Stator Fault Diagnosis of Single Phase Induction Motors Using Fuzzy Logic System

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Abstract

Fault diagnosis of electrical machine is gaining particular importance in view of machine down-time and revenue losses to the industry. Therefore, it is always essential to check motor performance from time to time. This paper use the technology of fuzzy logic for detecting and diagnosing the stator faults in single phase induction motor to avoid the damage of the motor. The application of fuzzy logic is simulated using fuzzy logic tool box in MATLAB. The main function of fuzzy logic fault detection consists of two inputs the first for stator current and the second for the rotor speed and one output which is the incipient fault.

تشخيص اعطال الساكن في المحركات الحثية احادية الطور باستخدام نظام المنطق المضبب

الخلاصة

تشخيص اعطال المكائن الكهربائية تلاقي اهمية كبيرة خاصة من اجـل تفـادي الخسـائر الصناعية التي قد تحدث بسبب هذه الاعطال ، لذا من الضروري دائما فحص اداء المحركـات مـن وقت لاخر. يهدف البحث الحال الى استخدام المنطق المضـبـب لتشخيص اعطال العضو السـاكن في المحرك الحثي احادي الطور، تم محاكاة تطبيق المنطق المضبب باستخدام fuzzy logic tool box in MATLAB تتضمن الدالة الرئيسية لمنظومة المنطق المضبب قيمتين للادخال الاولى تمثل تيار الساكن والثانية سرعـــة الدوار وقيمة واحدة للاخراج تمثل الخطأ المتوقع.

1. Introduction

Single phase induction motors are the most common type of electric motors which find wide domestic, commercial and industrial applications [1]. They are subjected to different ambient and working conditions. Which lead to occurrence of incipient faults at an early stage to the down time of the motor [2]. These incipient faults if left undetected, contribute to the degradation and eventual failure of the motor [3]. It is Preferable to find faults before complete motor failure. This is called incipient faults detection, often the motor can run with incipient faults but eventually it will lead to motor failure causing down time and large losses [4]. There are several different types of faults that can manifest themselves in an induction motor. Faults are often classified according to where they occur in motor. The percentage of

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failures in induction motors components are as following:-

- Stator faults (38 %).
- Rotor faults (10 %).
- Bearing faults (40 %).
- Other faults (12 %).

It is important to note that even if the stator fault account makes up (38 %) of the all faults it is very important to spot them in time because they can lead to the total destructions of the motor [5]. Many of the motor incipient fault detection schemes can be applied noninvasive on-line with out the need of expensive monitoring equipment by using microprocessor. With proper monitoring and fault detection schemes, the incipient faults can be detected in their early stages. Thus, maintenance and down time expenses can be reduced and reliability can be improved [6]. Methods of faults diagnostic are used to identify incipient faults involving several fields of science and technology. They are generally classified as those based on mathematical models of machine [2].

Fuzzy logic based technique is proposed in this paper to detect the stator winding faults in single phase induction motor. The data is provided by MATLAB Simulink of a (1/4) split-phase induction motor with fault in stator winding for two load conditions. The stator current and rotor speed are considered as the base parameters for constructing the member ship function.

2. Modeling of a single phase induction motor

The equivalent circuit of a single phase induction motor is shown in fig (1). The superscripts s and prime can be used to denote the transformed rotor variables in the stationary dq reference form and the referred quantities to the stator qs windings respectively. For simulation purposes the necessary quantities such as voltage, flux, torque and rotor motion equations are [7]: -

$$y_{qs} = w_b \int \{ v_{qs} + \frac{r_{qs}}{x_{lqs}} (y_{mq} - y_{qs}) \} d(t) \quad \text{..... (1)}$$

$$y'_{ds} = w_b \int \{ v'_{ds} + \frac{r'_{ds}}{x'_{lds}} (y'_{md} - y'_{ds}) \} d(t)$$

$$y'^{s}_{qr} = w_b \int \{ v'^{s}_{qr} + \frac{w_r}{w_b} y'^{s}_{dr} + \frac{r'_r}{x'_{lr}} (y_{mq} - y'_{qr}) \} d(t)$$

$$y'^{s}_{dr} = w_b \int \{ v'^{s}_{dr} - \frac{w_r}{w_b} \cdot y'^{s}_{qr} + \frac{r'_r}{x'_{lr}} (y'_{md} - y'^{s}_{dr}) d(t) \quad \text{.....(2)}$$

$$y_{mq} = x_{mq} (i_{qs} + i'^{s}_{qr}) \quad \text{..... (3)}$$
$$y'_{md} = x_{md} (i'_{ds} + i'^{s}_{dr})$$

$$y_{qs} = x_{l\,qs} \cdot i_{qs} + y_{mq}$$
$$y'_{ds} = x_{l\,ds} \cdot i'_{ds} + y'_{md}$$
$$y'^{s}_{qr} = x'_{lr} \cdot + y_{mq} \quad \text{........ (4)}$$
$$y'^{s}_{dr} = x'_{lr} . i'_{dr} + y'_{md}$$

$$\mathrm{T}_{em} = \frac{p}{2 \cdot w_b} (y'_{ds} \cdot i_{qs} - y_{qs} \cdot i'_{ds}) \quad \text{... (5)}$$

$$J \frac{dw_{rm}}{dt} = T_{em} + T_{mech} - T_{damp} \quad \text{... (6)}$$

where:-

y_{qs} = q-axis main winding flux linkage, w_b = base electrical frequency, v_{qs} = q-axis main winding voltage, r_{qs} = q-axis main winding resistance, $x_{l\,qs}$ = q-axis main winding leakage reactance, y_{mq} = q-axis main winding magnetizing flux linkage, ψ'_{ds} = d-axis auxiliary windings flux linkage referred to main winding, v'_{ds} = d-axis auxiliary winding voltage referred to main winding, r'_{ds} = d-axis auxiliary winding resistance referred to main winding, x'_{lds} = d-axis auxiliary winding leakage reactance referred to main winding, ψ'_{md} = d-axis magnetizing flux linkage referred to main winding, ψ'^{s}_{qr} = q- axis rotor flux linkage referred tov'^{s}_{qr} = q-axis rotor voltage referred to main winding, w_r = rotor speed, , r'_r =rotor resistance referred to main winding, x'_{lr} = rotor reactance referred to maim winding, ψ'^{s}_{dr} =d-axis rotor flux linkage referred to main winding, v'^{s}_{dr} = d-axis rotor voltage referred to main winding, i_{qs} = q-axis main winding current, i'^{s}_{qr} = q-axis rotor current referred to main winding, i'_{ds} = d-axis auxiliary winding current referred to main winding, i'^{s}_{dr} = d-axis rotor current referred to main winding, x_{mq} = q-axis main winding magnetizing reactance, x_{md} = d-axis main winding magnetizing reactance, T_{em} = development torque, w_b =base electrical frequency, J = rotor moment of inertia, T_{mech} = mechanical torque, T_{damp} = damping torque,

3. Fuzzy logic

Fuzzy logic (FL) is a multivolume logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low. It is a branch of mathematics that counters the traditional assumption that every thing within universe of discourse either belongs to a given set within that universe or doesn't [8].

Fuzzy logic concepts

Let X be some set of objects, with elements noted as x .Thus $X = \{x\}$

X is called universe of discourse and x represents the generic element of X the universe of discourse represent the input to the fuzzy logic and its range normalized data is a mapping of operating range to [0,1]. For checking the motor performance, the motor current operating range is chosen from (-2) to (1.7) and the rotor speed range is taken from (-10) to (300) these ranges are taken according to the simulation results of the healthy and faulty operation of the motor .

1. Fuzzy set

A fuzzy set A in X is characterized by a membership function mA(x) which maps each point in X onto the real interval [0.0 , 1.0]. As mA(x) approaches 1.0, the "grade of membership" of x in A increases [9].

2. Fuzzy set operations

Let A and B two fuzzy sets with membership functions m_A and m_B respectively. The set operations of union, intersection and complementation are defined in terms of characteristic function as follows [10].

Union

$m_A \cup m_B = \max(m_A(x)\ m_B(x))$... (7)

Intersection

$m_A \cap m_B = \min (m_A(x)\ m_B(x))$.. (8)

Compliment

$m_A - 1 = m_A{}'$ …….. (9)

3. Fuzzy number

A fuzzy number A is a continuous universe X. e.g. , real line, is a fuzzy set A in X which is normal and convex, i.e.

Max $m_A(x) = 1$ (normal)

$x \in X$

and

$m_A(l_{x1} + (1-l)x_2) \geq \min (m_A(x_1), m_A(x_2))$ (convex)

$x_1,\ x_2 \in X$

4. Linguistics variable

A linguistics variable speed (in general, X) is expressed as

T (speed) = {low, medium, high}

Where

T(x) is called term set and each term in t(x) is characterized by asset in a universe of discourse [11].

The linguistic variables in this research are (ids) and (w_r).

5. Derivation of rule

Generally, deign of fuzzy controllers is based on the operators understanding of the process instead of its detailed mathematical model. The main advantage of this approach is that it is easy to implement "rule of thumb" experiences and heuristics [11].

4. Simulated, Results and discussions

The MATLAB fuzzy logic tool box has been used to simulate the performance level of the motor considering the incipient faults. The data is generated for two incipient faults with two different load conditions; no load and step changing with load. fig. (2) Shows the simulation results of stator current and rotor speed with healthy and faulty situations.

The incipient faults considered are:-

1. Phase failure in auxiliary winding which can be simulated by increasing the value of auxiliary resistance.
2. Inter –turn short circuit which is simulated by decreasing the value of the auxiliary resistance to the half.

The stator current and rotor speed which are the input variables are classified in region with low (L), medium (M), and high (H) through the member ship function while the fault which acts as an out put variable is classified with phase failure (PH), short circuit (SC) and healthy (H) of operation thorough their fuzzy fault diagnosis system. The current range is chosen from (-2 to 1.7), rotor speed range is taken from (-10 to 300), and the fault rang from (0 to 1). The linguistic variables are given in table (1).

The membership functions used in this paper are the triangle membership which includes two values for input and one value for output. Fig. (3) shows the memberships for stator current, rotor speed and the output. The fuzzy rules from expert knowledge are given in table (2) the rules of fuzzy logic system are in if then form for example:-

If ids L and w_r L Then fault is PH with step change with load, this is rule no.(1). In the final stage the fuzzy action are reconverted in crisp ones by using the center of area method. According to this method, each affected output membership is cut at the level indicated by the previous max-rule, then the gravity center of the possible distribution is computed and becomes the numerical output value. Fig. (4) shows the test result for the cases of healthy, short circuit and phase failure of the motor. Fig (5) shows resulting surfaces for the output variable fault .it graphs the crisp values of fault condition versus stator current and rotor speed. The shape of this surface is depending upon the membership functions and fuzzy rule base.

The simulik model of faults detection system is shown in fig.(6).The fault will detect in this system according to the information in which the fuzzy logic fault detection system was built

5. Conclusions

The fuzzy logic system is proposed in this paper to detect the phase failure and inter-turn short circuit faults in single phase induction motor. The fuzzy logic system is used to simulate the problems related to fault detection in single phase motor by designing the proper membership functions. The stator current and rotor speed are considered as the base parameters for constructing the membership functions. Depending upon the linguistic variables, stator current and rotor speed whether low, medium or high . The simulation results show the use of fuzzy logic in fault detection provides more accurate results with less time and cost. Such a system can also be applied for other type of electrical machines by forming appropriate membership functions and rules by knowing the behaviors of the machines.

6. Appendix

The parameters of single phase induction motor in this paper are:-

1/4 HP, 110 V, 4- pole, 60 Hz

r_{qs} =2.02 Ω, $x_{l\,qs}$ = 2.79 Ω, r_{ds} = 7.14 Ω, x_{lds} = 3.22 Ω, y_{mq} = 66.8 wb.t, r_r = 4.14Ω, J= 1.46e-2 kg.m^2

7. References

[1] M.S. Ballal, Z.J. Khan, R.L. Sonolikar, "ANN Approach for The Incipient Faults Detection in Single phase Induction Motor", IE(1) Journal-EL, Volume 88, March 2008.

[2] V. Duraisamy, N. Devarajan, D. Somasundareswari, "Comparative Study of Fuzzy Logic Fault Diagnosis System for Single Phase Induction Motor", Academic Open Internet Journal, Volume 13, 2004

[3] Mishra M.K., Tarnekar S.G., Kothari D.P., Ghosh A., "Detection of Incipient Faults In Induction Motor Using Fuzzy Logic", Power Quality 98, 1998, pp.117-121.

[4] Jarmo Lehtonen, Heikki N. Koivo, "Fault diagnosis of Induction Motors With Dynamical Neural Network", 2001.

[5] Jover Rodriguez, P., Arkkio, A., "Detection of Stator Winding Fault in Induction Motor Using Fuzzy Logic", Applied Soft Computing, Vol.8, No.2, 2008, pp.1112-1120.

[6] Sinan Altig, Mo-Yuen Chow, H. Joel Trussell, "Fuzzy Inference Systems Implemented on Neural

Architectures for Motor Fault of ACM, March, 1994, Vol.37, No.3. Detection and Diagnosis", IEEE Transaction on industrial Electronics, Vol.46, No.6, December 1999.

[7] Chee. Mun Ong, "Dynamic Simulation of Electric Machinery Using Matlab/ Simulink", Prentic Hall, PTR, New Jersey, 1998.

[8] M. Hellman, "Fuzzy Logic Introduction", Laboratorial Antennas Radar Telectiom, University De Rennes, France.

[9] Scott, C., Winder, " Fuzzy Set and Fuzzy Logic Theory and Application", prentice Hall PTR, New Jersey.

[10] Toshinori Munakata, and Yashvant Jani, "Fuzzy System: An Over view", Commmunications where, L-low, M – Medium, H – High where, L-low, M – Medium, H – High

Table (1) linguistic variables

	L		M		H	
	min	max	min	max	min	max
ids	-2	0.3	0.25	1.4	1.37	1.7
w_r	-10	5.5	5.3	8	7.99	500

Table (2) fuzzy logic rules

rule	1	2	3	4	5	6	7	8	9
ids	L	L	L	M	M	M	H	H	H
w_r	L	M	H	L	M	H	L	M	H
fault	PH with step change with load	null	PH no load	null	Healthy with step change with load	Healthy no load	SC with step change with load	null	SC no load

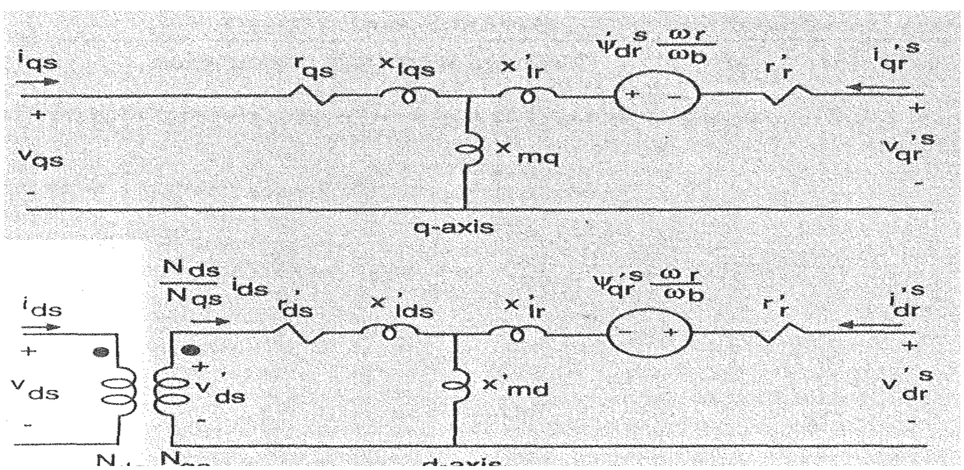
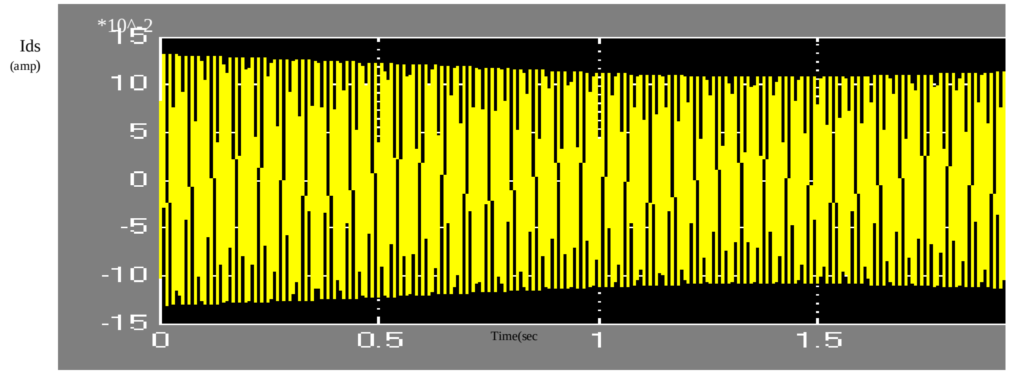
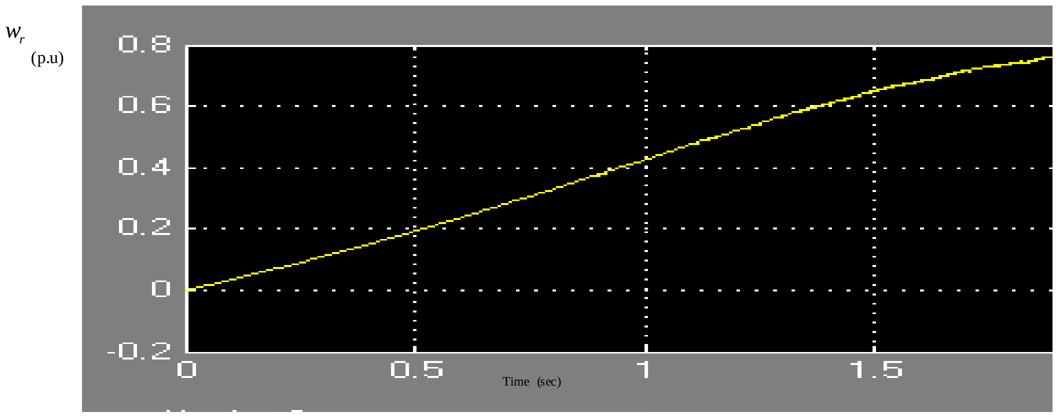


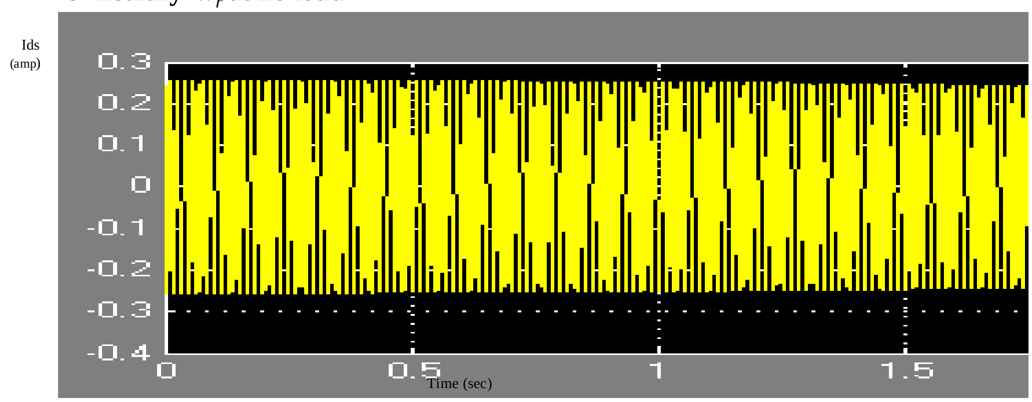
Figure (1) Equivalent circuit of single phase induction motor



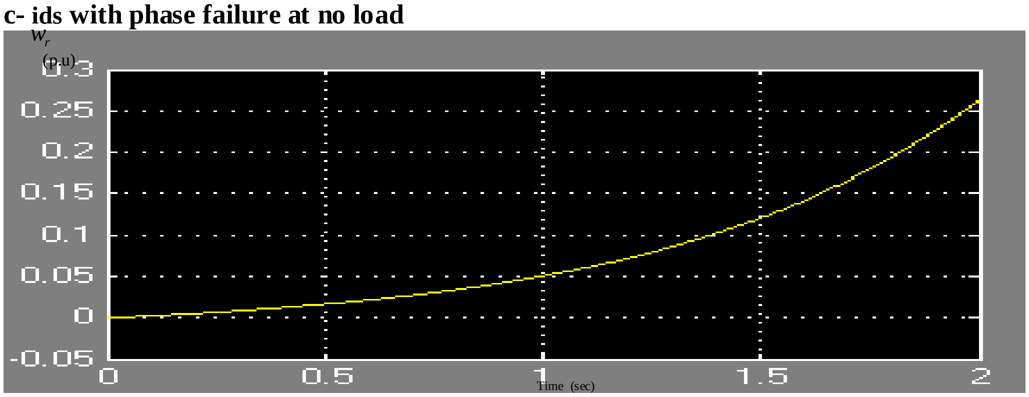
a- healthy ids at no load



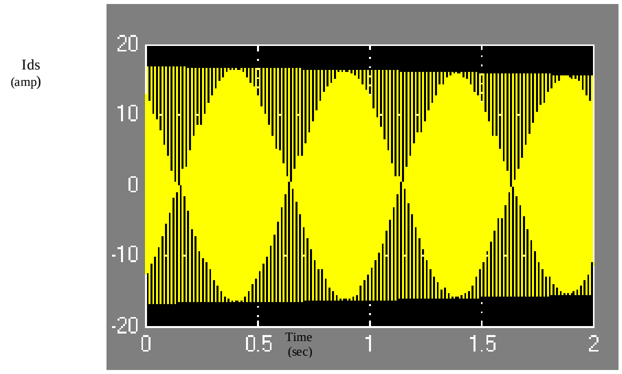
b- healthy w_r at no load



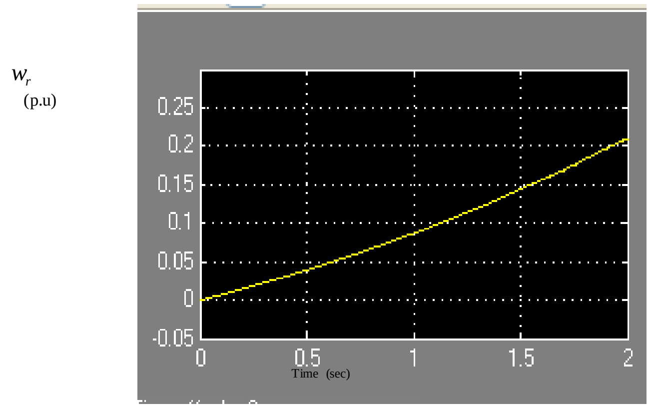
c- ids with phase failure at no load



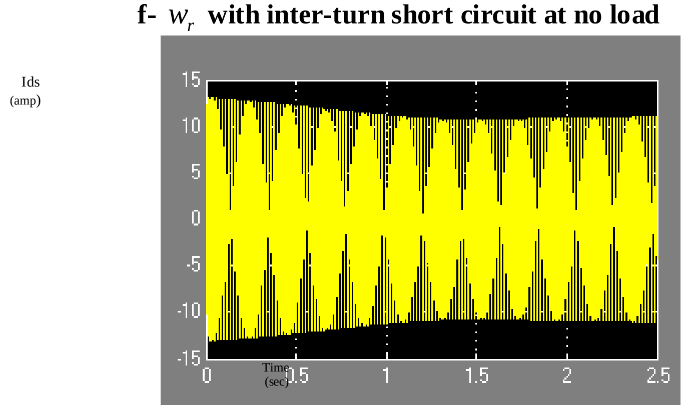
d- w_r with phase failure at no load



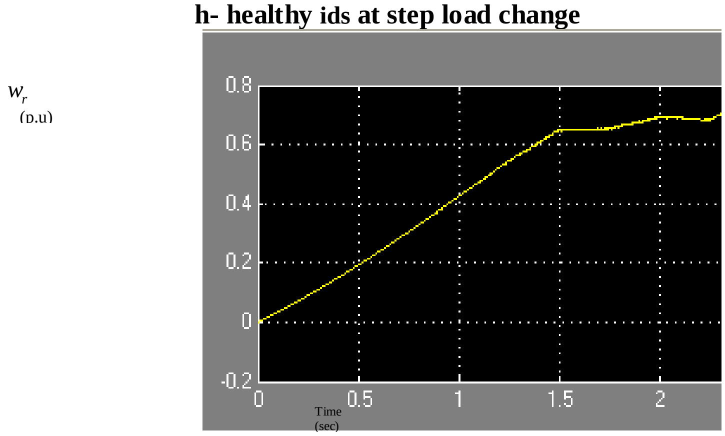
e- ids with inter-turn short circuit at no load



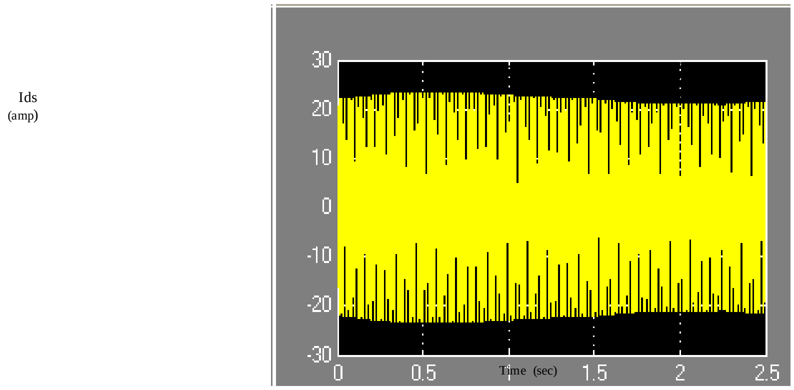
f- w_r with inter-turn short circuit at no load



h- healthy ids at step load change

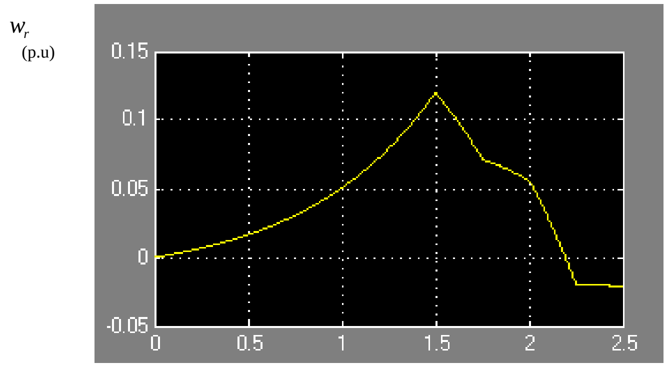


i- healthy w_r at step load change

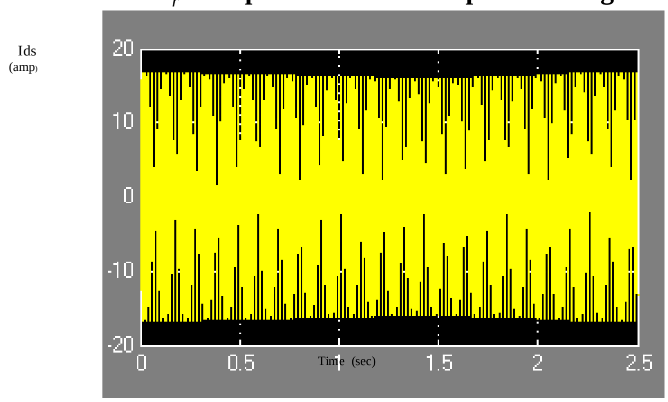


j- - ids with phase failure at step load change

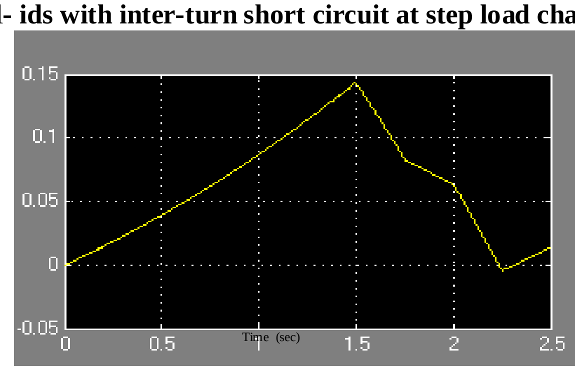
Figure (2) Stator current and rotor speed when healthy and faulty motor under different load conditions.



k- w_r with phase failure at step load change



l- ids with inter-turn short circuit at step load change



m- w_r with inter-turn short circuit at step load change

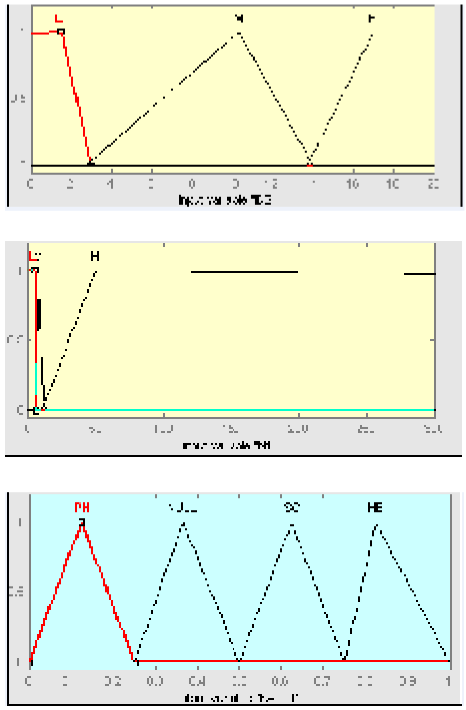


Figure (3) membership function

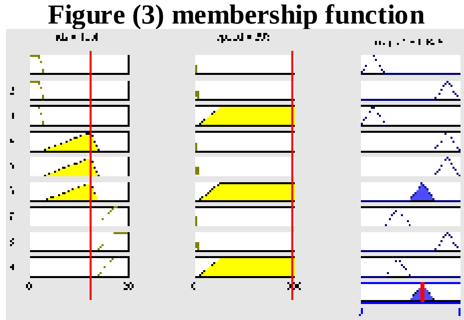


Figure (4) test results for the cases of healthy, short circuit and phase failure of the motor

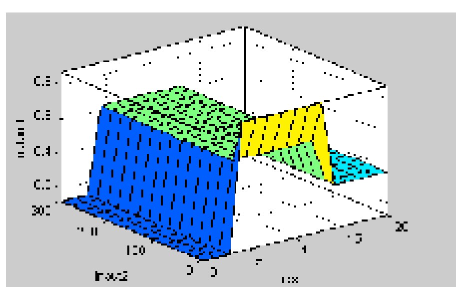


Figure (5) resulting surfaces for the output variable fault

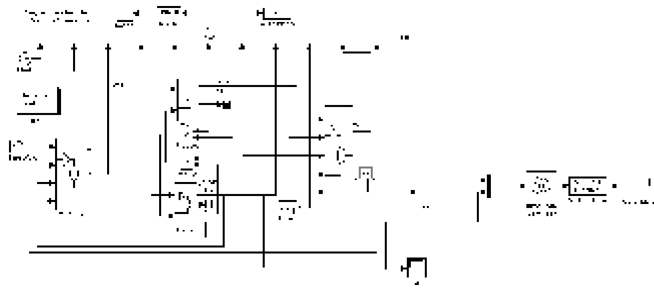


Figure (6) the simulink model of fault detection system