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THREE PHASE BUCK-BOOST CONVERTER WITH FUZZY LOGIC CONTROLLER FOR AIRCRAFT APPLICATIONS

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Abstract: In high power aircraft (More Electric Aircraft), converters, inverters, multi-kW rectifiers are required. In this paper, a three-phase buck-booster converter with three MOSFET switches and triggers the input inductors are connected to the delta configuration is provided for aircraft use. The proposed converter operates in continuous transmission mode (DCM) to achieve input induction current. This avoids the internal current control cycle that inhibits the current sensor. The converter requires only one output voltage sensor, the fuzzy logic controller (FLC), and uses a simple voltage control ring to regulate the output voltage. This makes the system cost effective, reliable and robust. Fixed level function, design calculation and simulation results are provided. Simulation results of the 2kW Matlab prototype have also been provided to confirm the functionality of the proposed converter.

***Index Terms* - more electric aircraft; buck-boost converter, DCM, AC to DC converter.**

I. INTRODUCTION

The main goals of More Electric Aircraft (MEA) are to make air travel more efficient and environmentally friendly by reducing the empty weight of the aircraft, decreasing engine emissions, decreasing engine noise and reducing fuel consumption [1]. In MEA, electrical, mechanical and pneumatic subsystems are replaced with electrical systems to meet these goals [2]. Also, a heavy mechanical gearbox called Integrated Drive Generator (IDG) is eliminated and the generator is directly connected to the main engine, resulting in variable frequency means of 400 to 800Hz [3]. Power electronic converters are required to convert variable DC to continuous DC with high power quality and reliability with variable frequency output variables and low number of sensors. In traditional commercial transport aircraft, passive diode based auto transformer multi pulse rectifiers are used for AC-DC conversion. Such rectifiers are simple and reliable, but heavy and occupy a large space due to line frequency transformers. In addition, the output DC bus voltage is dependent on the load and supply voltage [4].

These shortcomings can be overcome by using an active power conversion system. Popular topologies for AC-DC conversion are: buck, boost, buck-boost type rectifiers, which have a high degree of quality in input and output [5]. In MEA, since the DC link voltage is higher than the peak input AC voltage, boost or buck boost of rectifiers are suitable alternatives for AC-DC rectification. Three-phase two-level six-switch boost type rectifiers and six-switch Vienna-type rectifiers are traditional topologies, and have been widely discussed in the literature [6] [7]. In [8], a three-phase delta-switched rectifier with an optimized current controller modulation concept has been extended to reduce switching losses for use in MEA. Therefore in this paper, a three-phase buck-boost derivative PFC converter operates in a DCM with a small number of components and sensors presented. The comparison criteria include number of switches, number of diodes, number of sensors, control complexity, component voltage, current stress and power density.

Due to the DCM function, the switch current stress of the proposed converter is higher compared to CCM converters [9] and [10].All the rectifiers mentioned here are operated in continuous conduction mode (CCM) and require two control loops; one is to regulate the output voltage and the other is to shape the input current sinusoidal. Hence, the control algorithm requires at least five sensors two input voltages, two input currents, one output voltage for its implementation. By reducing the sensors count, there are several advantages like the cost reduction, robustness to high frequency noise, improvement in system reliability, reduction of system weight and slight improvement in efficiency [13]. To reduce the number of sensors, several approaches are reported in the literature for two level boost converter [14], where the system instability is the major concern during the load transients and also these control algorithms will not work in case of single phase open faults[15]. The number of sensors in a converter can be reduced by operating it in discontinuous conduction mode (DCM). A rectifier operating in DCM achieves natural power factor correction at ac input. Hence, the input current shaping circuit can be eliminated i.e., the two input current and two input voltage sensors can be also eliminated.

In DCM, the average value of input current in a switching cycle is determined by the input voltage, which means the average input current naturally follows the input voltage. In [16], a three phase boost converter by operating the input inductors in DCM is presented. Due to the boost type structure, the input current waveforms are presents the higher amplitude of lower order harmonics. Therefore, a large input filter is required for filtering, which results in low power density (not suitable for aircraft application). On the other hand, the discontinuous mode buck-boost type converters are perfect PFC regulators and the input current does not contain any lower order harmonics [17]-[19], hence a small input filter is sufficient to filter out the higher switching order harmonics. In literature, some three phase buck-boost type converters operating in DCM with a simple control are reported in [20]-[24]. The converters reported in [21],[22] are isolated converters derived based on flyback structure, and suffering from lower efficiency due to the flyback transformer. The converters reported in [22]-[24] are non-isolated converters, and involve higher component count. This study presents a three-buck buck-boost-derived BBC converter running in tens with treatments, a limited number of components and sensors. The comparison criteria includes the number of switches, number of diodes, number of sensors, control complexity, components voltage, current stresses and power density. However, the advantages of the proposed converter such as less number of components, less number of sensors and less control complexity significantly outweighs the disadvantage of high current stress. Besides, it works with zero current movement in converter switches and zero current off in bridge diodes, which reduces switching losses and increases efficiency.

The proposed converter requires only a simple voltage control ring to regulate the output voltage, hence only one sensor, which makes the system effective, reliable and robust. The basic idea of the proposed converter is discussed by G. Sivanagraju in [25]. In this paper, the analysis is extended further and the converter detailed design calculations are presented. He obtains analytical expressions for each component to calculate the mean and rms current estimates, obtained from the control loop FLC and verified with simulated values. The paper is organized as follows; section II describes the proposed converter and control strategy, section III presents the steady state analysis of the converter, section IV discusses the simulated results from the matlab prototype, and section V concludes the paper.

II. PROPOSED CONVERTER, CONTROL STRATEGY AND FUZZY SYSTEM

A.PROPOSED CONVERTER

The proposed converter as shown in Fig 1 is derived by combining the three single phase structures into a three phase three wire system, where a three phase bridge rectifier is used in place of three single phase bridge rectifiers. For a balanced three phase system, the four quadrant switches are no more required and just three switches are sufficient when they are operated synchronously, as shown in Fig.1. The input inductors are connected in delta configuration, as it results in 20% less the peak inductor current when compared to the wye configuration. Moreover, in case of a single phase failure or open switch fault, all the inductors participate for power transfer.

B. CONTROL STRATEGY

The objectives of a converter are;

1) The sinusoidal input current in phase with input voltage,
2) Regulated DC output voltage.

The first objective is achieved by operating the inductors in discontinuous conduction mode (DCM). The second objective is achieved by using a simple voltage control loop .It is considered that all the switches are operated synchronously and the value of input inductance in each phase is same. From the control loop, it can be seen that the duty cycle of the switches depends only on the error between the reference voltage and the output voltage i.e. for a given output power and input voltage, the converter duty cycle is constant and it does not change with input voltage sinusoidal variation. The duty cycle changes only if there is change in output voltage reference or any disturbances viz. load change or variation in source voltage amplitude etc. When all the switches are on, three inductors L_a, L_b, L_c come across the line voltages v_{ab}, v_{bc}, v_{ca} respectively. As a result, the induction currents $i_{La}, i_{Lb,} i_{Lc}$ begin to rise simultaneously from zero to the instantaneous values of the respective line voltages. The specific induction peak current values at each ON interval are proportional to the average values of their input line voltages at the same.

ON interval. Since each of these lines voltage average values vary sinusoidally, the inductor current peak and average values also vary sinusoidally. The LC filter placed at input side filters out the high frequency switching components of line currents and presents only the fundamental average component of line currents at mains supply which are sinusoidal and in phase with the phase voltages. There several controller types are available to control the regulated DC voltages. Compare to other controllers fuzzy is efficient and easier to control the duty cycle in this project.

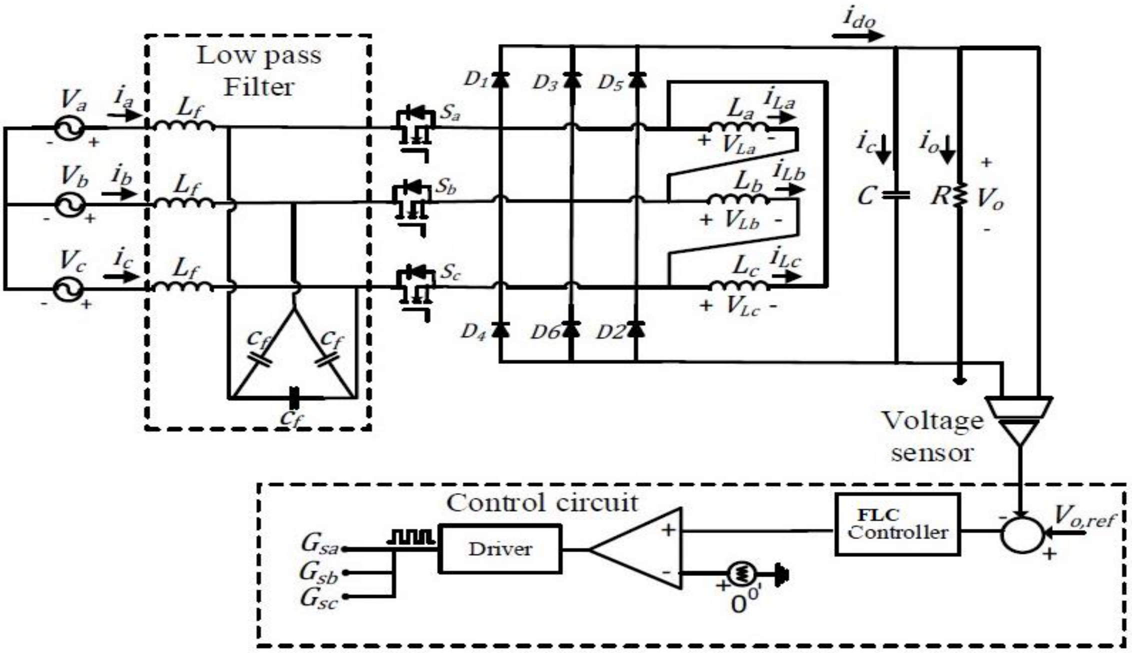

Fig.1.The proposed three phase buck-boost converter

C.FUZZY SYSTEM

The fuzzy system is developed in 1965. It is a mathematical method for describing ambiguity (inaccuracy) in linguistic terms instead of a correct mathematical explanation. They are appropriate for dealing with uncertainty and approximate rationality. Membership functions are vaguely defined to indicate the degree of truth of certain events or conditions. Membership function ranges from 0-1 in their linguistic from associated with imprecision concept. The fuzzy logic approach provides a simpler, quicker, and more reliable solution than conventional techniques. The fuzzy logic controller has three main components as fuzzification, rule base, and defuzzification. Fuzzification, which modifies crisp inputs (input values from real world) into linguistic Variables that activate the input physical signal to use the rule-base through membership functions. Rule-base where, fuzzy inputs are compared and based on membership functions of each input. Defuzzification converts back the fuzzy outputs of the rule-base to crisp ones and selects membership functions for the different control outputs from the rule-base.

1. Fuzzification

Fuzzy logic uses linguistic variables instead of numerical variables. For example, in a control system, error between reference signal and output signal can be assigned as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB). The triangular membership function is used for fuzzification. The process of fuzzification convert numerical variable (real number) to a linguistic variable (fuzzy number).

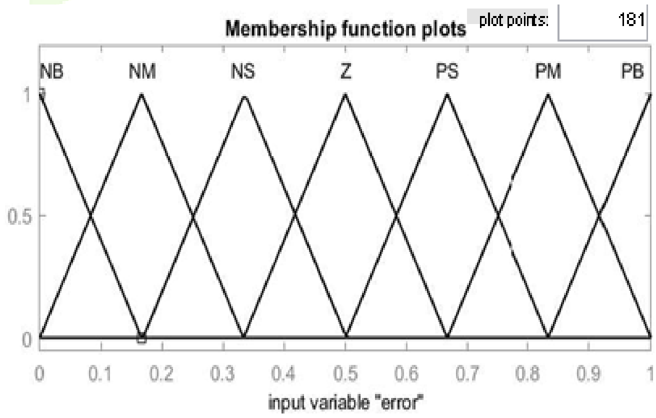

Fig.3. Membership function representing a First input (error)

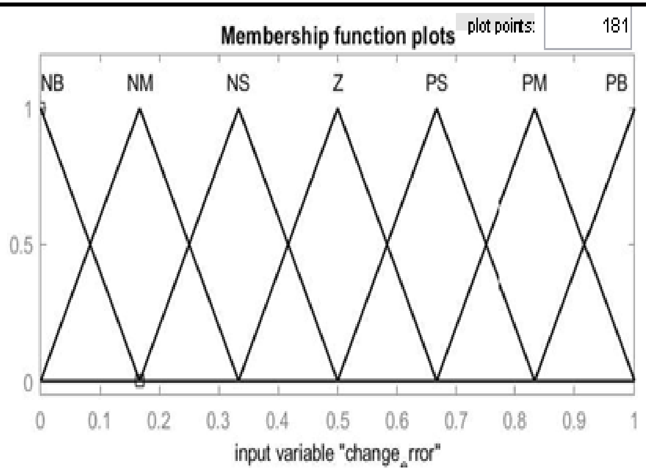

Fig.4. Membership function representing a Second input (change in error)

2. Rule Evaluator

Fuzzy logic controller uses linguistic variables instead of the numerical values. The linguistic variables of error signal change of error signal, and output represents degree of membership functions. The basic fuzzy set operations needed for evaluation can use one of threerules of AND (∩), OR (∪) or NOT (~).

Table I:IF-THEN rule base for Fuzzy logic control

E / CE	NL	NM	NS	ZE	PS	PM	PL
CNL	VL	VL	VL	LO	UM	UM	M
CNM	VL	VL	LO	LO	UM	M	AM
CNS	VL	LO	LO	UM	M	AM	B
CZE	VL	LO	UM	M	AM	B	VB
CPS	LO	UM	M	AM	B	B	VB
CPM	UM	M	AM	B	B	VB	VB
CPL	M	AM	AM	B	VB	VB	VB

In this work, AND-intersection is used as:

$$\mu_{A\cap B} = \min[\mu_A(X), \mu_B(X)]$$

The rule base stores the linguistic control rules required by rule evaluator (decision-making logic). Examples of the rules used in this work are listed in Table I. It is worth mention here that the Table-I is symmetrically diagonal about the membership function M (Medium) and every membership function is listed seven times. This structure works for the generator control unit, GCU, and, frequency control. For the power converters inside the studied aircraft system, this structure is modified to get better performance.

3. Defuzzification

The laws of fuzzy logic generate the output of demand into a linguistic variable; the linguistic variable has to be transformed into a crisp output (real number), according to real-world requirements. The options available for defuzzification defaults are many. So far, the choice of strategy is a compromise between accuracy and computational intensity databases. The membership functions used in this study are shown in fig 5. In defuzzification step, three different methods can be used such as center of area or centroid (COA), bisector, middle of maximum (MOM). The most popular method, the center of gravity or area is used for defuzzification.

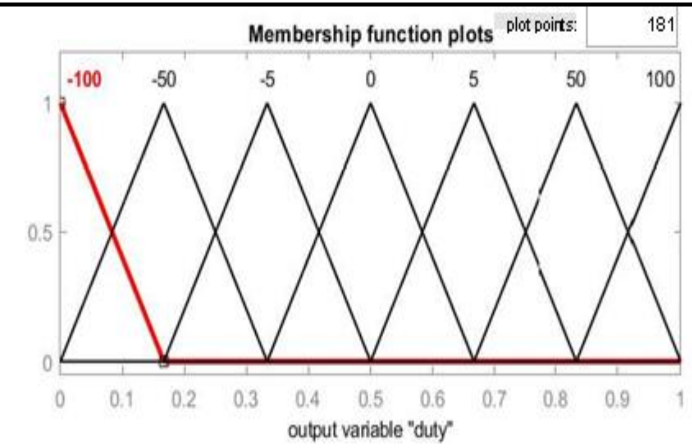

Fig.5. Membership function representing the output (duty cycle)

C.MODES OF OPERATION

The three phase sinusoidal signals are divided into 12 sectors of each 30^0 as shown in Fig. 6. Due to symmetric nature of the converter, its behavior is same in each sector. Hence, the analysis is presented only for sector-1 i.e. wt = 0 to $\pi/6$. The input inductor current waveforms of the converter for one switching cycle operating in DCM in sector-1 are shown in Fig. 7. It is observed that, the converter has four operating modes in one switching cycle.

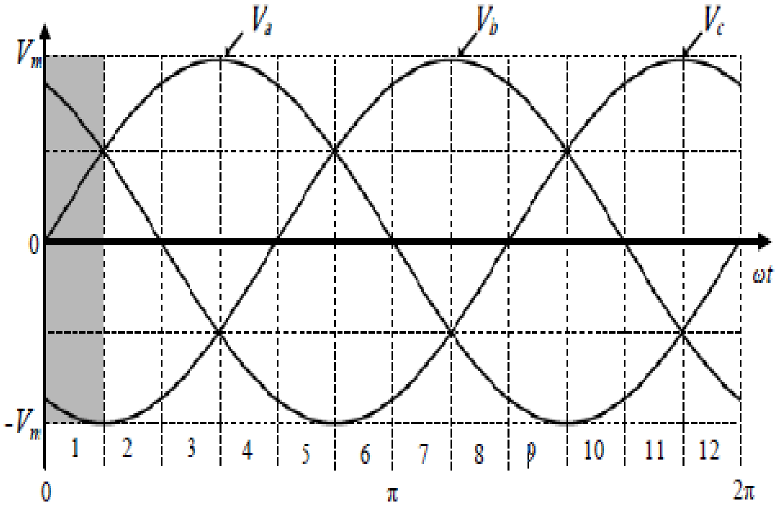

Fig.6. Three phase sinusoidal input voltages.

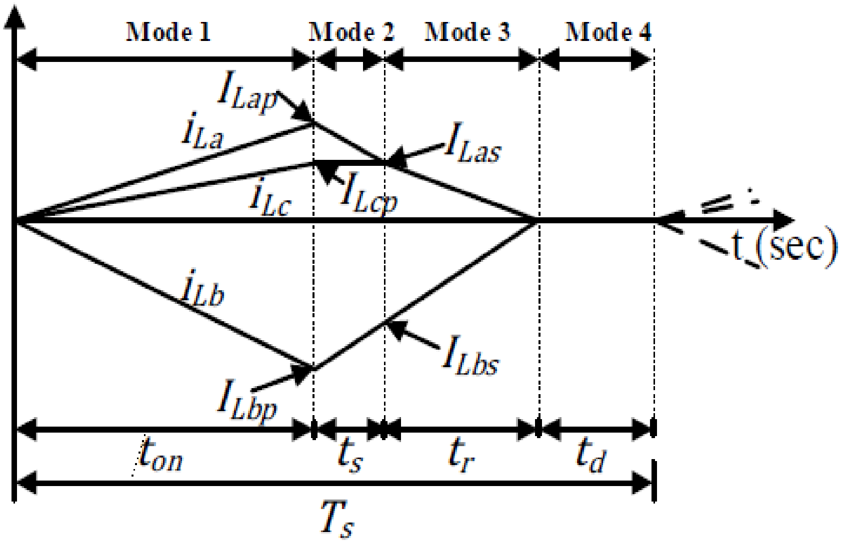

Fig.7. Input inductor current waveform in sector-1.

According to the modes of operation, the input inductor current equations are defined and tabulated in table-II

Description	Mode 1	Mode 2	Mode 3	Mode 4
$i_{La}(t)$	$i_{La}(t) = \frac{V_{ab}}{L} t$	$i_{La}(t) = I_{Lap} - \frac{V_0}{L} t$ $I_{Lap} = \frac{V_{ab}}{L} t_{on}$	$i_{La}(t) = I_{Las} - \frac{V_0}{2L} t$ $I_{Lap} = \frac{V_{ca}}{L} t_{on}$	$i_{La}(t) = 0$
$i_{Lb}(t)$	$i_{Lb}(t) = \frac{V_{bc}}{L} t$	$i_{Lb}(t) = I_{Lbp} + \frac{V_0}{L} t$ $I_{Lbp} = \frac{V_{bc}}{L} t_{on}$	$i_{Lb}(t) = I_{Lbs} + \frac{V_0}{L} t$ $I_{Lap} = -\frac{2V_{ca}}{L} t_{on}$	$i_{Lb}(t) = 0$
$i_{Lc}(t)$	$i_{Lc}(t) = \frac{V_{ca}}{L} t$	$i_{Lb}(t) = I_{Lcp}$ $I_{Lcp} = \frac{V_{ca}}{L} t_{on}$	$i_{Lc}(t) = I_{Lcs} - \frac{V_0}{2L} t$	$i_{Lc}(t) = 0$
Time Period	$t_{on} = DT_s$	$t_s = \frac{3V_a}{V_0} DT_s$	$t_r = \frac{2V_{ca}}{V_0} DT_s$	$t_d = (T_s - t_{on} - t_s - t_r)$

Mode 1:

This mode starts when all the three power switches S_a, S_b, S_c are turned on. Prior to this mode, L_a, L_b, L_c the input inductors are in fully demagnetized state. Hence, the switches turn on with zero current. The equivalent circuit of the converter in this mode is shown in Fig.8. In this mode, the input inductors store the energy according to the line voltages appear across the inductors, while the output capacitor supplies the load. At the end of this mode, the inductor currents reach their peak values as shown in Fig.7.

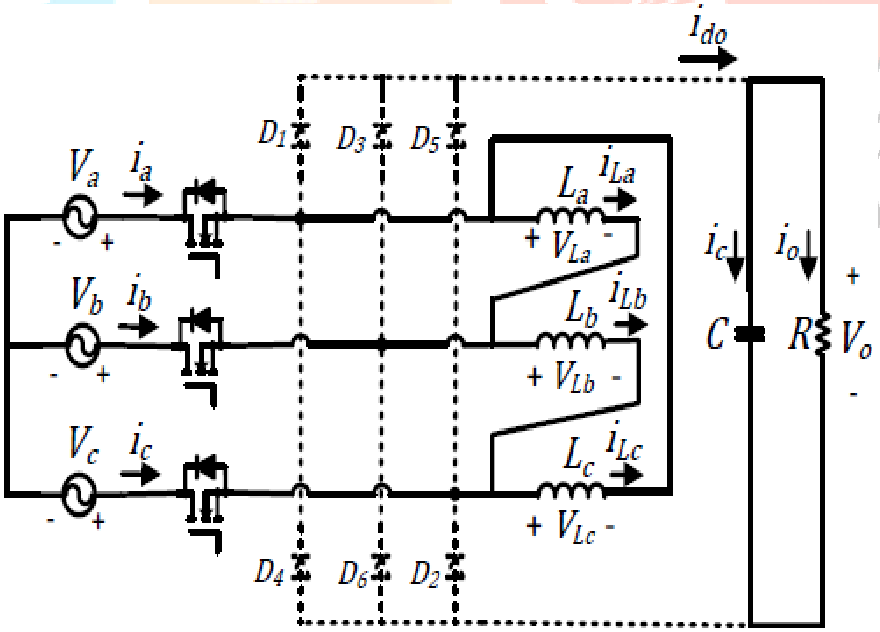

Fig.8. Equivalent circuit of Three phase buck-boost converter of Mode 1 operation.

Mode 2:

This mode starts when the gating signals for the switches are withdrawn. The equivalent circuit of the converter in this mode is shown in Fig. 9. In this mode, the inductors L_a, L_b start to reset by giving the stored energy to the load through diodes D_1, D_2, D_3 at a rate of $^{V_0}/_{L}$ and the inductor L_c retains its peak current value This mode ends when the inductor current 'i_{La}' equals to the inductor L_c peak current.

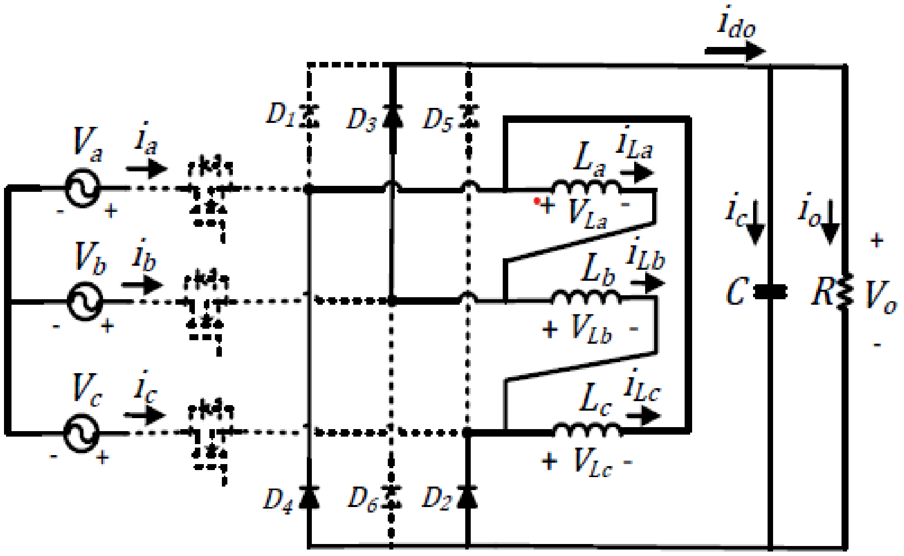

Fig.9.Equivalent circuit of Three phase buck-boost converter of Mode 2 operation.

Mode 3:

The equivalent circuit of the converter in this mode is shown in Fig. 10. In this mode, all three inductors L_a, L_b, L_c start to reset by giving the stored energy to the load through diodes D_2, D_3 at a rate of $^{V_0}/_{2L}, ^{V_0}/_{L}, ^{V_0}/_{2L}$ respectively. This mode ends when all the inductors currents reach zero as shown in Fig. 4.

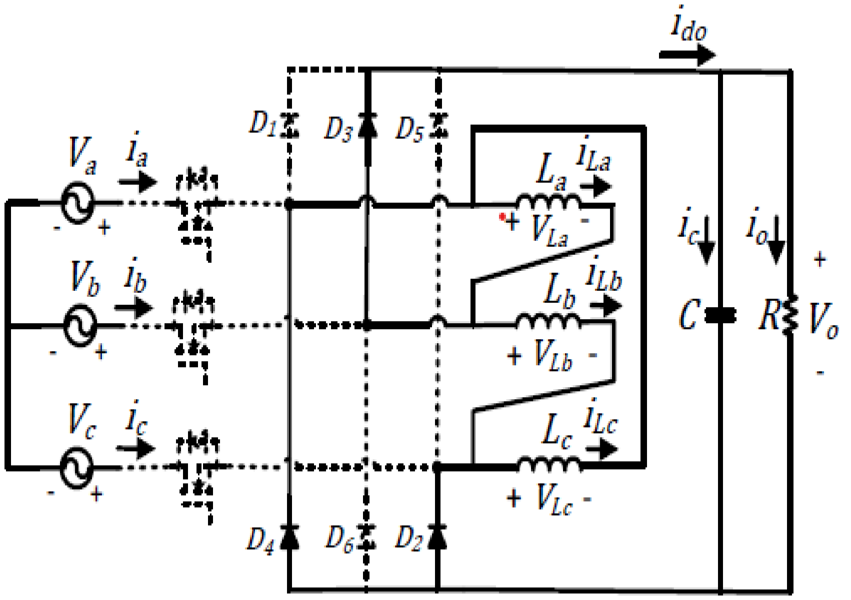

Fig.10. Equivalent circuit of Three phase buck-boost converter of Mode 3 operation.

Mode 4:

The equivalent circuit of the converter in this mode is shown in Fig. 11. In this mode, all the input inductors are in fully demagnetized condition and all the switches, diodes are in off state. The output filter capacitor supplies the load. This mode continues till the next switching period starts.

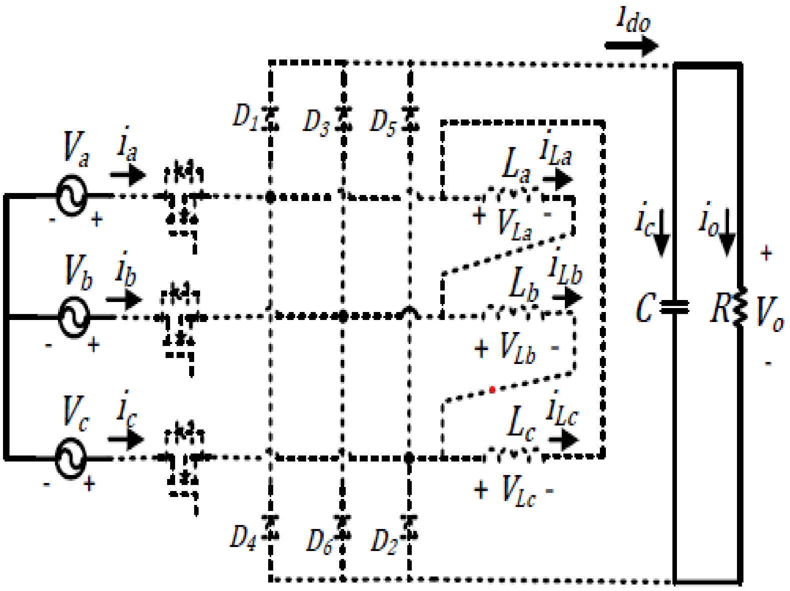

Fig.11. Equivalent circuit of Three phase buck-boost converter of Mode 4 operation.

III.STEADY STATE ANALYSIS AND DESIGN CALCULATIONS

In the analysis, the following assumptions are made

1. All the switches, inductors and capacitors are ideal.
2. The output filter is large enough to maintain the output voltage constant.
3. As switching frequency is much higher than line frequency, the phase voltages and output voltage are assumed constant in one switching cycle.
4. As defined in (1), the values of input inductances in each phase are same.

$$L_a = L_b = L_c = L \qquad (1)$$

A. Discontinuous Conduction Mode of operation:

To guarantee the converter DCM operation,

$$t_{on} + t_s + t_r \leq T_s \qquad (2)$$

On substituting t_{on}, $t_s$and t_r expressions from table-II in equation (2)

$$D \leq \frac{M}{M + \sqrt{3}\sin\left(wt + \frac{\pi}{2}\right)} \qquad (3)$$

The worst situation occurs when $\sin\left(wt + \frac{\pi}{2}\right)$= 1, which gives   = 0. Therefore, to operate in DCM

$$D \leq \frac{M}{M + \sqrt{3}} \qquad (4)$$

From (4), the critical value of conversion ratio which defines the boundary between continuous and discontinuous modes can be found and it is given by (5).

$$M_{cr} = \frac{\sqrt{3}\,D}{1 - D} \qquad (5)$$

In the proposed converter, the output voltage shall be higher than the peak line-to-line voltage to ensure the reverse bias of bridge diodes D_1 toD_6. Hence for a given duty cycle D, the converter is said to be operated in DCM when
$M > M_{cr} > \sqrt{3}$.

B. Average output current: In a switching cycle, the average current of the output filter capacitor is zero. Therefore, for the sector under the analysis, the average output current of the converter is given by

$$i_{o,avg} = \langle i_0 \rangle = \langle i_{d3} \rangle \qquad (6)$$

The equation of 'i_{d3}' in mode-2 is given by

$$i_{d3}(t) = i_{La}(t) - i_{Lb}(t) \qquad (7)$$

$$i_{d3}(t) = -\frac{3v_b}{L}DT_s - \frac{2V_o}{L}t \qquad (8)$$

Similarly, the equation of 'i_{d3}' in mode-3 is given by

$$i_{d3}(t) = \frac{3v_{ca}}{L}DT_s - \frac{3V_o}{2L}t \qquad (9)$$

From (8) and (9), the average value of output current in a switching cycle can be calculated and it is given as

$$i_{o,avg} = \langle i_{d3} \rangle = \frac{9D^2T_sV_m{}^2}{4LV_o} \qquad (10)$$

The average output current over a line period equals to

$$I_{o,avg} = \frac{6}{\pi}\int_0^{\pi/6} i_{o,avg}\, d(wt) = \frac{9D^2T_sV_m^{\,2}}{4LV_o} \quad (11)$$

From (11), the normalized average output current is defined and is given as,

$$I_{o\_n} = \frac{D^2V_m}{V_0} = \frac{D^2}{M} \qquad (12)$$

Fig. 12 shows the converter load characteristics, is a function of converter gain and normalized average output current is drawn by using (12). It is observed that the converter is tending towards CCM with the increase of load current. For a given conversion ratio and the output power, the converter CCM operation can be avoided by setting a limit on the duty cycle, defined from (4).

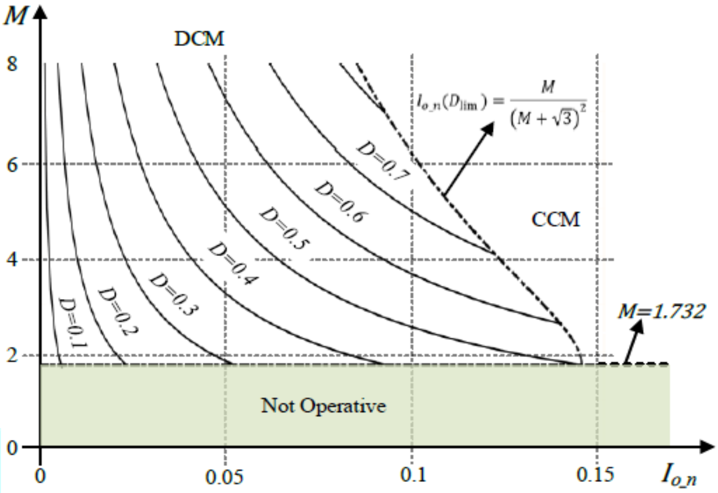

Fig.12.Converter load characteristics

C. Input Current: The expression for phase-A input current before filtering is,

$$i_a(t) = \begin{cases} \frac{3V_a}{L}t, & 0 < t \le t_{on} \\ 0 & , t_{on} < t \le T_s \end{cases} \qquad (13)$$

where, $V_a = V_m\sin(\omega t)$ is the instantaneous value of phase-A voltage. By taking the Fourier series of the input current for one switching period,

$$i_a(t) = \frac{a_0}{2} + \sum_{h=1}^{\infty}(a_h\cos(h\omega_s t) + b_h\sin(h\omega_s t)) \quad (14)$$

On combining the harmonic current components a_h andb_h, substituting $V_a = V_m\sin(\omega t)$ then

$$i_a(\omega t) = \frac{3V_m}{2L}D^2T_s\sin(\omega t) + \sum_{h=1}^{\infty}\frac{6V_mD}{h\omega_sL}\sin(\omega t)\sin(h\omega_s t + \delta_h) \quad (15)$$

Where,$\delta_h = \tan^{-1}\frac{b_h}{a_h}$,

The first term in equation (15) represents the fundamental current component and the second term represents the total harmonic current of input current 'i_a'. By designing a low pass LC filter with a cutoff frequency much lower than the switching frequency, the harmonic currents can be filtered out. Therefore, the resulting input current contains only the fundamental current component, and it is given as,

$$i_a(\omega t) = \frac{3V_m}{2L}D^2T_s\sin(\omega t) = I_m\sin(\omega t) \qquad (16)$$

Where,

$$I_m = \frac{3V_m}{2L}D^2T_s \qquad (17)$$

Equation (16) shows that the filtered phase-A input current is sinusoidal and is in phase with the input voltage, which in the unity power factor operation of the converter.

D. Input Inductor Design: The input inductor design is to be such that it has to maintain the DCM for minimum input voltage and maximum output power (rated power) condition. Because at this condition, the converter input current is maximum, and consequently the inductor current peak also will be maximum. If the inductor can demagnetize within a switching period at this condition, then the DCM would be ensured for all the input voltages above the minimum input voltage and for all the output powers below rated power. Therefore using (4), the maximum duty cycle to guarantee the DCM operation for minimum input voltage is given as,

$$D_{max} \le \frac{V_0}{V_0 + \sqrt{3}V_{m,min}} \qquad (18)$$

The average output current for the given rated power and the rated output voltage is expressed as

$$P_0 = V_0I_0 \qquad (19)$$

By using (11), (18) and (19), the value of the input inductor to operate the converter always in DCM is given as

$$L \le \frac{9{D_{max}}^2 {V_{m,min}}^2 T_s}{4P_0} \qquad (20)$$

E. Power switches S_a, S_b, S_c: From the operation of the converter, the expression for switch current in a switching cycle is given as

$$I_{sw,avg} = \frac{\sqrt{3} V_m D^2 T_s}{\pi L} \qquad (21)$$

$$I_{sw,rms} = \frac{\sqrt{3} V_m D T_s}{L} \sqrt{\frac{D}{2}} \qquad (22)$$

F. Diodes$D_{1\ to\ 6}$: The average and rms currents of the full bridge rectifier diodes are

$$I_{D,avg} = \frac{3{V_m}^2 D^2 T_s}{4LV_0} \qquad (23)$$

$$I_{D,rms} = \frac{\sqrt{3} V_m D T_s}{L} \sqrt{\frac{DV_m (3-\sqrt{3})}{\pi V_0}} \qquad (24)$$

G. Output filters capacitor, C: The rms current stress of the output filter capacitor can be calculated using

$$I_{c,rms} = \sqrt{{I_{do,rms}}^2 - {I_{do,avg}}^2} \qquad (25)$$

H. Input inductor, L: The expression for input inductor rms current is derived by using the input inductor equations and is given as

$$I_{L,rms} = \frac{V_m D T_s}{L} \sqrt{\frac{V_m D}{2\pi V_0}\left(\frac{\pi V_0}{V_m} + 4(3-\sqrt{3})\right)} \qquad (26)$$

To verify the above derived formulas, the average and rms currents for an output power of 2 kW and input line-to-line voltage of 110 V_{rms} are calculated.

IV. RESULTS AND DISCUSSION

A.SIMULATION PARAMETER

To validate the analysis of the proposed converter, a 2-kW Matlab prototype is designed and developed with the input specifications given in Table. The design results are given in Table II. With the input specifications and from Equation (20), the input inductance value is calculated and it shall be less than 79.77µH to operate the converter always in DCM. With consideration of losses in the converter, the input inductance value of L= 65µH is chosen for experimentation.

Table II:Simulation Parameters

S.NO	PARAMETER	VALUE
1.	Line to Line voltage,$V_{L-L,rms}$	110±15%
2.	Input Frequency f	400-800 Hz
3.	Output Power, P_0	2 KW
4.	Output voltage, V_0	270 V
5.	Switching Frequency,f_s	50 kHz
6.	Maximum Duty Cycle, D_{max}	0.78
7.	Input Inductance, L	65µH
8.	Output Capacitance, C	450µF
9.	Filter Inductance,L_f	200µH
10.	Filter capacitance, C_f	0.66µF

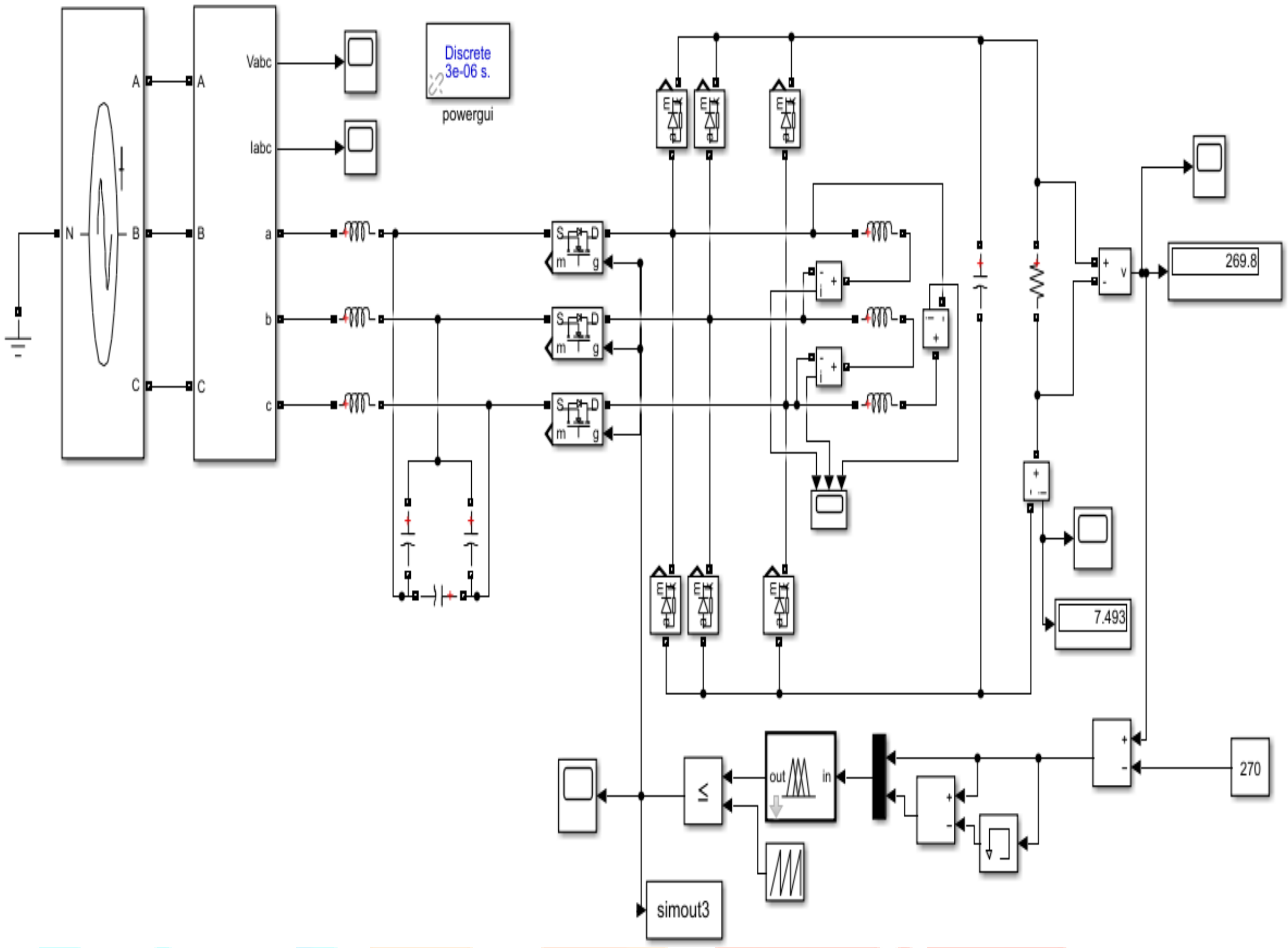

Fig.13. Simulation of the Proposed Three Phase Buck-Boost Converter

B.MATLAB RESULTS AND DISCUSSION:

Simulation of the converter was carried out in MATLAB simulink. The input supply line to neutral voltage is 110 Vrms at the frequency of 400Hz and the resistance load is considered. The input line voltage is shown in fig.The input voltage is almost sinusoidal with maximum of 155.5V. The input line current are shown in fig 15.The input current also sinusoidal. The maximum value of input line current is of order of 16.46A.

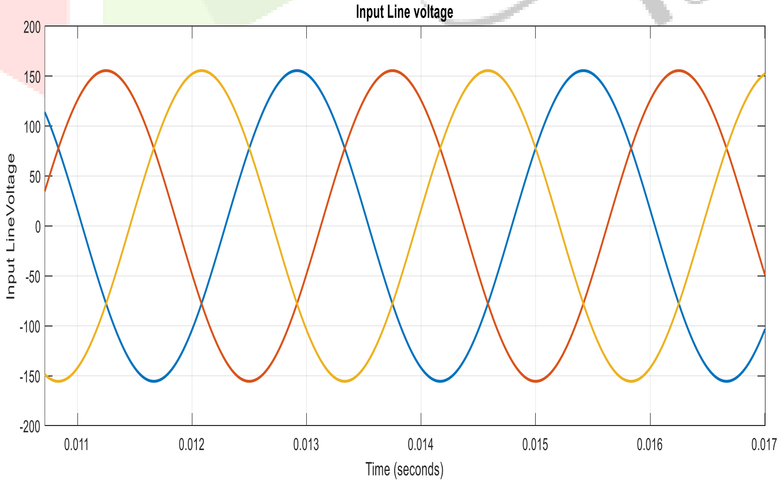

Fig.14.Simulation waveform of three phase Input voltage

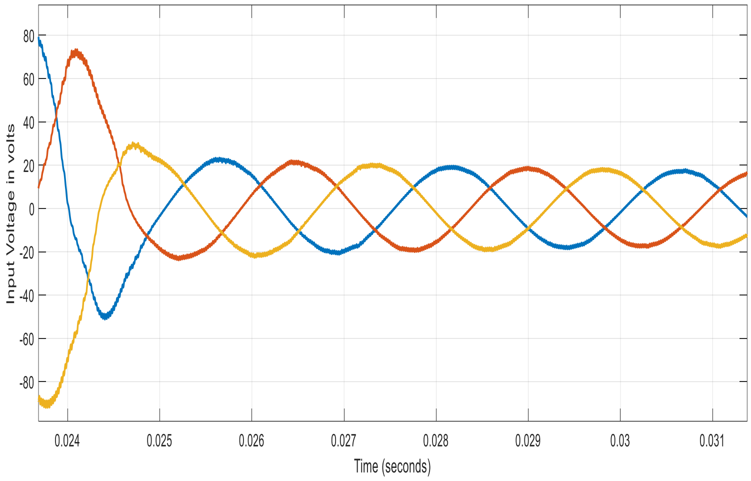

Fig.15.Simulation waveform of three phase Input current

Three Phase Buck-Boost Converter obtained output dc voltages as shown in fig 16. The determined value output voltage is 270V, which is obtained. The output dc current is obtained as 7.47A as shown in fig.17.

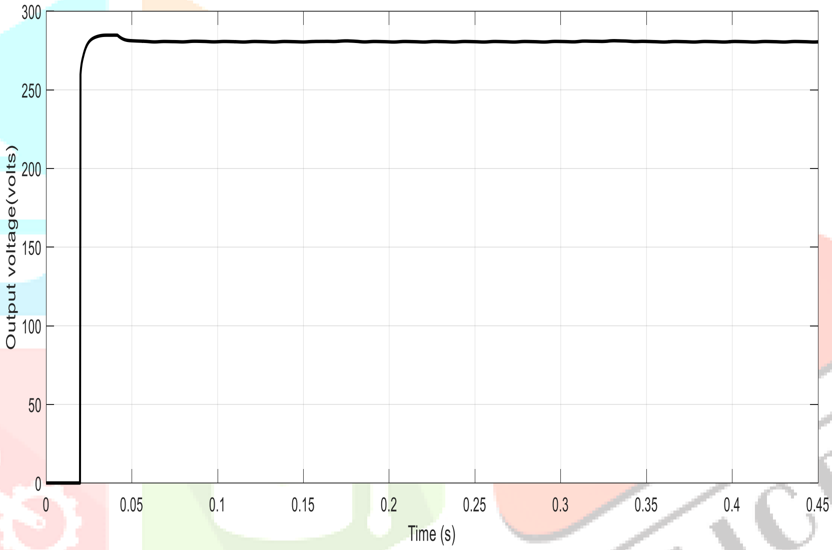

Fig.16.Simulation waveform of DC output voltage.

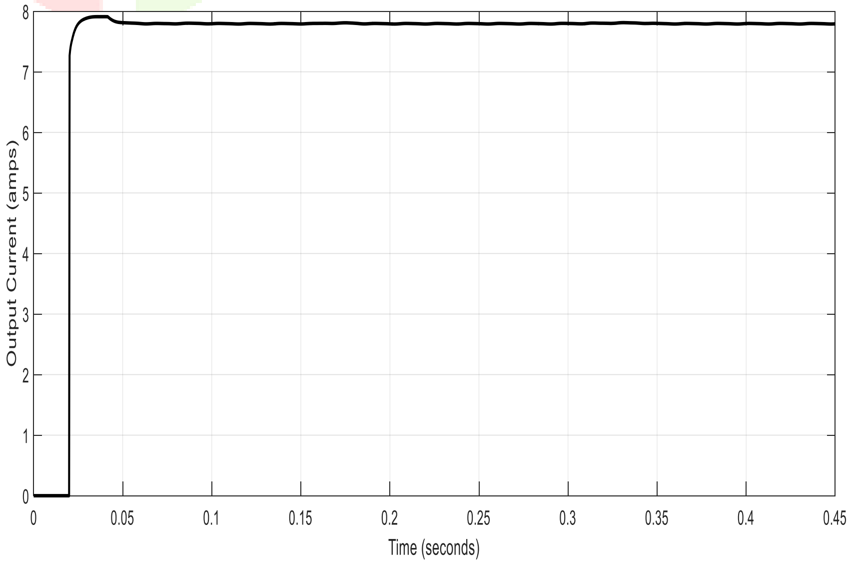

Fig.17.Simulation waveform of DC output current .

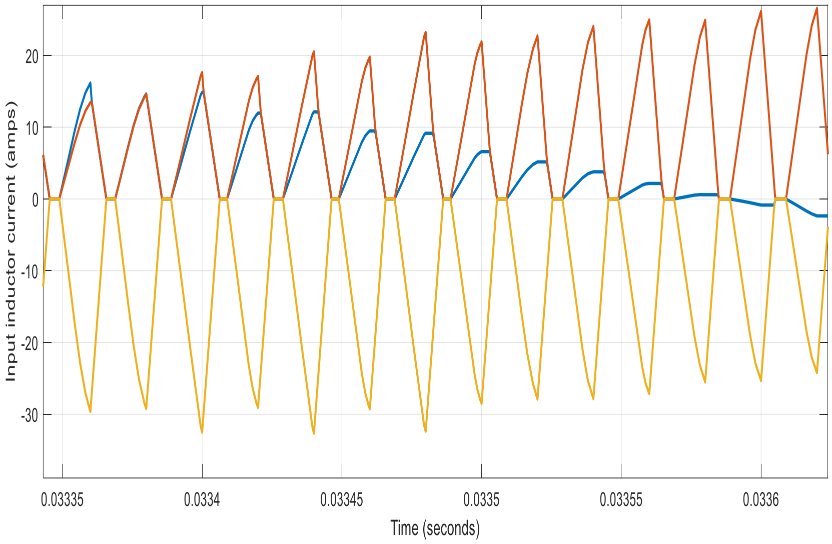

Fig.18.Simulation waveform of Input inductor current.

C.HARMONICS ANALYSIS:

Harmonics in power converters extended to the transmission of voltage in the electrical power system. Currently, the electrical power systems have a large number of nonlinear elements that generate other waves at different frequencies. They generate these waves from sinusoidal waveforms to network frequency. The analysis of harmonics is the process of calculating the magnitudes and phases of the fundamental and high order harmonics of the periodic waveforms. The resulting series is known as Fourier series. It establishes a relation between a function in the domain of time and a function in the domain of frequency.

$$\%\mathbf{THD} = \frac{\sqrt{\sum_{i=2}^{\infty}(x_i)^2}}{|x_1|}$$ Where, x_i is the voltage or current harmonics content.

HARMONICS IN INPUT LINE CURRENT FOR R=36 Ω

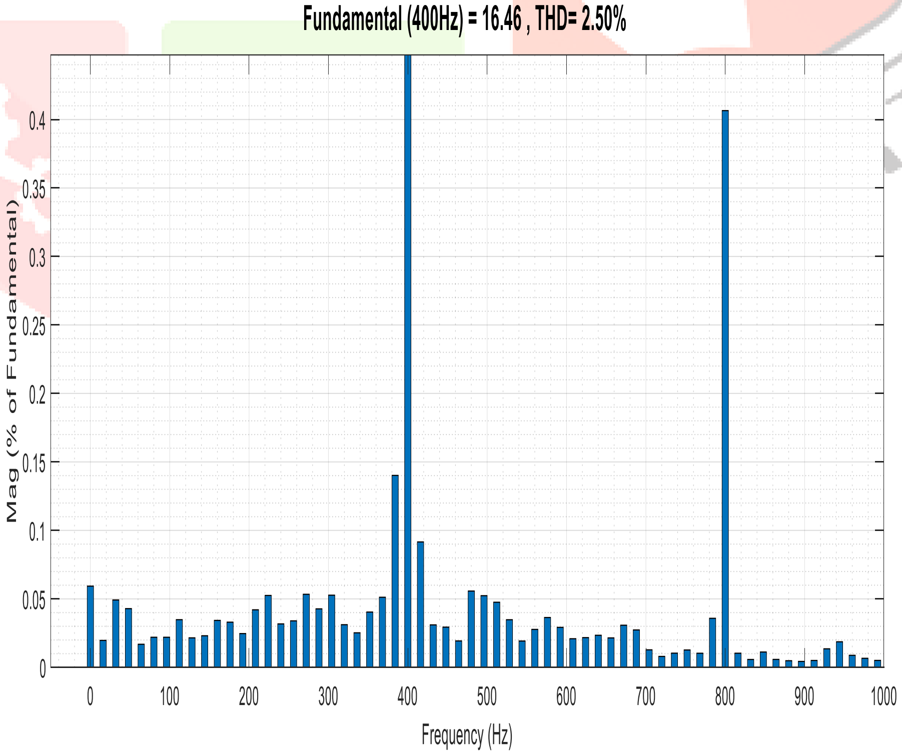

Fig.19.Harmonics of line current for R=36Ω

HARMONICS IN INPUT LINE CURRENT FOR R=18Ω

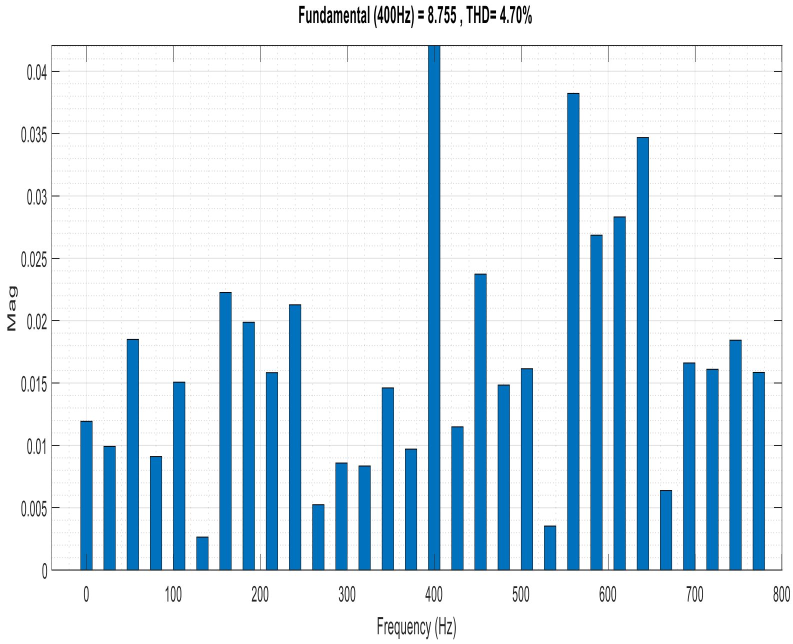

Fig.20.Harmonics of line current for R=18Ω

HARMONICS IN INPUT LINE CURRENT FOR R=54Ω

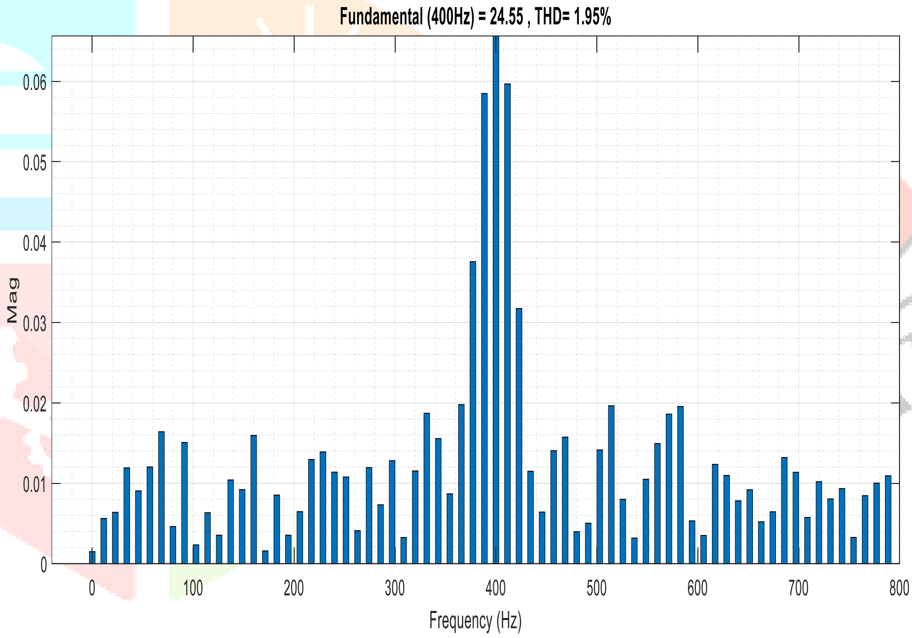

Fig.21.Harmonics of line current for R=54Ω

TABLE IV: Comparison of Harmonics in Input Current with Various R Load and Output Power

S.NO	VARIOUS R LOAD	OUTPUT POWER	%THD
1.	R=18Ω	1kw	**4.70%**
2.	R=36Ω	2kw	**2.50%**
3.	R=54Ω	3kw	**1.96%**

The proposed three phase buck-boost converter with input line currents THD is obtained as 4.70%, 2.50% and 1.96% for various R loads 54Ω, 36Ω, and 18Ω respectively. Therefore at the reduced load conditions, the line current THD will increase.

V.CONCLUSION

A new three phase buck-boost converter with inductors connected in delta configuration for more electric aircraft application is proposed. The proposed converter uses only three power switches and all the switches are driven by the same gate signal. The converter is operated in DCM to achieve input inductor current. The converter control is quite simple and requires only one simple voltage control loop to regulate the output voltage. The steady state operation of the converter, detailed design calculations are presented. The analytical expressions for each power component stresses are derived to simplify the converter design. Due to the DCM operation, the converter requires high rated current switches. However, the advantages of the proposed converter such as less number of components, less number of sensors and less control complexity significantly outweighs the disadvantage of high rated switches. The results from a 2kW Matlab prototype are presented to confirm the operation of the proposed converter. From the developed prototype, an input current THD as 2.50% was achieved. In the case of simulation work the output voltage is well tracking the reference voltage and getting settled in less than 30 msec.

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