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Design and Implementation of speed control for 3 phase induction motor using Active Front End Drive

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Abstract: *Power supply system difficulties include supply line disruptions, harmonics in line current, and low power factor. To tackle these challenges, a control system consisting of dc link voltage controller and proportional integral (PI) current controller using phase angle estimator is proposed. Current controllers are designed using PI controllers, and simulations are run with both PI and DQ model-based controllers. Fast reaction and enhanced power quality are shown by reduced AC mains harmonics, improved power factor, and well-regulated DC output voltage. This model can be simply used in the actual system, minimizing design and control complexity. This paper proposes vector control of AC/DC FEC using a single current sensor. V-phase current estimate uses grid side d-q axis current controller reference currents. FEC maintains steady DC-link voltage, which can be changed within limits. It pulls sinusoidal current from the mains and can alter input power factor. MATLAB/Simulink simulations justify the proposed current estimation method.*

Key Words: Active Front End drive (AFED), Variable frequency drive (VFD), v/f vector control method, and Induction motor (IM), PI Controller and PF improvement.

1. INTRODUCTION

Active front end converter converts AC to DC. The two main benefits of active rectifier systems over passive rectifier systems are output voltage regulation and reduction of AC input harmonics. Active rectifier is a non-isolated AC-DC converter. Since "rectifier" implies a unidirectional converter, the name "Active Front-end" perfectly describes the same thing. Instead of "output voltage," I prefer "DC link voltage," the DC side of the converter can be either the output or the input, and it is bi-directional. DC power is transferred to AC with the help of an active front-end or active rectifier. AFED is controlled by single current sensor. The AFED maintains the DC link voltage and restricts harmonic current. It transfers active power between load and grid. Single-current-sensor FEC uses vector control. Different methods are used to construct current signals in single-sensor AC motor drives.

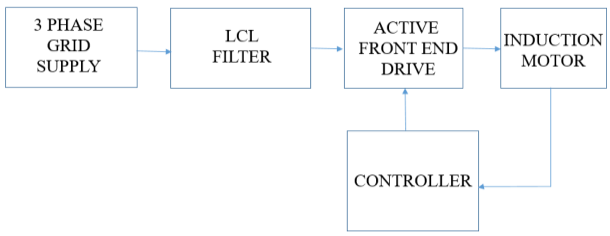

Figure 1 Block diagram of AFED

This single-current-sensor FEC is new. Active front end (AFE) has many advantages over the other techniques. AFE-based converters can reduce line current harmonics caused by high-frequency switching, generate power, maintain power factor, and regulate DC-link voltage. Non-sinusoidal input current causes harmonic distortion in conventional converters. PWM converters could help. PWM utilizes sinusoidal pulse width modulation, a kind of carrier-based PWM during which gating pulses are produced by comparing the sinusoidal modulating signal with the triangular carrier signal. PI-controllers are used. Associated controlled variables decoupling variables using dq transformation improves voltage response and reduces harmonic distortion.

1.1 Active Front End Drive

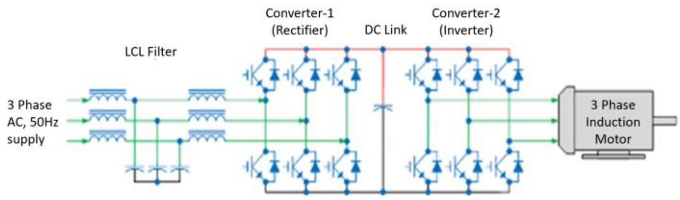

Figure 2 Circuit configuration of AFED

In an active front end, insulated gate bipolar resistors used to convert the incoming AC power to DC rather than diodes in the rectifier (IGBTs). IGBTs are electronic switching-controlled devices that is why the term "active" front end is used (as shown in Figure 2).

Total harmonic distortion (THD) is reduced to 5% or less by the active front end, which constantly monitors the line current waveform and shapes it to be sinusoidal. The switching frequency of the IGBTs leads to higher harmonics that have to be attenuated; THD is only evaluated for lower-order harmonics. In VFD applications, harmonic distortion also makes up the majority of the system's power factor. Two factors determine the power factor. The initial factor is the phase angle, also defined as the displacement, between the applied voltage and the generating current. For a variable frequency active frontend drive to function, voltage and current must remain in phase and their cosine distance must be kept close to unity (1). Total harmonic distortion is a second component that impacts power factor in an inverse manner; the higher the THD, the lower the power factor. Therefore, a front end with an active design that lowers harmonic distortion (for instance, from 45 to 5) significantly improves the system's power factor.

PF=cos θ/√ (1+ (⟦THD) ⟧^2) (eq.1)

1.2 Sinusoidal pulse width modulation

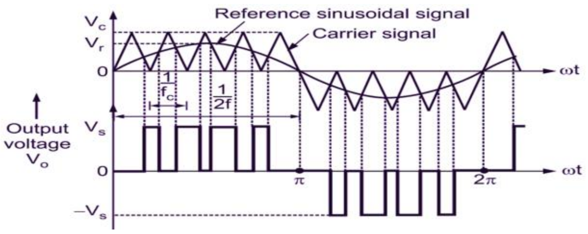

Figure 3 SPWM switching method

A basic source voltage inverter's switches can be switched on and off as required. The switch is activated or deactivated once for each cycle. Accordingly, a square waveform is formed (as shown in Figure 3). However, if the switch is periodically turned on, an improved waveform with a harmonic profile is produced. The sinusoidal PWM waveform is created by matching the desired modulated waveform with a triangular waveform with a high frequency. Depending on whether the voltage of the signal is less or more than that of the carrier waveform, the output voltage of the DC bus will either be negative or positive.

1.2.1 Closed loop control of 3-phase induction motor

When a three-phase induction motor is being controlled in a closed loop, the speed sensor is used to compare the actual speed to the reference speed first (as shown in Figure 4).

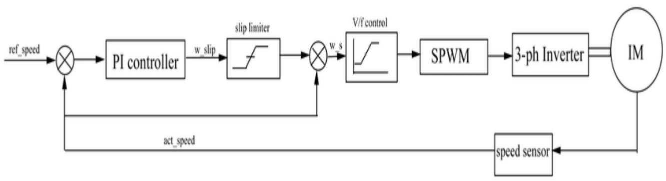

Figure 4 Closed loop control of IM

The error signal one which results from this compared is then fed to the PI controller, which provides the angular slip speed, which is then compared to the actual speed again with the slip regulator to keep the speed within allowable levels. At last, the error signal is fed to the V/F control block, which is fed to the SPWM, and and at last to the inverter,

Table -1: Specifications of AFED

Specifications			
Parameter	**Values**	**Induction motor parameters**	**Ratin g**
3-phase AC input voltage	415 V	Squirrel cage IM	5.4 HP
Input supply frequency	50 Hz	Power rating	4kW
DC link voltage	800 V	Voltage rating	400 V
IGBT switching frequency	20 kHz	Motor Speed	1430 RPM

1.2.2 Design of LCL Filter and Controllers

$$Z_b = \frac{E_n^2}{P_n} \qquad (eq.2)$$

$$C_b = \frac{1}{\omega_g Z_b} \qquad (eq.3)$$

$$\Delta I_{Lmax} = \frac{V_{DC}}{6 f_{sw} L_1} \qquad (eq.4)$$

$$\Delta I_{Lmax} = 0.1 I_{max} \qquad (eq.5)$$

$$I_{max} = \frac{P_n\sqrt{2}}{3V_{ph}} \qquad (eq.6)$$

$$L_1 = \frac{V_{DC}}{6 f_{sw} \Delta I_{Lmax}} \qquad (eq.7)$$

$$L_2 = \frac{\sqrt{\frac{1}{k_a^2}}+1}{C_f \omega_{sw}^2} \qquad (eq.8)$$

in eq. 8 k_a *is the attenuation constant considered as 20%*

C_f *is given as* $C_f = \frac{0.01}{0.05 C_b}$ (eq.9)

$$L_2 = rL_1 \qquad (eq.10)$$

in eq. 10 'r' is assumed as 0.6

$$\omega_{res} = \sqrt{\frac{L_1 + L_2}{L_1 L_2 C_f}} \; ; \; 10 f_g < f_{res} < 0.5 f_{sw} \qquad (eq.11)$$

Table -2: Results obtained from eq.2 to eq.11

Parameter	Value
L_1	0.54 mH
L_2	0.914 mH
C	60μF

1.2.3 Design of Controllers

Two control loops exist.
1) Constant outside voltage loop
2) The inner current loop must have a unity power factor

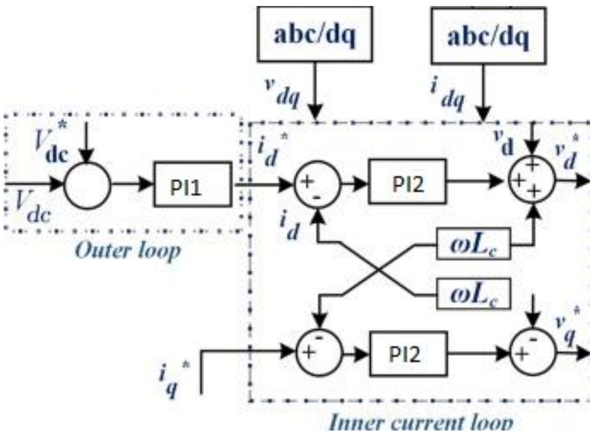

Figure 5 converter-1 control loop

Table -3: PI-Controller Design Parameters

Parameter	Value
K_{P1} K_{I1}	1.5 300
K_{P2} K_{I2}	10 400

2. Simulink model of Active Front End Drive fed Induction Motor

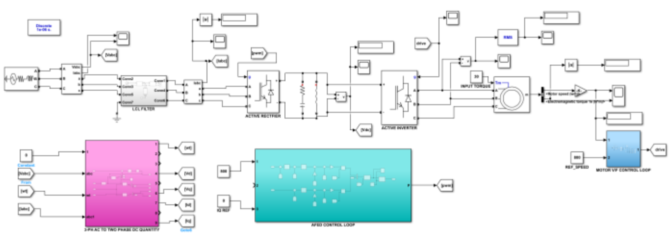

Figure 6 Simulink Model of AFED

2.1 Simulation Results

I. Line Current without filter

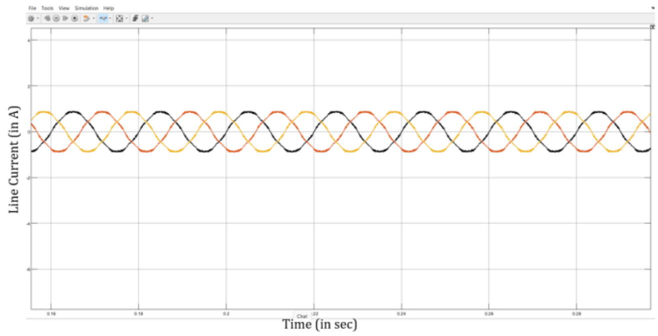

Figure 7 Line current without LCL Filter

As shown in Figure 7, It is observed that there is noise in line current which may damage the circuit components in eliminate noise we are introducing LCL filter at input side.

II. Line Current with filter

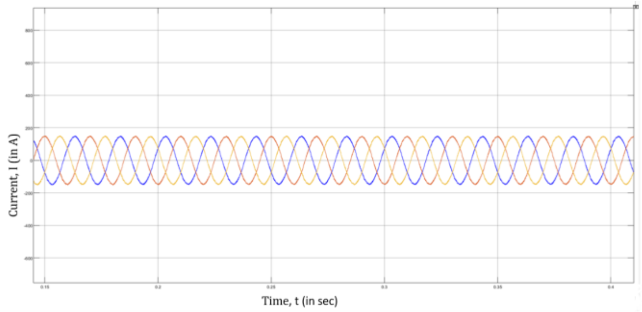

Figure 8 Line Current with LCL Filter

As shown in Figure 8, it is observed that noise in line current has been eliminated by using LCL filter. With the result we are able to achieve THD less than 5% as per industrial standard IEEE-519.

III. Harmonics Analysis

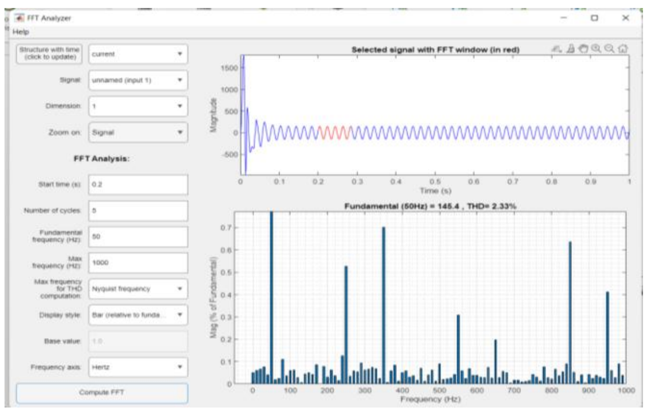

Figure 9 Harmonic Spectrum of Line current

As shown in Figure 9, it is observed that fundamental THD is 2.33% calculated by using FFT analysis using MATLAB software.

IV. Converter-1 Output Voltage and output current

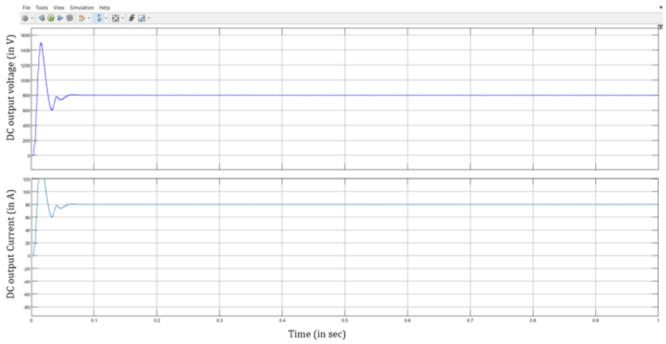

Figure 10 Converter1 output voltage and current waveform

As shown in Figure 10, We are able to achieve fixed DC output voltage of 800V from Converter 1 (Active Rectifier) which is input to the Converter 2 (Inverter drive).

V. Inverter output Voltage

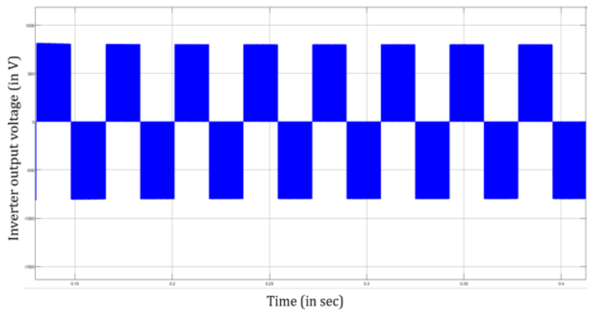

Figure 11 Inverter output voltage

As shown in Figure 11, it is observed that the obtained inverter output voltage is as that of expected output voltage.

VI. Speed Control

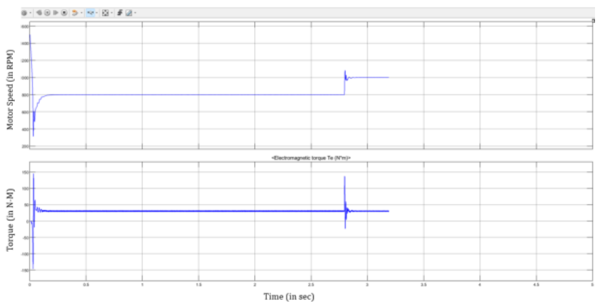

Figure 12 Speed control of Induction motor

As shown in Figure 12, it is observed that speed control of 3-phase induction motor is achieved by changing the reference speed according to the actual speed with the help of v/f control method.

2.2 Hardware Setup Model

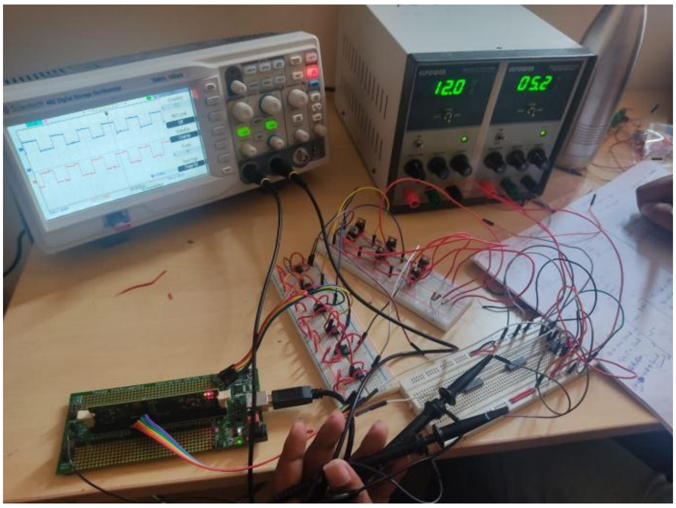

Figure 13 Hardware Setup model of AFED

Figure 14 IGBT switching test hardware setup using DSP-C2000

With the help of DSP-C2000 interface and IR-2113 driver circuit, we can generate switching pulses of 20 kHz for IGBT (as shown in Figure 14) (Also complete hardware setup of AFED is shown in Figure 13).

3. CONCLUSIONS

Using the constant V/F method for induction motor closed loop speed control, an active front end drive that is PWM based SPWM has been designed and implemented in this paper. MATLAB Simulink has been used to simulate the analysis. Basically speed change scenarios have been taken into consideration for assessing the performance of PWM-based converters, which includes a speed change from 800 rpm to 1000 rpm in t=2.14 sec at a constant torque of 30N-m. The Active Front End Drive circuit, which is simulated in the Simulink Model MATLAB software, enables variable speed control of a three-phase induction motor by controlling the motor's speed. Besides that, with the aid of actively obtaining a fixed DC voltage of 800V and a THD of 2.33%.

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