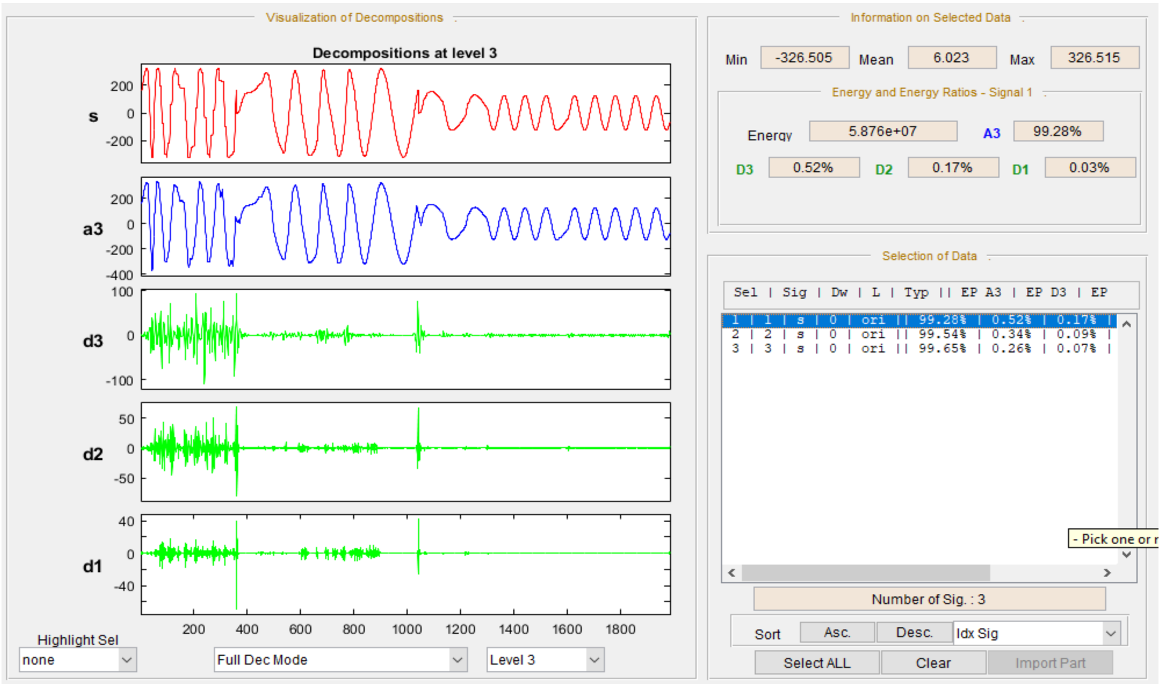

Figure-23: Wavelet multi-resolution analysis of voltage of phase A during Phase to ground fault in phase A to ground using DB3 Mother wavelet

Table-8: Wavelet transform energy during different conditions

Type of fault	Ia Energy	Ib Energy	Ic Energy	Va Energy	Vb Energy	Vc Energy
Phase to Gnd (AG)	5.233e10	1.979e8	2.936e8	5.955e7	1.077e8	9.886e7
Phase to Gnd (BG)	3.318e8	7.169e10	3.126e8	1.199e8	6.87e7	1.153e8
Phase to Gnd (CG)	3.12e8	2.185e8	6.694e10	1.08e8	1.21e8	6.26e7
Phase to phase (AB)	5.45e10	5.283e10	4.415e8	6.97e7	7.402e7	1.121e8
Phase to phase (BC)	4.029e8	5.232e10	5.095e10	1.098e8	8.101e7	6.465e7
Phase to phase (AC)	5.605e10	3.093e8	5.802e10	6.247e7	1.21e8	7.157e7
Short Circuit	2.681e10	2.07e10	2.394e10	5.126e7	6.277e7	5.334e7

From table 8, it is clear that,

- Energy calibrated during normal condition are threshold energy for three voltages and currents.
- In faulted phase, the energy for current is more than threshold energy.
- In faulted phase, the energy for voltage is less than threshold energy. Note that here threshold energy for voltages and current signals are 1.8e8 and 2.00e8 respectively.

Table-9: Comparison of FFT, Fuzzy Logic control and Wavelet transform techniques

Sr No	**FFT Analysis**	**Fuzzy Logic control Technique**	**Wavelet Transform Technique**
1	FFT analyzed frequency components of input voltage and current of stator.	Not analyzed frequency of three phase stator voltage and current	Detail analysis of time and frequency of three phase voltage and current
2	Not classify type of fault occurs in machine	Exactly classify each type of fault in three phase induction motor	For identification of faulted phase we need analyzed energy of each voltage and current

			signal
3	Time required for analysis is more	Time require for classification in very less.	Time required more analysis of each phase energy
4	Complex analysis	Easy analysis	Easy but time consuming
5	Not generalization for different machines	Generalization of rule base system design for any machine protection	Analysis done for any signals like voltage, current, frequency, power etc

From table 9, it is clear that fuzzy logic controller is most superior classifier for stator winding faults classification then after wavelet transform is second best method. And FFT analysis method is time consuming and not accurate method for classification of faults.

5. CONCLUSION

FFT analysis only analyzed total harmonics distortion of stator input voltage and current. FFT Analysis takes more time for analysis of fault condition. It requires analyzing each phase voltage and current THD. Fuzzy logic controller rule base system easily classifies each type of three phase induction motor fault conditions. Fuzzy logic controller classifies the fault with the short duration of time as compared with FFT analysis technique. Efficiency of fuzzy logic controller as compared with FFT analysis for three phase induction motor fault classification is more. Wavelet transform technique also classifies the different faulted phase of stator winding. But analysis time is more in wavelet transform.

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