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INDUCTION MOTOR STATOR FAULT DETECTION USING FUZZY LOGIC

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Abstract: Now day's artificial intelligence techniques are being preferred over traditional protective relays for the condition monitoring of induction motors. In this paper an attempt is made to review the applications of neural/fuzzy artificial intelligence techniques for induction motor condition monitoring. Various Systems like expert system, fuzzy logic system, artificial neural networks, and genetic algorithm have been extensively reported in literature. These systems and techniques are integrated into each other and also with more traditional techniques. A brief of various artificial intelligence techniques highlighting the merits and demerits of each has been discussed. The future trend on condition monitoring of induction motors are also indicated.

I. INTRODUCTION

The three phase Induction motors due to their simple construction, high reliability and low cost, have dominated in the field of electromechanical energy conversion by having more than 75% of motors in use. Though the probability of breakdowns of Induction motors is very low, the fault diagnosis has become almost indispensable. Particularly when they are working in sophisticated automated production lines.

To decrease the machine down time and improve stability on line diagnostic features are to be necessarily incorporated with the drives. In modern industry lots of machines depend on mutual operation, and the cost of unexpected breakdowns is very high. Hence condition monitoring techniques comprising of fault diagnosis and prognosis are of great concern in industry and are gaining increasing attention. The Artificial Intelligence (AI) techniques have certain distinct advantages over traditional condition monitoring approaches [4-5].

In the present paper an effort has been made to present a review of the application of AI techniques especially neural network and fuzzy logic for induction motor condition monitoring. These systems can be integrated together and also with other traditional techniques [4]. In this we are presenting a review on the subject of applications of neural/fuzzy techniques for induction motor condition monitoring. A number of publications have been reviewed. This paper contain introduction, the subsequent sections cover the classification of induction motor faults, the various AI techniques, Neural/Fuzzy techniques for induction motor condition monitoring, comparison of various AI techniques, futuristic trends and the conclusion.

II. INDUCTION MOTOR FOR VARIOUS FAULT CONDITIONS

A. Introduction

A theory is often a general statement of principle abstracted from observation and a model is a representation of a theory that can be used for prediction and control. To be useful, a model must be realistic and yet simple to understand and easy to manipulate. These are conflicting requirements, for realistic models are seldom simple and simple models are seldom realistic. Often, the scope of a model is defined by what is considered relevant. Features or behaviors that are pertinent must be included in the model and those that are cannot be ignored. Modeling here refers to the process of analysis and synthesis to arrive at a suitable mathematical description that encomposes the relevant dynamic characteristics of the component, preferably in terms of parameters that can be easily determined in practice.

In mathematical modeling, we try to establish functional relationships between entities that are important. A model supposedly imitates or reproduces certain essential characteristics or conditions of the actual – often on a different scale. It can take on various forms: physical, as in scale-models and electrical analogs of mechanical systems; mental, as in heuristic or intuitive knowledge; and symbolic, as in mathematical, linguistical, graphical, and schematical representations.

Simulation can be very useful in many scientific studies that proceed as follows:

1. Observing the physical system.
2. Formulating a hypothesis or mathematical model to explain the observation.
3. Predicting the behavior of the system from solutions or properties of the mathematical model.
4. Testing the validity of the hypothesis or mathematical model.

Every model has parameters, which are to be estimated. The model must lend itself to methods by which these parameters can be determined experimentally; otherwise the model will be incomplete. The developed model must be verified and validated. Verification involves checking the consistency of the mathematics, the solution procedure, and the underlying assumptions. Validation is the determination of how adequately the model reflects pertinent aspects of the actual system that are represented by it. When a discrepancy in unacceptably large, the model must be revised and the cycle repeated. Modeling and simulation have appropriate uses. They are especially beneficial in situations where the actual system does not exist or is too expensive, time-consuming, or hazardous to build, or when experimenting with an actual system can be cause unacceptable disruptions. Changing the values of the parameters, or exploring a new concept of operating strategy, can often be done more quickly in a simulation than by conducting a series of experimental studies on an actual system Simulation can also be a very useful training aid; it is a technique by which students can learn more and gain greater insight and better understanding about the system they are studying. A frequent question about simulation is its validity. Do the simulation results reflect those of the actual system for the condition simulated? Even with valid component models, the use of them in a larger simulation must be done carefully with consistency; otherwise, the results could be meaningless. Finally, in interpreting the results, we should not overlook the simplifications and assumptions made in devising the model. In this chapter, the three-phase induction motor model has been derived instead of two phase model (d-q representation), which is very commonly used. This is because the two-phase model is driven under balance operation. This model constrained the driven solution for any problem to balance operation, which severely limits the scope of many practical problems that may be studied. Also, it impairs the accuracy of these solutions since absolute balanced conditions rarely apply. Three-phase representation of all system components has been chosen so as to allow for unsymmetrical operation and to enhance the practical significance of the derived model. Such a representation is able to represent in accurate detail the many unsymmetrical phenomena encountered, which is not possible when using d-q modeling methods. So, in order to gain an understanding of problems that does not comply directly with balanced operating conditions and for which d-q methods of analysis are inappropriate, three-phase representation becomes essential.

B. Induction Machine Equations

The figure 1. shows the two dimensional diagram of three-phase induction motor with stator and rotor windings.

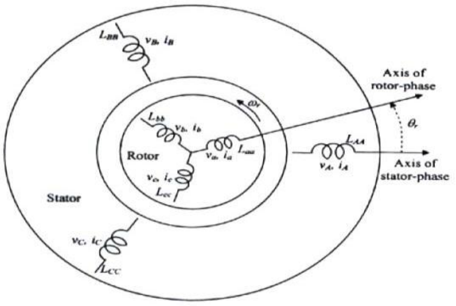


Fig.1. Three phase Induction motor

The voltage equations for a three-phase induction machine can be expressed as: ,

Stator equation is $V_A = R_A i_A + \frac{d\lambda_A}{dt}$;
$V_B = R_B i_B + \frac{d\lambda_B}{dt}$; $V_C = R_C i_C + \frac{d\lambda_C}{dt}$.

Rotor equation is $V_a = R_a i_a + \frac{d\lambda_a}{dt}$;
$V_b = R_b i_b + \frac{d\lambda_b}{dt}$; $V_c = R_c i_c + \frac{d\lambda_c}{dt}$

The flux linkages associated with the interactions between stator and rotor windings are represented by

Stator

$$\lambda_A = L_{AA} i_A + L_{AB} i_B + L_{AC} i_C + L_{Aa}\cos(\theta_r)\, i_a + L_{Ab}\cos(\theta_r + \tfrac{2\pi}{3})\, i_b + L_{Ac}\cos(\theta_r - \tfrac{2\pi}{3})\, i_c$$

$$\begin{aligned}\lambda_B = L_{BA} i_A + L_{BB} i_B + L_{BC} i_C &\\ + L_{Ba}\cos(\theta_r - \frac{2\pi}{3})\, i_a &\\ + L_{Bb}\cos(\theta_r)\, i_b &\\ + L_{Bc}\cos(\theta_r + \frac{2\pi}{3})\, i_c &\end{aligned}$$

$$\begin{aligned}\lambda_C = L_{CA} i_A + L_{CB} i_B + L_{CC} i_C &\\ + L_{Ca}\cos(\theta_r + \frac{2\pi}{3})\, i_a &\\ + L_{Cb}\cos(\theta_r - \frac{2\pi}{3})\, i_b &\\ + L_{Cc}\cos(\theta_r)\, i_c &\end{aligned}$$

Rotor

$$\begin{aligned}\lambda_a = L_{aA}\cos(\theta_r)\, i_A + L_{aB}\cos(\theta_r + \frac{2\pi}{3})\, i_B &\\ + L_{aC}\cos(\theta_r - \frac{2\pi}{3})\, i_C + L_{Aa} i_a &\\ + L_{Ab} i_b + L_{Ac} i_c \lambda_b &\\ = L_{bA}\cos(\theta_r + \frac{2\pi}{3})\, i_A &\\ + L_{aB}\cos(\theta_r)\, i_B &\\ + L_{aC}\cos(\theta_r - \frac{2\pi}{3})\, i_C + L_{ba} i_a &\\ + L_{bb} i_b + L_{bc} i_c &\end{aligned}$$

$$\begin{aligned}\lambda_c = L_{bA}\cos(\theta_r - \frac{2\pi}{3})\, i_A + L_{cB}\cos(\theta_r + \frac{2\pi}{3})\, i_B &\\ + L_{cC}\cos(\theta_r)\, i_C + L_{ca} i_a + L_{cb} i_b &\\ + L_{cc} i_c &\end{aligned}$$

The electromechanical torque equation is:

$$T_e = -\frac{1}{2}\begin{bmatrix} i_A\left\{i_a[L_{Aa}+L_{aA}](\sin\theta_r) + i_b[L_{Ab}+L_{bA}]\sin(\theta_r+\frac{2\pi}{3}) + i_c[L_{Ac}+L_{cA}](\sin\theta_r-\frac{2\pi}{3})\right\} \\ +i_B\left\{i_a[L_{Ba}+L_{aB}](\sin\theta_r-\frac{2\pi}{3}) + i_b[L_{Bb}+L_{bB}]\sin(\theta_r) + i_c[L_{Bc}+L_{cB}](\sin\theta_r+\frac{2\pi}{3})\right\} \\ +i_C\left\{i_a[L_{Ca}+L_{aC}](\sin\theta_r+\frac{2\pi}{3}) + i_b[L_{Cb}+L_{bC}]\sin(\theta_r-\frac{2\pi}{3}) + i_c[L_{Cc}+L_{cC}](\sin\theta_r)\right\} \end{bmatrix}$$

The dynamic load equation is:
$T_e - T_L = J\frac{d\omega_r}{dt} + D\omega_r$; $\frac{d\omega_r}{dt} = \frac{T_e - T_L}{J}$; $\omega_r = \frac{1}{J}\int (T_e - T_L)dt$

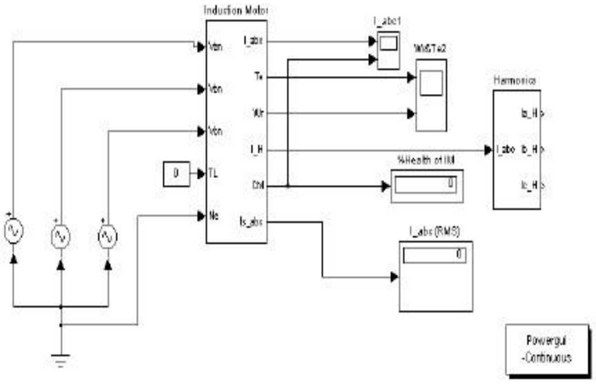
C. Induction Machine model in a three-phase reference frame

When induction machines are expressed in three-phase axes, many of the inductances are function of the rotor displacement and therefore functions of rotor speed and time as shown in the following

Stator Inductances: It is assumed that the air gap of the induction machine is uniform and the stator and rotor windings are sinusoidally distributed, all the stator self-inductances are identical. $L_{AA} = L_{BB} = L_{CC} = L_{ls} = L_{ms}$
The mutual inductance between any two stator windings is the same due to symmetry
$L_{AB} = L_{BA} = -0.5L_{ms}$;$L_{BC} = L_{CB} = -0.5L_{ms}$; $L_{CA} = L_{AC} = -0.5L_{ms}$
Rotor Inductances:
$L_{aa} = L_{bb} = L_{cc} = L_{lr} = L_{mr}$,$L_{ab} = L_{ba} = -0.5L_{mr}$;$L_{bc} = L_{cb} = -0.5L_{mr}$,$L_{ca} = L_{ac} = -0.5L_{mr}$
In the same manner to that given for the stator, the rotor self-inductances and mutual inductances are:
$L_{Ac} = L_{Ba} = L_{Cb} = L_{msr}\cos(\theta_r - 120^\circ)$,$L_{Ab} = L_{Bc} = L_{Ca} = L_{msr}\cos(\theta_r + 120^\circ)$,$L_{Aa} = L_{Bb} = L_{Cc} = L_{msr}\cos(\theta_r^\circ)$
The mutual inductance between a stator winding and any rotor winding varies sinusoidally with rotor position.

III. INDUCTION MOTOR MODEL IMPLEMENTATION WITH MATLAB/SIMULINK

In this section, the implementation of the stationary reference abc model of a three-phase induction motor using Simulink, using the equations listed in the previous section has been given. Figure 4.shows an overall diagram of the induction motor in the stationary three-phase reference frame. The details of the subsystems in the main blocks are given in figure 2



The parameters inside the induction motor three-phase model and the three phase source can be set by executing a m-file which stores the all parameters used in the model. By running the m-file all the values of the parameters can be accessed by the model from the workspace.
Machine Parameters:
The parameters of the machine used for simulation are listed below:
Rated Voltage V = 380v
Frequency f=50Hz , Stator Resistance Rstator = 15.3Ω
Rotor Resistance Rrotor = 7.46Ω,
The stator and rotor self-inductances are equal to
Lstator = Lrotor = Lleakage+Lmutual = .035+.55 = .585H
The mutual inductance between any two stator and any tow rotor windings is equal to
Lss,mutual = Lrr,mutual = -0.5Lmutual = -0.275H
The mutual inductance between a stator winding and any rotor winding is equal to Lsr,mutual = Lmutual =0.55H
Number of Poles p = 4, Inertial constant J = 0.023kg.m2

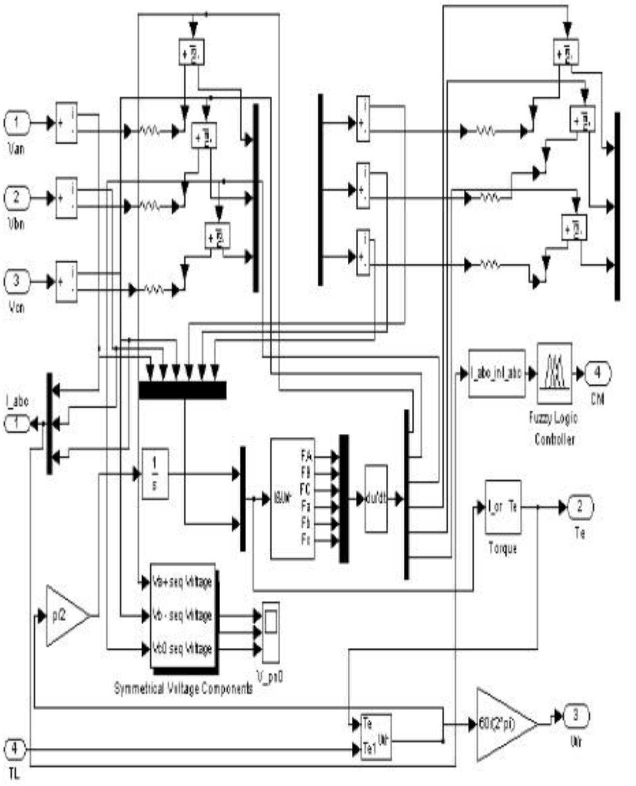


Fig. 2. Simulink Model of Induction Motor Subsystem

IV. DESIGN OF CONDITION MONITORING OF INDUCTION MOTOR USING FUZZY LOGIC CONTROLLER

Condition monitoring of the induction motor is a process of continuous evaluation of the health of the motor throughout its serviceable life. Condition monitoring and protection are obviously closely related functions.
The various AI techniques, reported in literature, for the induction motor condition monitoring are ESs, ANNs, FLSs, and Neuro-Fuzzy systems.

A. Artificial Neural Network for Induction Motor Condition Monitoring:-

The fault severity evaluation can be done by the supervised neural network, which can synthesize the relationship between the different variables constituting input vectors and the output diagnostic indexes, which indicate the fault severity, starting from examples utilized in the learning procedure. Condition monitoring should be designed so as to preempt faults that can occur in the induction motor. It can be extended to provide primary protection, but its real function must always be to attempt and to recognize the development of faults at an early stage. Such advanced warning is desirable since it allows maintenance person greater freedom to schedule outages in the most convenient manners. By condition monitoring we can reduce unexpected failures and downtime, increase the time for standards maintenance, and reduce maintenance and operational cost.

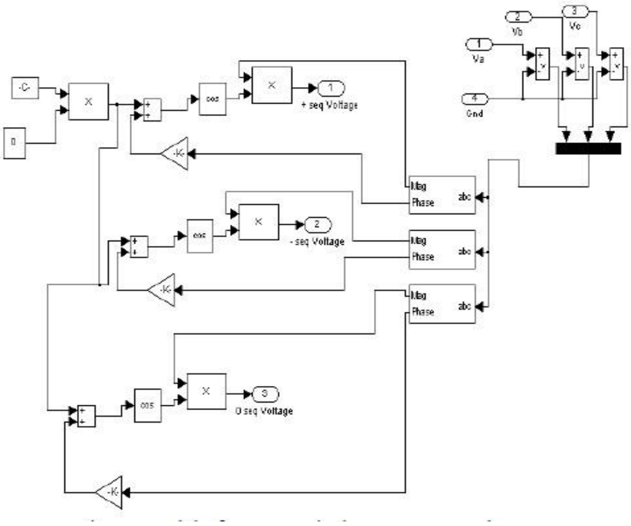


Fig.3. Model of Symmetrical components subsystem

V. MOTOR OPERATION DURING VARIOUS CONDITIONS

A. Normal Operation

The Stator current and health of induction motor, Stator input voltage, speed and torque, symmetrical components of stator current, symmetrical components of stator induced voltage, symmetrical components of stator input voltage are in nominal range. From condition we concluded that after the transient period is over, the health of the motor is good, and there is no negative sequence component in both stator induced voltage and stator current.

B. Blocked Rotor

The blocked-rotor test was also performed multiple times, because tests had to be repeated when the power meter was installed correctly. The use of a VSD was probably not the best motor drive to be used for this test, as the speed had to be increased until the line current value displayed on the power meter was equal to the rated current for the machine. This method proved undesirable as, for the protection of the motor, this test should be performed as fast as possible, and there was a considerable lag between the VSD and the results displayed on the power meter. This meant it was a tedious process trying to get the required speed that would result in the required current reading, meaning that the tests took much longer then they should have which could have possibly destroyed the motor through overheating the of stator windings.

C. Turn-Turn short in one phase winding

In this case we short circuit in the part of the winding in R phase has been carried out. At this condition the value of the stator resistance at short circuit fault is equal to Rstator, fault = 13.1Ω, we can find the value of the inductance at the fault state by using the ratio between the value of the resistance at both state (normal and fault). Thus the value of the inductance is replacing the values of the stator resistance and stator self-inductance in phase R by these values the results can be obtained. The simulation is started up with normal state parameters. After obtaining steady state at 0.5 second the turn fault has been created by changing the above said parameters. From these results it can be concluded that during normal operation(before fault), the health of the motor is Good, and there is no negative sequence component in both stator induced voltage and stator current. As soon as the fault is created the stator current becomes unbalanced, and the health of the induction motor goes seriously damaged and finally settles to Damaged state, and we can notice that there is presence of negative sequence component in both stator induced voltage and stator current waveforms during fault conditions.

D. Break in stator winding

For simulation of the break fault in the stator winding at R phase, it is not possible to apply a break in the phase by putting the value of the stator resistance and the stator inductance to infinity. It is assumed that the value of the stator resistance is very large and corresponding to this value we can calculate the value of the inductance by this equation: With simulation of a break in the stator winding at R phase, it is not possible to apply a break in the phase with the value of the R_{stator} and the L_{stator} to infinity or very high. It is assumed that the value of the R_{stator} is very high. Replacing these values in phase R by these values, simulation is using normal state parameters. From the results it can be observed that during normal operation, the motor has Good health, and there is no negative sequence component in both stator induced voltage and I_{stator}. When the fault is created the I_{stator} becomes unbalanced, and the health of the IM goes to Seriously Damaged and finally settles to the same state, and the presence of negative sequence component in both stator induced voltage and I_{stator} variations during fault conditions can be noticed.D. Unbalanced in input voltage The simulation of induction motor with voltage unbalance can be simulated by simply varying the voltage magnitude in any one of the phase, no other parameters need to be changed. As in the previous case, the machine is started up with normal value, and at 0.5 second, the current takes its steady state value, now the fault has been created by changing the voltage of B phase. In this case a 6% of the rated voltage in C phase was reduced to create unbalance. Figure 20 and 21 shows the Stator current and health of induction motor, speed and torque, symmetrical components of stator current, symmetrical components of stator induced voltage, and symmetrical components of input voltages are shown. The simulation is started up with normal state parameters. After obtaining steady state at 0.5 second the turn fault has been created by changing the magnitude of B phase voltage. From these results it can be concluded that during normal operation(before fault), the health of the motor is Good, and there is no negative sequence component in both stator induced voltage and stator current. As soon as the fault is created the stator current becomes unbalanced, and the health of the induction motor goes seriously damaged and finally settles to Damaged state, and we can notice that there is presence of negative sequence component in both stator induced voltage and stator current waveforms during fault conditions.

VI. CONCLUSION

A Matlab based measurement and health evaluation system has been developed and implemented. This application allows fast failure state estimation. The more detailed investigation to point out the difficult conditions of the machine under different stator fault conditions of induction motor can be performed. This is a highly versatile technology for condition monitoring and fault analysis of motors. It solves the shutdown Problems and ensures safe working environment in continuous process industry to have greater role in induction motor.

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