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Speed Control of Induction Motor Using Fuzzy Logic Control

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Abstract: Measurements validation is a critical feature in monitoring systems required by most industry applications to achieve higher level reliability. This paper presents the use of the measurement thresholds generated from the propagation of parametric uncertainty using fuzzy logic to validate the sensor measurements of an induction motor drive by means of fuzzy techniques. If measurements fail the validation check, they are replaced by reconstructed data to maintain the operation. Reconstruction is performed with fuzzy logic, which also supports the evaluation of the thresholds. The algorithms proposed here have been implemented and tested both in simulation and in real time experiments on a field oriented controlled induction machine.

Keywords: Fuzzy Logic Contol(FLC), Induction Motor(IM), Pulse Width Modulation(PWM), Uncertainty

I. INTRODUCTION

In most of the application control, co-ordination and management requires taking measurement and therefore relying on sensors. The reliability of measurement is thus essential. Since engineering system are usually interconnected, invalid data caused by sensor failure may lead to catastrophic failures of the whole system[1]. So, it is critical to develop strategies to diagnose the measurement themselves, and reconstruct data to replace the invalid measurement provided by inoperative or defective sensor. In this method various operations in sensor validation were integrated, first failure detection, second failure declaration, third defective sensor isolation and finally, missing data reconstruction[1]. The first two stages are diagnostic procedure and termed as sensor failure diagnosis[2]. The integration if diagnostic and monitoring an operation in the control frame work offers the opportunity to improve the reliability. Unfortunately, these approaches are far from satisfying for both economic and reliability requirements. This limitation pushed the development of the concept of analytical redundancy of sensors, also known as soft sensors or logic redundancy is commonly used technique in which sensors featured with mathematical models that provide virtual measurements. In the validation of missing sensors for a flight control system is presented. Efforts in the developing sensor failure tolerant control of static synchronous series compensator of power system have been done. The application of sensor validation for chemical plant control was conducted. Other strategies include knowledge redundancy which related to process fault and measurement aberration detection which only look at the input and output of sensor instead of the system operation.

The basic idea of all the reported methods, belong to analytical redundancy strategy, is to detect and declare sensor failure based on a predetermined threshold or a residual which is generated between normal data and the measurement data[12]. Data reconstruction is achieved by replacing the bad measurements with model based predictions. Uncertainty could simply be defined as the occurrence of events that are beyond one's control. Parametric uncertainty can make the use of model. This characteristic makes the measurement validation even more challenging when the target system is a closed loop system. Here the objective of this work is to determine the sensor response and quickly provide the threshold to dynamically bind measurements in uncertain, dynamic closed loop control systems. In this case, the time for diagnostic has to be as fast as possible in order to avoid the propagation of fault. For example, in the switching of communication systems or power electronic systems. It is important to highlight that the fault detection stage is the one which takes up most of the delay time because the first physical contact when the fault is carried out occurs at this phase. An interesting application, for the case study in switching systems of power electronics is the induction motor drive[13].

Generally, this kind of application is integrated to many critical processes where the speed tracking problem is an essential issue to maintain the quality of products and reliability of the process to avoid production cut a, such as in the metallurgical and paper industries, among others, where there are many fault tolerant schemes applied to motor drive. The important point is that the fault detection in the

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redundant units is performed during the steady state and not during the transient state. Very early the fault detection can be possible during switching in order to avoid fast fault propagation by short circuit in the complementary power device of the same inverter pole. It has to be avoided in less than 10μs. a problem detected in the literature is that the fault localization only identifies the inverter pole or cell damage[4] instead of the power device affected, which is of crucial importance for the fault-tolerant motor drive or neutral point clamped inverter made with a single pack as a redundant unit instead of a complete inverter leg[4]. The main interest of these tolerant converter types appear because the manufacturer tends to package high power device as a single module type. In this project, a failure detection technique and is analog circuit for insulated gate bipolar transistors (IGBTs), under open and short circuit failure, are proposed. This technique is applied to a three-phase induction motor drive system. The technique is adapted to detect failure of short circuit and open circuit failure in the IGBT, which is based on gate-signal monitoring[2],[14]-[26]. The short circuit is detected by using current transformer and additional zero-crossing circuit. The temperature of the motor winding is detected and feedback is given to the fault detection unit[1]. The settings are made in the fault detection system and accordingly the protection schemes are formulated. The most important issue of this technique is the reduction of time for fault detection.

II **FUZZY DIAGNOSIS INFERENCE**

The application of the sensor failure detection and control recovery to ac motor drives is proposed here[2-6]. The development of an automatic diagnostic and validation strategy for the ac electrical measurement of a general motor drive is proposed. It is assumed that the drive circuitry is integrated in a single module, and the only accessible points are the ac- measurements (could be either currents or voltage) from the sensors. As the purpose of this work is the test and verification of a novel method to validate sensor measurement, to isolate the problem it is assumed that no other physical faults[10] are present in the system. This implies that as long as all sensors provide the correct measurements for the drive circuit, the whole system operates normally.

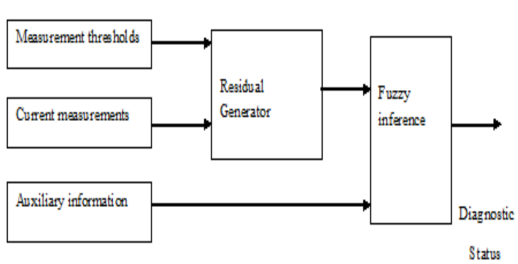

Fig 1 Block Diagram Of Fuzzy Diagnosis Inference

III FAULT DETECTION METHOD

A. Analytical Prediction Method

An analytical technique for predicting the self-inductance and mutual inductance of different parts of a phase coil under a partial-turn short-circuit fault condition by quantifying the slot-leakage flux associated with both the healthy and partially short-circuited turns. The results can be used to provide a computationally efficient tool for identifying the worst-case short-circuit scenario in a design stage and formulating an effective remedial action that can be used to limit the short-circuit current to a permissible level. The proposed model can effectively predict the inductances and the short-circuit current under partial-turn short-circuit fault conditions. Both FE and experimental results have validated the proposed analytical model.

B. FBGA Based Real-Time Power Converter

The design, implementation, experimental validation and performances of an FPGA-based real-time power converter failure diagnosis for three-leg fault tolerant converter topologies used in WECS. The approach introduced in this method minimizes the time interval between the fault occurrence and its diagnosis. This method demonstrates the possibility to detect a faulty switch in less than 10 μs by using a new methodology based on a “time criterion” and a “voltage criterion”. To attain this short detection time, an FPGA is used. The proposed fault detection method is implemented using an FPGA and evaluated in the application case of a back-to-back converter used in a new fault tolerant WECS topology with DFIG. We examine the proposed failure diagnosis method and the response of the WECS when one of the power switches is faulty. Two cases are studied: The fault can either occur over the GSC or the RSC. The experimental results based on “FPGA in the loop” hardware prototyping verify the theoretical study and the performances of the proposed diagnosis method. The WECS can still operate in nominal conditions even if a power switch is faulty.

C. Current Control Method

An analyzed some post fault current control strategies to operate a five-phase PM motor indefinitely in the presence of fault. One-phase fault and two-phase faults were considered. The main aim is to operate the faulty motor to achieve an adequate average torque with minimum torque ripple and no zero-sequence currents. The results show that appropriate current control strategies enable the drive to operate in the presence of fault exhibiting a smooth torque and adequate average torque. The current control strategies have been tested on a five phase PM motor prototype. An appreciable agreement with the predicted results is achieved. Finally, the aim of this method has been to give the results in analytical form so as to give the rules to apply the proper current control strategies to any five-phase PM motor[4].

ISSN 2321 – 2004
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Vol. 2, Issue 1, January 2014

The problem of these techniques is the very long detection delay time that is not suitable for avoiding a short-circuit fault that may spread immediately to the complementary power device of the same inverter leg in a failure-tolerant system[1]. Other techniques used to detect faults in power devices are based on the voltage-level change, such as in the control signal normalized current deviation and voltage slope. These techniques are faster than the previously mentioned techniques with regard to the delay time.

In this project, a new technique and experimental results of an analog circuit implemented in the gate driver to detect failure by open circuit and short circuit in the IGBT are presented. The detection technique is adapted to detect failures of short-circuit and open-circuit in the IGBT, which is based on gate-signal monitoring. The most important issue of this technique is the reduction of time for fault detection.

IV CONSTRUCT VALIDATION THRESHOLDS THROUGH PCT

One of the major advantages of OCT is the possibility to solve a stochastic system of differential equations (affected by para-metric uncertainty) as a set of deterministic differential equations. The PCT solutions yield the PCT reprenstation of the probability density function of each variable at every time instant. The solution is found with a single run of the numerical simulation of the model as opposed , for example to Monte carlo methods. This feature of the PCT models is particularly important for the sensor failure detection which involves run time processing.

Let us consider the dynamic model of a generic AC motor drive is given by a set of differential equations as

$$\frac{dx}{dt} = f_d(x, p, t) \quad (1)$$

Where

x vector of the states

f_d vector of function

p set of system parameter

t time variable

Consider p a set of uncertain parameters. The corresponding stochastic model of the motor drive in PCT domain can be determined according to the expansion procedure. In particular, the PCT form can be written as

$$\frac{dx_{pct}}{dt} = f(x_{pct}, p_u, p_d, t) \quad (2)$$

Where

p_d set of deterministic parameters

p_u set of uncertain parameters with known

Probability density function

x_{pct} vector of the uncertain states in PCT form

f vector function after expansion

An arbitrary variable y (a state variable or any other variable) of the system, can be defined in PCT domain and truncated as

$$y_{pct} = \sum_{n=0}^{p} y_n \psi_n(\xi_1, \xi_2, \dots \dots \xi_n) \quad (3)$$

Where

P truncation term of the expansion

y_n coefficients of the expansion

ψ_n chosen polynomial basis

ξ random variables associated to uncertainties

With known PDF

N rank of p_u

Notice that if y is a time dependent variable, also the coefficients y_n of the expression are time dependent. Formal time dependence of the coefficients has been omitted in the equation for readability. At every time instants, the extreme values of y can be determined using the external values of the polynomial functions.

Let us consider a measured variable, y dependent from the uncertain states through circuit laws. The interval of reasonable values of the measured variable y is defined as y_t

$$y_t = [y_{min}, y_{max}] \quad (4)$$

Where

$$y_{min} = \min\left[\sum_{n=0}^{p} y_n \psi_n(\xi_1, \xi_2, \dots \dots \xi_n)\right] \quad (5)$$

$$y_{max} = \max\left[\sum_{n=0}^{p} y_n \psi_n(\xi_1, \xi_2, \dots \dots \xi_n)\right] \quad (6)$$

y_n coefficients of expanded measured variables

And dependent on x_{pct}.

The most cases, the minimum and maximum are actually on the boundary of the domain, thus very straightforward to compute. The interval y_t is considered as reasonable range of values of the measured variable. Notice that, in this case, the reasonable range corresponds to the full range of possible values. The boundaries of such intervals are employed in this work as thresholds to assess if y is an acceptable measurement. Calculation of both thresholds and

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Vol. 2, Issue 1, January 2014

estimation of the measured variable are performed online by the observer set up based on the PCT model.

A. Residual Generation: Find The Acceptable Margin

The value of a variable measured from a healthy sensor should always remain within extended uncertainty thresholds, mainly dependent on the natural variability of the system. This is true time instant by time instant. An example of the upper and lower acceptable margin for a general AC measurement in time domain, which define the range between the expected value and the upper and lower thresholds.

The residuals, that are used in this work to perform diagnosis via fuzzy inference, are generated from actual measurement and upper and lower thresholds calculated as absolute values of the instantaneous threshold and measurements. So ideally residuals are nonnegative values in failure free condition.

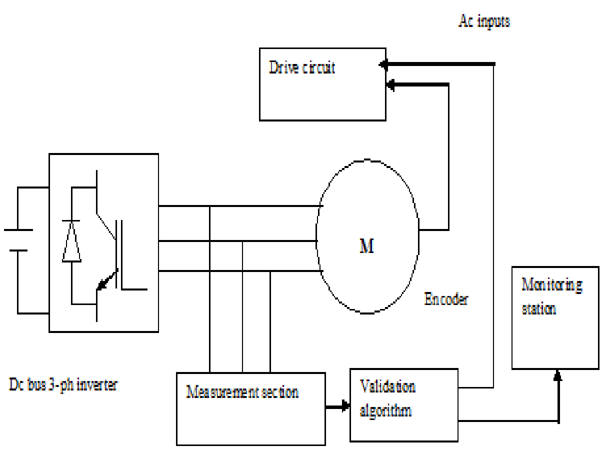

Fig 2 Motor Speed Control

V. GENERAL MEASUREMENTS MONITORING AND VALIDATION STRATEGY

B.*Fuzzy Diagnosis Approach*

The fuzzy diagnostic inference developed here is a fully automatic mechanism to diagnose and monitor the status of each sensor via the determination of the acceptability of the measurements. Once the critical elements are identified and computed, a fuzzy clustering method can be adopted to diagnose the validity of the measurements. The following information is deemed critical for general AC measurements diagnosis and constitutes the input of the fuzzy inference.

- Residuals
- Information of the system current operating condition (initialization, transient, or steady state)
- Information of the measurement variability caused by external effects

The general procedure for residual generation has been presented in this section. The latter two types are termed auxiliary information and maybe different from case to case. A fuzzy inference system used to diagnose the measurements of the AC motor drive is designed as follows

- Outputs: status of monitored sensor
- Inputs: RESIDUAL-U and RESIDUAL-L . Different rules for RESIDUAL-U and RESIDUAL-L are used because in general there is no guarantee that actual measurements are actually distanced from the upper and lower thresholds.

The diagnostic process here is two-folded. While processing in stage 1, all sensors use the default status. Stage 2 includes all the rules to diagnose the status of the sensors. For instance, sequence corresponds to table and it means that “if the motor is in steady state and the measurements is out of the upper thresholds and the sensitivity of the noise is not important, then the status of this sensor is failed’.At the same time, measurements uncertainty Can be considered in the membership function design of the residuals by using the CTR-SENS signals.

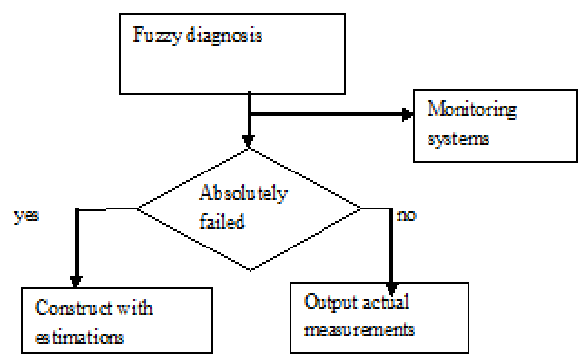

Fig 3 Failure Isolation And Missing Data

Construction

Failure isolation is realized by permanently locking the sensor status at “-1” if only if the fuzzy index falls into the “absolutely failed area”. In this area, every fuzzy is smaller than the one where the centroid of the triangle is failed.

The simplified logic of replacing unusable measurements is summarized estimation of the measurements and determination of the thresholds is performed online by the observer, which is built upon the PCT model. The sensor

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Vol. 2, Issue 1, January 2014

status diagnosed by the fuzzy inference acts as trigger of the reconstruction. As long as the sensor status falls into the "yes" branch, as schematically shown. The corresponding measurement from the bad sensor is isolated from the controller and the missing data is replaced with the estimation.

VI. FUZZY INFERENCE DESIGN

The fuzzy inference used here for detecting measurement failures is designed according to the general procedure. There is vast selection of possible membership function shapes, although most actual fuzzy control designs draw from a very small set. For each input membership function, a trapezoidal shape is selected. We set the mean values as the central value as the central and then slope on either side. the estimated value of the residual PDF is used as the maximum measurements uncertainty.

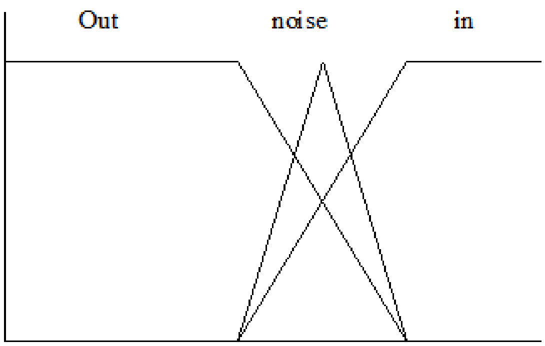

Fig 4 Input Membership Function

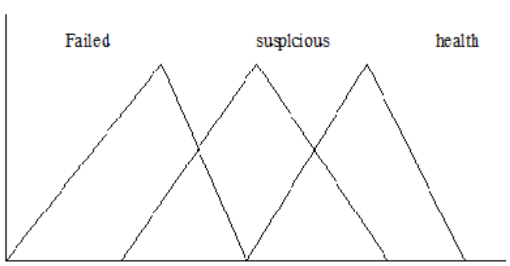

Fig 5 Output membership function of fuzzy inference

VII SIMULATION RESULT AND ANALYSIS

Simulation result for an closed loop field oriented control of induction motor drive are presented. We assume that the stator current sensors provide the only accessible measurements. These sensors may not fail concurrently, and the motor load may vary during the operation. A fuzzy inference was implemented with the fuzzy logic toolbox of Simulink. The COG defuzzification is performed by the fuzzy controller whose output is a defuzified value representing the sensor status. The same system and operation is tested in the real time. In this case the induction motor is loaded with a DC motor. The AC stator current measurements are retrieved by two current sensors located on the three phase inverter board.

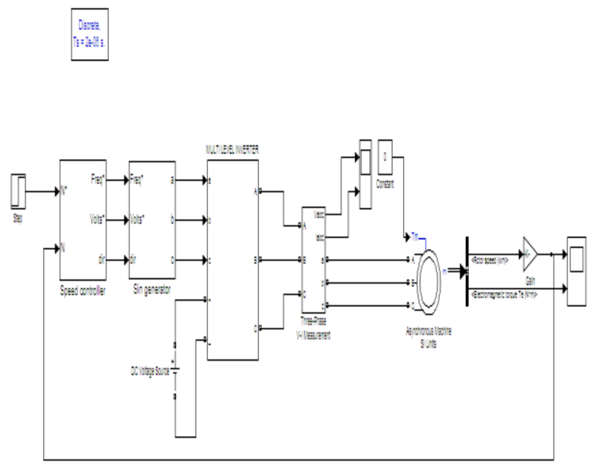

Fig 6 .Simulation Circuit Diagram

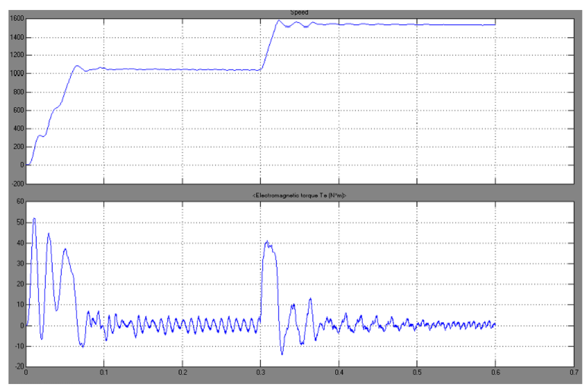

Fig 7 Output Speed And Torque

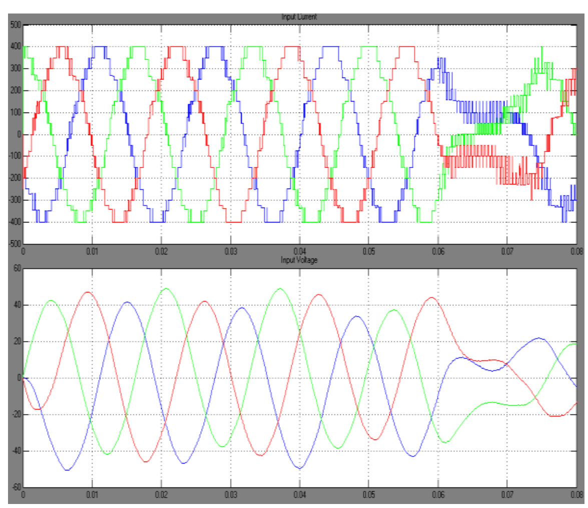

Fig 8 Input voltage and current

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Vol. 2, Issue 1, January 2014

VIII **CONCLUSION**

The work introduced here presents a novel approach based on PCT to dynamically bound measured quantities for validation and hence monitoring of sensors behavior. The fuzzy inference has been implemented to combine all the available information related to the status of the sensors. This has been shown to be effective in measurements validation of AC motor drives. Reconstruction of invalid measurements and isolation of faulty sensors are achieved based on the fuzzy status yielded by the fuzzy inference. The strategy has been tested on an application of field oriented control of induction machines. Results from both simulations and real time experiments are presented and analyzed.

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BIOGRAPHY

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Vol. 2, Issue 1, January 2014

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