Australian Journal of Basic and Applied Sciences, 8(3) March 2014, Pages: 188-194

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

PI and Fuzzy based Fault tolerant control of four switch SVPWM voltage source inverters fed three phase induction motor

[1]M. Ayyakrishnan and [2]V. Manikandan

[1]*Research scholar, Anna University Chennai India.*
[2]*Professor, Coimbatore Inst of Technology India.*

ARTICLE INFO

Article history:
Received 12 January 2014
Received in revised form 20 March 2014
Accepted 25 March 2014
Available online 2 April 2014

Key words:
PI controller (PIC), Four switch voltage source inverter(FSVSI), Space vector pulse width modulation(SVPWM),

ABSTRACT

This paper presents a proportional integral (PI) controller and fuzzy logic controller (FLC) based fault tolerant scheme for four switch voltage source inverter (VSI). The proposed fault tolerant VSI accommodates only four switches in two legs instead of six switches in three legs, two switches in auxiliary leg and two triac switches . The cost, electromagnetic interference (EMI) and switching losses are reduced due to absence of two switches in four switch inverter. In this paper fault tolerant control of the above two methods are designed to detect and isolate the fault which occurs in any one of the switches in the inverter. The merit of this system minimizes the time between the fault occurrence and its isolation. In all methods, respective controllers generate necessary gate pulses for the power switches to drive three phase induction motor. In comparison, the modeling and simulation results show that the Fuzzy based scheme is found to be better dynamic characteristics, less switching losses and better fault recovery time of below 15 ms. whereas 25 ms in PI controller.

To Cite This Article: M. Ayyakrishnan and V. Manikandan., PI and Fuzzy based Fault tolerant control of four switch SVPWM voltage source inverters fed three phase induction motor. ***Aust. J. Basic & Appl. Sci.,*** *8(3): 188-194, 2014*

INTRODUCTION

Three phase voltage source inverters (VSI) are main power components to apply speed control of variable speed drives, uninterruptible power system (UPS) and active power filter. VSI together with three phase induction motor is being used as AC driving units in various fields. In three phase voltage source inverters, there are six power semiconductor switches (MOSFET or IGBT) in three legs with DC input voltage. The main objective of static power inverters is to produce an ac output waveform from a dc power supply. In recent technology, three phase voltage source inverters with four switches are mainly used in the applications of power electronics. The cost due to less number of switches, reduction in switching losses and less chances of destroying the power switches, four switch voltage source inverters (Blaabjerg, F., *et al*., 1999; Ribeiro, R.L.A., *et al*., 1996; Liang D.T.W. and J. Li, 1997) are preferred over six switch voltage source inverters.

Fault is an unexpected change or malfunction to lead sudden failure or breakdown in any system. In power inverters, the fault may destroy the power semiconductor switches due to open circuit or short circuit. If any one of power switches fails, voltage waveform of inverter will be changed and crucial damages can occur in the inverter. To avoid and control the fault existence, fault tolerant control (FTC) is essential to identify the fault and its isolation. Fault occurs in the power semiconductor switches can be isolated by the controllers like PI Controller and Fuzzy controller.

Three phase induction motors (Liang D.T.W. and J. Li, 1997; Uddin, M.N., *et al*., 2002) are used as ac motor drives and require dynamic response and recovery of speed from any external faults or disturbances .This dynamic behavior of three phase induction motor can be improved by vector control theory. So space vector modulation analogy is preferred for the dynamic performance.

This paper presents the design of SVPWM (Blaabjerg, F., *et al*., 1997; Liang D.T.W. and J. Li, 1997; Blaabjerg, F., *et al*., 1999) generation and fault tolerant control using above two controllers (PI and Fuzzy) in four switch voltage source inverters and comparison of those methods. In application part, FSVSI is connected to three phase induction motor. FTC of PI, and Fuzzy were implemented and also verify the dynamic characteristics (speed and torque) and fault recovery time for three phase induction motor.

Corresponding Author: M. Ayyakrishnan, Research scholar,Anna university chennai India.

Australian Journal of Basic and Applied Sciences, 8(3) March 2014, Pages: 188-194

Operating Principles And Modeling:

Figure 1 shows the circuit of four switch voltage source inverter with three phase Induction motor. The proposed inverter having primary circuit composed of three legs with four switches (S1 toS4) in two legs and two dc-link capacitors in third leg. Additionally fourth leg (auxiliary leg) which is formed by two more switches (S5 and S6) is connected to the primary circuit through bidirectional triac switches .Due to fault existence at the any one of the switches in the inverter, the proposed system detects and isolates the faulty leg. The isolation is implemented by removing the gate signal for the particular faulty switch and triggers the bidirectional triac switch (T1and T2). For example If the fault occurs in S_1, auxiliary leg replaces the faulty leg by triggering of bidirectional switch T_1. So the process continues in the operation even though the fault occurrence.

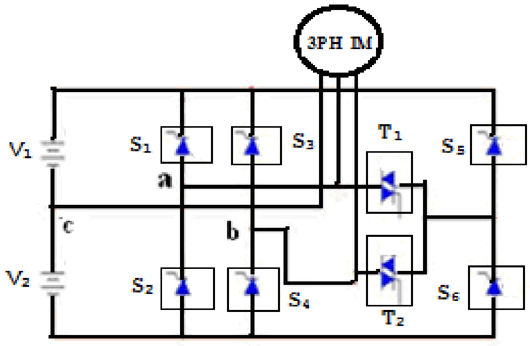

Fig. 1: Four switch VSI fed 3 phase induction motor

Two phases ‘a’ and ‘b’ are connected through two legs of the four switch inverter and third phase of the induction motor is connected the middle point of DC link capacitors V1 and V2. (Blaabjerg, F., *et al.*, 1999) which acts as third leg of three phase voltage source inverter.

According to space vector modulation analogy, components of αβ of the voltage vectors can be obtained from abc voltages by clark’s transformation can be written as (1)

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1}$$

In space vector pulse width modulation, there are four possible space vectors for main circuit power switches and two vectors for auxiliary leg power switches. Each voltage space vector is displaced by 90^0. Table I shows the different modes of operations and output voltage vector of the inverters.

Table 1: Switching Functions And Voltage Vectors

S1	S3	$\vec{V} = V_\alpha + V_\beta$
0	0	$V1 = V_{dc}/3*e^{-j2\pi/3}$
1	0	$V2 = 2V_{dc}/3*e^{-j\pi/6}$
1	1	$V3 = V_{dc}/3*e^{j\pi/3}$
0	1	$V4 = 2V_{dc}/3*e^{j5\pi/6}$

Space Vector Modulation and PWM Generation:

In recent years, high switching frequency power devices like IGBT are used to develop high frequency pulse width modulation control techniques. PWM (Lai, Y.-S. and F.-S. Shyu, 2003; Holtz, J., 1994) produces required gate pulses for turn on or off the concerned power switches within the particular sampling period. Vector durations can be developed by using space vector pulse width modulation (SVPWM). There are six sectors with four voltage vectors and pulse patterns for switching are calculated and obtained as shown in Figure 2 and Figure 3.

Australian Journal of Basic and Applied Sciences, 8(3) March 2014, Pages: 188-194

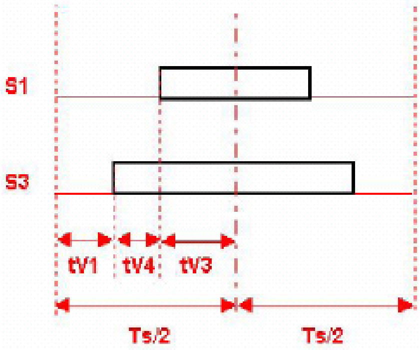

Fig. 2: Pulse patterns for switching in the sector I,V,VI.

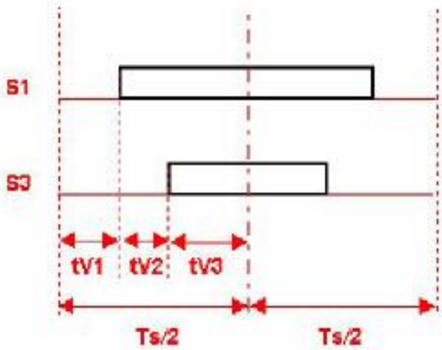

Fig. 3: Pulse patterns for switching in the sector II,III,1V.

Control scheme and PI controller:

Stability is a requirement factor for determining the dynamic characteristics of the system. So every system should be designed as stable system whether the system is normal or not. Due to external disturbances or fault existence, state variables of the system are deviated from the normal condition. PI Controller (O'Dwyer, A., 2003; O'Dwyer, A., 2006) is a powerful compensator in control engineering for solving methodology in embedded control and information processing. PI controller is conventional controller which compensates the error by tuning of the controller parameters.

PI controller forms the control signal is given by

$$u(t)=K_p\left[e(t)+\frac{1}{T_i}\int e(\tau)d\tau\right] \tag{2}$$

Transfer function of PI controller is obtained by laplace transformation

$$U(s)=K_p\left[1+\frac{1}{T_i s}\right]E(s) \tag{3}$$

where:

Ti = integral time constant of PI controller

K_p = proportional gain

$K_i=\frac{K_P}{T_i}$ = Integral constant

When fault occurs in the proposed inverter, there is a time delay (error) between observed value and desired value. PI Controller adjusts the values of K_p and K_i to reduce or minimize the lagging time and maintain the system(three phase induction motor) remains stable condition. That means speed and torque characteristics of IM can be controlled with our require time period.

Ziegler-Nichols recommendations (O'Dwyer, A., 2003; O'Dwyer, A., 2006) for closed loop transfer function are given in Table 2.

Table 2: Ziegler-Nichols recommendation

Controller type	K	T_i	T_d
P	0.5 K_u	-	-
PI	0.45 K_u	0.833T_u	-

Australian Journal of Basic and Applied Sciences, 8(3) March 2014, Pages: 188-194

where : K_u = ultimate Gain, T_u= ultimate time

Control Scheme-Fuzzy Controller:

Fuzzy logic controller (Uddin, M.N. and M.A. Rahman, 2006; Uddin, M.N. and M.A. Rahman, 2000) is a powerful problem solving methodology with a myriad of applications in embedded control and information processing. Fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions. It is better than crisp sets.

Membership function (MF) specifies the degree to which a given input belongs to a set. Here, seven membership function have been used to explore best dynamic responses, namely NL (Negative Large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (positive Medium), and PL (Positive Large). Each fuzzy variable is a member of the subsets with a degree of membership varying between "0 "and "1". Fuzzy rules are conditional statement that specifies the relationship among fuzzy variables. Formation of rules helps us to describe the control action in quantitative terms and have been obtained by examining the output response to corresponding inputs to the fuzzy controller. At the past, speed control of an IPM Synchronous Motor using Fuzzy logic controller was explained (Uddin, M.N. and M.A. Rahman, 2000).

Simulation Results:

Simulation block diagram for PI and Fuzzy proposed system is shown in Figure 5. Simulation is carried out by using MATLAB/SIMULINK. (Matlab, Simulink User Guide, 2003). During the fault conditions, waveforms of stator phase currents, stator phase voltages, speed and electromagnetic torque with various times are simulated.

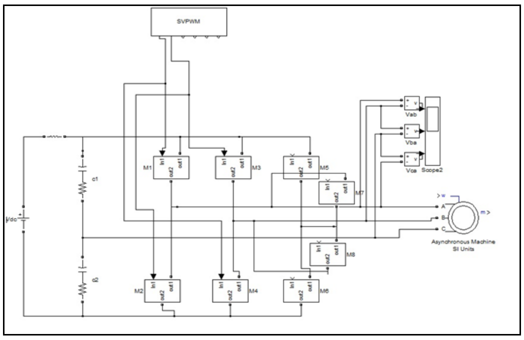

Fig. 4: Simulink model for Fault tolerant topology

a). Simulation Result for PI Controller:

A fault is introduced at t=0. Simulation results of speed and torque characteristics for induction motor during the fault condition in the proposed scheme using PI Controller are shown in Figure 5, Figure 6 and Figure 7. In this wave form, speed of three phase induction motor is oscillating until t=25 ms. which indicates in dotted line. After that speed attains the steady state condition. Similarly an electromagnetic torque of 3 phase induction motor oscillates until the same period shown in Figure 8. Simulation of stator currents is shown in Figure 9.

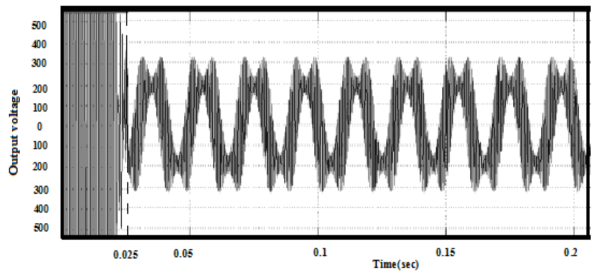

Fig. 5: Simulation result for output voltage at fault condition.

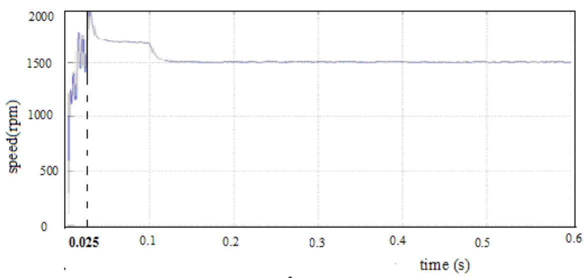

Fig. 6: Simulation result of speed wave form at fault condition.

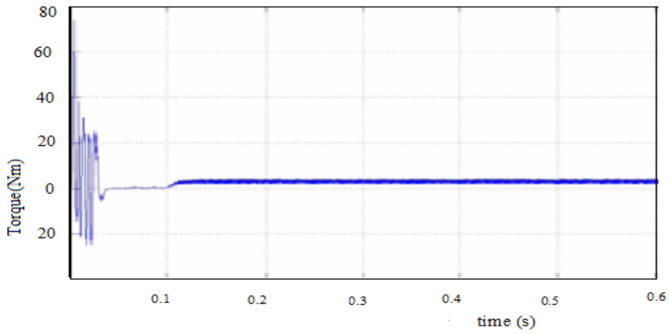

Fig. 7: Simulation result of torque wave form at fault condition.

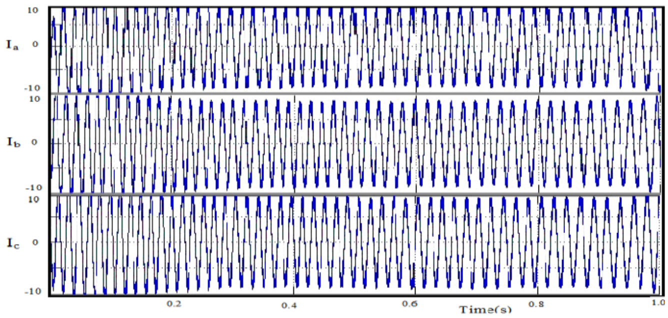

Fig. 8: Simulation result of stator currents.

b). Simulation Results for Fuzzy Controller:

Here fault occurs at time t=0, an output voltage and speed of three phase induction motor reaches to the steady state condition after 15 ms which are shown in the Figure 9.and Figure 10. it means the fault was cleared at the same period. Figure 11. shows torque wave form during the fault occurrence.

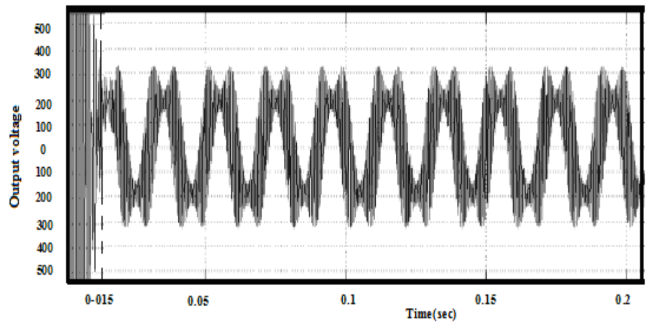

Fig. 9: Simulation result of output voltage at fault condition.

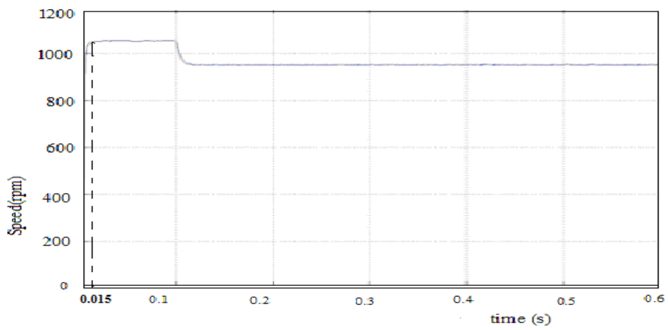

Fig. 10: Simulation result for speed wave form at fault condition.

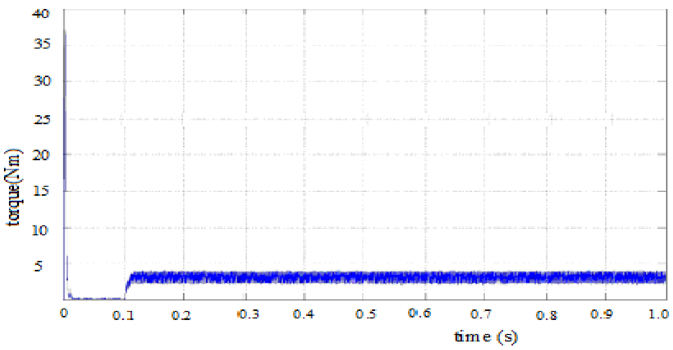

Fig. 11: Simulation result of torque wave form at fault condition.

Comparison Results:

From the above simulation results, comparison of two methods is shown in Table **3**.

Table 3: Comparison Results

S.No	*Fault tolerant control methods*	*Fault diagnosis time*
1	PI controller based drive	> 25 ms
2	Fuzzy controller based drive	> 15 ms

In PI Controller scheme, due to fault at *t=0*, speed and torque wave forms oscillating between *t=0* to 25*ms*.and then gradually reaching to the normal. “i.e.” fault is isolated within the above range. In Fuzzy controller scheme, it has fewer oscillations due to fault which is better than the previous and cleared by *15 ms*. So regarding size and minimization of fault diagnosis time, Fuzzy controller is effective than PI controller.

Conclusion:

This paper presents a PI and Fuzzy based fault tolerant control schemes in four switch voltage source inverter with space vector pulse width modulation. Dynamic characteristics of three phase induction motor are determined at fault conditions. Simulation results show that occurrence of faults can be effectively diagnosed with minimum tolerant time. The simulation results of the above three proposed systems are compared and it concludes Fuzzy controller is the better than PI controller for finding and isolating the fault by minimum time period.

REFERENCES

Azizur Rahman, M., Mahinda Vilathgamuwa, M. Nasir Uddin, and K.J. Tseng, 2003. Nonlinear Control of Interior Permanent Magnet Synchronous Motor, IEEE Trans.on Ind. Applications, 30(2): 408-416.

Blaabjerg, F., D. Neacsu and J. Pedersen,1999. Adaptive SVM to compen-sate DC-link voltage ripple for four-switch three-phase voltage-source inverters, IEEE Trans. Power Electon.,14(4): 1331-1337.

Blaabjerg, F., D.O. Neacsu and J.K. Pedersen, 1999. Adaptive SVM to Compensate Dc-Link VoltageRipple for Four-Switch, Three-Phase Voltage Source Inverter, IEEE Trans. on Power Electronics, 14(4): 743-751.

Blaabjerg, F., S. Freysson, H.H. Hansen and S. Hansen, 1997,A new op-timized space-vector modulation strategy for a component-minimized voltage source inverter, IEEE Trans. Power Electon., 12(4): 704-714.

Cruise, R.J., C.F. Landy and M.D. McCulloch, 1999. Evaluation of a Reduced Topology Phase-ConverterOperating a Three-phase Induction Motor, *IEEE/IEMDC Conf.* Record, Seattle, USA, pp: 466-468

Holtz, J., 1994. Pulsewidth modulation for electronic power conversion, I*nProc. IEEE,* 82(8): 1194-1214.

Jacobina, C.B., M.B.R. Correa, E.R.C da Silva and A.M.N. Lima, 1997. Induction Motor Drive System for Low Power Applications, *IEEE IAS Annual Meeting Conf.* Record 1997, New Orleans, Louisiana, USA, pp: 605-612.

Jahns, T.M., G.B. Kliman and T.W. Neumann, 1986. Interior Permanent Magnet Synchronous Motors for Adjustable-Speed Drives, IEEE Transactions on Industry Applications, 1A(22): 738-747.

Julian, A.L., G. Oriti, and T.A. Lipo, 1999. Elimination of common-mode voltage in three-phase sinusoidal power converters, IEEE Trans.Power Electron., 14(5): 982-989.

Kim, G. and T.A. Lipo, 1995. VSI-PWM rectifier/inverter system with a reduced switch count, *in Proc. IEEE-IAS Annu. Meeting,* pp: 2327-2332.

Lai, Y.-S. and F.-S. Shyu, 2003. Optimal common-mode voltage reduction PWM technique for induction motor drives with considering the dead-time effects for inverter control, Proc. IEEE-IAS Annu. Meeting, pp: 152-159.

Australian Journal of Basic and Applied Sciences, 8(3) March 2014, Pages: 188-194

Larsen, J.S., K. Jespersen, M.R. Pedersen, F. Blaabjerg and J.K. Pedersen, 1998. Control of a Complete Digital Based Component-Minimized Single-Phase to Three-Phase AC/DC/AC Converter, *IEEE/IECON 1998*, Aachen, Germany, pp: 618-625.

Liang D.T.W. and J. Li, 1997. Flux vector modulation strategy for a four-switch three-phase inverter for motor drive applications,*inProc. IEEE PESC*, pp: 612-617.

Matlab, Simulink User Guide, 2003. *The Math Works Inc.*,

O'Dwyer, A., 2003. Handbook of PI and PID controller tuning rules. London, U.K.: Imperial College Press, 1st edition.

O'Dwyer, A., 2006. Handbook of PI and PID controller tuning rules. U.K.: Imperial College Press, 2nd edition.

Ribeiro, R.L.A., C.B. Jacobina, E.R.C. da Silva, and A.M.N. Lima, 1996. AC/AC converter with four switch three phase structures, *in Proc.IEEE PESC*, pp: 134-139.

Rubaai, A., D. Rickattes and M.D. Kankam, 2002. Development and im-plementation of an adaptive fuzzy-neural network controller for brush-less drives, IEEE Trans. Ind. Appl., 38(2): 441-447.

Takijawa, S., M. Tabata, T. Tanigawa, S. Igarashi and K. Kuroki, 2000. High Efficiency Drive Techniques for the Brushless DC Motor Using a Four Switch, Three-Phase Inverter, *Proceedings of IPEC* 2000, Japan, pp: 1692-1697.

Uddin, M.N. and M.A. Rahman, 2000, Fuzzy Logic Based Speed Control of an IPM Synchronous Motor Drive, International Journal of Advanced Computational Intelligence, 4(3): 212-219.

Uddin, M.N. and M.A. Rahman, 2006. Fuzzy Logic controller Based cost effective four switch three phse inverter fed IPM Synchronous Motor Drive, IEEE Transactions on industry applications, 42(1): 21-30.

Uddin, M.N., T.S. Radwan and M.A. Rahman, 2002. Performances of fuzzy logic based indirect vector control for induction motor drive, IEEE Trans. Ind. Appl., 38(5): 1219-1225.