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POWER FACTOR CORRECTION FOR BRIDGELESS BOOST AC-DC FED TO INDUCTION MOTOR

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Abstract— As most of the electronic appliances use DC power so improvement in AC–DC converter was introduced for induction motor drive applications is always at large by the researchers. The factors of improvement of power quality are reduction in total harmonic distortion and improvement in power factor at input ac, and tight output dc regulation. In such context, the AC-DC boost converters have gained significant importance, especially when they are used in Continuous Conduction Mode (CCM). This work presents a bridgeless AC DC boost converter operating in CCM. The implementation of input current and output voltage controller is also discussed. Then a comparative analysis based on simulation results of bridgeless and bridge boost rectifier is presented. Bridgeless boost AC-DC converter has outperformed the conventional techniques due to lower conduction losses, lower THD of input current and improved input power factor. The Bridgeless Boost AC-DC Converter is fed to a induction motor drive and the performance of the motor is analyzed by using Matlab/Simulink software.

I. Introduction

Rectification is a process in which electric power is applications as most of electronics appliances nowadays require DC power Conventional AC-DC converters, such as Bridge rectifiers, have been developed for this purpose but there are few factors to be controlled in this regard. The Non sinusoidal current drawn at the input side results in lower distortion as well displacement factors. Commanding the line current to follow the line voltage in a sinusoidal manner can gives higher efficiency with improved power factor and lower THD. AC side power factor (PF) is needed to be improved along with lowering of Total Harmonic Distortion of input line current. Tight regulation of the output voltage even in the case of dynamic loads is also a stringent requirement of DC-DC converters. A controller that simultaneously controls both the input as well as the output parameters is the choice. To gain a high power factor, different power factor correction (PFC) techniques have been introduced which can be divided into two parts, passive and active. Passive techniques consist of passive components such as inductors and capacitors that are used as input filter to reduce line current harmonics. However, improvements are not significant and another drawback is the relatively large size of these passive elements. Moreover, these techniques may not be able to handle dynamic loads. On the other hand, active PFC technique is more efficient solution, having a combination of switches and passive elements. Due to presence of switches, controllers can be implemented on active techniques of PFC. At the cost of complexity, the controlled active techniques can increase Power factor and reduce THD in the input AC current. Along with it active techniques can also bring precise DC regulation for variable loads. The active PFC technique uses a diode bridge rectifier followed by a dc–dc converter and the bulk capacitor. By controlling the dc–dc converter, the input line current is commanded to follow the input line voltage and in this way Power Factor approaches to unity. For medium and high power applications boost dc-dc converter works better for power factor correction than other dc-dc converters such as buck boost and buck converters because of lower electromagnetic interference. Moreover, in case of boost PFC converter there is low requirement of filtering because of continuous line current, whereas other dc-dc converters such as buck, buck-boost, and fly back have higher requirement of filtering because of pulsating line current. As boost converter is capable of handling much higher power levels as compared to its other counterparts, much research has been carried out on many different PFC techniques of this topology[1]-[6]. Among all these techniques of improvement of robustness, power efficiency and cost the bridgeless topology has outperformed almost all the techniques. A brief performance evaluation of bridgeless boost PFC is presented in [7], [8].Different new topologies of bridgeless boost DC-DC converter topology have also been discussed in some recent research [9]-[11]. In this project a new topology of bridgeless boost PFC converter has been analyzed. Its performance has been analyzed by applying a simple controller on it. To avoid complexity and get maximum advantage of the controller we have applied Proportional Integral (PI) controller by using double stage Pulse Width Modulation (PWM). This controller works for both ac and dc side. The control technique is capable of improving Power Factor and reducing THD at ac side along with regulating DC voltage at the output tightly. To get best performance for variable loads, a resistor observer has been applied. Moreover a comparison has been made between bridgeless boost PFC and conventionally used diode bridge boost PFC. The comparison clearly shows that the proposed topology and controller is giving a simple and easily implementable solution to all the discussed issues.

2 BRIDGE TYPE BOOST PFC CONVERTER

For the active Power Factor Correction in ac-dc converters we mostly use dc-dc converter. Among all the basic dc-dc converters, the boost converter is more effective than others in PFC applications. Mostly we use dc-dc boost converter with the output of ac-dc converter to get power factor approaching unity. This process also has simplicity, higher conversion efficiency and lower harmonic distortion as compared to the other converters. The dc-dc converter which steps up the voltage is known as boost dc-dc converter. This type of converters requires some energy storage element such as inductors, along with switching elements; diodes and transistors.Most of the times the boost PFC type ac-dc converter do not require much filtering because it gets continuous current from the ac source. Only a simple filter consisting of a capacitor can fulfill the requirement of filtering for such converter. However, higher level of filtering is required for all other converters such as buck and buck-boost. This is because their input current is pulsating type. So the BOOST converter used for PFC is our main focus in this paper. In this paper we will analyze different operating modes and controlling of this topology to obtain the best possible results with this topology. We will also do some modifications in the structure of conventional boost PFC and its control.In this PFC technique bridge rectifier is followed by a Boost converter. We can control the output dc voltage and the power factor by controlling this boost converter. This converter can operate in different regions that are defined on the basis of inductors current behavior. The regions in which a boost converter can operate are the continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In DCM, the inductor current ripples are very high due to which power losses are high so the DCM operation restricts it to low power applications [13]. At the other end in CCM, the inductor current ripples are very small due to which power losses are low, which makes it optimal for medium and high power applications. Moreover in case of DCM we just have to use the voltage control loop but in case of CCM operation of boost PFC converter, we have to use both the current and the voltage control loops. The current control loop is used to force the input line current to follow the input line voltage while the voltage control loop is used to regulate the output dc voltage.DCM operation offers a number of advantages such as inherited power factor correction and simple control of power electronic switches. Moreover it also reduces reversed recovery losses of the diode due to soft turn off of freewheeling diode. On the other hand, in CCM, complex controller is required to control voltage and current simultaneously but the inductor current ripples are very low. Therefore, at the cost of complex control strategy the size of inductor is reduced. Whereas, DCM requires a high-quality boost inductor for extremely high current ripples.The control of this system is divided into two loops; the output voltage control loop and the input current control loop. Fig.1 shows the block diagram of the control strategy in which one loop calculates the voltage error and the other loop calculates the current error. Both of these errors are then fed to PI controller.

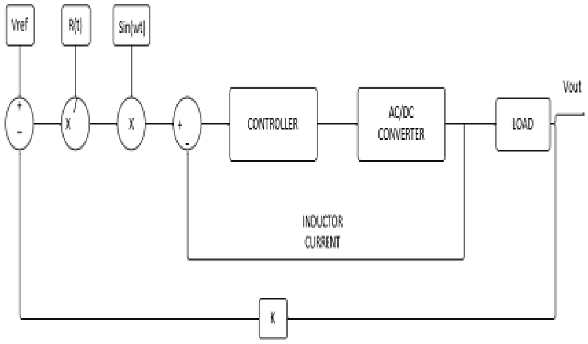

Fig.1. Block diagram of the control methodology of Boost PFC converter

As discussed earlier, there are two states of this system; capacitor voltage and inductor current. In this particular system both of these states need to be controlled but there is only one control input available for controlling the system so this is an under actuated electric system.

3 CONTROLLER AND RESISTOR OBSERVER

The control strategy of Boost PFC AC-DC Converter is designed in such a way that, first it calculates the error between the reference and the output voltage and then this DC value is converted to the reference current that follows the input voltage by multiplying it with the rectified sinusoidal wave and dividing it with the load resistance. Now this reference current is then subtracted from the actual inductor current to get an error, which is then fed to the controller to achieve our goal of tracking. Fig.2 is the schematic diagram of Boost PFC with Diode Bridge and controller. In equation (1) PI controller is shown which is applied on the error obtained by subtraction of reference current i_{ref} from inductor current i_L. In equation (2) the reference current i_{ref} waveform is generated using required output DC voltage, connected load and the sinusoidal waveform of AC voltage. V_{ref} is the desired output voltage of the converter and V_o is the actual output voltage. The variable resistive load is denoted by R (t) and k_1, k_2 are the gains.

$$u = K_p(i_{ref} - i_L) + K_i \int (i_{ref} - i_L)dt \tag{1}$$

$$i_{ref} = \frac{(V_{ref} - k_1 V_o)}{k_2 R(t)} |\sin(\omega t)| \tag{2}$$

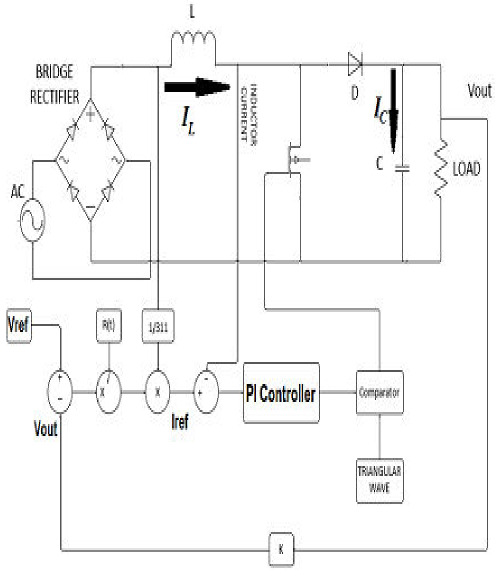

Fig.2. Schematic diagram of Boost PFC converter with control diagram

As output of the controller has to switch the power electronic switch of boost converter so we have to convert u into PWM. In this paper, fixed frequency Sinusoidal PWM (SPWM) is used. As this converter is designed for variable switching load so we have to observe the value of load. As the equation of controller totally depend upon the generation of reference signal and reference signal depends upon connected load so value of load must be known. The load observer can be described as:

$$R(t) = \frac{V_{ref}}{I_o} \tag{3}$$

V_{ref} is reference dc voltage and Io is defined as:

$$I_o = (i_L - i_C)\overline{u} \tag{4}$$

i_L is the current passing through inductor and i_c is the current passing through capacitor.

$$i_C = C\frac{dV_C}{dt} \tag{5}$$

4 BRIDGELESS BOOST PFC CONVERTER

As the requirement of high power quality is always there so it is an active research area. Therefore, efforts are always made to get higher power factor and lower total harmonic distortion. Previously, boost power factor correction converter has been widely used because of its simplicity, inherent PFC capability and high output power. But this topology has harmonic distortions and low efficiency due to number of semiconductor switches in the line. To lower the losses and to increase the efficiency single phase bridgeless boost PFC converter was introduced [12]-[13]. In the literature bridgeless boost AC-DC converter is also called as dual-boost converter. In this converter the conduction losses are reduced due to reduction in the semiconductor switches in the path of current. Bridgeless boost PFC converter is highly efficient topology because in this topology bridge-rectifier is omitted and there are only two nonlinear switches in any given conduction path. This bridgeless topology consists of two boost converter circuits. The control strategy is same as Boost PFC converter, but the only difference is during positive half cycle one boost circuit is used and during negative half cycle second boost circuit is used. Where as in boost PFC, first negative half cycle is converted to positive half cycle by using bridge rectifier and then it is fed to the boost converter. Fig.3 shows the schematic diagram of bridgeless boost PFC converter.

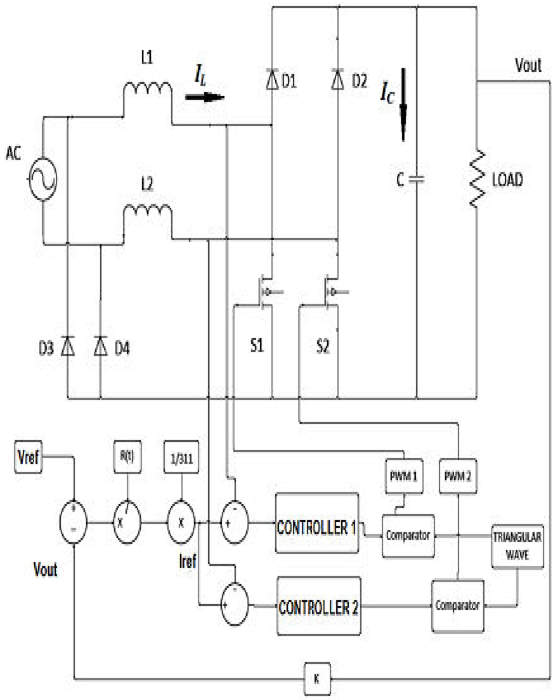

Fig.3. Schematic diagram of Bridgeless Boost PFC converter

4.1 Working principle of Bridgeless PFC converter

This bridgeless topology is actually made from two converters that's why it is also known as dual boost converter. In conventional boost converter DC is fed to the inductor but in bridgeless topology AC is directly fed between the inductors of two DC converters. There are four modes of operation of bridgeless power factor correction converter. Positive half cycle of the ac line voltage consists of Modes I and II while negative half cycle of ac line voltage consists of modes III and IV.

i) Positive half cycle

For the duration of the positive half cycle of the ac line voltage, the current follows the path of first dc/dc boost converter; L1-D1–S1-D4. Diode D4 completes the circuit without including the inductor L2 and connecting the output ground. Furthermore, there are two modes of operation of positive half cycle. Fig.4 shows the working principle of mode I. The switch S1 is turned on to store the energy in inductor L1. The path Vin-L1-S1-D4 is followed in this mode.

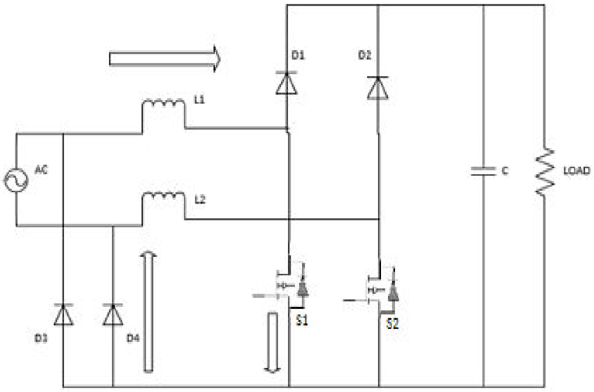

Fig.4. Mode I positive half cycle

Fig.5 shows the working principle of mode II in which switch S1 is in off state. As S1 is turned off so the current uses the path of diode D1 to pass through the load. In this mode the charged inductor L1 of mode I gets discharged by using the path of diode D1, load and diode D4.

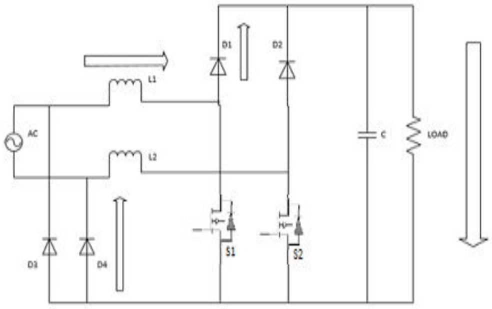

Fig.5. Mode II positive half cycle

ii) Negative half cycle

For the duration of the negative half cycle of the ac line voltage, the current follows the path of second dc/dc boost converter; L2-D2–S2-D3. Diode D3 completes the circuit without including the inductor L1. This diode also connects the ground with the diode D3. Same like positive half cycle there are two modes of operation of negative half cycle (Mode III and Mode IV). Fig.3.6 shows the operation of mode III. The switch S2 is turned on to store the energy in inductor L2. The path followed during this operation mode, consists of Vin-L2-S2-D3.

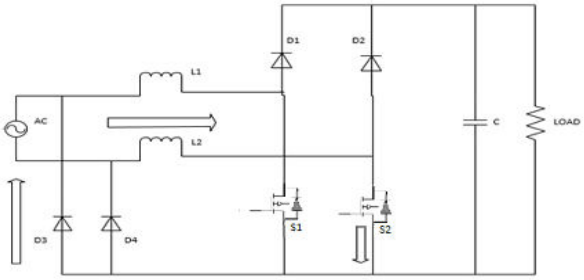

Fig.6. Mode III negative half cycle

Fig.7 shows the mode IV of operation in which switch S2 is turned off. As switch S2 is off so the current uses the path of diode D2 to pass through the load. In this mode the charged inductor is discharged through the path of diode D2, load and diode D3.

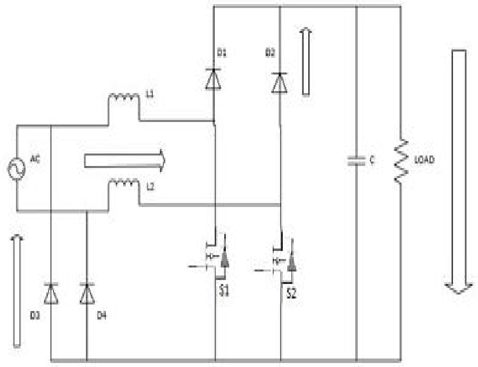

Fig.7. Mode IV positive half cycle

5. INDUCTION MOTOR

An asynchronous motor type of an induction motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor can therefore be made without electrical connections to the rotor as are found in universal, DC and synchronous motors. An asynchronous motor's rotor can be either wound type or squirrel-cage type.Three-phase squirrel-cage asynchronous motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives (VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and variable-frequency drive (VFD) applications. Variable voltage and variable frequency drives are also used in variable-speed service.In both induction and synchronous motors, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. Whereas a synchronous motor's rotor turns at the same rate as the stator field, an induction motor's rotor rotates at a slower speed than the stator field. The induction motor stator's magnetic field is therefore changing or rotating relative to the rotor. This induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding, when the latter is short-circuited or closed through external impedance. The rotating magnetic flux induces currents inthe windings of the rotor; in a manner similar to currents induced in a transformer's secondary winding(s). The currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. Due to Lenz's Law, the direction of the magnetic field created will be such as to oppose the change in current through the rotor windings. The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding currents the rotor will start to rotate in the direction of the rotating stator magnetic field. The rotor accelerates until the magnitude of induced rotor current and torque balances the applied load. Since rotation at synchronous speed would result in no induced rotor current, an induction motor always operates slower than synchronous speed.The difference, or "slip," between actual and synchronous speed varies from about 0.5 to 5.0% for standard Design B torque curve induction motors. The induction machine's essential character is that it is created solely by induction instead of being separately excited as in synchronous or DC machines or being self-magnetized as in permanent magnet motors.

For rotor currents to be induced the speed of the physical rotor must be lower than that of the stator's rotating magnetic field (n_s); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors. An induction motor can be used as an induction generator, or it can be unrolled to form a linear induction motor which can directly generate linear motion.

Synchronous Speed:

The rotational speed of the rotating magnetic field is called as synchronous speed.

$$Ns = \frac{120 \text{ x } f}{P} \quad \text{(RPM)} \qquad (1)$$

Where, f = frequency of the supply
P = number of poles

Slip:

Rotor tries to catch up the synchronous speed of the stator field, and hence it rotates. But in practice, rotor never succeeds in catching up. If rotor catches up the stator speed, there won't be any relative speed between the stator flux and the rotor, hence no induced rotor current and no torque production to maintain the rotation. However, this won't stop the motor, the rotor will slow down due to lost of torque, and the torque will again be exerted due to relative speed. That is why the rotor rotates at speed which is always less the synchronous speed.

The difference between the synchronous speed (Ns) and actual speed (N) of the rotor is called as slip.

$$\% \text{ slip} \quad s = \frac{Ns - N}{Ns} \text{ x } 100 \qquad (2)$$

6 MATLAB/SIMULATION RESULTS

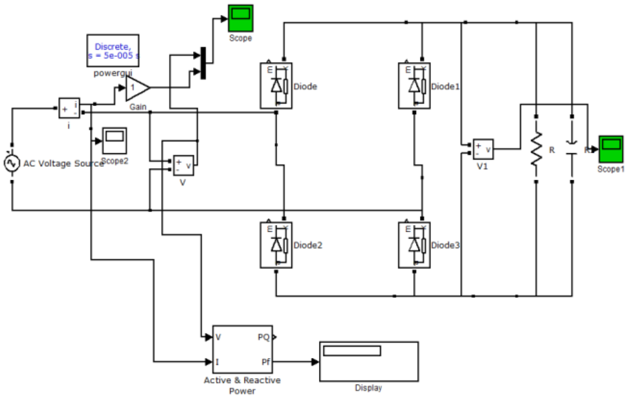

Fig 8 simulink diagram of ac to fixed dc with filter

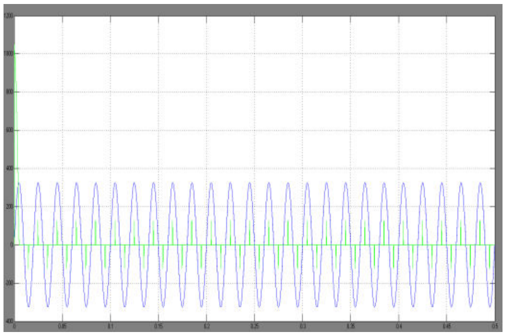

Fig 9 input voltage and current of ac to fixed dc with filter

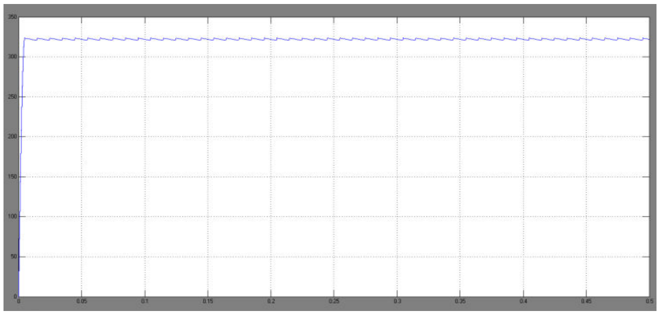

Fig 10 load voltage of ac to fixed dc with filter

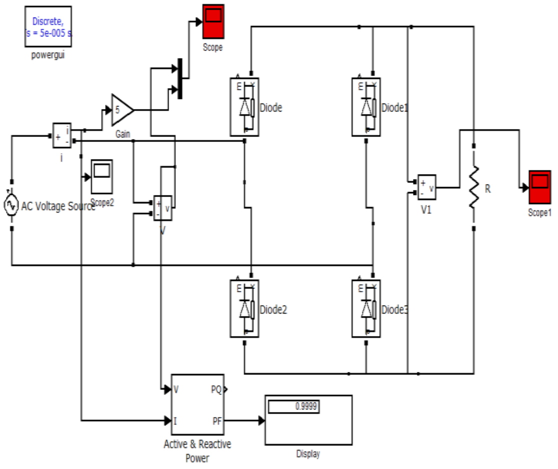

Fig 11 simulink diagram of ac to fixed dc without filter

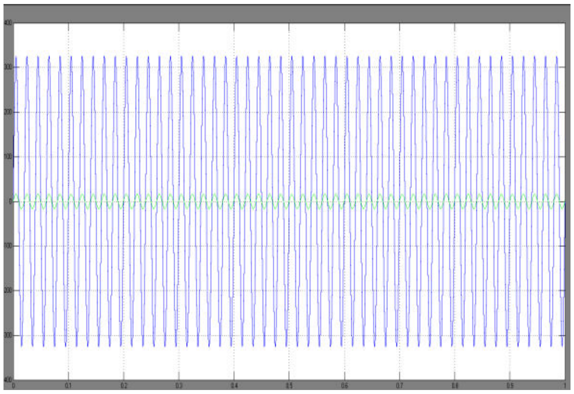

Fig 12 input voltage and current of ac to fixed dc without filter

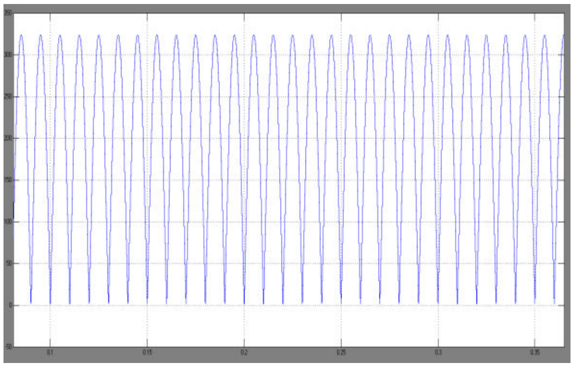

Fig 13 load voltage of ac to fixed dc with filter

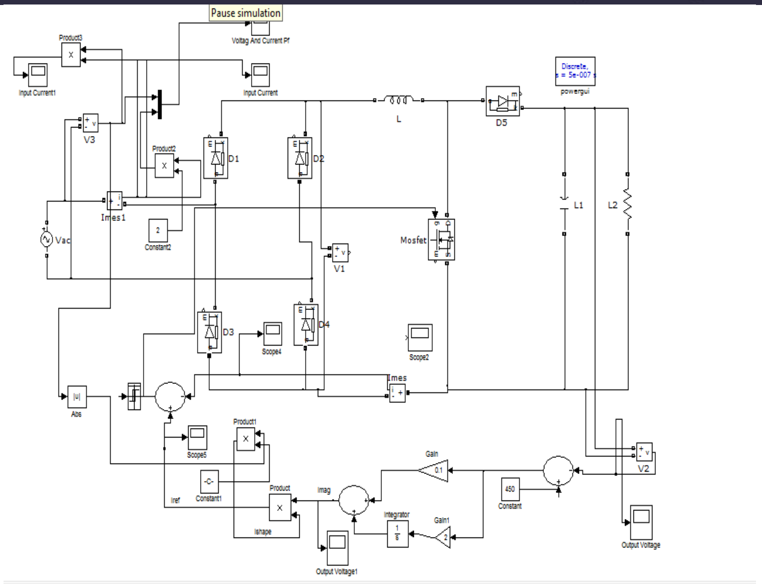

fig 14 simulink diagram of Boost Power Factor Correction Converter.

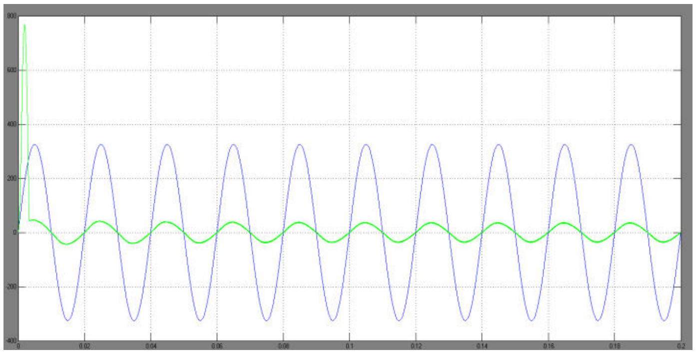

fig 15 scaled voltage and Current waveform of Boost Power Factor Correction Converter.

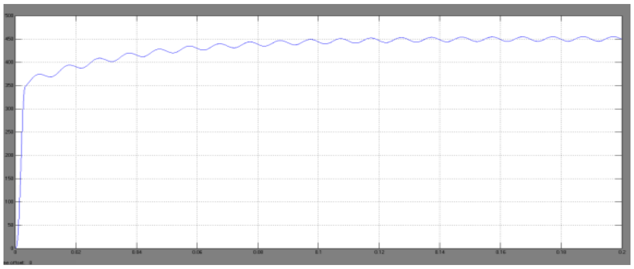

fig16 load voltage of Boost Power Factor Correction Converter.

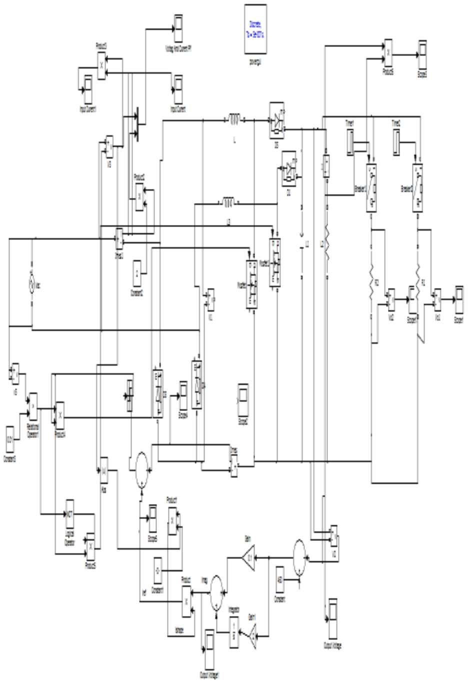

fig 17 simulink diagram of Bridge Boost Power Factor Correction Converter.

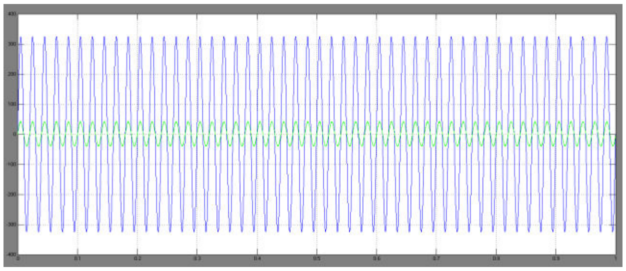

fig 18 scaled voltage and Current waveform waveform of Bridge Boost Power Factor Correction Converter

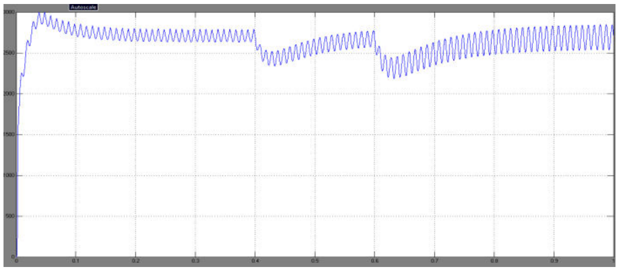

fig 19 Output Power of the Bridgeless Boost PFC converter

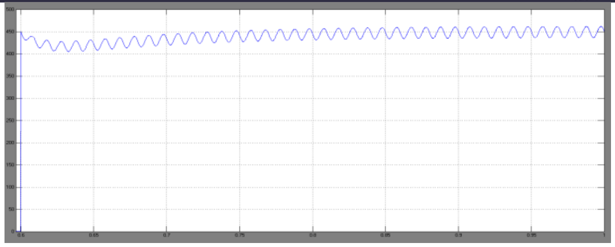

Fig. 20. Output voltage regulation of the Bridgeless Boost PFC converter

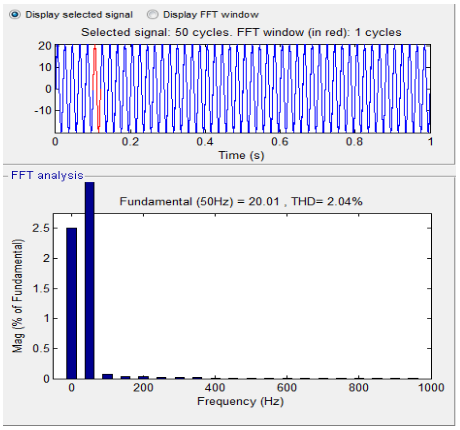

Fig. 21. Frequency Response of input line current of Bridge Boost PFC Converter

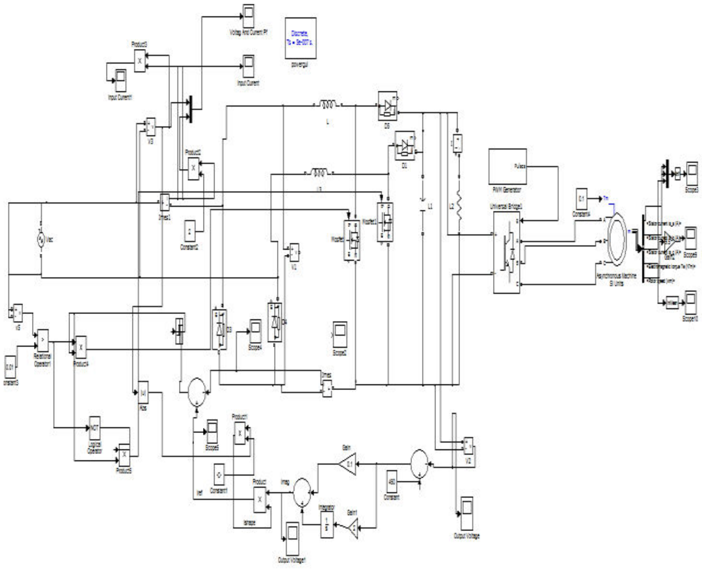

fig 22 simulink diagram of Bridge Boost Power Factor Correction Converter with induction motor

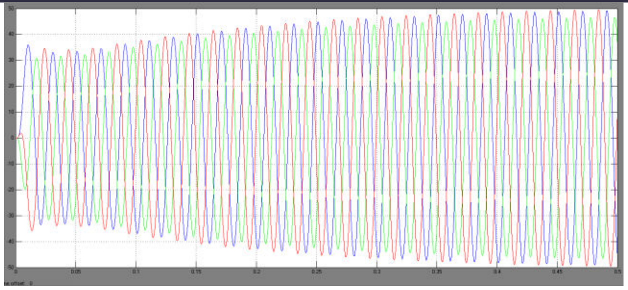

fig 23 stator current characteristics of induction motor

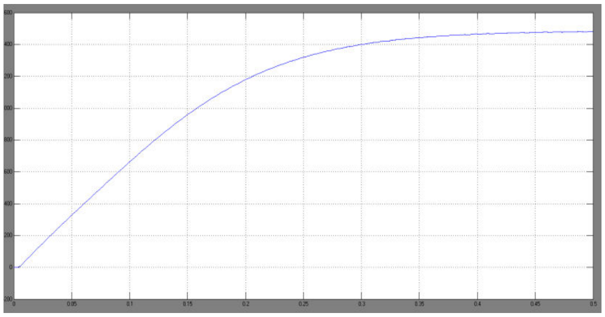

fig 24 speed characteristics of induction motor

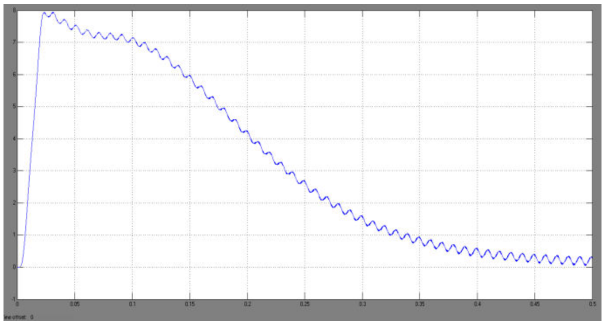

fig 25 torque characteristics of induction motor

7. conclusion

In this paper, total harmonic distortion, the power factor and power efficiency of two types of Boost PFC Rectifiers was introduced for induction motor drive applications are compared under identical conditions. Different operational modes are explained for bridgeless topology, and the simulation results of line voltage and current are compared to conduct comparative analysis. The controller is implemented to control both, the input ac current and the output dc voltage. The efficiency and power factor of the controlled bridgeless boost PFC Converter is higher than the bridge boost PFC converter. The total harmonic distortion of bridgeless boost PFC converter is also reduced to 5%. As we have designed the load observer, so the controllers have performed according to the variable loads and have given better response for wide range of switching loads. The proposed circuit is applied to Induction Motor Drive to check the performance of entire system. Simulation results are shown. THD also reduced with filter in the converter circuit.

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