SINGLE–PHASE BRIDGELESS PFC FOR PI CONTROLLED THREE PHASE INDUCTION MOTOR DRIVE

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ABSTRACT

A current regulation under IEC-555 imposes requirements on the harmonic current content, which can be sent back to utility lines for all consumer electronic devices consuming more than 75W of power. To meet that requirement, the active Power Factor Correction (PFC) must be employed. The most common PFC solution, a boost converter, requires the use a full-bridge diode rectifier ahead of the boost converter in the circuit. This design greatly impairs the efficiency, as the two diodes in the bridge rectifier are in the direct power path for either positive or negative half-cycle of input ac line voltage. Thegoal of this paper is to propose a topology for induction motor drive with reduced components in the rectifier bridge. The utilization of 2 switches replacing 4 switches in the rectifier bridge of induction motor drive helps to implement a low-cost system for various applications. The static power converter side is implemented by a single-phase bridgeless pfc cascaded with a six-switch inverter. The new bridgeless PFC converter operates directly from the ac line, the proposed system consists of a single-phase rectifier with a bridgeless power factor correction circuit; six switch inverter to feed the motor. In this configuration, a standard three-phase squirrel cage induction machine is used. Speed control is employed using PI controller based on volts/hertz technique. Simulation results are provided to illustrate the operation of the systems.

KEYWORDS: *Bridgeless rectifier, power factor correction (PFC), induction motor drive, low-cost, closed loop constant V/f speed control.*

I. INTRODUCTION

Single-phase motors have often been used in consumer electronics, hence a single to three- phase converters are in demand [1]. As the amount of equipment using conventional diode rectifiers increases, harmonic input currents are becoming a problem. Harmonic current limits are recommended by the IEC standards (IEC 555). With the stringent requirements of power quality, power-factor correction (PFC) has been an active research topic in power electronics, and significant efforts have been made on the developments of the PFC converters. In general, the bridgeless PFC topology may improve efficiency and reduce the conduction loss by reducing the number of semiconductor components in the line current path.

The electric drive systems used in industrial applications are increasingly required to meet the higher performance and reliability requirement. Today above 90% of all industrial motor applications use three phase induction motors because they are simple in design, easy to maintain, and are less costly than other designs . Out of the several methods of speed control of an induction motor the closed loop constant V/f speed control method is most widely used. In this method, the V/f ratio is kept constant which in turn maintains the magnetizing flux constant so that the maximum torque remains unchanged. Thus, the motor is completely utilized in this method.

This paper proposes a single-phase to three-phase inverter operation for the motor drive, which uses V/f control strategy. The objective of this paper is to improve the performance of the induction motor drive by reducing the conduction loss. The proposed paper constitutes four sections; initially the characteristic of the conventional rectifier circuit is described. Next, the implementation of bridgeless boost converter for improving power factor is discussed and then the speed control performance of V/f controlled induction motor drive is discussed. Finally, the validity of the proposed circuit will be demonstrated by simulation results.

II. CONVENTIONAL BRIDGE RECTIFIER

Bridge rectifiers have wide application in industries, many commercial drives operates by rectifying the input ac line voltage and filtering with large electrolytic capacitors. The capacitors draws current in short pulses; this introduces several problems including reduction in the available power and increased losses. This process involves generation of harmonics in the line current. The non-linear characteristics of load in variable speed motor drives in various applications have made harmonic distortion a common occurrence in electrical distribution systems. However when operating in large numbers, the cumulative effect of these loads have the capability of causing serious harmonic distortions. This results in a poor power quality, voltage distortion, poor power factor at input ac mains, slowly varying rippled dc output at load end and low efficiency. Reduction in input current harmonics and the improvement of power factor operation of motor drives and switching power supplies is necessary from energy saving point of view.

The following assumptions are taken for the analysis of single phase rectifier:-

1) The ac source is considered to be ideal and the local voltage is assumed to be ripple free and the load is assumed to be purely resistive.
2) The filter capacitance is assumed to be such a large value that the output voltage is ripple free constant dc voltage.
3) All switching power devices are considered to be ideal.

III. POWER FACTOR CORRECTION

Many input wave shaping methods have been proposed to solve the problem of poor power factor which can be classified as active and passive methods. The passive techniques introduce filtering stage consisting of inductors and/or capacitors that reduce the amplitude of low frequency harmonics. On the other hand, an active technique uses a high frequency converter that shapes the input current to almost sinusoidal waveform with small harmonic content.

3.1.Active PFC

An active PFC is the most effective way for power factor correction. Here, we place a boost converter between the bridge rectifier and the main input capacitors [2]. The converter tries to maintain a constant DC output bus voltage and draws a current that is in phase with and at the same frequency as the line voltage.

3.2.Operating Principle

The incoming supply voltage passes through a bridge rectifier that produces a full wave rectified output. No current flows into the holdup capacitor unless the line voltage is boosted above the voltage present in the holdup capacitor. This allows the control circuit to adjust the boost voltage to maintain a sinusoidal input current. The control circuit uses the input voltage waveform as a reference, to maintain a sinusoidal input current. Active PFC function includes active wave shaping of input current, filtering of high frequency switching, feedback sensing of the source current for waveform control and feedback control to regulate output voltage. Active PFC approaches are frequently used in practice due to its wide input voltage range and its feature of automatically adjusting to operate on AC power.

3.3. Conventional Boost Converter

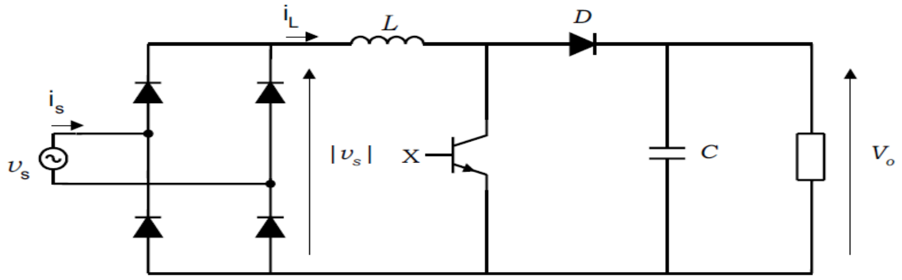
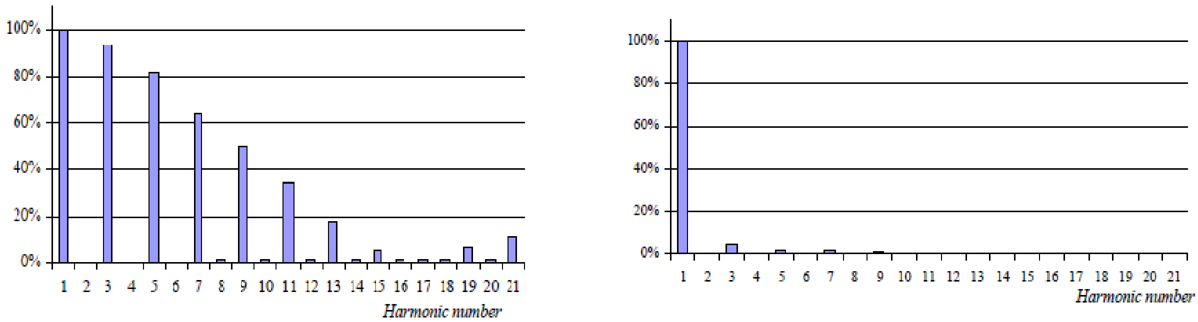


Figure 1 Conventional Boost Circuit

Figure 1 shows the circuit diagram of a conventional boost circuit; here the input current is controlled by changing the conduction state of transistor [3]. By switching the transistor with appropriate firing pulse sequence, the waveform of the input current can be controlled to follow a sinusoidal reference. By employing DC-DC boost converter harmonic content of the current waveform obtained from a rectifier circuit is considerably reduced, which can be substantiated by figure 2; where figure 2. a) Gives the harmonic content of current waveform obtained from a rectifier circuit and figure 2. b) Gives the harmonic content of current waveform obtained from a boost PFC converter.



a) Harmonic content of the current waveform obtained from a rectifier circuit

b) Harmonic content of the current waveform of a boost PFC converter

Figure 2 Harmonic Comparison

IV. PROPOSED BRIDGELESS PFC (BPFC)

BPFC is one of the most reliable PFC topologies, which achieves high efficiency by eliminating the line-voltage bridge rectifier. The major problem with the conventional rectifiers is harmonic pollution. Bridgeless PFC (BPFC) has the ability to reduce conduction loss without the input rectifier bridge, this makes BPFC more attractive [4].

Figure 3 shows the schematic of the proposed bridgeless PFC. In this configuration the boost converter is implemented by replacing a pair of bridge rectifiers with switches and employing an ac-side boost inductor. There are two switching operations at each half cycle as shown in figure4. Each operation consists of a power MOSFET and a diode.

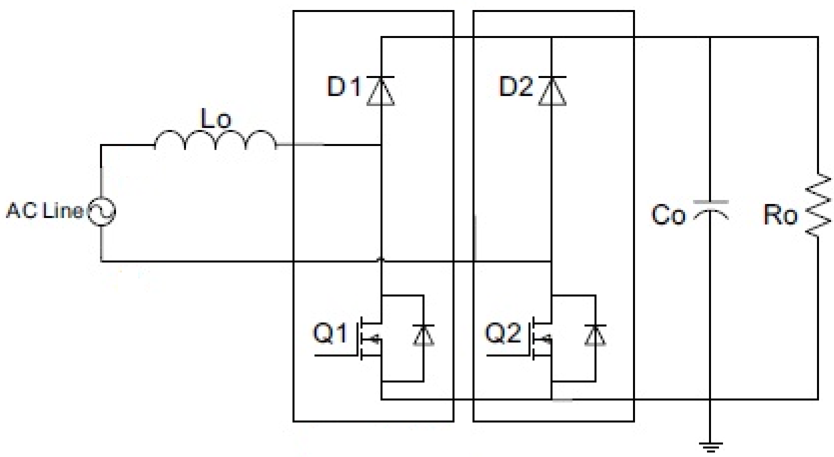


Figure 3 Bridgeless PFC Circuit

Q1 and D1 operate in Boost switching mode for the first half cycle and the body diode of Q2 is conducted as current return path. On the other half cycle, Q2 and D2 operate as Boost switching mode and the body diode of Q1 is conducted as current return path. Hence with a bridgeless topology, one such rectifier is eliminated from the line-current, which minimizes the conduction loss. The proposed BPFC can work both in continuous mode (CCM) and discontinuous mode (DCM). Figure 4 (a) shows the mode of operation in positive cycle and figure 4 (b) shows the mode of operation in negative half cycle.

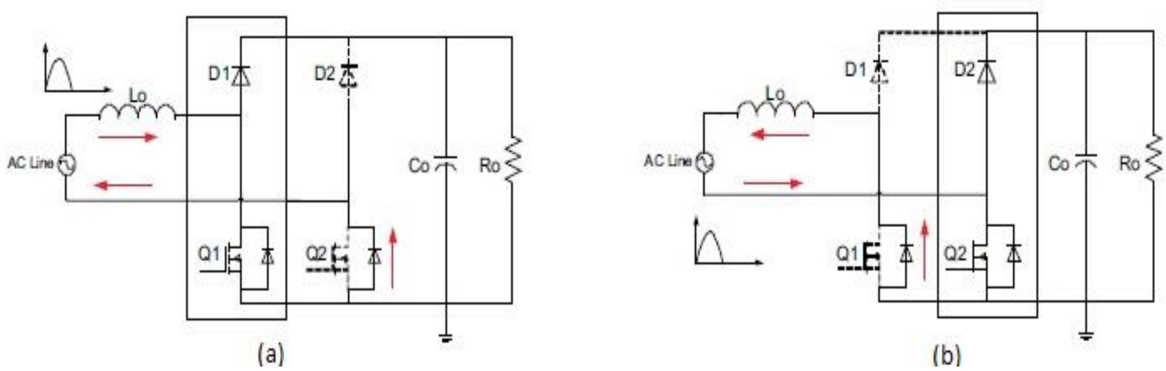


Figure 4 Operating Modes

Compared to a conventional Boost PFC topology, the losses due to the bridge rectifier are eliminated. Overall there is only one diode conduction loss for a bridgeless PFC compared to conduction loss from two diodes in a conventional Boost PFC also the rectifier circuit is made cost effective.

V. VOLTS/HERTZ CONTROL

Induction motor can run only at its rated speed when they are connected directly to the main supply [5]. However, variable speed operations are in various industrial processes such as in applications like the induction motor-based centrifugal pump, where a speed reduction of 20% results in an energy savings of approximately 50%. Driving and controlling the induction motor efficiently are prime concerns in today's energy conscious world. Although various induction motor control techniques are in practice today, the most popular control technique is by generating variable frequency supply, which has constant voltage to frequency ratio. This technique is popularly known as V/Hz control; figure 5 shows the block diagram of V/Hz control of induction motor [6].

$$\frac{V}{\omega} = \frac{1}{2\pi}\frac{V}{f} \qquad \textbf{(1)}$$

By employing this technique, the magnitude of the magnetic field in the stator is kept at an approximately constant level throughout the operating range. Thus, (maximum) constant torque producing capability is maintained. When transient response is critical, switching power converters also allow easy control of transient voltage and current applied to the motor to achieve faster dynamic response [7].

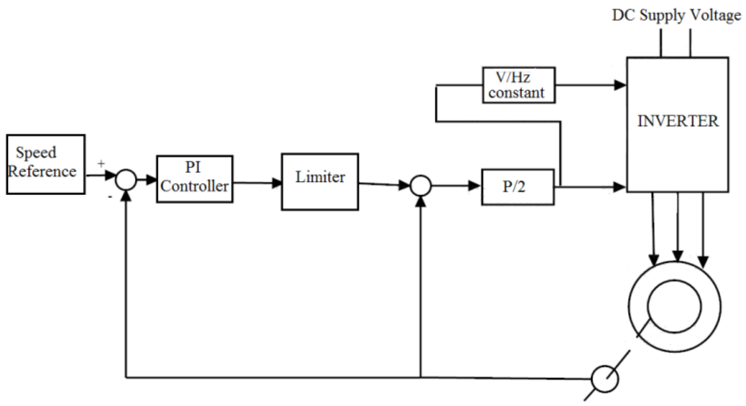


Figure 5 V/f Block Diagram

VI. PROPOSED BRIDGELESS PFC INDUCTION MOTOR DRIVE WITH CLOSED LOOP V/f CONTROL

The block diagram of proposed drive is shown in the block diagram given in figure6, the drive comprises of single phase to three phase inverter fed to the induction motor and the control signals generated based on the V/f control of induction motor using PI controller. Here the conventional rectifier circuit is replaced with a bridgeless PFC rectifier to improve the efficiency and reduce the conduction losses in rectifier bridge. The BPFC output is filtered using a capacitor and fed to the voltage source three phase inverter. Speed of the motor is sensed using a speed sensor, sensor out is compared with reference speed and passed through a PI controller; PI controller minimizes the speed error. PI controller along with the V/f constant value generates control voltage for switching the inverter.

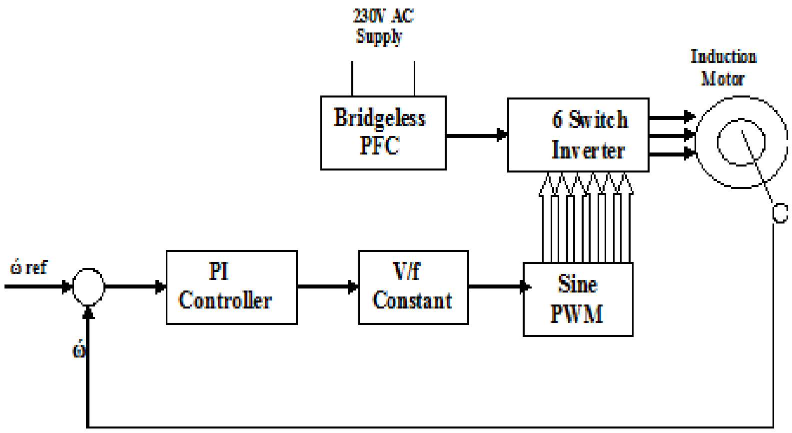


Figure 6 Proposed Block Diagram

6.1. SINE PWM

Sine pulse width modulation (SPWM) is used for switching; here control voltage is compared with the carrier wave and consecutive switching signals are generated for the three phase inverter. Figure 7 shows the waveform for gate voltage of switches in inverter.

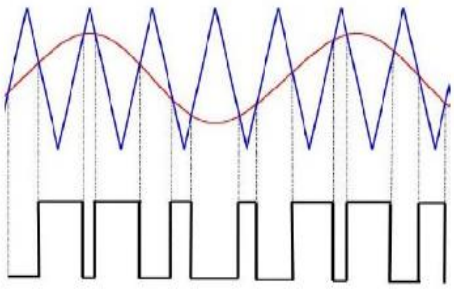


Figure 7 Gate Voltage

VII. Simulation Results

Simulation of the proposed drive is done in Matlab /Simulink. The parameters of the induction motor used in the simulation are listed in the Table 1. The switching frequency of MOSFET is chosen as 100 KHz. The supply voltage is 230V; a PI controller is used in simulation. Figure 9 and 10 shows the stator voltage of induction motor and DC link bus voltage. The power factor is improved to 96% with the help of bridgeless pfc circuit. The simulation block diagram is shown in Figure 8.

Table 1. Motor Parameters.

Motor Power	750 W
Poles	4
Stator Resistance	1.98 Ω
Stator leakage inductance	0.0091 Ω
Rotor Resistance	1.85 Ω
Rotor Leakage inductance	0.0091 Ω
Magnetizing inductance	0.1986 H
Moment of inertia	0.089 $Kg.m^2$

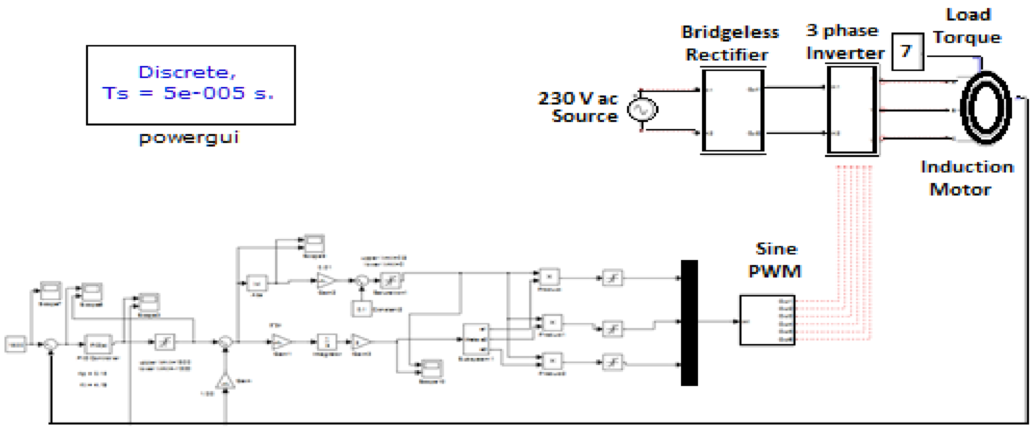


Figure 8 MATLAB Model of Proposed Induction Motor Drive

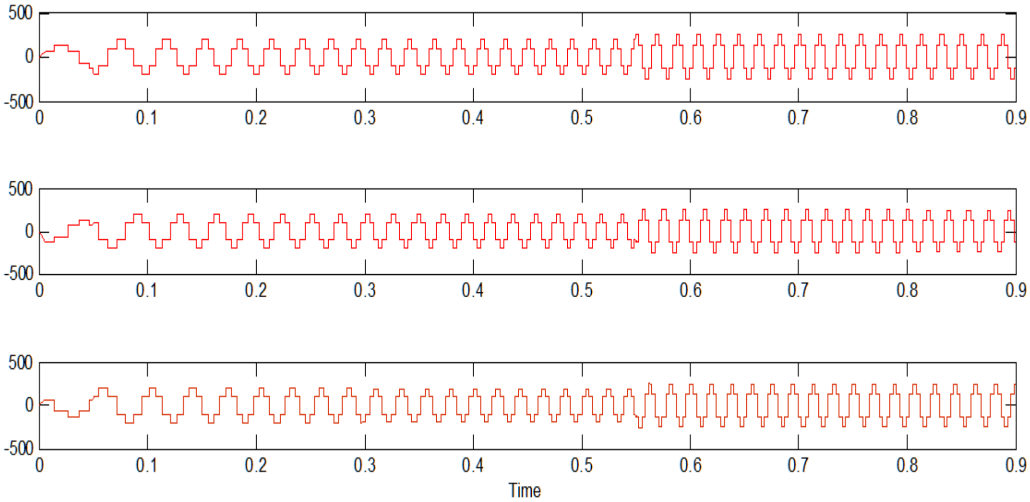


Figure 9 Stator Voltage Waveform

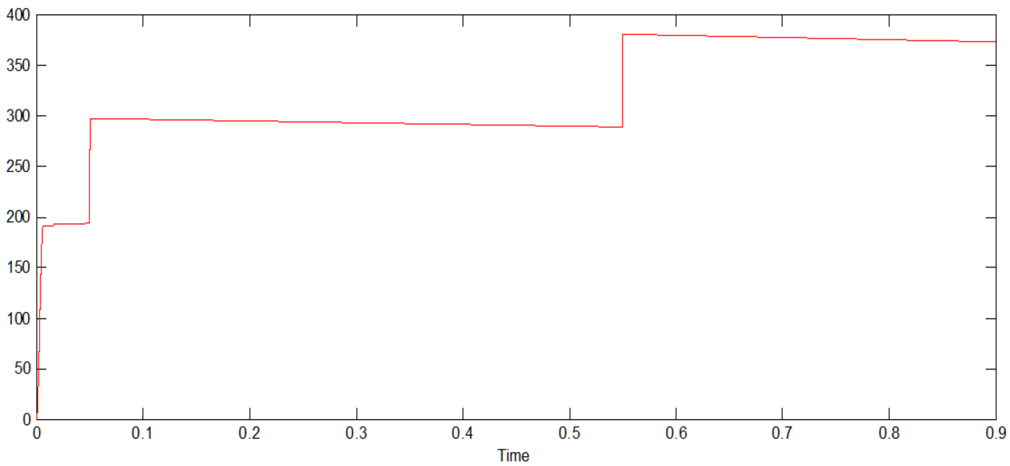


Figure 10 DC Link Voltage Waveform

Reference speed was chosen as 1500 rpm for simulation, figure 11 (a) shows the waveform for actual speed estimated. Simulation is done with a load torque of 7 NM; figure 11 (b) shows the torque waveform. Figure 11 (a) substantiate the output speed of the motor as the set speed. Hence a successful speed control is achieved, the load torque settles at applied load torque as in figure 11 (b).

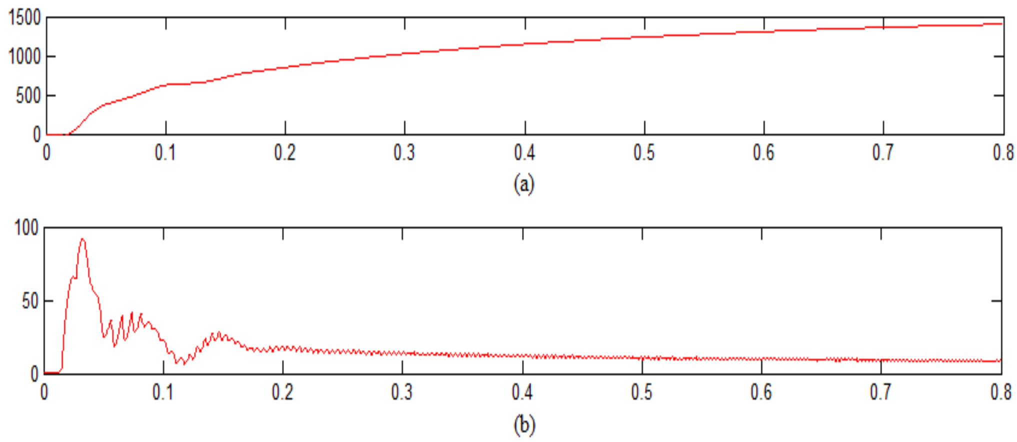


Figure 11 Estimated Speed and Electromagnetic Torque Waveform

Further researches have been taking place in the area of reducing the conduction losses in a motor drive to improve the power quality. Future works include a proposal of motor drive with bridgeless rectifier cascaded with reduced switch inverter thereby making the drive system cost-effective.

VIII. CONCLUSION

Bridgeless PFC Converter is modeled and simulated using Matlab. Closed loop models are developed and they are used successfully for simulation. In this paper bridgeless PFC induction motor drive is proposed to improve the power factor of input supply and thereby reducing the conduction loss. This topology will serve a classical solution for cost effective power factor correction circuit. V/f control with PI controller provides accurate speed control of induction motor by sensing the motor speed. The simulation studies indicate that the accurate speed control is done with improved power factor. Industries welcome this topology for its improved power factor correction and cost effectiveness.

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