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An Active Power Factor Correction Technique for Bridgeless Boost AC-DC Converter

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Abstract: As most of the electronic appliances use DC power so improvement in AC–DC converter 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.

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 buckboost 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 flyback 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

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and controller is giving a simple and easily implementable solution to all the discussed issues.

II. DEFINITION AND TYPR OF POWER

The actual amount of power used, or dissipated in a circuit is called real power. It is measured in Watts (W) and is represented mathematically by *P* . True power is based on the circuit's dissipative elements, such as resistors, *R*. Reactive loads such as inductors and capacitors dissipate another type of power called Reactive power, which is measured in VoltAmpReactive (VAR) and represented by *Q*. It is a function of a circuit's reactance, *X*. The integration of reactive power and true power is called the apparent power. It is a multiplication of the voltage and current without the phase shift between them. Apparent power is measured in VoltAmps (VA) and is represented by *S*. Apparent power is a function of a circuit's total impedance *Z*. The true, apparent and reactive power are represented in (1), (2) and (3), respectively.

$$P = V^2/R = I^2 R = V \cdot I \cdot PF \quad (1)$$

$$S = V^2/Z = I^2 Z = V \cdot I \quad (2)$$

$$Q = V^2/X = I^2 X = \sqrt{S^2 - P^2} \quad (3)$$

A. Power Factor(PF)

PF measures how efficiently the current is being converted into real work. With a low PF, more electrical current is required to provide the same amount of real power. For instance, a PF of 1 will result in the most efficient loading of the supply; on the other hand, a load with a PF of 0.5 will result in higher losses in the distribution system [8]. PF is the ratio between the real power and the apparent power drawn by an electrical load (see (4)). In an inductive load, such as a motor, active power performs the work and reactive power creates the electromagnetic field.

$$PF = \cos\Theta = P/S \quad (4)$$

For a purely resistive circuit, the PF is 1 since the reactive power equals zero. For a purely inductive circuit, the PF is zero since true power equals zero. Same for a purely capacitive circuit. Thus, if there are no dissipative (resistive) components in the circuit, the true power must be zero, making any power in the circuit purely reactive. PF is an important aspect to consider in an AC circuit; because any power factor less than 1 means that the circuit's wiring has to carry more current than what would be necessary to deliver the same amount of (true) power to the resistive load. Thus, the poor power factor indicates an inefficient power delivery system. Poor PF can be corrected by adding another load to the circuit drawing an equal but opposite amount of reactive power, to cancel out the effects of the load's inductive reactance. Inductive reactance can only be canceled by capacitive reactance, so we have to add a capacitor in parallel to the circuit as additional load. The effect of these two opposing reactance in parallel is to bring the circuit's total impedance equal to its total resistance (to make the impedance phase angle equal, or at least closer, to zero).

The reactive load of an industrial feeding system usually consists of a large number of AC induction motors. This can cause the total load to be up to 50% inductive. The large inductive loads cause the apparent power to be 25% to 40% higher than the actual power. If the utility billing is based on the real power (kW) only, the utility should provide up to 40% more capacity than what they charge for. Overall, there are several consequences of low PF; these consequences include the reduced capacity of the system, increased system losses, and extra cost.

III. 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 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. There fore 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. 2 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.

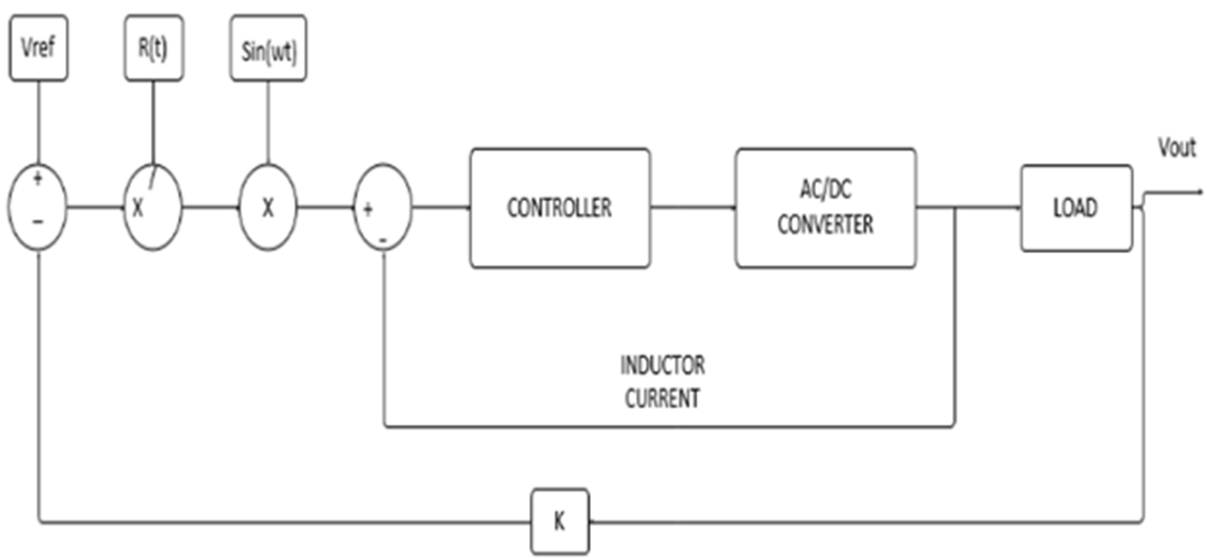

Fig 1 : Block diagram of the control methodology of the boost PFC converter

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.

IV. 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 $iref$ from inductor current iL. In equation (2) the reference current $iref$ waveform is generated using required output DC voltage, connected load and the sinusoidal waveform of AC voltage. $Vref$ is the desired output voltage of the converter and Vo is the actual output voltage. The variable resistive load is denoted by R(t) and $k1$,$k2$ are the gains.

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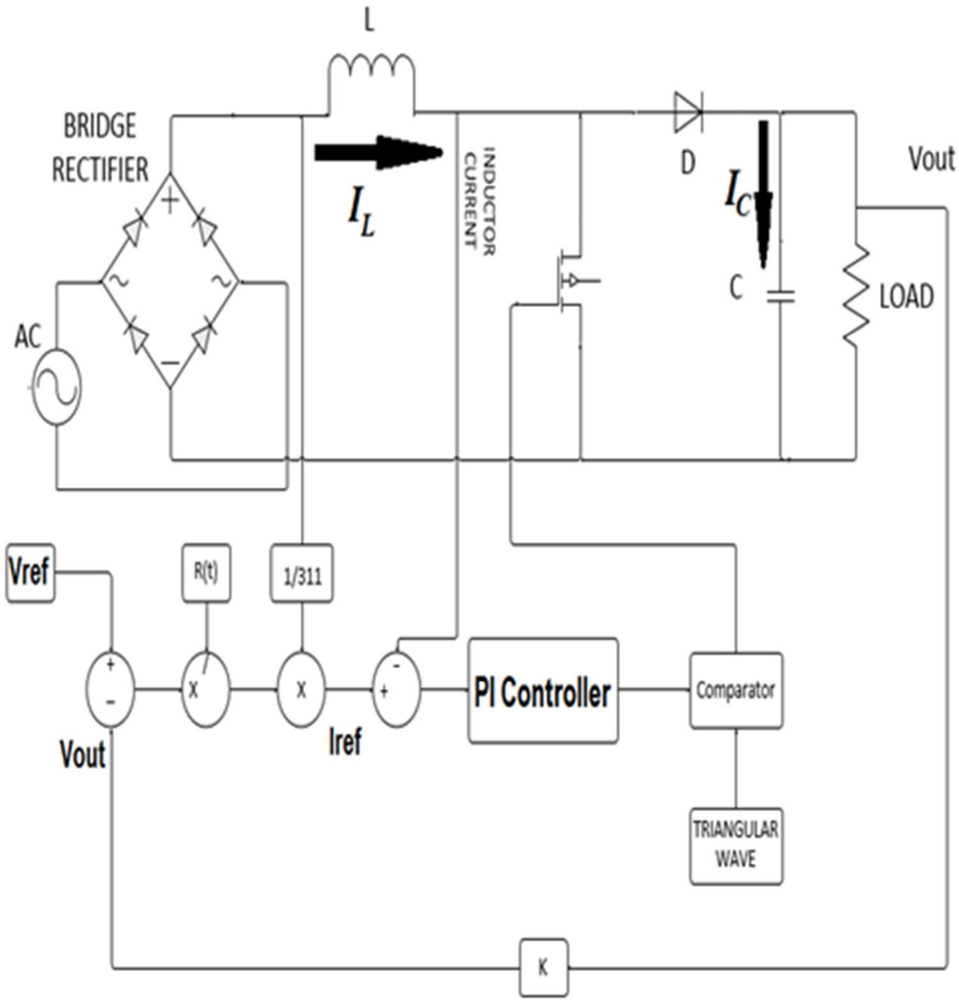

Fig 2 : Schematic diagram of boost PFC converter with control diagram

$$u = Kp\,(iref - iL) + Ki \int (iref - iL)\,dt \qquad (1)$$

$$iref = \frac{(Vref - k1Vo)}{k2R(t)} \sin(\omega t) \qquad (2)$$

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:

$$R(t) = \frac{Vref}{Io} \qquad (3)$$

Vref is reference dc voltage and Io is defined as:

$$Io = (iL - iC)u \qquad (4)$$

iL is the current passing through inductor and ic is the current passing through capacitor.

$$i_C = C\,\frac{dVc}{dt} \qquad (5)$$

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V. 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 semicondutor 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

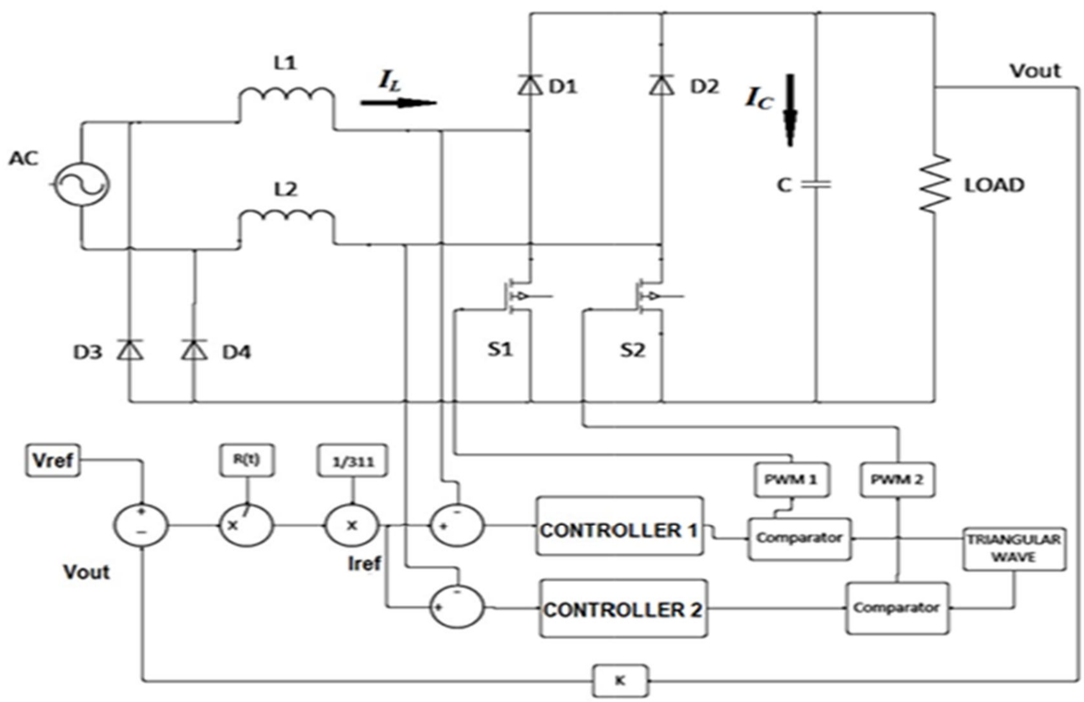

Fig 3 : Schematic diagram of bridgeless boost PFC converter

A. *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.

B. *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.

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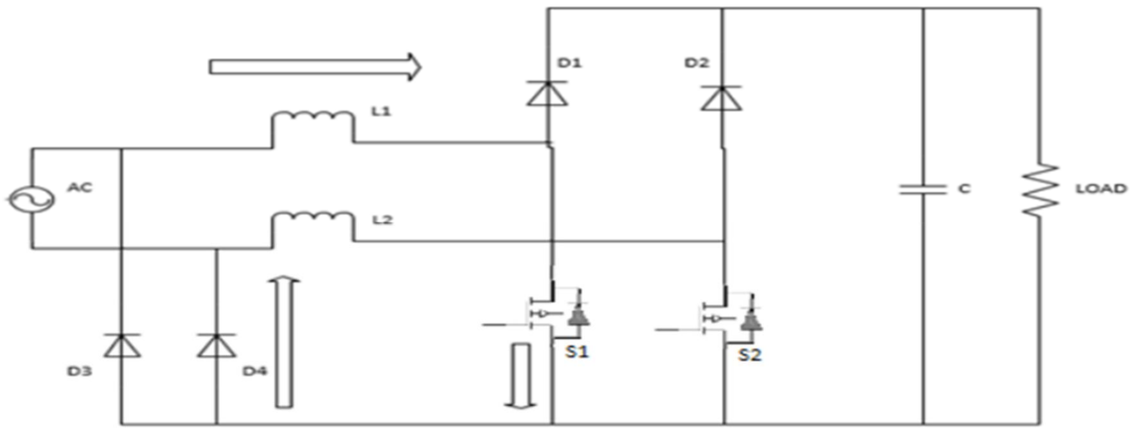

Fig 4: Mode 1 positive half cycle

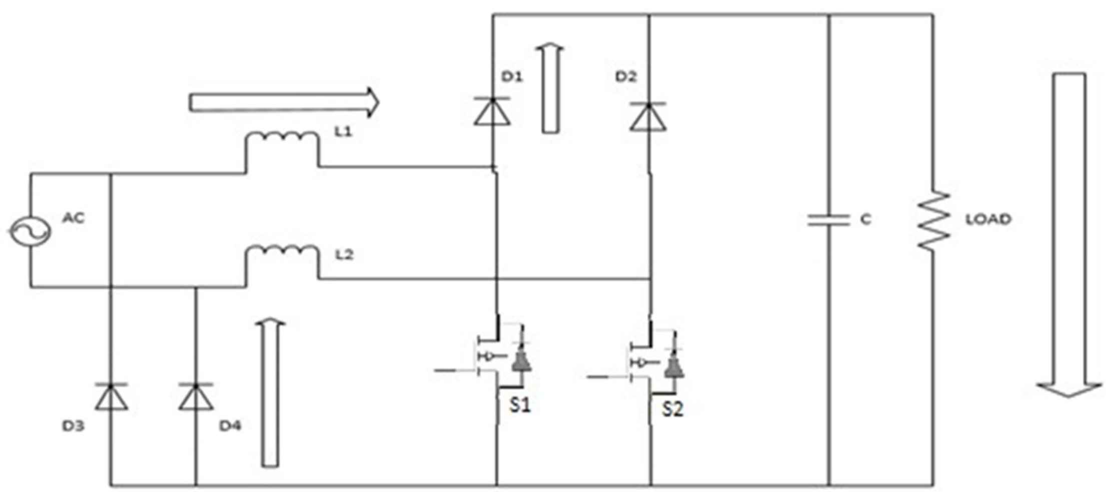

Fig 5 : Mode 2 positive half cycle

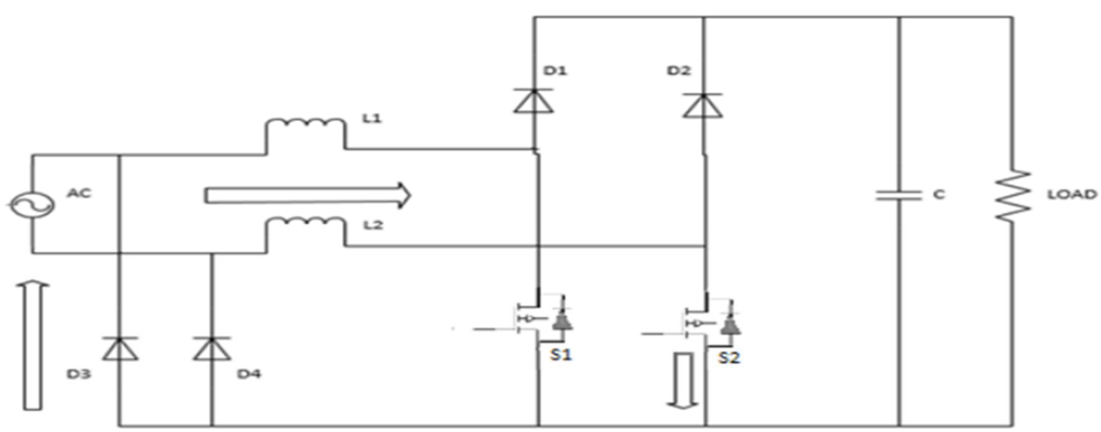

Fig 6 : Mode 3 Negative half cycle

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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.

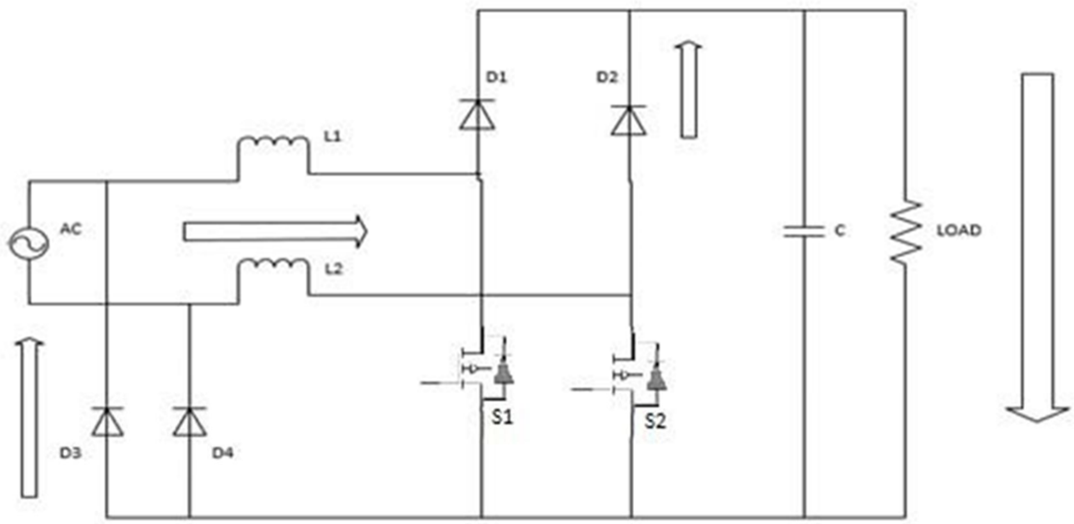

Fig 7 : Mode 4 Negative half cycle

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.

C. 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 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 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.

VI. SIMULATION AND EXPERIMENTAL RESULTS

Both the Boost PFC Converter and Bridgeless Boost PFC converter were simulated using Matlab to generate the comparison between them. The rectifiers were tested for same specifications and control system. As we have used the fixed frequency PWM so the switching frequency was set to 10 KHz, which can be efficiently used with high power Semiconductor switches. The power was set to 1.5KW with DC output of 400V and connected resistive load of 100ohm. The circuits were designed for the AC input of 220V (50Hz). Conventional Boost PFC topology is controlled by single PWM controller operating S1 switch. Whereas in Bridgeless Boost PFC topology two separate controllers of almost same structure are used to control their respective switches S1 and S2. First controller will operate S1 during the positive part of the cycle, whereas during negative part of the cycle the second controller will operate S2.

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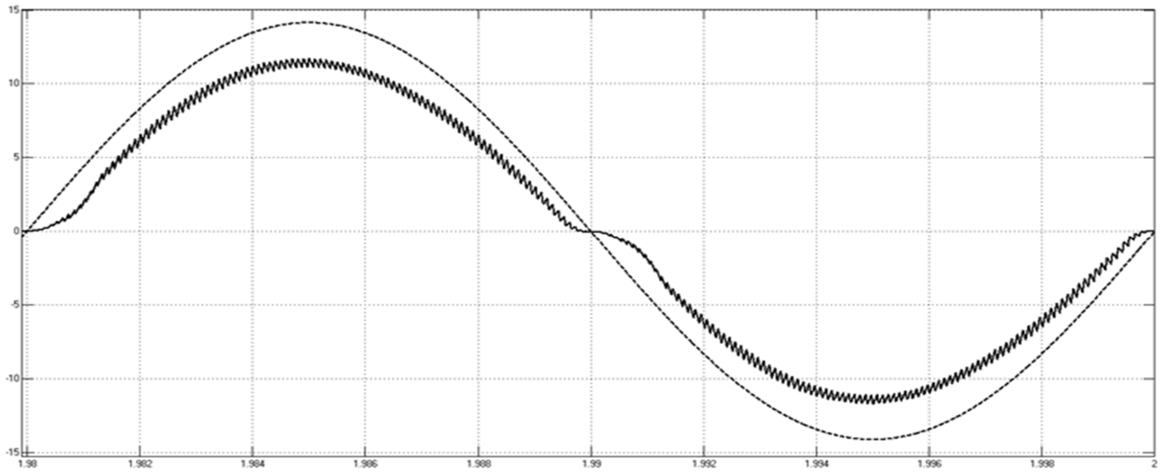

Fig 8 : Current waveform and scaled voltage waveform of Bridgeless Boost Power Factor Correction Converter. (Voltage scaled by 22)

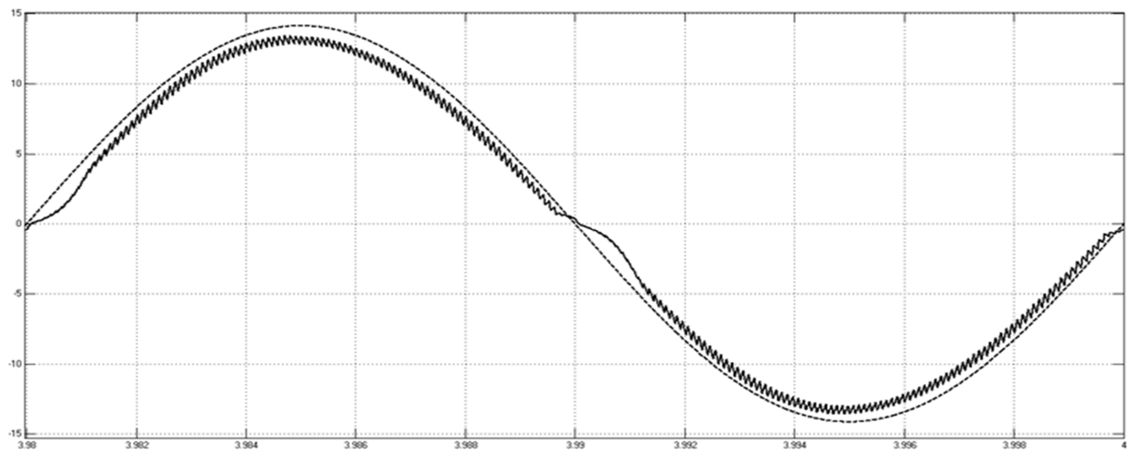

Fig 9 : . Current waveform and scaled voltage waveform of Bridgeless Boost, Power Factor Correction Converter. (Voltage scaled by 22)

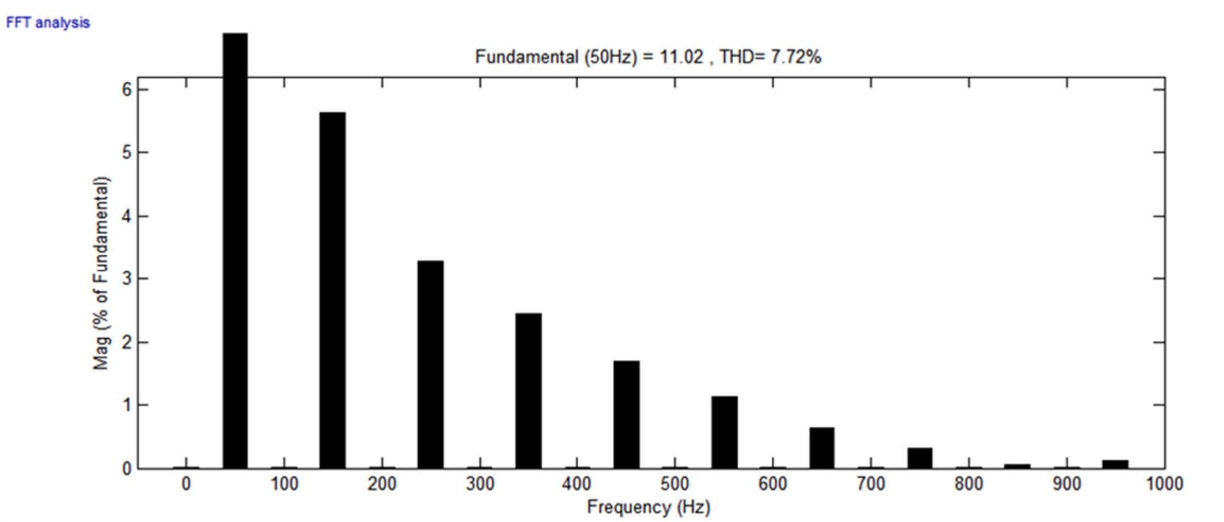

Fig 10 : . Frequency Response of input line current of Bridge Boost PFC Converter

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Fig. 8 shows the comparison of waveform of input line current with the scaled input line voltage of Boost PFC converter. It can easily be observed that the line current waveform is in phase with the line Voltage waveform but in the vicinity of zero crossing the current remains zero for 0.0005 seconds.

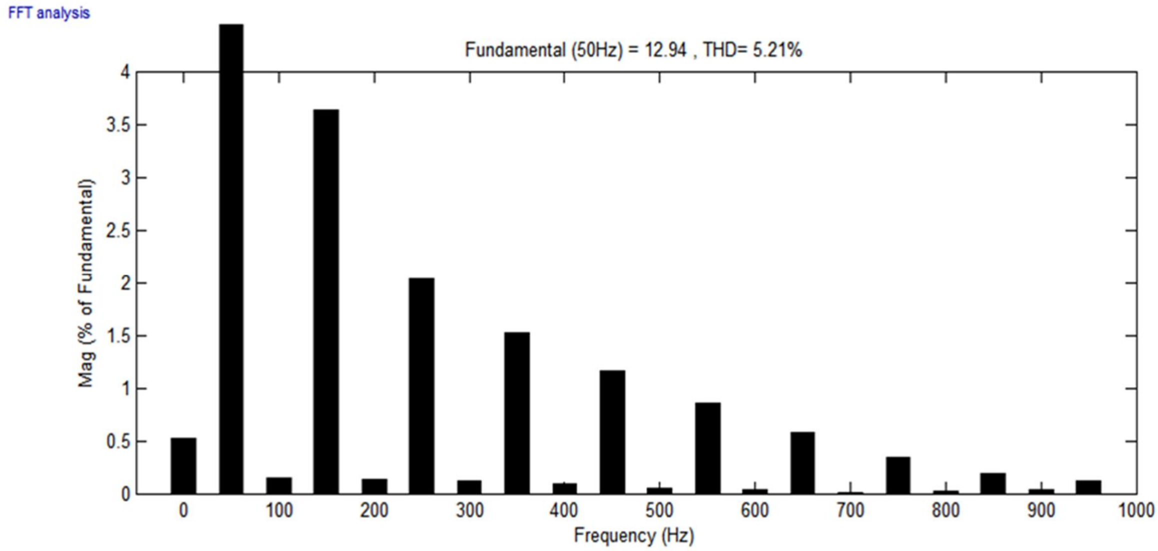
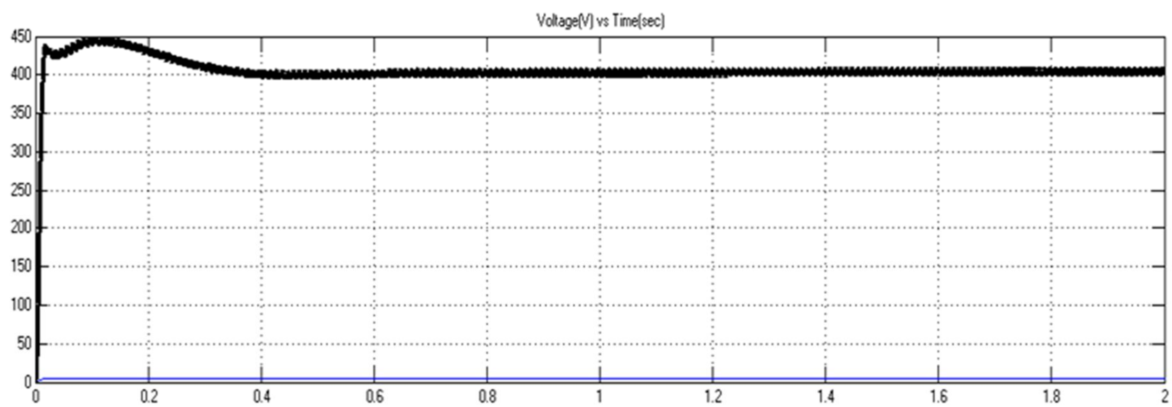
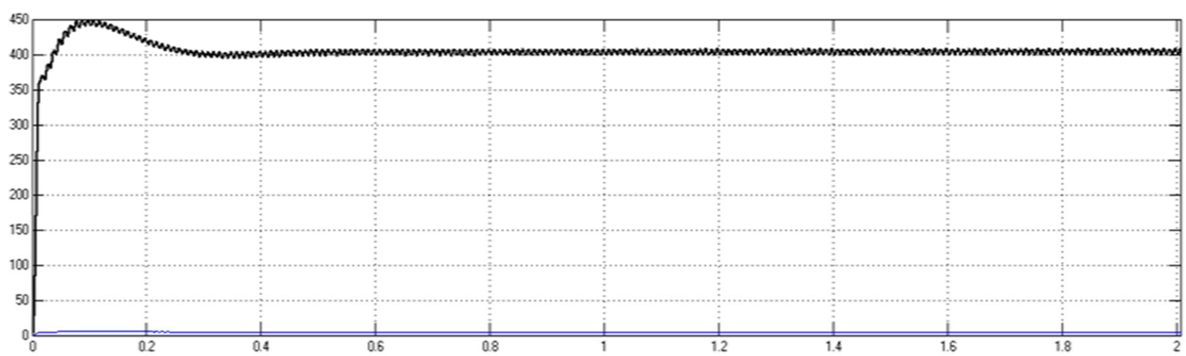


Fig 11 : . Frequency Response of input line current of Bridgeless Boost PFC Converter



(a)



(b)

Fig. 12. (a) The output voltage regulation of Bridge Boost PFC Converter. (b)The output voltage regulation of Bridgeless Boost PFC Converter

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The power factor or this converter reaches 0.995 after 1 second Fig. 9 shows the waveforms of input line current and scaled input line voltage of bridgeless boost PFC converter. It can easily be seen that input line current is in phase with the input line voltage and the input line current doesn't stay at zero on zero crossing. Therefore, the power factor of this converter is increased to 0.998 after 1 second. As our another main focus was on the reduction of Total Harmonics Distortion (THD) so here we have also generated the comparison of Fast Fourier Transform (FFT) of input line current of both the topologies. In Fig. 10 the histogram of Boost PFC Rectifier is showing that THD is almost 7.72% of the input ac current. Whereas Fig. 11 is showing that the Bridgeless Boost PFC Converter has almost 5.21% THD.

Fig. 12 shows the output regulation of both the topologies and it is clearly noticeable that fluctuations of Bridgeless Boost PFC converter are much less than bridge boost PFC converter. At the end of our comparison we have generated the efficiency graph for both the topologies at different loads. As we have implemented the resistance observer in both cases so the regulation remains perfect and efficiency remains high, while switching the loads.

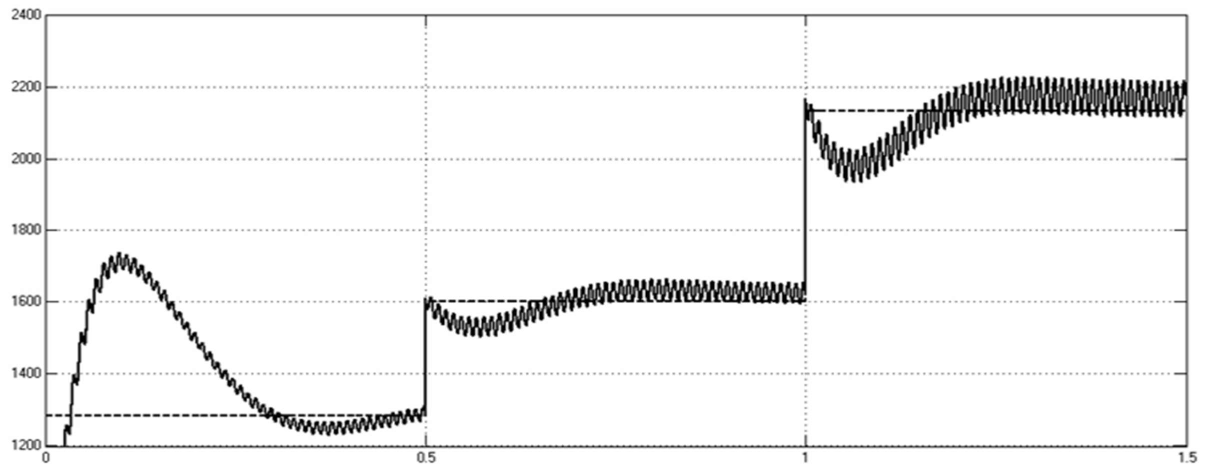

Fig 13 : Output Power of the Bridgeless Boost PFC converter for switching loads of 1.28KW, 1.6KW& 2.13KW

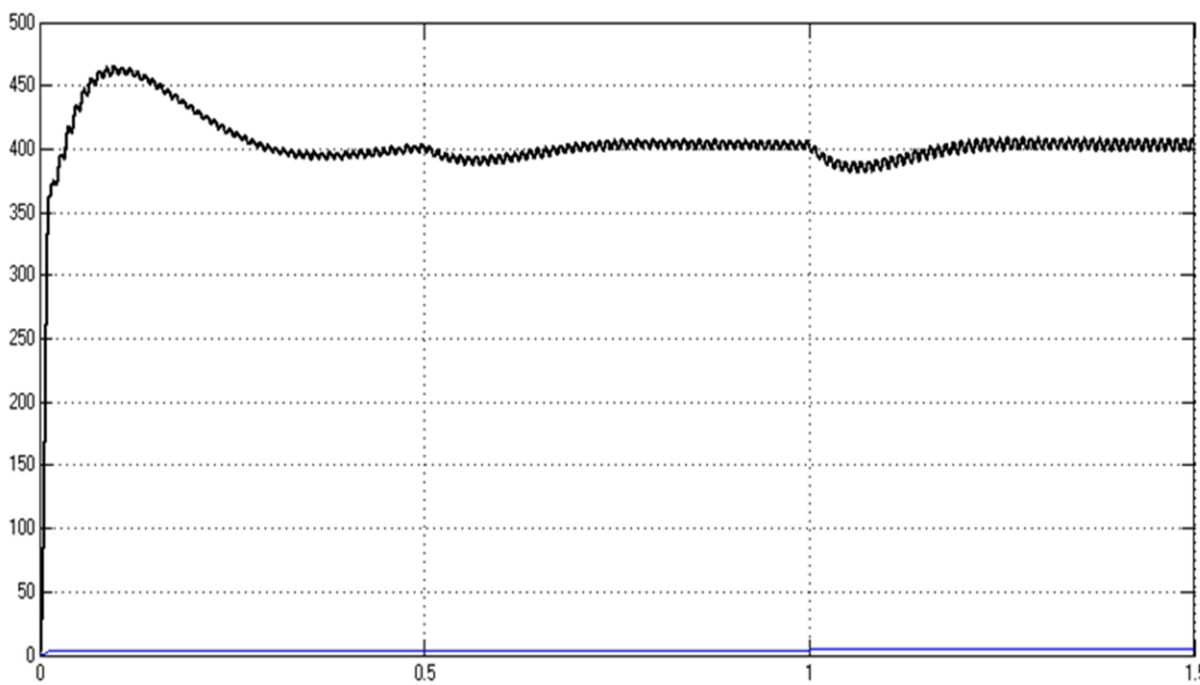

Fig 14 : Output voltage regulation of the switching loads of 1.28KW, 1.6KW& 2.13KW

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To check the performance of the load observer, we have used the switching load. The value of output resister is varied from 125ohm to 100ohm and then to 75ohm. Fig. 13 shows the output power of the converter for above mentioned loads. The transient response of output power decay in 0.5seconds after the switching. Fig. 14 shows the output voltage regulation at 400V. It is clearly observable that the output dc voltage is not varying with the change in load.

VII. CONCLUSION AND FUTURE WORK

In this paper, total harmonic distortion, the power factor and power efficiency of two types of Boost PFC Rectifiers 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.

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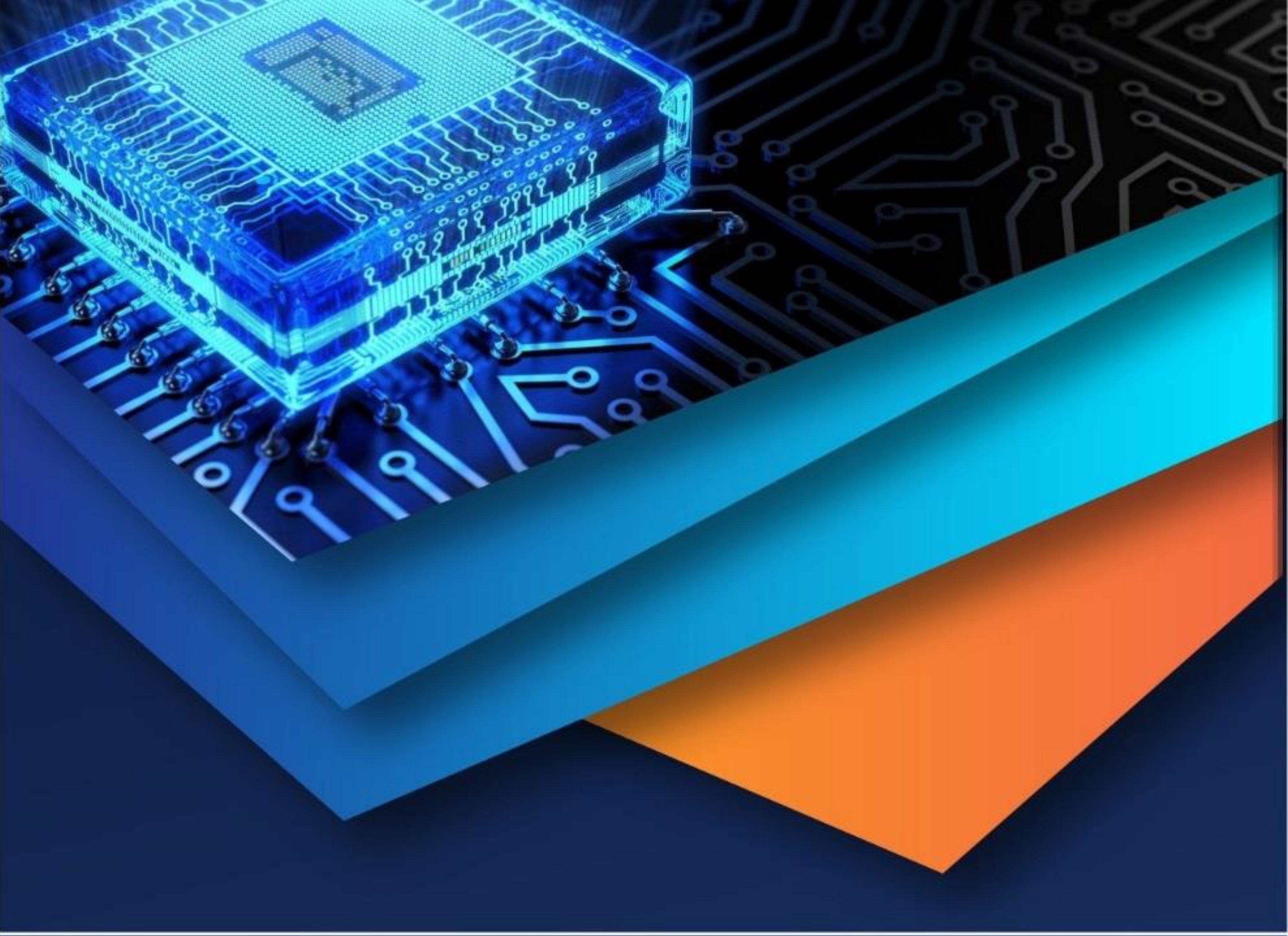

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