# Multiple Fuzzy Diagnosis for Voltage Source Inverter Open Circuit Fault in Torque Direct Control Induction Motor Drive

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**Abstract.** This article aims to examine the possibility of fault detection and diagnosis in an induction motor powering a three-phase inverter using artificial intelligence (AI) techniques. Due to the weakness of the switches contained in a three phase inverter. Early detection of these fault switches that may occur in the inverter will be very important in order to find a way to allow us to control the operation and the protective action to avoid regular failures. We present the simulation results of a fault diagnosis system using an artificial intelligence technique with direct torque control (FDTC) of fuzzy logic of the induction motor. In this article, we provide a detailed explanation of the multiple open circuit switching faults in the inverter with a simple feature extraction technique to investigate the possibility of detecting and diagnosing these faults. The search and identification of faulty switches is recognized in limited current periods. Classification performance for multiple defects is improved by the use of a fuzzy logic detection approach.

**Keywords:** Direct Torque Control (DTC), Multiple Fault Detection, Induction Motor, Fuzzy Logic Control, Voltage Source Inverters (VSI).

## 1. Introduction

Among all control methods for induction motor drives, DTC is considered particularly interesting being independent of machine rotor parameters and requiring no speed or position sensors. The basic DTC scheme is characterized by the absence of coordinate transformations, current regulators and PWM signals generators. This control strategy was first introduced by Takahashi in 1986 [1].

A voltage-fed inverter induction motor drive system can develop various types of faults that can be classified as follows [2]:

- Input supply single line to ground fault,
- Rectifier diode short-circuit fault,
- Transistor base drive open fault,
- Transistor short-circuit fault,

### 2. Direct torque control

The direct torque control DTC scheme for induction motor drive is shown in Fig. 1.

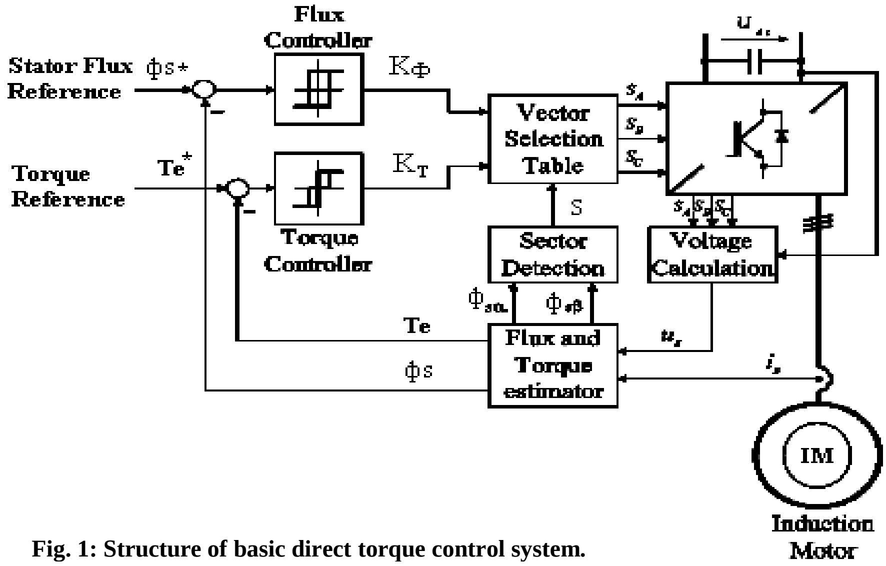



**Fig. 1: Structure of basic direct torque control system.**

As can be seen, the error between the reference torque Te* and the estimated torque Te is the input of a three level hysteresis comparator, whereas the error between the reference stator flux magnitude ϕs* and the estimated stator flux magnitude ϕs is the input of a two level hysteresis comparator [3-4]. The estimated flux and the estimated torque can be determined by means of a suitable flux and torque estimator, which uses the motor variables. The switching table, exploiting the outputs of the hysteresis comparators and the stator flux vector position, selects the most appropriate configuration of the two-level VSI [5-7].

### 2. Structure of Fuzzy Fault Diagnosis System

Status monitoring and performance diagnosis for variable speed AC drives today is a need, more or less, depending on their application. Diagnosis can help to avoid unplanned standstill, to make possible to run an emergency operation in case of a fault or to keep the time to repair short in case of a fault. For the voltage source inverter several faults are possible. One class is dedicated to the healthy domain and twenty for single and multiple faults are to each fault inverter switch.

### *A. Feature Extraction System*

In order to take into account the uncertainty of classification; a mathematic functions characterizing the difference between different classes, must be introduced. There is not a general method for building the mathematic model. In our case, we must determine a function that applies the following [8]:

1. Localization of each pattern class in between limits defined by a threshold.
2. Make the feature extractor universal for different speed references by normalized functions.

The function giving the feature extractor used in this paper is as follow [8-10]:

$$S_i = \frac{\sum_{j=1}^{N} Is_i(j)}{length(Is_i) \times \max(abs(Is_i))} \qquad , i = a,b,c \qquad (1)$$

*N*, define the number of samples contained in $Is_{\alpha,\beta}$. The choice of *N* depends on diagnosis decision time.

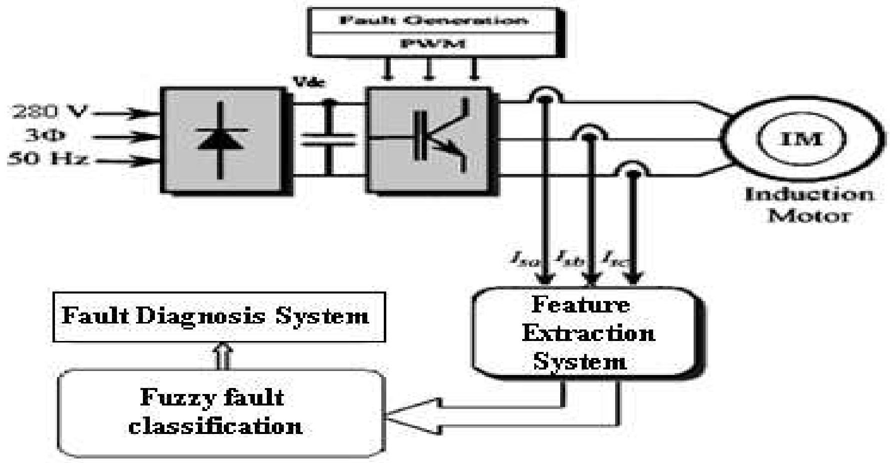
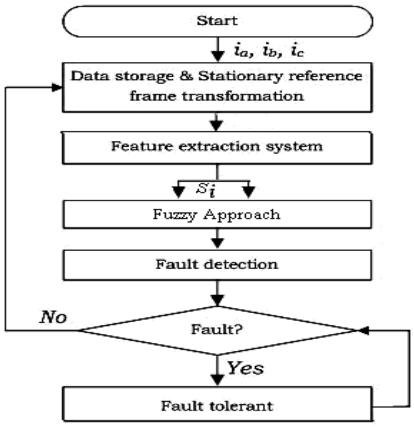
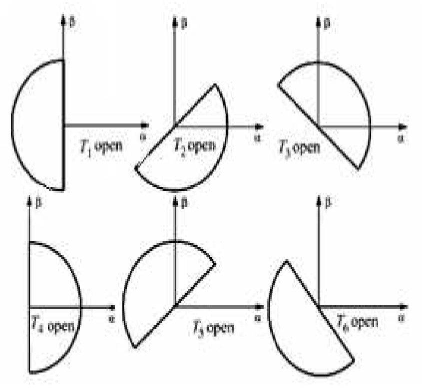



**Fig 2. Structure of Fault Diagnosis System**

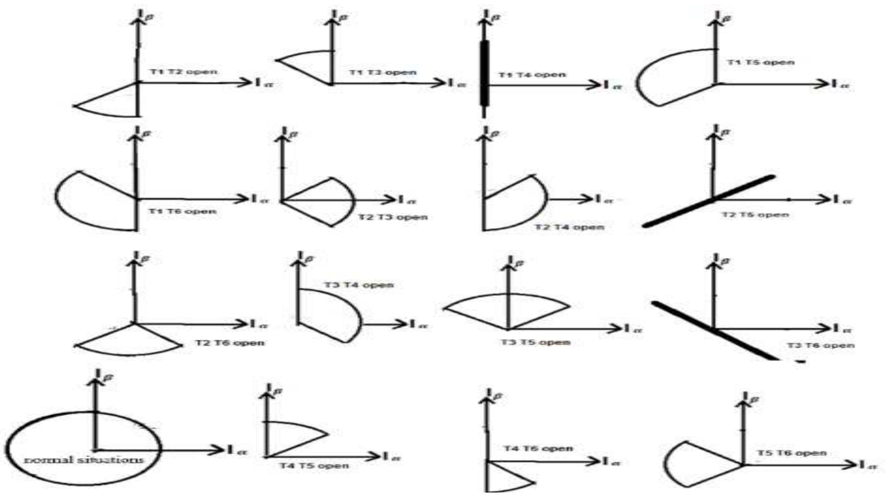
### *B. Fuzzy fault Classification*

The flowchart in Figure 3.aillustrates the Fuzzy classification method. Figure 6.b shows the single faulty current pattern andFigure 6.c shows multiplefaultscurrent patternwhich indicates the location of the faulty switch can be distinguished into six-patterns for single fault and fifteen patterns for multiple faults occurrence.The current pattern in a healthy condition is a circle, apart of circle shapeif one or two open switch fault has occurred, therefore, represents an open fault condition. The angle of the circle corresponds the location of faulty switches [11-15].




a b




c

**Fig. 3. a. Flow Chart of Fuzzy Fault Diagnostic System, b.Single Fault Current Patterns, c. Multiple Faults Current Patterns.**

Fig. 4, show that the proposed fuzzy controller gives the appropriate de-correlation between different patterns of switching fault. The proposed fuzzy controller is Sugeno model, using triangular and trapezoidal membership for inputs. Sa,Sb,Sc, the algebraic surface sum given by equation (1) are the inputs.

Ti, i=0, …6,Tij ij=12,13, ….., 56 is the output. Ti=0, illustrate the healthy state and that indicate that there is no switching faults in the VLSI inverter.

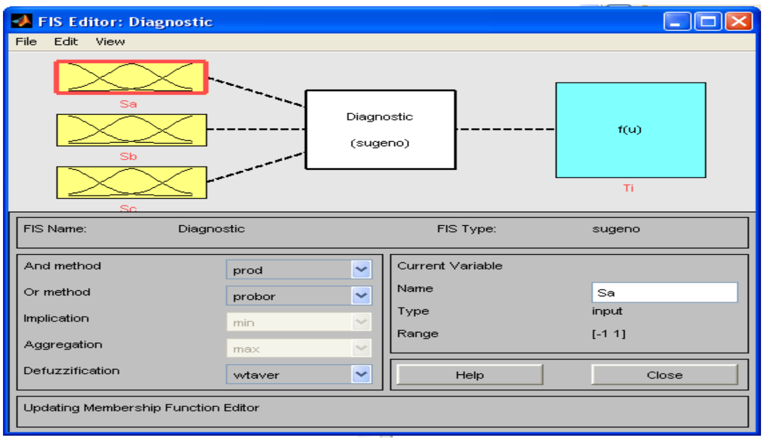



**Fig 4. Inputs/Outputs Fuzzification**

The control strategy depends mostly on inference rules. The inference is based on the method of sum-product inference. For defuzzification, the center of gravity method was used. To simplify the description of inferences, we use 22 rules to describe the function of fuzzy classification method as follow:

*If Sa is **Z**, and If Sb is **Z**, and If Sc is **Z**, Than **Ti=0**: Healthy mode*

*If Sa is **P**, and If Sb is **Z**, and If Sc is **Z**, Than **Ti=1**: T1 switch is defect*

*If Sa is **Z**, and If Sb is **P**, and If Sc is **Z**, Than **Ti=2**: T2 switch is defect*

*If Sa is **Z**, and If Sb is **Z**, and If Sc is **P**, Than **Ti=3**:T3 switch is defect*

*If Sa is **N**, and If Sb is **Z**, and If Sc is **Z**, Than **Ti=4**: T4 switch is defect*

*If Sa is **Z**, and If Sb is **N**, and If Sc is **Z**, Than **Ti=5**: T5 switch is defect*

*If Sa is **Z**, and If Sb is **Z**, and If Sc is **N**, Than **Ti=6**: T6 switch is defect*

*IfSa is **P**, and If Sb is **P**, and If Sc is **Z**, Than **Ti=7**: T1T2switchesare defect*

*IfSa is **Z**, and If Sb is **P**, and If Sc is **P**, Than **Ti=8**: T1T3switches are defect*

*IfSa is **Z**, and If Sb is **Z**, and If Sc is **Z**, Than **Ti=9**:T1T4switches are defect*

*IfSa is **P**, and If Sb is **N**, and If Sc is **Z**, Than **Ti=10**: T1T5switches are defect*

*IfSa is **P**, and If Sb is **Z**, and If Sc is **N**, Than **Ti=11**: T1T6switches are defect*

*IfSa is **Z**, and If Sb is **P**, and If Sc is **P**, Than **Ti=12**: T2T3switches are defect*

*IfSa is **N**, and If Sb is **P**, and If Sc is **Z**, Than **Ti=12**: T2T4switches are defect*

*IfSa is **Z**, and If Sb is **Z**, and If Sc is **Z**, Than **Ti=14**: T2T5switches are defect*

*IfSa is **Z**, and If Sb is **P**, and If Sc is **N**, Than **Ti=15**:T2T6switches are defect*

*IfSa is **N**, and If Sb is **Z**, and If Sc is **P**, Than **Ti=16**: T3T4switches are defect*

*IfSa is **Z**, and If Sb is **N**, and If Sc is **P**, Than **Ti=17**: T3T5switches are defect*

*IfSa is **Z**, and If Sb is **Z**, and If Sc is **Z**, Than **Ti=18**: T3T6 switches are defect*

*IfSa is **N**, and If Sb is **N**, and If Sc is **Z**, Than **Ti=19**: T4T5switches are defect*

*IfSa is **N**, and If Sb is **Z**, and If Sc is **N**, Than **Ti=20**: T4T6 switches are defect*

*IfSa is **Z**, and If Sb is **N**, and If Sc is **N**, Than **Ti=21**: T5T6 switches are defect*

Fig. 5 gives the fuzzification of different inputs and output.

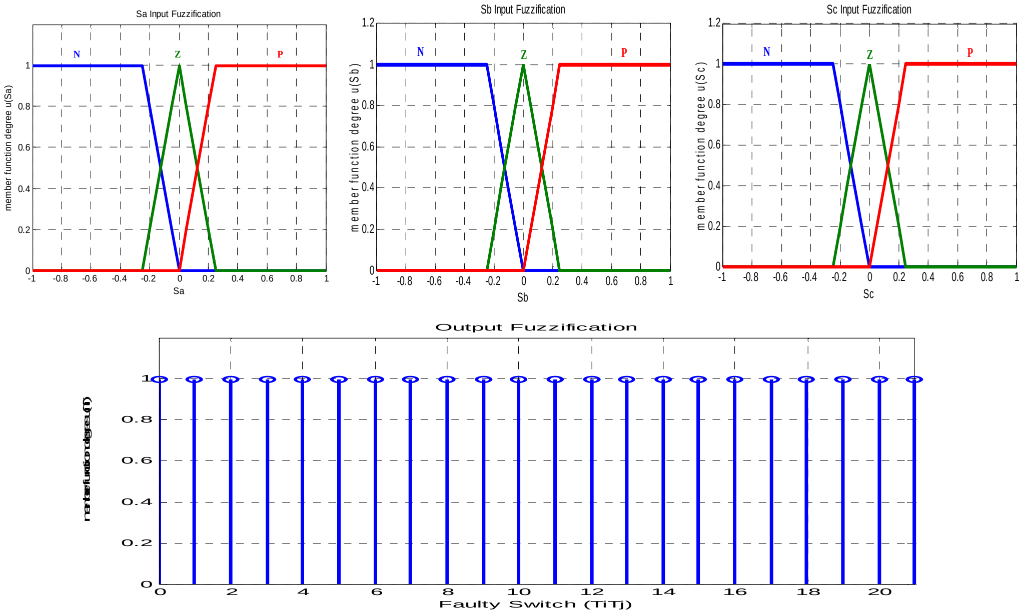



**Fig 5. Inputs/Outputs Fuzzification**

## 3. Fault Diagnosis Simulation

The simulation results of Healthy and different single faulty modes are illustrated in Figure 6

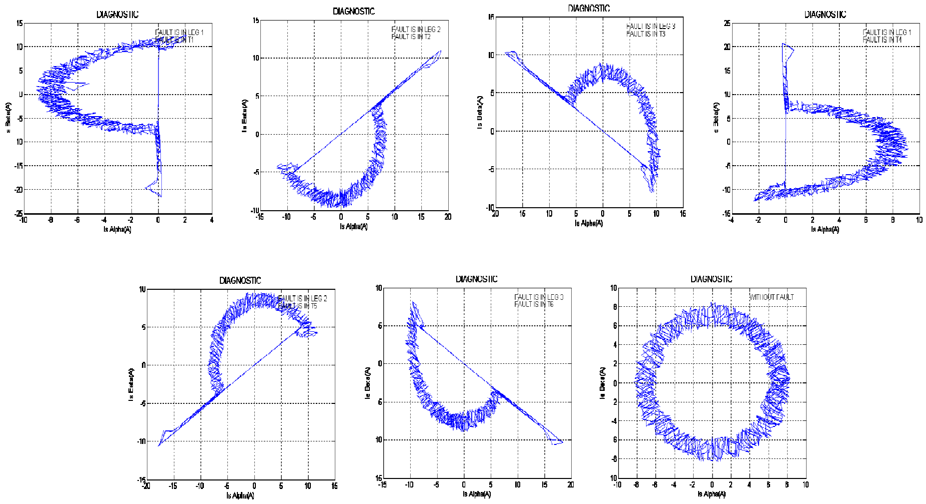


**Fig. 6. Current patterns of VSI inverter under fault of a sequence of single transistor open circuit. (T1→T2→T3→T4→T5→T6→ Healthy)**

The simulation results of Healthy and different multiple faulty modes are illustrated in Figure 7

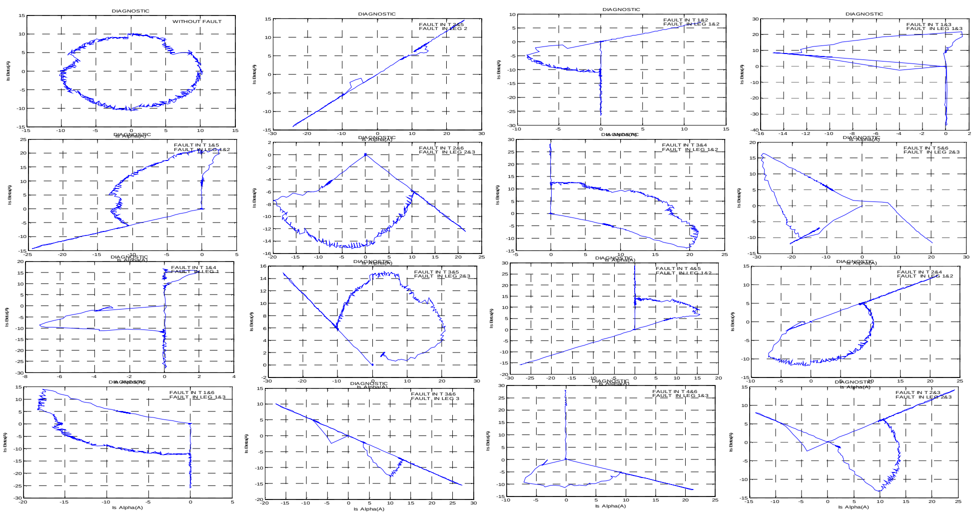


**Fig. 7. Current patterns of VSI inverter under fault of a sequence of multiple transistor open circuit (Healthy→T12→T12→T13→T14→T15→T16→T23→T24→T25→T26→T34→T35→T36 →T45→T46→T56).**

8

Voltage Source PWM power converters with an open transistor fault show a typical current wave form in the time domain, see figure8 for steady state fault condition. The current in one phase becomes zero during a part of the period and it is unsymmetrical [15-16]. The converter continues to operate. Because of the irregular current waveform, the operation is affected. The fault has to be detected and as a consequence, stop of operation or emergency operation, has to be decided.
The simulation is done like the following:

We made (0.1s) for healthy mode after each (0.1s) we made a fault corresponding to the single faultsswitches in (T1, T2, and T3) and multiple faults in (T23, T12)a result is shown in Figure. 8

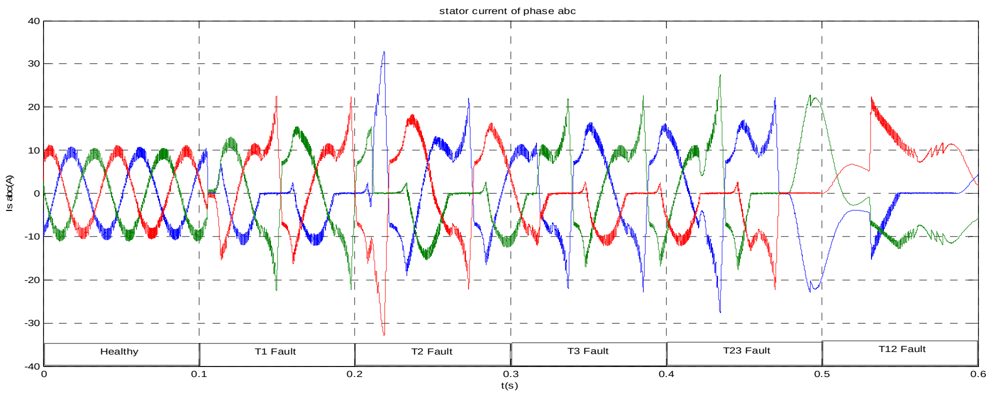



**Fig. 8. Converter AC Current, Under Fault of a Sequence of Transistor Open Circuit (Healthy→T1→T2→T3→T23→T12)**

## 4. Conclusion

ADTC fault diagnosis system using Fuzzy fault classification method has been proposed. A feature extractor based on normalized algebraic sum is utilized to transform output stator current signals inorder to rate the signal value as an important characteristicfor classifying a fault hypothesis. The proposed method has the ability toclassify and to identify the faultlocation of both single and multiple open circuit with a good performance.

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