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# Enriched I-Q Active Filter Based Harmonics Mitigation in Rectifier-Inverter Fed Induction Motor Drive

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**Abstract:** In recent decade, an introduction of innovative technological development in power electronics sector is to perform significantly for compensation of power quality issues. The sugar industry's widespread implementation of variable-frequency induction-motor drives cause the electrical distribution systems to become worse. Greater harmonics produced by semiconductor current converters affects the sinusoidal voltage and increase reactive component of current by voltage. To overcome the aforementioned issues, the research paper examines issues of power quality in an induction motor (IM) drive system attached to utility grid system. The addition of filters, which reduces the power quality, issues in induction motor drives by providing lower THD. The IM drive system with an enhanced filter is employed to reduce harmonics produced by power semiconductor switches to keep the three-phase power supply in good condition. So, the instantaneous imaginary controller-based shunt active power filter (I-Q active filter) is employed to lessen the harmonic content that exists in the current at the point of source. To enhance the electrical network system's power quality, the proposed filter is injected parallel within the source and the IM drive system. The outcomes of simulations are analysed and it is executed by MATLAB/Simulink.

**Keywords:** harmonics; induction motor drive; I-Q active filter; power quality; sugar industry

## 1 INTRODUCTION

The necessity for electronic systems and devices has risen substantially over the past few decades, primarily as a consequence of growth in the economy and population [1]. As a consequence, power electronics and AC machine drives are making progress in a number of industries, such as manufacturing, electronic goods, electric vehicles, non-conventional energy and power generation plants [2, 3]. Because of the variable speed, high efficiency, and affordability, three phase IM drives are frequently utilized in manufacturing applications. The progress in solid-state power conversion has opened up opportunities for the flexible deployment of variable frequency induction motor drives (VFIMDs) in various fields such as air conditioning, blowers, rolling mills, and others. With increasing demand, industries are now providing solutions with power ratings reaching up to MW for purposes like electric propulsion, rolling mills, traction systems, and hybrid electric vehicles, highlighting the escalating significance of VFIMDs in contemporary industrial and transportation sectors [32]. The IM drive must function effectively on both the machine and the drive section. A diode bridge rectifier is used by Voltage Source Inverters (VSI) to supply the dc link voltage for three-phase induction motor drives. Huge currents are drawn from the supply line as a result of the power electronic switches' nonlinear behavior that raises the power requirement and machine rating [4]. This raises the total expense of operating the system. Induction motor drives are examined in various ways to monitor their efficacy in various scenarios. Subsequently enhancing power quality reduces the price of electricity, power quality assessment of induction motor drive systems is a highly significant research field [5]. In many recent applications, such as the drive of variable frequency induction motors, AC-DC converters are now widely used. Although certain applications, such as AC drives, occasionally call for DC power during transitional stages, they typically require DC power to operate. The aforementioned AC-DC converters, commonly referred to as rectifiers, are utilized in medium power applications and are powered by a three phase AC supply with a 33 kV or 11 kV voltage along with a step-down transformer [6]. The AC-DC converters, however, possess low input power factor, raised DC voltage ripple, increased THD, and poor input power quality. Various approaches have been developed to overcome these restrictions [7]. The filters are usually employed to eliminate harmonics that can be either passive or active. These filters raise losses and complexity of circuits while being inefficient. Due to their remarkable efficiency, higher reliability, and simple structure, multi pulse rectifiers have become increasingly popular for enhancing the input power quality and decreasing harmonics. In addition, multi-pulse rectifiers do not need LC filters, removing the potential for LC resonances. Additionally, the common mode voltage generated by rectifiers is removed through the use of a phase-shifting transformer [8]. The research investigation examined difficulties with reliability of power in a distributed multi-drive system linked to an uncontrolled rectifier. The primary use of an uncontrolled rectifier is as a front-end converter to supply direct current to inverters driving induction motors. So, a shunt active power filter is used to lessen the harmonic content that is present in the source current. To enhance the grid system's power quality, an active filter is parallel injected among the source and the multi-drive mechanism. The primary limitation associated with an active filter is its pricey, intricate control mechanism. Both back-to-back converter actions are subject to an ongoing research into predictive model control, which serves as an active power filter to compensate for harmonics and supply sinusoidal grid current. Power quality and harmonics removal are considered in this optimization. The main disadvantage of model predictive control is that it was designed to handle output disturbances and may struggle with input issues [9]. The study offers a technique for creating hybrid power filters that minimize distortion caused by harmonics and thus enhance power factor and lessen the harmonics issues. The primary drawback this kind of filter are high computational expenditure [10]. By employing the harmonic injection method, an induction motor's harmonics that are present in its current, voltage, space, or time parameters have been attempted to be reduced. In order to achieve harmonic distortion levels up to or less than 3% THD, harmonics injection method first cancels up to the 50th harmonic [11]. The installation of an active rectifier to a frequency converter is one of the promising methods for enhancing power quality while an AC VFIMD is operating. In mining equipment with VFIMD, frequency converters with active rectifiers are an efficient tool for improving power quality and reducing consumption of energy [12]. The investigation examined the reference value of the total harmonic factor, requiring an AR filter and considering feed line length when configuring AR current controllers, ensuring compliance with recommendations for transient and steady state processes. [13]. Numerous studies on PWM methodologies' impact on VSI in Induction motor drives, however, only address specific parameters like torque ripple and line current THD. [14]. The research explores a selective harmonic reduction approach in a three-level NPC inverter-fed induction motor drive to minimize torque harmonics and mechanical and electrical resonance. [15]. certain torque and current harmonics which could cause disturbances as well as mechanical and electrical resonance are avoidable because of the different modes of operation. In a three-level NPC inverter-fed induction motor drive, the research investigated the selective harmonic reduction approach to minimize the determined torque harmonics [16]. For [17] enabling the drive to absorb or inject reactive power and deliver current supply that has minimal harmonics, a field-oriented control scheme has been established. The industries, which utilize numerous induction motor drives concurrently, require greater, less expensive approaches to enhancing the electrical performance. Existing Research proposes a control method for a dynamic voltage restorer (DVR) that protects an adjustable speed drive (ASD) from harmonics, imbalance, drop, and swell [18]. The sources of current harmonics are the various non-linear loads. Waveform changes in current and voltage are commonly caused by the harmonics in the current. As a consequence of the various loading scenarios, distorted current is injected from the point of common coupling to supply [19]. The addition of filtering circuit with enhances power quality with lower THD, enhancing the converter's efficiency and the induction motor's dynamic performance [20]. The IMD system with an enriched filter is used to reduce harmonic produced by power semiconductor switches. It also offers reactive power compensation to keep the three-phase power supply's quality significant that is necessary for preserving the functionality of other devices linked to the converter circuit.

The proposed research primary contribution consists comprising the following:

- For the minimization of harmonics, the power supply from the grid system, in sugar industry, an enriched I-Q active filter has been implemented.
- To instantaneous active and reactive power theory employed in the suggested design to extract the features
- The drive performance analysed in terms of power quality such as THD analysis and voltage and current maintenance.

The accompanying would be the format of this paper: Section 1 provides an introduction of drives. Section 2 elaborate the drive system of sugar industry. Section 3 depicts generation of harmonics in varying load situation. Section 4 describes the proposed methodology and system modelling. Section 5 explain the proposed methodology outcomes. The conclusions of this work are described in Section 6, and the references are given in subsequent section.

## 2 DRIVE IN SUGAR INDUSTRY

In a sugar mill, there are many different driven machineries, but generally, there are merely three main kinds of drives:

- Constant speed
- Variable speed over a limited range
- Variable speed over an extensive range.

The adjustable speed drives (ASD) known as variable frequency drives (VFDs) have been used in industrial settings to regulate the machinery's two major operating parameters, namely torque and speed. Fig. 1 depicts the block diagram for a three-phase motor drive system. The ASD method is used in industrial applications because distinct equipment in various sectors operates at distinct speeds [21]. VFD contributes a significant function in reducing the amount of harmonics.

The selection of AC and DC drives depends on the needs of the industrial application. While DC drives are employed to have high starting torque and constant speed. The objective for utilising AC drives is to have good control processes and minimize energy consumption, for example, they are used in boiler feed pumps and power generators. In the present research, the induction motor's speed and torque are controlled by an AC drives system. The impact of harmonics is greater in VFD. The nonlinear behaviour of the load may also be responsible for the VFD's poor power factor, which decreases with a reduction in motor speed and results in a significant quantity of induction harmonics being supplied again to the electric power supply [22].

### 2.1 Induction Motor Drives

The three-phase induction motor is ideal for constant speed drives in sugar factories, while the slip ring and squirrel cage motors are suitable for high torque and long run-up times, with easy-to-understand control gear. Approximately 400 electrical drives, varying in size about a few kW to a few MW, are used in a typical contemporary sugar factory for various operations. Solely three or four of these locations use SRIMs, which account for about 30% of their overall electrical usage. The aforementioned SRIMs are set up at precrushing equipment that essentially uses large rotating knives to chop the cane, followed by heavy rotating hammers to shred it, to prepare the cane for effective squeezing the highest-performance motor in the industry, which uses nearly 15% of the installed power, is used for cutting operations.

Sugarcane industries commonly employ cogeneration plants, with induction machines for braking functions. Flywheels are fitted to mitigate load swings, particularly during breaking. Switched reluctance induction motors.

(SRIMs) with high inertia are recommended for heavy knife operations. However, SRIMs require external rheostats for starting and maintain slip resistance to minimize current fluctuations. Despite load stability benefits, significant energy is wasted in slip resistance. [23].

A variable frequency drive (VFD) is an electrical system that connects an electric motor to a supply system, supplying it with a variable frequency alternating supply voltage, allowing variable motor torque and speed. Modern VFDs consist of a rectifier, DC-link, and inverter sections. [24]. Three phase induction motor drives as shown in Fig. 1

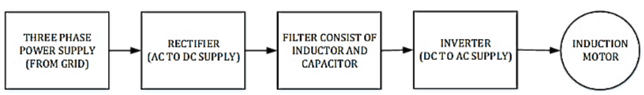


**Figure 1** Three phase induction motor drive system

## 3 HARMONIC ANALYSIS IN INDUCTION MOTOR DRIVE

Power electronic converters are now frequently used to regulate the flow of electricity for digitization and energy conservation in both manufacturing and household usages. These kinds of converters frequently consume harmonic current as well as reactive power through the AC distribution, which negatively affects power quality [25, 26]. Rapid electricity rises in either a positive or negative direction, creating harmonics. As a consequence, the wave form of an electrical converter voltage supply's output is non-sinusoidal. In this sort of wave form, square waves and pulse waves create a swift and unexpected rise. Harmonic currents are caused by unpredictable masses that are rigid and produce a current wave that is completely distinct from the employed voltage wave.

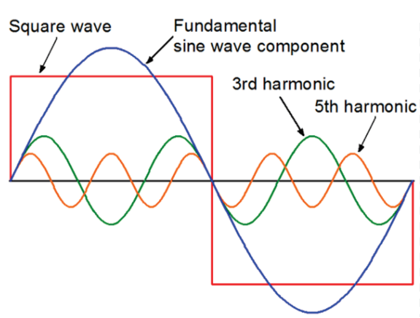


**Figure 2** Electrical Waveforms Harmonic

Solid state power changers like diodes, thyristors, SCRs, and transistors transform DC power, making up most electronic gadgets. Harmonic frequencies in power systems are created by non-linear electronic and electrical devices. [27]. Fig. 4 illustrates the way the fundamental frequency produces non-sinusoidal distorting wave forms when combined with other order harmonics. The electric wave form harmonics depicts in Fig. 2. Harmonic current arises from rigid non-linear masses, causing a different current wave shape than applied voltage. Solid state power change devices, however, possess distinct voltage and current shapes.

Harmonic current arises from rigid non-linear masses, causing a different shape than the applied voltage wave. Modern technological masses have distinct voltage and current shapes, with electric potential appearing undulating but current waves moving slowly. Harmonics can be produced on the supply or load side depending on the load type. Current harmonics [28] are usually produced by voltage provides. The result could be the amount of distortion created as the facility line's current flows.

## 4 PROPOSED METHODOLOGY AND SYSTEM MODELLING

Voltage and current waveform degradation is being caused by the usage of power conversion devices and non-linear loads in consumers' and industries' applications. Increased distribution power losses, communication system interference, and malfunctions in delicate electronic equipment are all brought on by harmonics in electric lines. International electrical power quality standards impose limitations on supply voltage distortion and prohibit machinery from producing harmonic contents above specific thresholds. While they solve harmonic current problems, passive filters have disadvantages. The latest initiatives have focused on the creation of active filters to address these drawbacks.

### 4.1 Active Filters

Active power filters (APF) can be divided into two basic categories: shunt type and series type. It is possible to come across active filters acting in concert with passive filters and/or other active filters. The circuitry layout of a shunt active filter, that can correct both the harmonics of current and power factor in a three-phase generator with neutral wire, is illustrated in Fig. 3. Additionally, it enables load distribution, which cuts down on electricity in the neutral wire. Since the active filter doesn't need an internal power distribution, the power stage is essentially a voltage-source inverter (VSI) which regulates itself to behave like a current source. It has just one a capacitor on the DC side of the circuit.

The controller determines the reference currents $I_{fa}$, $I_{fb}$, $I_{fc}$ needed through the inverter for generating the compensation currents $I_{ca}$, $I_{cb}$, $I_{cc}$ based on the results of the measurement of the phase voltages $V_{ca}$, $V_{cb}$, $V_{cc}$ as well as currents at load $I_a$, $I_b$, $I_c$ There is no requirement for compensation for the current in neutral wire for balanced loads lacking third order current harmonics. The series active filter operates as a high impedance to the current harmonics generated by the power source side however does not compensate for harmonics in the load current. It ensures that passive filters subsequently installed at the load input will prevent harmonic currents from draining into the remaining components of the power system. Utilizing a shunt active filter to make sure that both the voltage at the load and the supply currents have sinusoidal wave forms is another way to address the load current harmonics. The basic structure of shunt active filter shown in Fig. 3.

A non-linear load current that is divided into two distinct elements can identify a current harmonic. They are the fundamental nonlinear load current and the harmonic nonlinear load current utilized for harmonic injection into the utility grid system. Eqs. (1) - (5) depicts the grid voltage operation, non-linear current at the load, fundamental non-linear load magnitude, and load current.

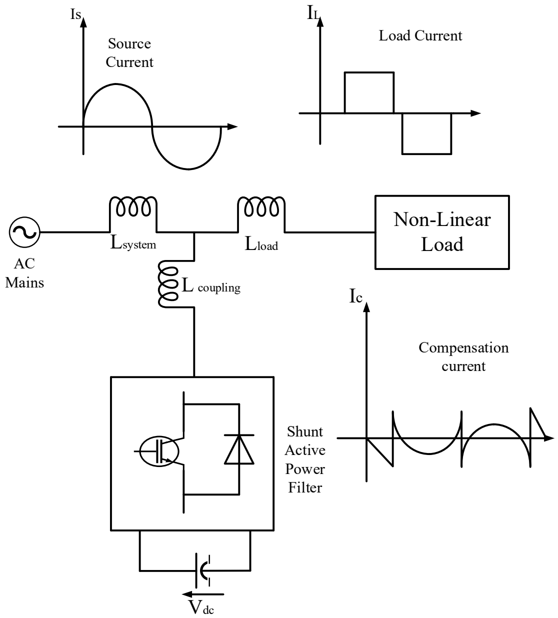

**Figure 3** Basic scheme of shunt active power filter

The current harmonics can be determined using Eq. (6).

$$V_g(t) = V_g \cos(\omega t) \tag{1}$$

$$I_{nl}(t) = I_1 \cos(\omega t + \alpha_1) + \sum_{k=2}^{\infty} I_{kh} \cos(\omega t + \alpha_k) \tag{2}$$

$$I_{fundm,\, nl} = \frac{1}{\pi} \int_{-\pi}^{\pi} (I_1 \cos(\omega t + \alpha_1) \cos(\omega t) d\omega t \tag{3}$$

$$I_{fundm,\, nl} = I_1 \cos \alpha_1 \tag{4}$$

$$I_{fundm,\, nl}(t) = I_1 \cos \alpha_1 \cos(\omega t) \tag{5}$$

$$I_{kh}(t) = I_{nl}(t) - I_1 \cos \alpha_1 \cos(\omega t) \tag{6}$$

Where $V_g(t)$ denotes the voltage function at grid, $I_{nl}(t)$ represents the nonlinear current at load, $I_{fundm,\, nl}(t)$ indicates the fundamental nonlinear current at load. $I_{kh}(t)$ specifies current harmonic function and nonlinear current function magnitude.

### 4.1.1 Mathematical Model of Active Power Filter

To investigate the DC-link potential response and current monitoring ability, condensed analytical designs of the APF was developed. When the suggested control approach is employed, harmonics in the current are quickly compensated for and variations in the voltage at the DC-link during fluctuating and stable conditions are efficiently reduced.

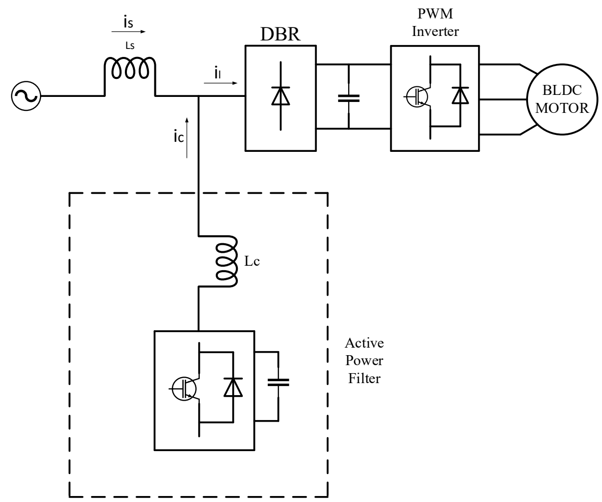

**Figure 4** Active power filter in induction motor drive

The schematic diagram for the APF is shown in Fig. 4. As shown in Fig. 5, one can obtain the equivalent circuit of the APF. The switch status represented as $d_s$ in Eq. (7).

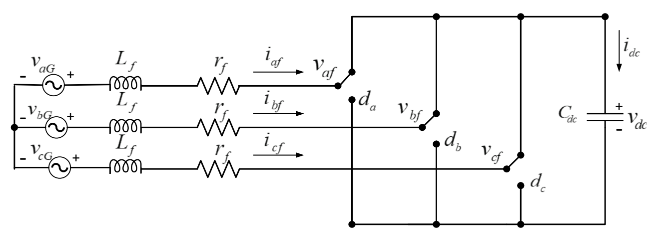

**Figure 5** Active power filter equivalent circuit

$$d_s = \begin{cases} 1 \text{ if } T_s^+\text{: on, } T_s^-\text{: off} \\ 0 \text{ if } T_s^+\text{: off, } T_s^-\text{: on} \end{cases} \tag{7}$$

Where $T_s^+$ and $T_s^-$ denotes the power switching transistor and s represents phase terminal a, b, c. The switching voltage for phase representation is denoted as $V_{af1}$, $V_{bf1}$, $V_{cf1}$. The voltage $V_{dc}$ indicates the voltage at DC link and it can be expressed in below equations.

$$\begin{bmatrix} V_{af} \\ V_{bf} \\ V_{cf} \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} d_a \\ d_b \\ d_c \end{bmatrix} \tag{8}$$

The APF differential equations are expressed from the Fig. 5, which is expressed below.

$$L_{\mathrm{fl}}\frac{\mathrm{d}}{\mathrm{d}t}i_{\mathrm{af}}=V_{\mathrm{a1M}}-r_{\mathrm{fl}}i_{\mathrm{af}}-V_{\mathrm{af}}$$
$$L_{\mathrm{fl}}\frac{\mathrm{d}}{\mathrm{d}t}i_{\mathrm{bf}}=V_{\mathrm{b1M}}-r_{\mathrm{fl}}i_{\mathrm{bf}}-V_{\mathrm{bf}} \tag{9}$$
$$L_{\mathrm{fl}}\frac{\mathrm{d}}{\mathrm{d}t}i_{\mathrm{cf}}=V_{\mathrm{c1M}}-r_{\mathrm{fl}}i_{\mathrm{cf}}-V_{\mathrm{cf}}$$

$$C_{\mathrm{dc}}\frac{\mathrm{d}}{\mathrm{d}t}v_{\mathrm{dc}}=d_{\mathrm{a}}i_{\mathrm{af}}-d_{\mathrm{b}}i_{\mathrm{bf}}-d_{\mathrm{c}}i_{\mathrm{cf}} \tag{10}$$

Induction motor phase voltage denotes as $V_{\mathrm{a1M}}$, $V_{\mathrm{b1M}}$, $V_{\mathrm{c1M}}$. Three phase power converter input voltage represent as $V_{\mathrm{af}}$, $V_{\mathrm{bf}}$, $V_{\mathrm{cf}}$. The filter resistance and inductance indicate as $r_{\mathrm{f1}}$, $L_{\mathrm{f1}}$.The dc link capacitance is denoted as $C_{\mathrm{dc}}$.

### 4.2 Enriched Active Filters

Extensive use of power converters and dynamic loads causes waveform degradation, resulting in harmonics and voltage drops. This leads to efficiency losses, increased power distribution losses, and equipment malfunctions. I-Q Active Filter is proposed to mitigate these issues. It transforms three-phase potential and current into orthogonal coordinates for instantaneous power assessment, applicable to various operations and waveforms.

$$\begin{bmatrix}V_0\\V_\alpha\\V_\beta\end{bmatrix}=\sqrt{\frac{3}{2}}\begin{bmatrix}\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}\\1&\frac{-1}{2}&\frac{-1}{2}\\0&\frac{\sqrt{3}}{2}&\frac{-\sqrt{3}}{2}\end{bmatrix}\begin{bmatrix}v_{\mathrm{a}}\\v_{\mathrm{b}}\\v_{\mathrm{c}}\end{bmatrix} \tag{11}$$

$$\begin{bmatrix}I_0\\I_\alpha\\I_\beta\end{bmatrix}=\sqrt{\frac{2}{3}}\begin{bmatrix}\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}&\frac{1}{\sqrt{2}}\\1&\frac{-1}{2}&\frac{-1}{2}\\0&\frac{\sqrt{3}}{2}&\frac{-\sqrt{3}}{2}\end{bmatrix}\begin{bmatrix}I_{\mathrm{a}}\\I_{\mathrm{b}}\\I_{\mathrm{c}}\end{bmatrix} \tag{12}$$

Instantaneous zero sequence electrical power, real power derived, Instantaneous reactive power derived can be expressed as

$$p_0=v_0i_0 \tag{13}$$
$$p_i=v_\alpha i_\alpha+v_\beta i_\beta \tag{14}$$
$$q_i=v_\alpha i_\alpha-v_\beta i_\beta \tag{15}$$

The electrical power representation $p_{\mathrm{i}}$ and $q_{\mathrm{i}}$ associated with and $\beta$ electric potential and current and it can be derived as

$$\begin{bmatrix}p_{\mathrm{i}}\\q_{\mathrm{i}}\end{bmatrix}=\begin{bmatrix}v_\alpha&v_\beta\\-v_\beta&v_\alpha\end{bmatrix}\begin{bmatrix}i_\alpha\\i_\beta\end{bmatrix} \tag{16}$$

The reference compensating current equation for orthogonal coordinates represented as

$$\begin{bmatrix}i_\alpha\\i_\beta\end{bmatrix}=\frac{1}{v_\alpha^2+v_\beta^2}\begin{bmatrix}v_\alpha&v_\beta\\-v_\beta&v_\alpha\end{bmatrix}\begin{bmatrix}\tilde{p}_{\mathrm{i}}\\\tilde{q}_{\mathrm{i}}\end{bmatrix} \tag{17}$$

To determine the compensation reference current in $\alpha$ and $\beta$ the power compensation is expressed as $\tilde{p}_{\mathrm{i}}-\bar{p}_0$ and $q_{\mathrm{i}}$.

$$\begin{bmatrix}i_{\mathrm{c\alpha}}^*\\i_{\mathrm{c\beta}}^*\end{bmatrix}=\frac{1}{v_\alpha^2+v_\beta^2}\begin{bmatrix}v_\alpha&v_\beta\\v_\beta&-v_\alpha\end{bmatrix}\begin{bmatrix}\tilde{p}_{\mathrm{i}}-\bar{p}_0\\\tilde{q}_{\mathrm{i}}\end{bmatrix} \tag{18}$$

Where:

$\bar{p}_0$ Denotes the mean value of instantaneous zero-sequence power transmitted by means of zero-sequence current and voltage components from the power source to the load.

$\tilde{p}_0$ Represents instantaneous zero-sequence power alternate value. The three-phase systems with neutral wire that have zero-sequence power are those.

$\tilde{p}_{\mathrm{i}}$ Denotes alternate instantaneous real power value, which is transmitted via the a-b-c coordinates among the electrical power source as well as the load.

$\tilde{q}_{\mathrm{i}}$ Represents instantaneous imaginary power. This includes the electrical energy which is transferred across the load phases.

In a system consisting of three phases with balanced sinusoidal voltages, the supply currents must also be sinusoidally balanced, in phase with the electrical potential and compensated for any undesirable power elements. Compensation of current based on coordinates shown in Fig. 6.

The zero sequence current should be compensated. The reference current compensation for zero coordinates is denotes as 0 and it can have expressed as

$$i_{\mathrm{c0}}=i_0 \tag{19}$$

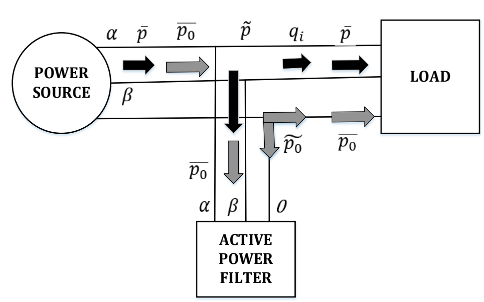


**Figure 6** Power component current compensation-based coordinates

The reference compensated current in orthogonal coordinates $\alpha$ and $\beta$, the Eq. (20) in inverted and the compensated power are utilized

$$\begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p_y \\ q_y \end{bmatrix} \tag{20}$$

$$p_y = \tilde{p}_{\mathrm{i}} - \Delta\bar{p}_{\mathrm{i}} \tag{21}$$

$$\Delta\bar{p}_{\mathrm{i}} = \bar{p}_0 \tag{22}$$

$$q_y = q_{\mathrm{i}} \tag{23}$$

$$q_{\mathrm{i}} = \bar{q} + \tilde{q} \tag{24}$$

The inverse of transformation is expressed to determine the reference current for compensation

$$\begin{bmatrix} i_{ca}^{*} \\ i_{cb}^{*} \\ i_{cc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c0}^{*} \\ i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} \tag{25}$$

$$i_{cn} = -(i_{ca}^{*} + i_{cb}^{*} + i_{cc}^{*}) \tag{26}$$

### 4.3 Proposed Methodology for Harmonic Mitigation

The selection of AC and DC drives depends upon the needs of the application in the industry. While dc drives are utilized to have higher starting torque and constant speed, they are usually employed in motors. The reason for utilising AC drives is to achieve excellent control over processes and minimize consumption of energy. In the present investigation, the induction motor speed and torque are controlled by an AC drives mechanism [29].

Induction motor drive systems include a voltage source inverter, diode bridge rectifier, and speed control circuit. The intermittent power switching of electronic devices creates harmonics, leading to power quality issues. The block diagram of proposed investigation is illustrated in Fig. 7.

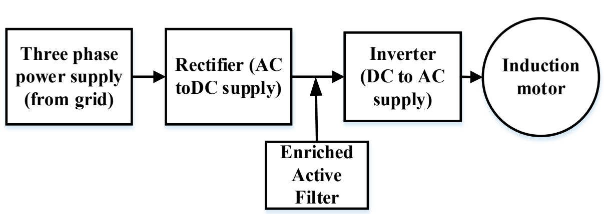


**Figure 7** Block diagram of proposed system

A typical shunt active filter comprises two main components: a hysteresis current control section for providing gate pulses to the inverter, and a shunt active power filter controller unit. The hysteresis control processes power signals and synthesizes compensation current from the electrical grid, while the active filter controller continuously provides compensating current references to the hysteresis converter for real-time determination. This setup, illustrated in Fig. 3, consists of a voltage-fed converter, an active filter controller, and a hysteresis current controller, implementing an almost instantaneous control technique. Closed-loop operation is utilised by the shunt active filter controller used to determine the instantaneous values of the current compensation reference $i_c^*$ for the hysteresis converter while continually detecting the current of load $I_l$.

Shunt active filter control is accomplished in three distinct phases.

- At initial stage, the respective current signals are sensed which is utilized to rectify the harmonics.
- In next stage, the instantaneous imaginary controller technique is implemented to derive compensating demands in relation to current.
- At final stage of controlling function, the hysteresis current control method is used to generate the gating signals for the three-phase inverter.
- The imaginary controller examines reference current via shunt active filter load current, employing frequency and time-domain adjustments to generate compensation commands. The imaginary power method transforms electrical potential and current into $\alpha$, $\beta$, 0 coordinates, determining instantaneous power. The real and imaginary portion of power is represented as $p^*$ as well as $q^*$. The instantaneous reference current $i_{ca}^*, i_{cb}^*, i_{cc}^*$ determined by the inverse transformation of $\alpha$, $\beta$, 0 to a, b, c. subsequently obtaining the reference values and actual quantities based on the evaluations, hysteresis control is implemented to create the transferring instructions for the VSI switching circuits. Hysteresis current control systems employ two-level comparators within a feedback loop. Switching commands activate when errors surpass designated tolerance bands.
- Total Harmonic Distortion (THD) is a metric utilized to evaluate the fidelity of electrical systems by measuring the discrepancy between an actual signal and an ideal sinusoidal reference. It is computed by normalizing the root mean square (rms) value of the signal's harmonic content (V) to the total rms value of the signal ($V_{\mathrm{total}}$).

$$THD = \frac{\sqrt{\sum_{k=2}^{k_m} (V_{K,k})^2}}{V_{\mathrm{total}}} \tag{27}$$

- The *THD* rate, known as the rms or effective *THD*, is commonly employed in power system applications.

## 5 SIMULATION RESULT

The proposed work is modelled, along with the impact of current and voltage at the load and source side is analysed to demonstrate the current and voltage behaviour when drives mechanisms are implemented. The induction motor drive system is the three-phase non-linear system that is under assessment for investigation of proposed research for harmonic analyzation and it is modelled in MATLAB/Simulink, which is shown in Fig. 8.

The system parameter depicts in below Tab. 1.

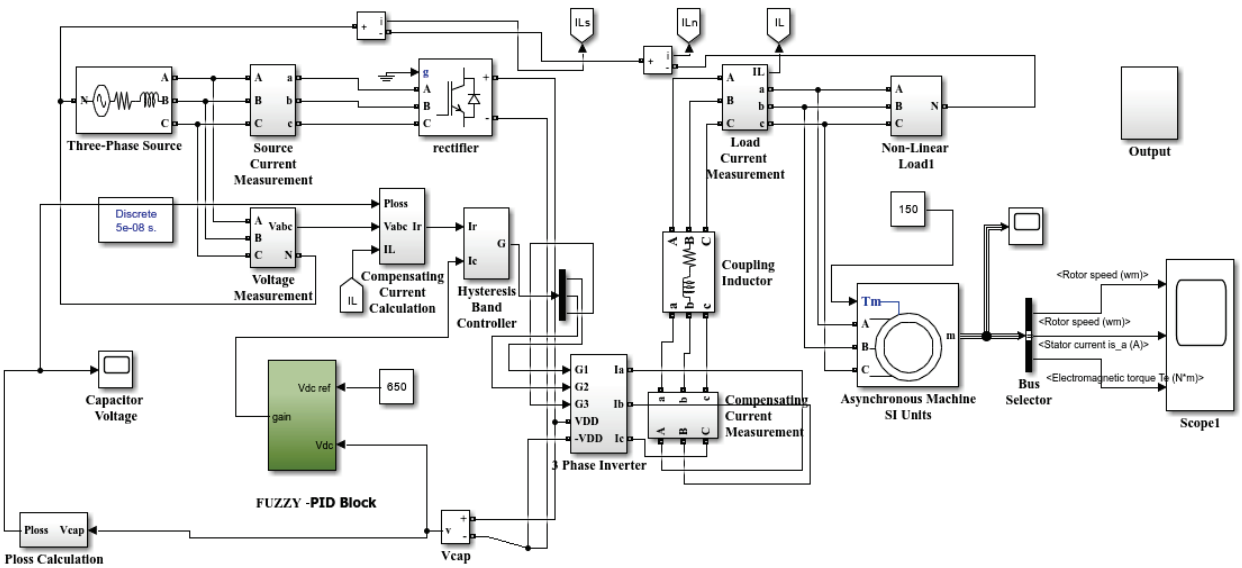

**Figure 8** Proposed work MATLAB/Simulink model

**Table 1** Simulation specifications

| System Parameter | Values |
|---|---|
| Source side | 415 V, $f$ = 50 Hz, $R_s$ = 0.89 Ω, $L_s$ = 0.165 mH |
| ad Side | $R_L$ = 0.73Ω, $L_L$ = 0.3 mH |
| Filter Side | $R_L$ = 0.8 Ω, $L_L$ = 0.6 mH, $C_{DC}$ = 1000 µF |
| Diode Bridge Rectifier | $R$ = 15 Ω, $L$ = 80 mH |
| DC Side Capacitor | 1000 µF |
| PI controller gains | $K_p$ = 7.5, $K_i$ = 9 |
| VSI parameters | 4700 µF, $V_{dbus}$ = 560 V |
| Induction Motor | 10 HP, 400 V, 50 Hz, 1440 rpm |

Simulation runs for 1 second pre-compensation, then enriched I-Q active filter provides compensation current for immediate waveform analysis, with compensating currents and dc link capacitor voltage at zero before compensation. The source voltage wave form shown in Fig. 9.

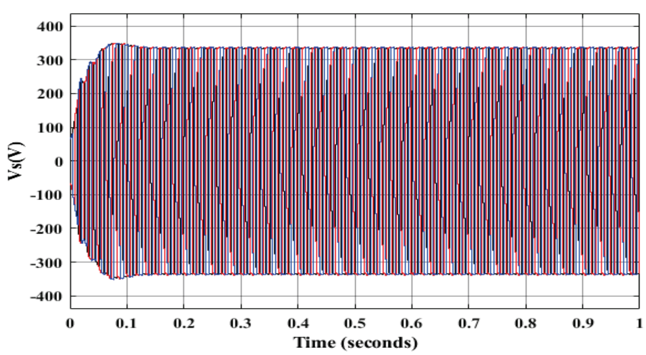

**Figure 9** Source voltage output wave form

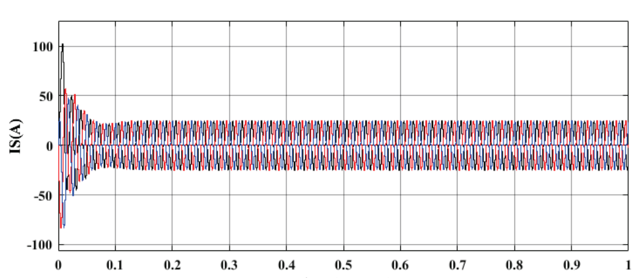

**Figure 10** Source current

Since it can be observed, enriched filter compensation leads to the current from the source to evolve into sinusoidal. The source current output waveform depicts in Fig. 10. The generation of compensation current from the filter controller shown in Fig. 11 and the current delivered to the load current is indicates in Fig. 12.

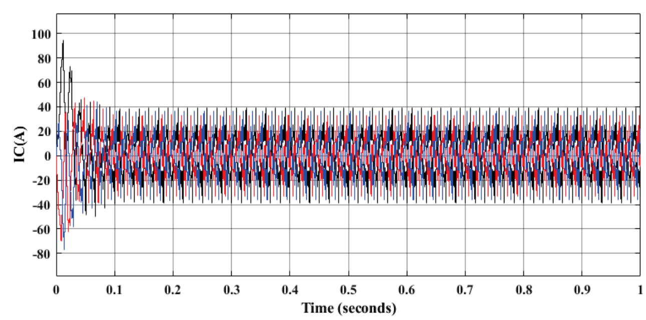

**Figure 11** Compensation current

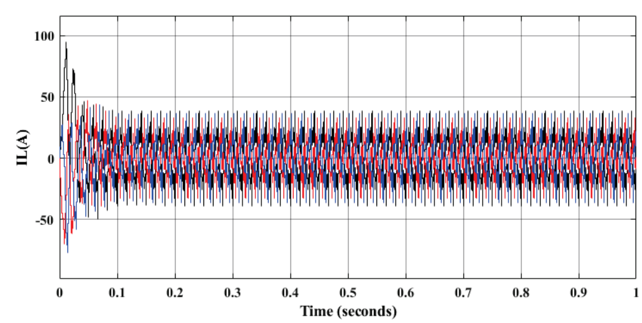

**Figure 12** Load current

When an induction motor load is attached, the electrical current is distorted because of the harmonics in the load. Hysteresis control approach is subsequently utilized to produce switching signals after reference currents for the active filter have been generated through the instantaneous imaginary power strategy. The capacitor voltage shown in

Fig. 13. The induction motor stator current representation waveform is denoted in Fig. 14.

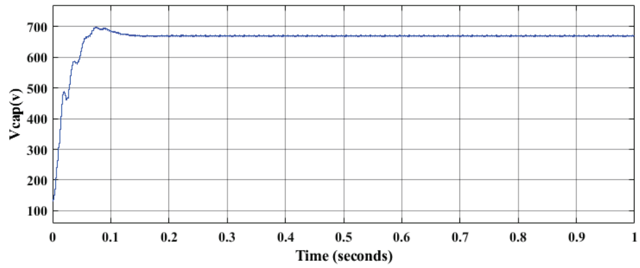


**Figure 13** Capacitor voltage waveform

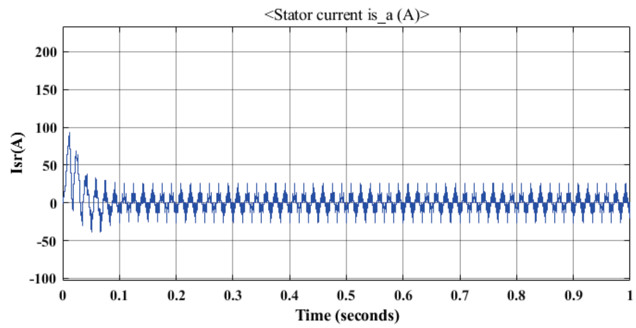


**Figure 14** Induction motor stator current waveform

A three-phase rotor speed, and electromagnetic torque are illustrated as shown in Fig. 15 and Fig. 16. The rotor current oscillates up to 0.35 seconds and it attains a stable state and maintains steady after 0.35 seconds.

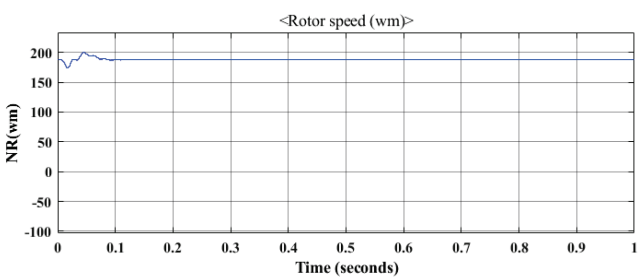


**Figure 15** Rotor speed representation wave form

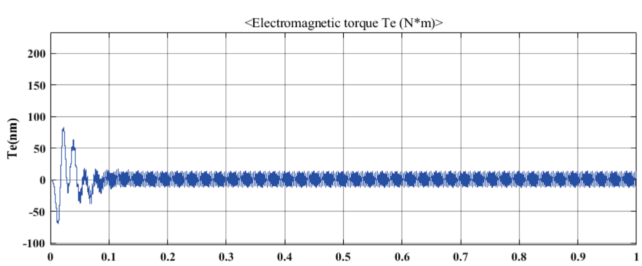


**Figure 16** Electromagnetic torque wave form

The dynamic torque applied to the load, transitioning from full load to zero at specific time intervals ($T_{\mathrm{fl}}$ = 49.7 Nm, $T_{\mathrm{fl}/2}$ = 24.86 Nm, $T_{\mathrm{fl}/4}$ = 12.43 Nm, $T_0$ = 0 Nm) at $t$ = 0.2 s, 0.5 s, and 0.7 s, as depicted in Fig. 17, poses a challenge for maintaining stable rotor speed. However, the proposed model effectively compensates for these fluctuating load torque conditions, ensuring a consistent speed of 150 rad/s which is shown in Fig. 18. Our proposed model dynamically responds to load torque fluctuations, stabilizing rotor speed and enhancing system reliability, crucial for unpredictable real-world conditions, ensuring consistent operation and minimizing instability risks.

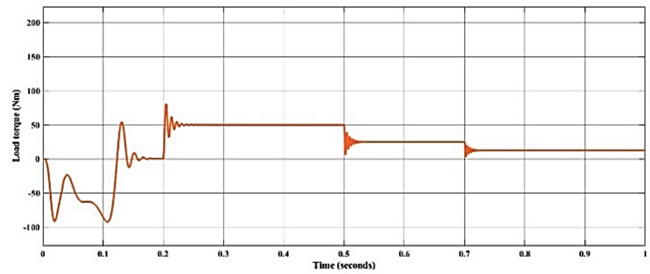


**Figure 17** Varying load torque

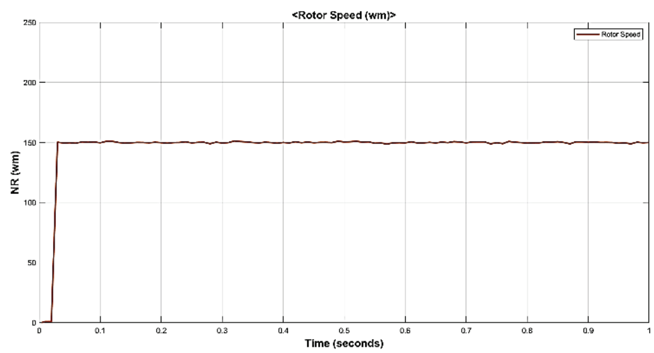


**Figure 18** Rotor speed

When a single drive technique's THD is investigated, it should be observed that the single drive system's THD percentage is 25.68% without the presence of filter and it is shown in Fig. 19. At these circumstances, the THD% does not fall within the acceptable range as specified by the IEEE requirement. In order to limit the THD an enriched shunt active power filter is attached to the system in between the electrical grid and drive systems.

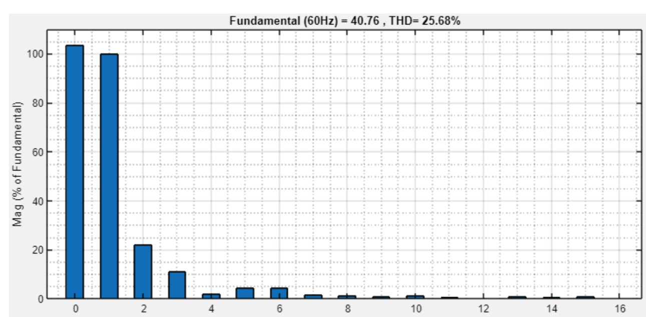


**Figure 19** Percentage of THD without considering filter

The filter gets used for harmonics in the current based on variations on the load side. The most effective approach for driving motors with the fewest harmonics present, which subsequently enhances effectiveness and generation, is to add filters that minimize THD by nearly 1.75% for single drive systems, respectively. When the voltage at as well as the current from the source are in phase during compensation, the harmonics are removed from the source current, that improves the power quality of entire grid connected drive system. The percentage of THD shown in Fig. 20.

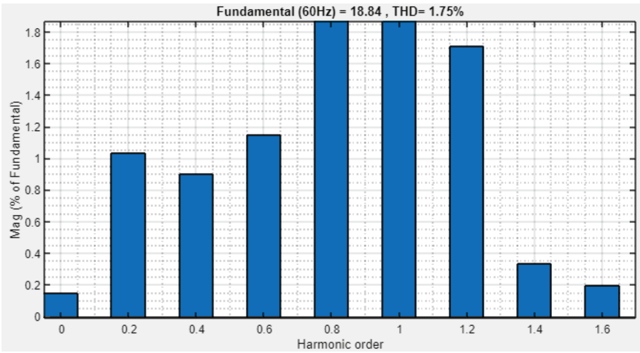

**Figure 20** Percentage of THD with filter

The percentage of THD analysed for induction motor drive system in both without filter and with filter scenario and the respective percentage is shown in Tab. 2.

**Table 2** Proposed filter THD percentage

| THD analysis | Percentage of THD for load current without filter (%) | Percentage of THD for load current with filter (%) |
|---|---|---|
| Steady state condition at load current | 25.68 | 1.75 |

The performance of proposed filter is analysed with the existing shunt active filter [30, 31] for single drive induction motor system. The percentage of THD is illustrated in below Tab. 3 and the comparative analysis shown in Fig. 21.

**Table 3** THD analysis comparison

| THD analysis | SAF | PI-SAF | PID-SAF | FLC-SAF | Proposed enriched SAF |
|---|---|---|---|---|---|
| Percentage of THD for single drive system without filter (%) | 46.47 | 20.29 | 16.51 | 7.52 | 25.68 |
| Percentage of THD for single drive system with filter (%) | 5.45 | 13.60 | 3.86 | 2.66 | 1.75 |

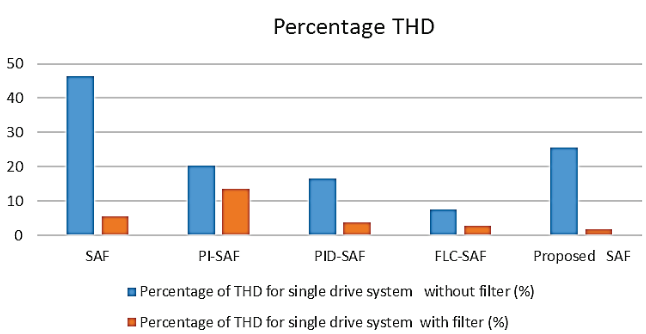

**Figure 21** Comparative THD analysis of various filter

When the absence of shunt active filter with induction motor drive system, the occurrence of harmonics is about 46.47%. While implementation of filter with the drive circuit it will reduced as 5.45%. The absence of PI based SAF with motor drive system produce 20.29% THD. While implementing filter, it reduces the THD value to 13.60%. The percentage of THD while absence of PID-SAF is about 16.51%. Then the presence of PID-SAF eliminate the harmonics and decrease the THD to 3.86%. Without FLC-SAF the drive circuit produces the THD value of 7.52%. FLC-SAF with drive circuit rectifies the harmonics and its THD value is about 2.66%. The proposed filter initially not connected with the drive circuit and it induces the harmonics. The percentage of THD without filter is about 25.68%. Then the filter is connected with the drive circuit and its percentage THD is decreased to 1.75%. The comparison analysis of THD of different filter conclude that the proposed filter performs outstanding in terms of elimination of harmonics.

## 6 CONCLUSION

Maintaining the quality of power in the electrical distribution network is vital, particularly when irregular loads are linked into three phase AC lines. When nonlinear loads are connected through the three-phase distribution system from the utility grid, it is feasible that the critical loads are going to be impacted. Poor power quality conditions on the load side of the sugar processing plant create vulnerable condition in performance of induction motor drive when it serving as load. The proposed investigation provides an efficient way to enhance the power quality of the three-phase supply which is delivered into induction motor drive using the improved shunt active power filter. The phenomenon of hysteresis control technique as well as an enriched instantaneous imaginary controller based shunt active power filter (I-Q active filter) is implemented for obtaining the compensation current. The present research simulates a VSI fed induction motor drive and analyses output voltage and current waveforms. The variable frequency drive system normally employs an induction motor. In this instance, the harmonics caused by the variable frequency system are eliminated through a shunt active power filter with an improvised controller. The proposed work employed a single drive system and generation of harmonics are eliminated by proposed filter. The percentage of THD in single drive system without an implementation of filter obtained as 25.68%. While implementing the proposed filter, the percentage THD is reduced significantly and it is reduced as 1.75%. The proposed improvised filter performance is compared with existing shunt active filter. From the investigation it is concluded that the proposed enhanced controller based filter provide excellent outcomes in terms of harmonic reduction in induction motor used in sugar industry that adhere to harmonic control norms set by IEEE-519. The presented approach has been examined by the simulations result obtained from MATLAB/Simulink and the power quality criteria comply with the necessary standards.

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