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Mitigation of supply current harmonics in fuzzy-logic based 3-phase induction motor

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ABSTRACT

A parallel active power filter is employed to enrich the quality of power in the power grid with non-linear loads. The induction motor drive requires better performance in many applications. The overall performance enhancement is performed by mitigating the delivery of current harmonics and related warmness losses in an induction motor. In this paper, comprehensive performance evaluation of a 3-phase induction motor is mentioned with fuzzy logic controller-based shunt active filter (SAF), and the outcomes are compared with proportional integral (PI) and proportional derivative controller (PID) controller. In this work, a new scheme of shunt active filters is connected at the supply side of the vertical speed indicator VSI fed induction motor. The simulation was performed by a fuzzy logic controller (FLC) based 3-ϕ induction motor drive (IMD) using parallel SAF. Simulation result from MATLAB/Simulink software has been presented to understand the reduction in harmonics by introducing an active filter near the supply side. A fuzzy suitable judgment controller is brought on this work to develop the induction motor dynamic response. Analysis of the simulation outcomes, the usage of MATLAB/Simulink software program for the proposed FLC managed induction motor had been demonstrated and overall performance enhancement of induction motor was discussed.

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1. INTRODUCTION

Induction motor drives are in use for domestic, agriculture, and industrial applications owing to the many specifications related to cost, size, portability, operational conditions, and high performance they provide to the tip users. The high-performance AC drive system has been employed with the modern power electronic converter. Power electronic converter fed induction motor (IM) drive system may introduce additional electrical noises and disturbances through harmonics injected into the power system. The cause for power quality glitches in power systems is the failure of the electrical components and the evolution of these harmonics. A diode rectifier fed motor for power factor correction circuits employing 1-ϕ active power filter fashioned out of power switches and reactive components are presented [1]. One cycle control [2] had achieved an active power filter with reduced switching loss. Harmonic mitigations have been done with fuzzy controller tuned proportional derivative controller (PID), with d-q-0 reference frame theory for three-phase power shunt active filter (SAF) enhancing power quality has been reported [3]–[5]. A similar result of the total harmonic distortion (THD) values using proportional integral PI and fuzzy logic controller (FLC) controller with RL and RC loads was presented by [6]. The FLC-based speed control of the induction motor, ANN-controlled active filter is discussed in [7] and [8]. Underbalanced and unbalanced load conditions with three-phase SAF using proportional integral (PI) and fuzzy logic controller (FLC) suggested reduction of harmonics [9]. Various ways like condenser banks, passive filters, active filters, and hybrid filters, are recommended and adopted for reducing the harmonics caused by power electronic converters and nonlinear loads. Recent research has been reported in [10]–[20] to reduce the harmonic effects in the induction motor drive with SAF integrated PI, PID, fuzzy, and artificial neural network (ANN) controllers.

The above literature does not confirm the curtailment of harmonics using SAF at the supply side of a vector-controlled IM drive. The overall performance of the proposed induction motor (IM) with parallel SAF has been found out the usage of PI, PID, and fuzzy logic controller. To understand the reduction in the current harmonic analysis, the SAF is connected to the supply-side to diminish the current harmonics in power systems. In the present work, a fuzzy logic (FL) controller is implemented to improve the IM drive performance and to limit the supply current harmonics was proposed.

2. PROPOSED SYSTEM

Nowadays, nonlinear loads are predominantly used in many applications such as uninterruptible power supply (UPS), switched mode power supplies (SMPS), electric furnaces, fluorescent lamps, various power electronic converters and electric drives. These nonlinear loads draw non-sinusoidal currents from the supply, i.e., harmonic currents, and create severe power quality problems such as heating losses, resonance, electromagnetic interference (EMI) disturbances in a communication network, de-rating of the motor. The current SAF method has been used to reduce harmonics and improve power factors using reactive power compensation techniques are addressed [21]–[27]. The adjustable speed drive system used with a front 3ϕ diode bridge rectifier or controlled rectifier acts as a front converter. The general block diagram in Figure 1(a) illustrates the vertical speed indicator voltage source inverter (VSI) fed IM drive without an active shunt power filter and Figure 1(b) presents the general block diagram of the existing induction motor drive system with an influence of shunt active filter (SAF). In this system, a 1-ϕ input power SAF was introduced parallel at the supply side of PI, PID, and FLC-based VSI fed induction motor drive system. The in-depth simulation studies and analysis have been carried out with PI, PID, and FLC based IM drive with SAF.

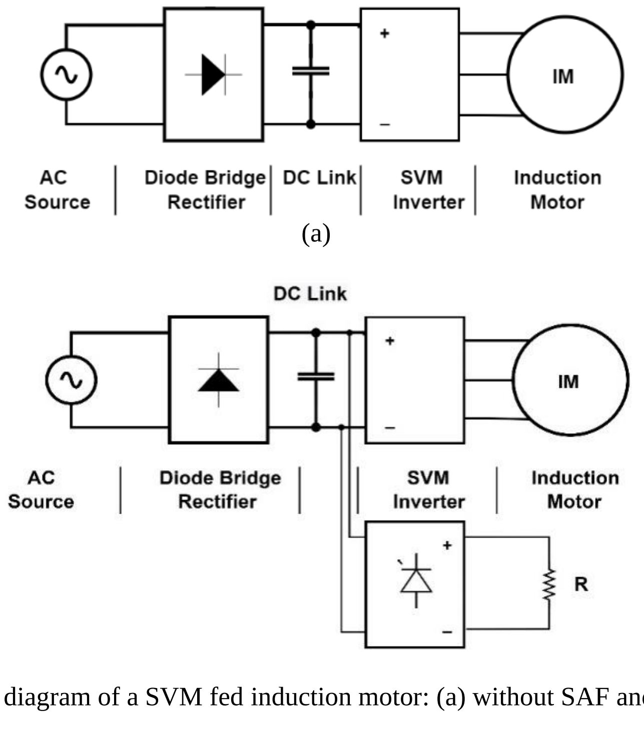


Figure 1. Block diagram of a SVM fed induction motor: (a) without SAF and (b) with SAF

Figure 2 illustrates the circuit elements within the projected system with a shunt active power filter. For DC-AC conversion, a 1-ϕ diode rectifier is utilized in the front-end converter. A DC-link capacitance is exercised for load-balancing energy storage between the 1-ϕ diode bridge rectifier and three-phase voltage supply inverter. Vector control will control the motor speed by exploiting the stator voltage.

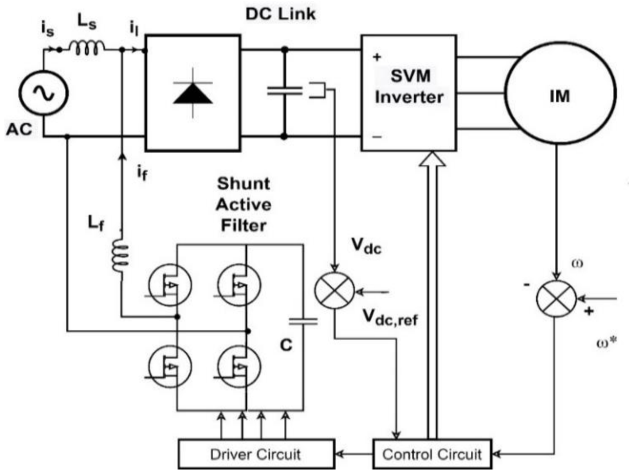


Figure 2. Circuit diagram of the proposed system using an active power filter

3. CONTROL TECHNIQUE

Various control methods are adopted to extract harmonic compensating currents in both the frequency domain and time-domain approaches. Harmonic compensating currents are compared with the generated reference current to switch pulses to the parallel SAF and inverter. In this proposed work, 1-ϕ instantaneous power (PQ) theory is applied to control active shunt power filters and to extract harmonic compensating current. In this system, PI, PID, and Fuzzy logic controllers are adapted for generating switching signals applied to SAF and the inverter to maintain source current harmonics and boost the IM performance, were reported [28]–[31]. SAF is introduced here to yield the compensating harmonic current, which is opposite to the current drawn by non-linear loads, and it reduces the source current harmonics. The active and the reactive powers have been computed using (1).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{\alpha 1} & v_{\beta 1} \\ v_{\beta 1} & -v_{\alpha 1} \end{bmatrix} \begin{bmatrix} i_{\alpha 1} \\ i_{\beta 1} \end{bmatrix} = \begin{bmatrix} \overline{p} + \hat{p} \\ \overline{q} + \hat{q} \end{bmatrix} \tag{1}$$

Both the real and reactive powers consist of harmonic and fundamental components, and from (1), the compensating harmonic reference current is given by (2).

$$\begin{bmatrix} i_{\alpha 1} \\ i_{\beta 1} \end{bmatrix} = \begin{bmatrix} v_{\alpha 1} & v_{\beta 1} \\ v_{\beta 1} & -v_{\alpha 1} \end{bmatrix}^{-1} \begin{bmatrix} \hat{p} \\ \hat{q} \end{bmatrix} \tag{2}$$

The THD of the source current can be calculated by using the (3).

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \times 100 \tag{3}$$

Where I_1 characterizes the fundamental component of source current, and I_h indicates h^{th} harmonic current of non-linear loads contributes to the harmonic currents. Equations involved in the proposed system are given in (4) to (11).

$$v_{s1}(t) = V_{m1} sin\omega t \tag{4}$$

$$i_{s1}(t) = I_{m1} sin\omega t \tag{5}$$

$$i_f(t) = i_L(t) - i_{s1}(t) \tag{6}$$

$$C\frac{dV_{dc}}{dt} = mi_f \tag{7}$$

$$L\frac{di_f}{dt} + Ri_f = V_{dcref} - mV_{dc} \tag{8}$$

From (7) and (8).

$$m = \frac{1}{V_{dc}}\left(v_s - Ri_f - L\frac{di_f}{dt}\right) \quad (9)$$

$$m = \frac{1}{i_f} C \frac{dV_{dc}}{dt} \quad (10)$$

$$i_f = k_p(V_{dc,ref} - V_{dc}) + k_i \int (V_{dc,ref} - V_{dc})\, dt \quad (11)$$

By taking Laplace transform on the differential of PID controller mentioned in (12), the transfer function is derived, and revealed in (13).

$$u(t) = k_c e(t) + k_i \int e(t)\, dt + k_d \frac{de(t)}{dt} \quad (12)$$

$$G_c(s) = k_c\left(1 + \frac{1}{sT_i} + T_d s\right) \quad (13)$$

The PID controller parameters are tuned by means of Ziegler-Nichols method in many applications. Ziegler-Nichols method are step response and frequency response methods. The PID controller parameters are tuned by Ziegler-Nichols self-oscillatory method. This method is traditionally easier and is based on measurement of ultimate or critical gain K_u and ultimate or critical period T_u from the measured quantity of closed-loop system. The required PID controller gains such as k_c = 0.56, k_i = 0.45 and k_d = 0.38 are used in this simulation analysis.

The many control algorithms are enforced to FLC. Figure 3 shows the elementary architecture of an FLC. The FLC has fuzzification, rule evaluator, and de-fuzzification blocks. Input variables are depicted in a linguistic manner, the logical thinking mechanism takes acceptable control action supported rule base block, and the output control signals have been converted into real-time signal with a de-fuzzification block. The fuzzy controller may be a content expressed in terms of fuzzy inference rules and a fuzzy inference engine with two input variables; error voltage (ε) and changes in error voltage (Δε), to come up with the required signal to satisfy the real-time system and Figure 3 shows the schematic representation block of the current reference generation.

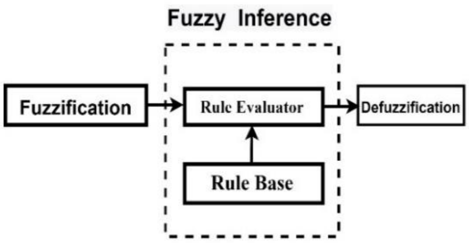


Figure 3. Elementary architecture of an FLC

In the vector control method, 3-ϕ induction motor is reflected as DC shunt motor (separately-excited), which distinctly controls the decoupled torque and flux component of the induction motor stator currents. The error signal is detected by comparing DC link voltage with actual DC bus voltage. This error (ε) and change in error voltage (δε) are fed to PID/FL controllers to generate the reference currents. Hysteresis controllers are employed here to generate gate pulses of shunt active filter and SVM inverter. The control block for switching pulse generation using hysteresis current controller and FLC-PID is shown in Figure 4.

Comparing the reference and actual speed of the IM drive, an error signal (e) is generated. The specified gate pulses are generated with the influence of an error signal in the course of PI, PID, and FL controller. The provision of current harmonics has been regulated through the parallel SAF. Still, the FL controller provides higher performance with reduced supply current THDs. Within the system, the Mamdani kind, logical thinking engine has been adopted as a result of its just like human input. Error (ε) and change in error (δε) signals are delineated through seven fuzzy linguistic states negative-big (NB), negative-medium (NM), negative-small (NS), zero (ZE), positive-small (PS), positive-medium (PM), positive-big (PB)). Fuzzy variables are characterized by triangular membership functions within the fuzzification method, and therefore the PLL management approach is estimated by MATLAB/Simulink power tools. Fuzzy inference system (FIS) plays a vital role in the control system, i.e., in the fuzzy logic controller, which is defined in Table 1.

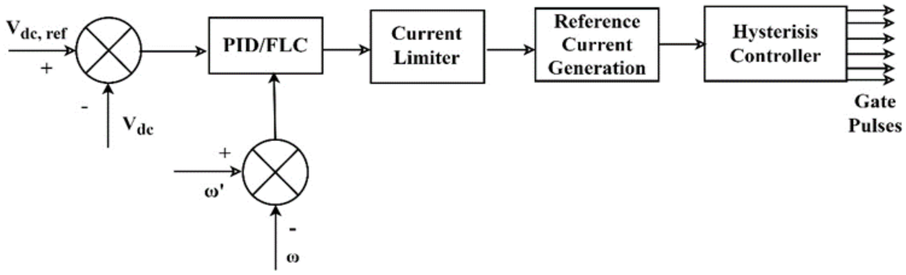
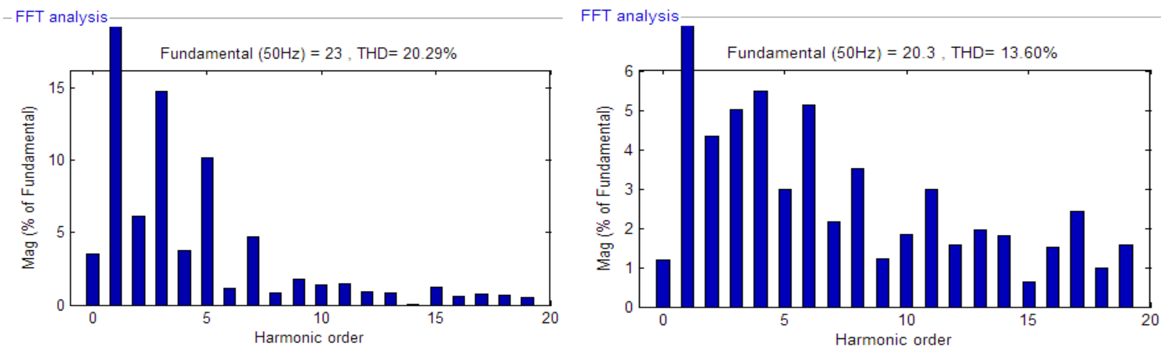


Figure 4. Control block diagram for switching pulse generation using HCC

Table 1. Rule basedefined for fuzzy logic controller

δε \ ε	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	ZE	PN
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NB	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The control of the asynchronous motor drive based on the PI and PID controller without an active filter is simulated with the MATLAB/Simulink software. Here, the PI controller regulates the motor speed. The frequency FFT analysis of the asynchronous motor based on a PI controller without an active filter as shown in Figure 5(a), and the source current harmonics (THD) is found at 20.29%. Figure 5(b). depicts the THD of the drive, employing a PID controller, with no SAF, and the THD is 13.60%. The simulation parameters for the suggested system are given in Table 2.



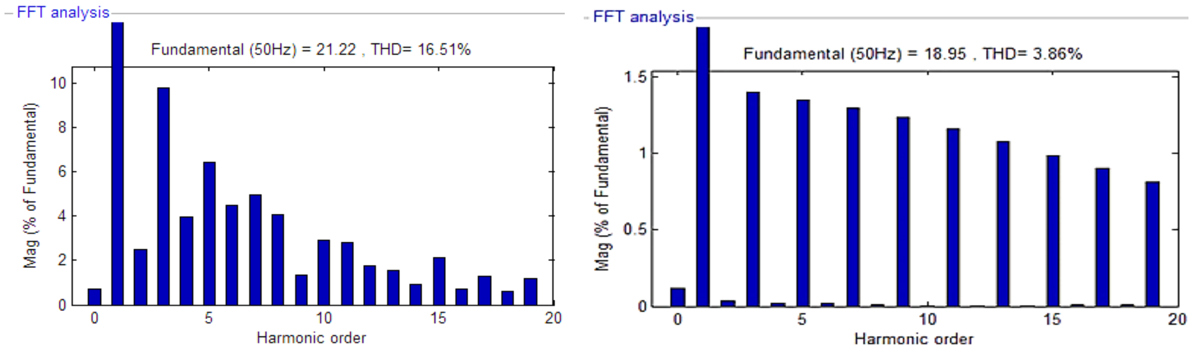
(a) (b)

Figure 5. THD of the induction motor without SAF (a) PI controller and (b) PID controller

Table 2. Parameters of electrical components

Parameter	Value	Parameter	Value
Source inductance (L_S)	5 mH	Supply voltage (V)	415 V
Filter inductance (L_F)	9 mH	Frequency (F)	50 Hz
Filter capacitance (C_F)	1000 µF	Speed (N)	1430 rpm
DC-link capacitance (C_{dc})	1200 µF	Pole-pair (P_P)	2
DC-link capacitor voltage (V_{CDC})	250 V	Stator and rotor resistance (R_s, R_r)	1.405 Ω, 1.395 Ω
Motor load	3ϕ, SCIM	Stator and rotor inductance (L_{ls})	5.839 mH, 5.839 mH
Power (P)	5.4 HP/4 kW	Mutual inductance (L_m)	0.1722 H
Moment of inertia (J)	0.0131 kgm^2		
Friction coefficient (F)	0.2985 Nms		

Closed-loop control of the IM drive employing PI and PID controllers with SAF implementation, is laid out in Figure 6. The THD of the supply current, employing PI and PID controllers with SAF based IM drive, is revealed in Figure 6, and the THD of the supply current is found as 16.51% in Figure 6(a). From the frequency spectrum, Figure 6(b) depicts the THD of the induction motor drive with PID–SAF is found as 3.86%.



(a) (b)

Figure 6. THD of the induction motor with SAF (a) PI controller and (b) PID controller

A fuzzy controller-based induction motor with a parallel shunt active filter (SAF) is laid out in Figure 7. The speed and torque responses of IM drive control by means of the FL controller with SAF are as shown in Figure 8(a) and Figure 8(b) respectively. The speed and torque responses of the FLC-IM by means of SAF is exhibited in Figure 9(a) and Figure 9(b). From the FFT analysis, the THD of the FLC-based IM drive without SAF is found at 7.52% in Figure 10(a). From the FFT analysis, the THD of the FLC-SAF controlled induction motor drive revealed in Figure 10(b) was found as 2.66%. The FLC is considerably enhancing the speed and torque response of the IM drive when compared with PI and PID controllers. Additionally, FLC reduces the source current harmonics %THD is from 3.86 % to 2.66%.

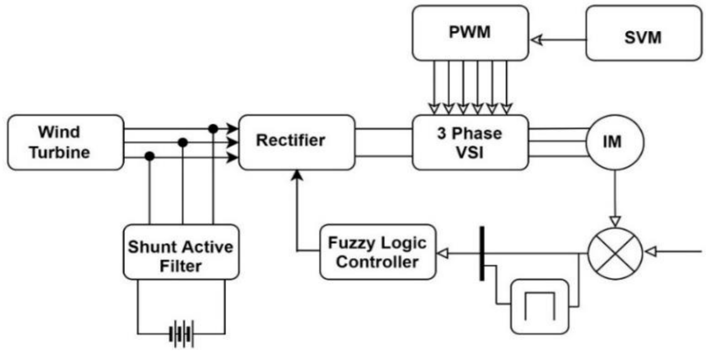


Figure 7. Fuzzy logic controller-based induction motor with SAF

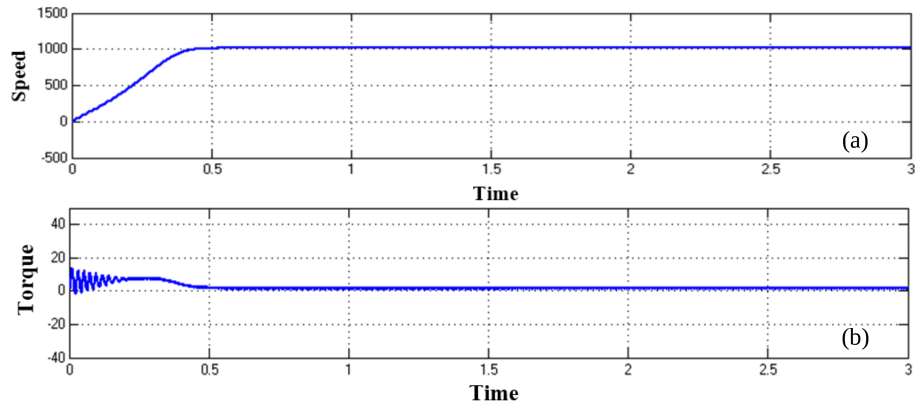


Figure 8. Fuzzy logic controller-based induction motor without SAF (a) speed and (b) torque

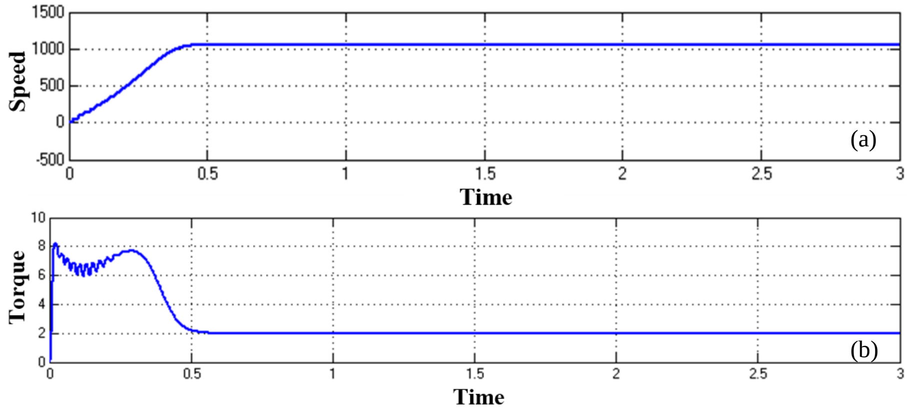
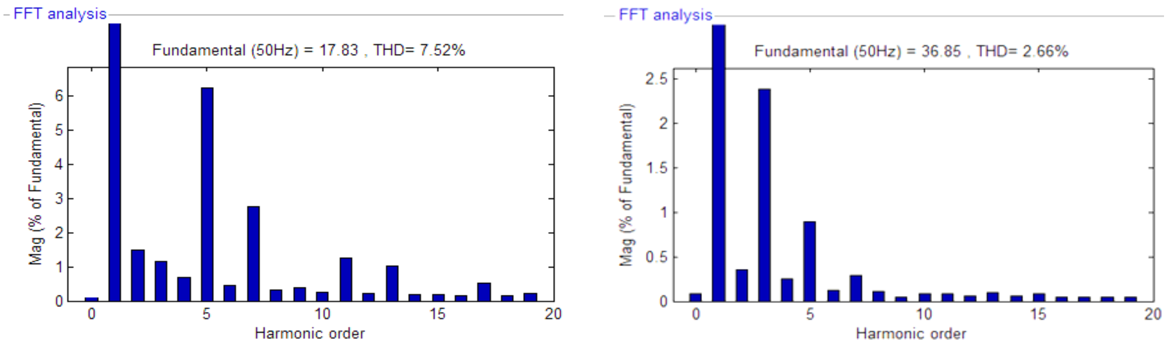


Figure 9. Fuzzy logic controller-based Induction motor with SAF (a) speed and (b) torque



(a) (b)

Figure 10. THD of FLC controller-based induction motor (a) without SAF and (b) with SAF

Comparison of the time-domain parameters in PI, PID, and FLC controlled induction motor with and without parallel SAF is portrayed in Table 3. Comparison of source current harmonics (%THD) of the PI, PID & FL controller-based IM, with and without parallel SAF is depicted in Figure 11. Comparative analysis of supply current harmonics (%THDs) of PI, PID, and FL controller-based induction motor drive implementing with & without parallel SAF is tabulated in Table 4. The FLC is considerably enhancing the speed and torque waveform response of the induction motor drive when compared with PI and PID controllers. Additionally, FLC reduces the source current harmonics %THD is from 3.86 % to 2.66%. It was reported that the %THD is 2.66% for using Fuzzy logic controller. Therefore, in relation to the PID controller, the Fuzzy logic controller improves the dynamic response of the induction motor and the reduction of the source current THD.

Table 3. Comparison of performance indices of PI, PID, and FLC based IM drive with and without SAF

Induction motor control		T_r sec	T_p sec	T_s sec	% e_{ss}
PI controller	without SAF	0.01	0.15	1.8	2.4
	with SAF	0.2	0.25	1.9	2
PID controller	without SAF	0.17	0.2	1.4	1
	with SAF	0.01	0.08	0.1	0.7
Fuzzy logic controller	without SAF	0.38	0.4	0.5	0.3
	with SAF	0.33	0.38	0.4	0.02

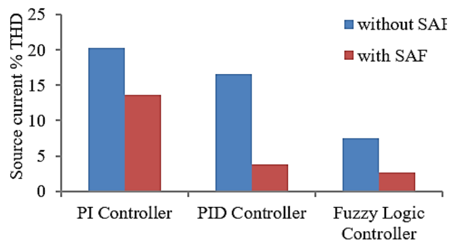


Figure 11. Comparison of %THD of different controllers for induction motor drive with and without SAF

Table 4. Comparison of source current harmonic %THD for different controllers

Induction motor drive with and without SAF	%THD	
	without SAF	with SAF
PI Controller	20.29	13.60
PID Controller	16.51	3.86
Fuzzy logic controller	7.52	2.66

4. CONCLUSION

In this work, the supply current harmonics are minimized by using parallel-connected SAF at the end. The system has a three-phase IM drive in a closed loop with PI, PID, and Fuzzy logic controllers, which are analyzed and simulated using MATLAB/ Simulink software. Simulation results indicate the dynamic response of the Fuzzy logic-controlled induction motor drive system could be advanced to PI and PID-controlled induction motor drive systems. The main reason is, the settling time of the system was reduced to 0.4sec by including FLC. The total harmonic distortion of supply current (%THD), employing FLC with shunt active filter for induction motor drive is 2.66%, that's beneath the 5% restriction of the global standards (IEC 61000-3-2 and IEEE 519). Therefore, the Fuzzy logic-controlled IM system is superior to the PID-controlled system.

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