Indian Journal of Electronics and Electrical Engineering (IJEEE)
Vol.2.No.2 2014pp 72-78.
available at: www.goniv.com
Paper Received :15-04-2014
Paper Published:25-04-2014
Paper Reviewed by: 1. John Arhter 2. Hendry Goyal
Editor : Prof. P.Muthukumar

A PASSIVE 36-PULSE AC–DC CONVERTER WITH INHERENTLOAD BALANCING USING COMBINED HARMONICVOLTAGE AND CURRENT INJECTION

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ABSTRACT

This paper proposes a 36 pulse ac –dc converter with With Inherent Load Balancing Using Combined Harmonic Voltage And Current Injection. This topology consists of two six pulse converter which are connected in series with a injection circuit. The main advantage of this converter is the absorption of sinusoidal currents from the ac system which has a harmonic content of 2.5% of Total Harmonic Distortion (THD). The performance achievements of a 36-pulse converter can also be achieved by a 12-pulse system, which are obtained by connecting two six pulse ensures low harmonic current absorption and the converter in series with an addition of low harmonic injection current. Hence this topology has a lower component current than other converter circuits. Therefore the performance of this topology experimental results are discussed.

Keywords:Bridge converter, three phase multi-pulse rectifier circuit, low harmonic

1. INTRODUCTION

In Conventional method 36-pulse ac-dc conversion system was used to meet the stringent aircraft power quality parameters. But the 36-pulse system consists of nine wound components,36 diodes and a high components count, which were considered to be more complex and expensive. The nine wound components are primary side turns and secondary side turns of the line side three phase transformer in addition to the three line inductors. Also the conversional system requires more electric drives and actuator loads to draw input current.

In order to give an alternate solution for the above said draw backs 12-pulse ac-dc converter is proposed. The proposed system is robust and simple with 400Hz supply frequency. The rating of the magnetic component of this system is reduced by 30% when compared to36-pulse system.

The proposed system can be designed by connecting to individual 6-pulse channels in series to form a 12-pulse ac-dc converter system instead of auto transformer a line side inter phase transformer is added which offers a low overall VA rating. An additional aspect of this proposed system is that this system is built on the principle of injecting a waveform into the dc side of the rectifier circuit with the help of an injecting circuit to enhance the ac input currents. So the proposed twelve pulse system gives performance characteristics equal to the 24-pulse system without using more complex phase shifting devices and additional rectifier bridges. Therefore the overall system has a low component count and gives a high immunity to the imbalance problems and this paper deals with the performance characteristics and operation of this kind of system with ripple injection technique.

2. CONVERTER DESCRIPTION AND OPERATION

Fig. 1 shows that converter module consists of two three phase six pulse diode rectifiers connected in series, in which one of the rectifiers is supplied from the secondary windings of the star delta phase shifting transformer and the other one is supplied from the primary windings of the transformer. The rectifiers are considered to be current fed because of the series inductance of the primary circuit. Also by the 1:1.732 transformer ratio, the rectifiers can be fed with the same current. The input currents to the bridge rectifiers are determined by the difference between the multilevel waveforms and the supply voltage across the line inductors. Practically the transformer leakage inductance is used as the input inductance and therefore the component count can be reduced.

An important feature of any aerospace applications is aiming at the reduced weight. The weight and size of the overall converter can be reduced by feeding only one of the rectifiers by the primary winding of the transformer. Therefore VA rating of the transformer is only fifty percent of the power throughput. This can be achieved by nil galvanic isolation between the input and output of the converter and the output voltage cannot be adjusted by the transformer turns ratio. The dc filter capacitors are big enough to filter out all the output current ripples.

The analysis can be made easy and understandable by the idealized waveforms and the circuit operation without injection. The output current ripples can be minimized by the dc filter capacitors C_1 and C_2. The transformer turns ratio of 1.732 can be perfectly achieved by making the transformer magnetizing current negligible. The steady state operation can be arrived by considering the circuit components to be ideal.

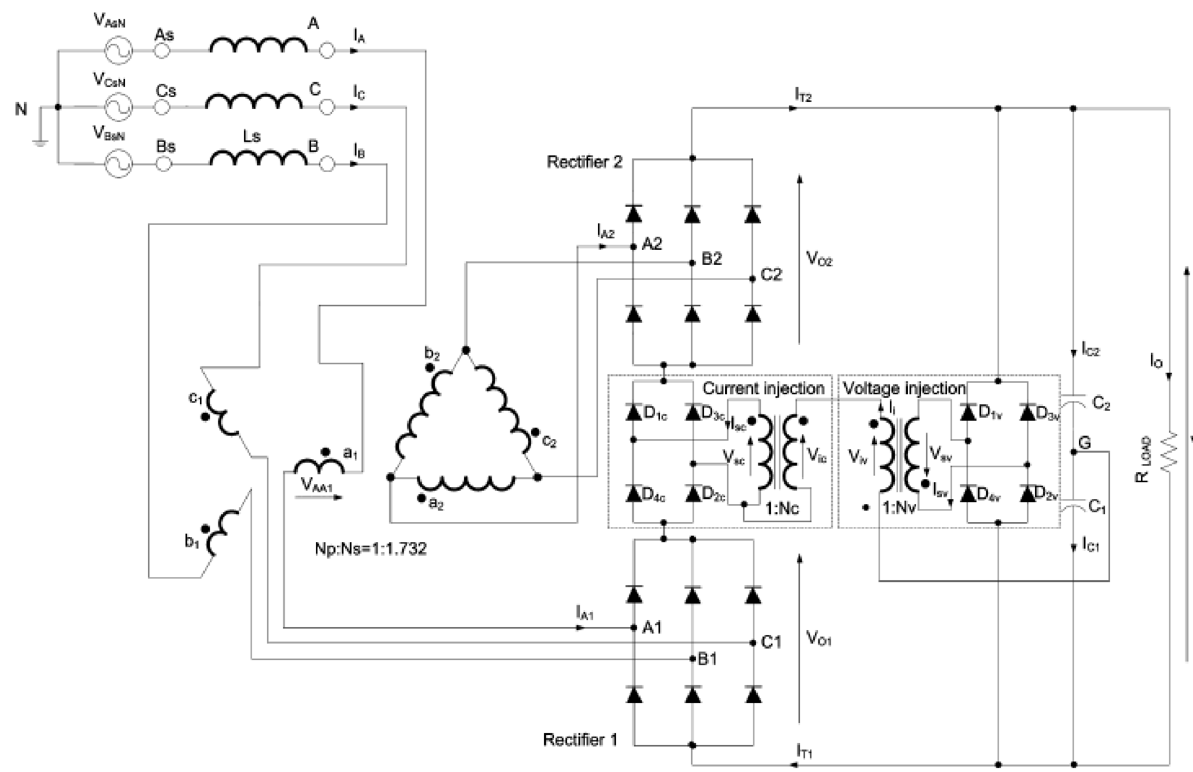


Figure 1 proposed36-pulse voltage converter with combined voltage and current injection.

3. PROPOSED CONVERTER

When the current fed rectifiers are connected in series a current mismatch between the rectifier outputs will arise and this mismatch can be eliminated by connecting the midpoint of the output filter capacitors and the common point of the series connected rectifiers as shown in the Fig.2, resulting in the flow of current having frequency about six times of the supply frequency between the filter and the rectifier currents.

The source of the rectifiers is a rectified three phase input current, which is having six pulse ripples. This six pulse ripple will be out of phase when two kinds of current source, one formed by the series connection of the primaries and the another one formed by the phase shifting device like star delta transformer having identical mean values. But the instantaneous values of the above said current sources are not equal and due to thefact a mismatch will be arised.This drawback can be solved by making the difference current, known as injection current to flow between the capacitors and the rectifiers. If the connection between the midpoints was reversed, current mismatch will result in a natural commutation of the rectifier. The above explained feature can also be used to produce 24-pulse type input line currents. These can be clearly elaborated in the following waveforms in the Fig. 3. It shows the current (I_1) supplied by the lower rectifier, the current (I_2) supplied by the upper rectifier. The difference current, also known as injection current, between (I_1) and (I_2) is shown in the Fig. 3 depicts the voltage across the injection winding of the voltage injection transformer, represents the output voltage (V_{01}) across the bottom rectifier which is obtained as the addition of the injectionvoltage (V_{iv}) and $V_0/2$.

4. INJECTION CIRCUIT OPERATION

The injection voltage of the injection winding modifies the rectifier output voltages V_{01} and V_{02} in the following way.

$$V_{01} = \frac{V_0}{2} + V_1 \qquad (1)$$

$$V_{02} = \frac{V_0}{2} - V_1 \qquad (2)$$

When i_{R1},the output current of rectifier 1, is greater than the i_{R2}, the output current of rectifier 2, injection voltage become positive and the injection current I_i will be negative. When this negative injection current is flowing through the sensing winding, the diodes 3 and 4 in the Fig. 1 will come to the conduction state and as a result a voltage V_o will be reflected in the injection winding asV_0/N,where N is the injection transformer turns ratio.

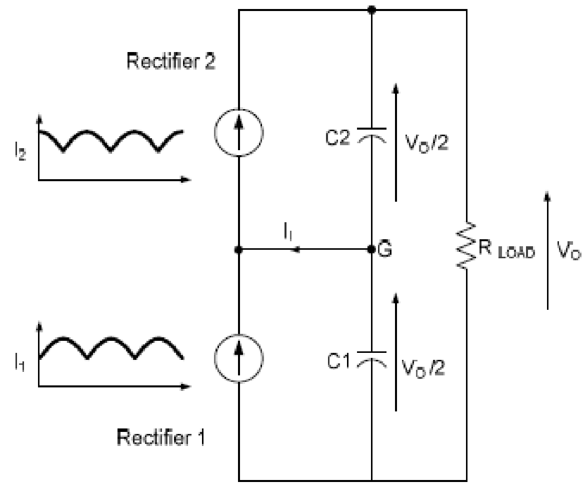


Figure 2 Equivalent circuit of injection circuit

Therefore the output voltages of the main rectifier will become:

$$V_{01} = \frac{V_0}{2} + \left(\frac{V_0}{2} \cdot \frac{2}{N}\right) \qquad (3)$$

$$V_{01} = \frac{V_0}{2}\left(1 + \frac{2}{N}\right) \qquad (4)$$

$$V_{02} = \frac{V_0}{2} - \left(\frac{V_0}{2} \cdot \frac{2}{N}\right) \qquad (5)$$

$$V_{02} = \frac{V_0}{2}\left(1 - \frac{2}{N}\right) \qquad (6)$$

As well as when i_{R1}, the output current of rectifier 1, is smaller than i_{R2}, the output current of rectifier 2, the injection current I_i reverses and the injection voltage become negative.Finally the phase shift of 30^0 between the rectifier currents i_{R1} and i_{R2} makes the injection current and voltage to have a frequency of six times of the supply frequency.But the injection voltage is smaller than the output voltage by N times and also the RMS value of the injection current is smaller than the output current andhence the rating of the injection circuit is small of the order of 2% of the power throughput.

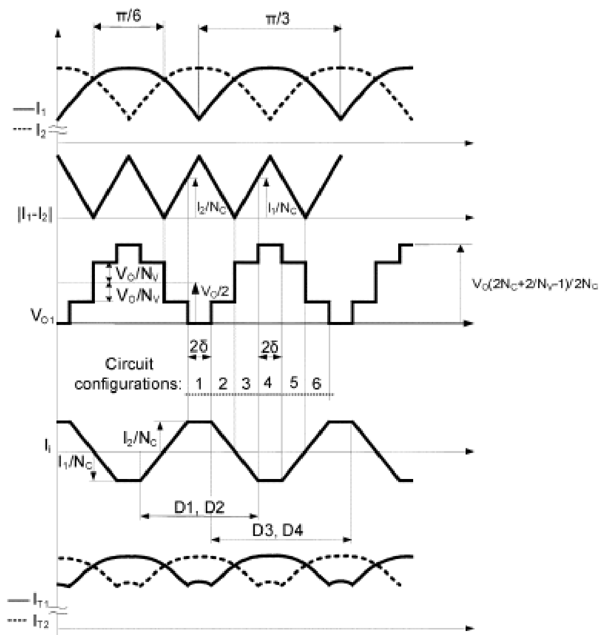


Figure 3 Idealized waveforms for the injection circuit

5. GENERATING OF 36-PULSE WAVEFORMS

The above diagram shows the stepped waveforms of 24-pulse at the righthand side of the inductors.The input voltage waveforms of the lower rectifier with respect to the mid-point of the output dc link are shown in the first three waveforms (V_{RIG}, VYIG, and VBIG) of the above figure. When the input current I_{R1} is negative, the bottom diode of the R_1 leg conducts and the V_{RIG}voltage equals Vo/2 and when the I_{R1} is positive ,R_1 is connected to the positive rail of rectifier 1,then the voltage V_{RIG} equals the injection voltage V_1.The waveforms V_{YIG} and V_{BIG} are identical to V_{RIG} but phase-shifted 120^0 and 240^0.

The common mode voltage V_{NG} is calculated using the equation (5) which is given as

$$V_{NG} = (V_{RIG}+V_{YIG}+V_{BIG})/3 \quad (7)$$

The input voltages waveforms V_{R2G} and V_{B2G} to the upper rectifier are shown in the 6^{th} and 7^{th} waveforms of the Fig. 4.

When the input current I_{R2} is positive ,the R_2 input terminal is connected to the positive output of the converter and also the voltage V_{R2G} equals to Vo/2.When the I_{R2} is negative ,the bottom diode conducts, connecting R_2 to the negative output terminal of the upper rectifier. Therefore V_{R2G} becomes equal to the injection voltage V_1 and V_{B2G} is identical V_{R2G} and phase shifted 240^0 .Next V_{RR1} is calculated by the equation $V_{RR1} = (V_{R2G} - V_{B2G})/1.732$ and V_{RN} is described as the addition of V_{R1N} and V_{RR1}.

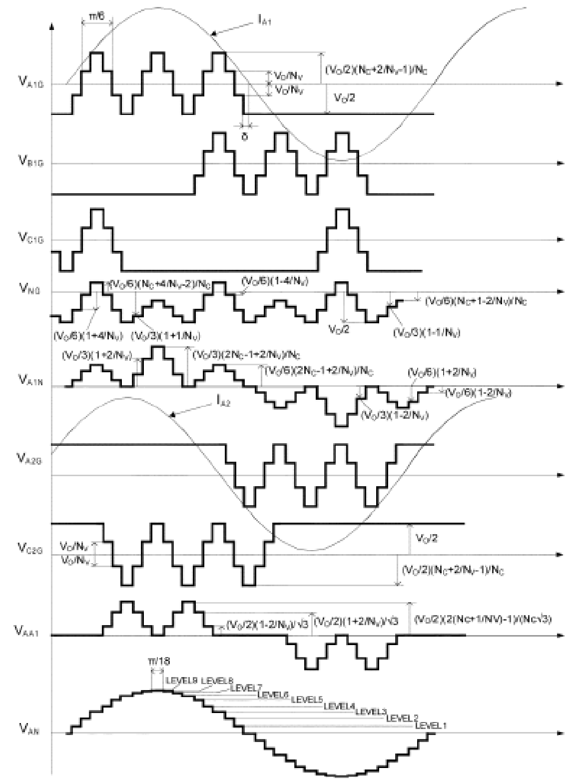


Fig. 4 Production of 36- pulse shows the V_{RN} waveform

6. CALCULATION OF THE OUTPUT VOLTAGE

The fundamental component of the multilevel waveform is determined based on the assumption that the converter is designed with the optimum injection transformer turns ratio of N=4.07 and from the equation of

$$V_{RN-1} = \frac{V_o}{1.544}\angle 0^0 \quad (9)$$

The value of equivalent resistor R_E,whichis connected between the point R and the supply neutral,N,is determined using the following input –output balance equation.

$$\frac{V_0^2}{R_{LOAD}} = \frac{3V_{RN-1(rms)}^2}{R_e} \quad (10)$$

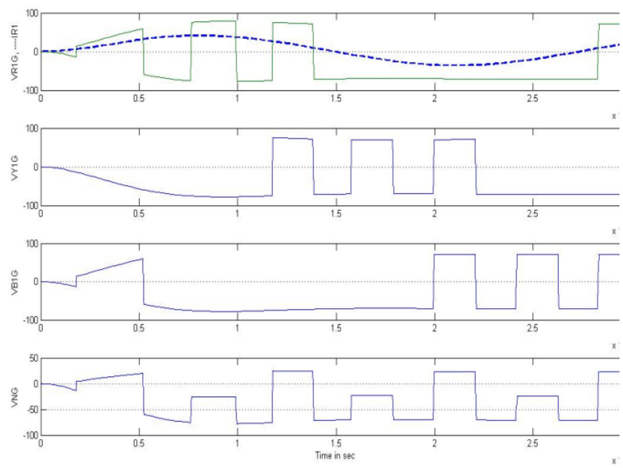
By using equation (9) to eliminate V_{RN-1}:

$$R_e = \frac{3R_{LOAD}}{2(1.544)^2} = 0.6292R_{LOAD} \quad (11)$$

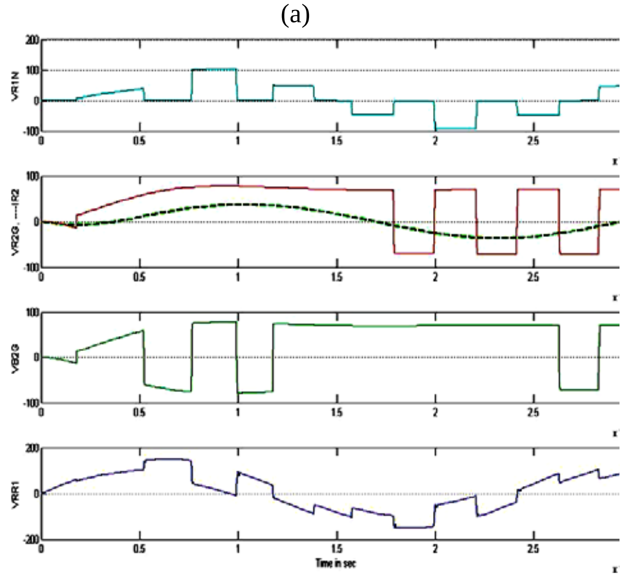
To calculate steady state operating conditions, $I_{R1}$is first determined:

$$I_{R1} = \frac{V_{RsN}}{R_e + j\omega Ls} \qquad (12)$$

Finally the calculation of V_0 was using (9),by allowing calculation of $V_{RN-1.}$



(a)



(b)

Fig 5.(a) and (b) Simulation results of the idealized waveforms for series connection of rectifiers

7. CALCULATION OF THD AND POWER FACTOR:

Since the input impedance with fundamental frequency of the uncontrolled converter consists of the series combination of source resistance R_{se} and source inductance L_S. The input displacement factor $\frac{R_{Load}}{\omega Ls}$ will be decreased. However, due to the larger values of Ls, the input current displacement factor of the converter will decreased. Input current harmonics are determined by $\frac{V_{RN(Harmonics)}}{Z_{SOURCE}}$. The choice of source inductance L_S is to compromise between reducing the current harmonics, while maintaining the input displacement factor close to unity. It is found that the overall power factor of the converter is greater than 0.98 when the ratio $\frac{R_{Load}}{\omega Ls}$ is in the region 10 to 100.

8. SIMULATION DIAGRAM FOR36 -PULSE AC-DC CONVERTER WITH AND WITHOUT CURRENT AND VOLTAGE INJECTION

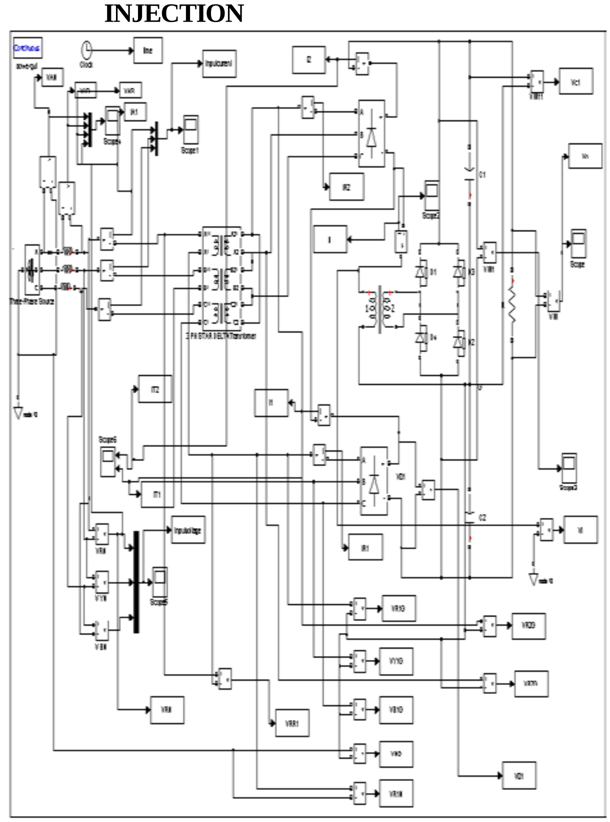
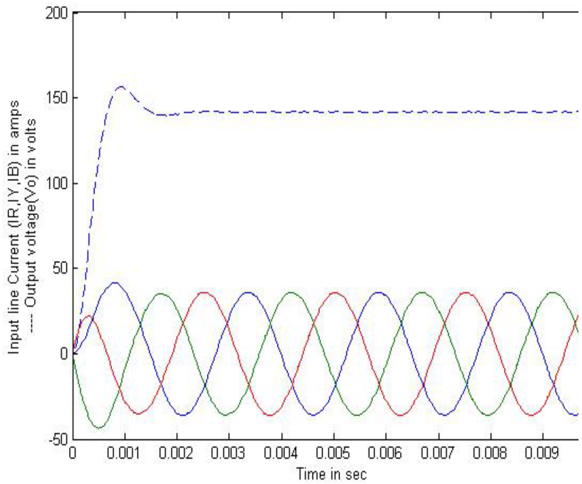
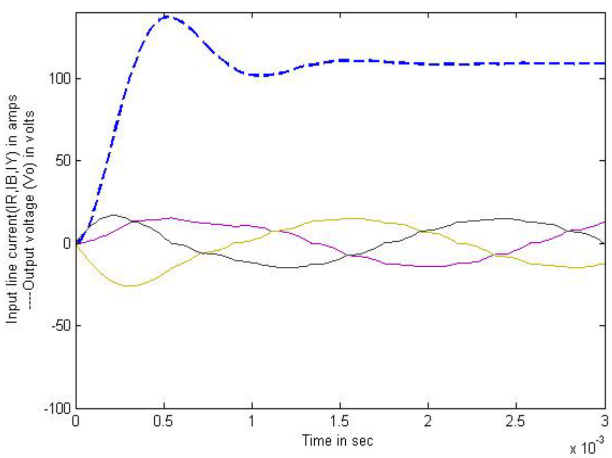


Fig. 6. Simulation Model of 36 -pulse ac-dc converter with and without current and voltage injection.

9. SIMULATION RESULTS FOR 36 -PULSE AC-DC CONVERTER WITH AND WITHOUT CURRENT AND VOLTAGE INJECTION

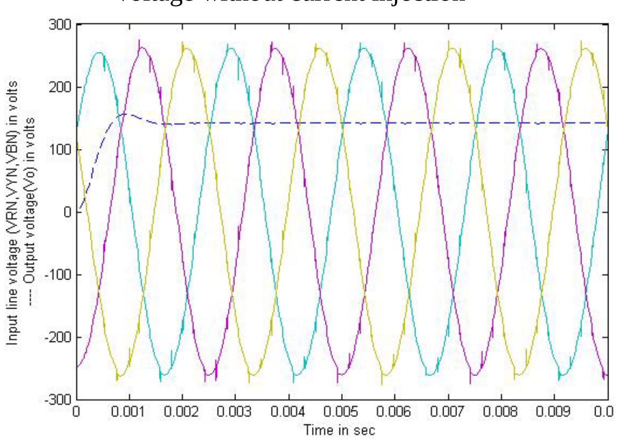


(a)

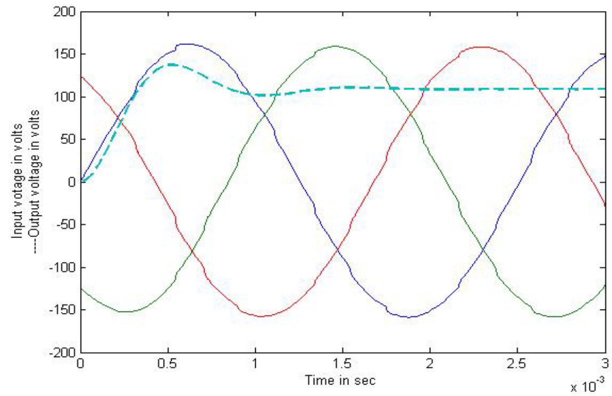


(b)

Fig. 7.(a) Input Line current and output voltage with current injection, (b) Input Line current and output voltage without current injection

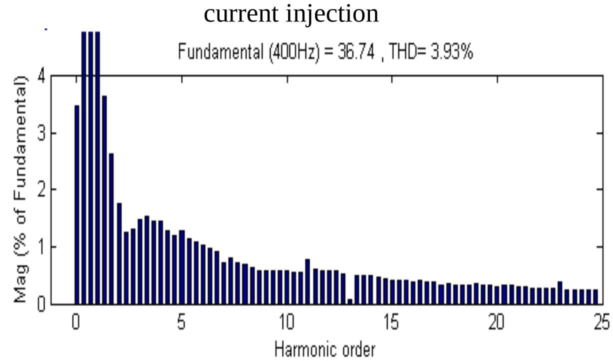


(a)

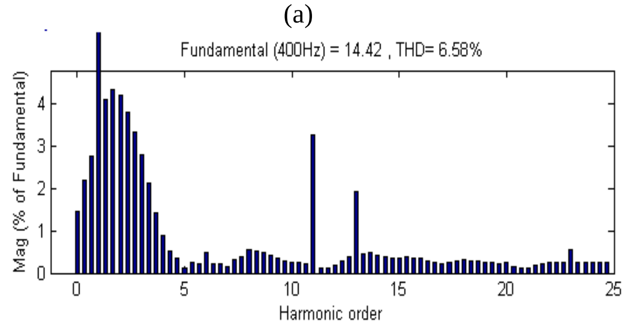


(b)

Fig. 8.(a) Input voltage and output voltage with current injection,(b) Input voltage and output voltage without current injection



(a)



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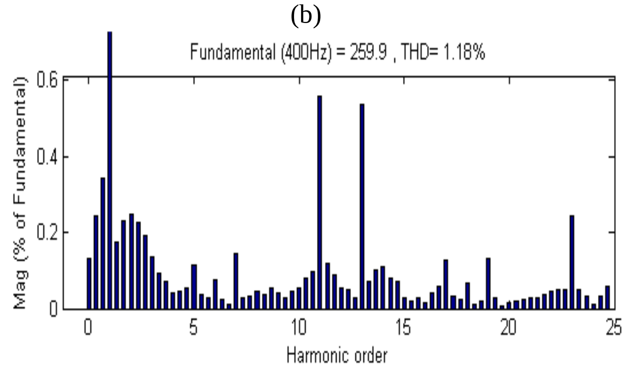

(c)Fig. 9(a) Normalized input line current harmonics with current injection, (b) Normalized input line current harmonics without current injection and (c) Normalized input line voltage harmonics with current injection

10. ANALYSIS OF SIMULATION RESULTS AND DISCUSSION

Operation of the converter was verified in MATLAB Simulink using ideal components as Fig.6. The parameters are the supply line to neutral voltage was 115Vrms at the frequency of 400Hz, the assumed input source inductors were 115μH and the load resistance was 4Ω. The assumed value of the source inductance L_S is a comparatively large and this is sufficient to produce a significant phase angle between the line current and supply voltage.

From the previous section, by using the procedure of steady state calculation results in an output voltage of 142.8V, peak line current of 36A, and phase angle of 12.5^0 between the fundamental line current and the supply voltage.Fig.7. shows the simulated waveforms of the input source current I_{R1}, and inductor line current I_R andFig.5. shows two six pulse waveform $V_{RR1.}$ The simulated results of the output voltage was 141.7Volts, very close to the determined value and also the peaks of source current I_{R1}, input supply voltage and phase angle of I_{R1} and supply voltage are very nearer to the predictions. The total harmonic distortion (THD) of the source current was calculated to be 3.93% as Fig.9 and power factor of the converter is 0.976.

11. CONCLUSION

The proposed converter has totally passive elements and less number of components and it draws almost sinusoidal current with the THD level of less than 4% was presented.The typical performance of this converter is same as the 24 pulse system and it based on a current fed two 6-pulse rectifier system with current injection circuit. The analysis of converter, idealized waveforms has been studied in this paper and also determined the THD and overall power factor of the converter was very close to the unity. The injection circuit uses the naturally occurring voltage switching waveforms at the output of the rectifiers and injects a current that wave-shapes the rectifier output voltages by adding an additional voltage level. It can attractive for future aircraft applications.

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