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Single Transistor Active Injection Enabled High- Performance Multipulse Rectifier

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ABSTRACT

A single transistor active injection enabled multipulse rectifier presented here modifies the 12 pulse rectifier into 24 pulse operation. The line current thereby resulted is characterized by a sinusoidal line current with a THD of 1.09% for 24 pulse operations. The circuit operation and modulation strategy are explained, and simulation results are presented.

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INTRODUCTION

The use of 12-pulse rectifiers as line interface converters for actuators and motor drives is becoming commonplace in sensitive electrical systems such as on an aircraft. These circuits offer a simple and robust solution, and furthermore, their size and weight may be minimized by replacing the fully isolated, delta-star transformer by an autotransformer or a line interphase reactor. However, the increasing penetration of rectifier-fed equipment into aircraft systems, a consequence of the migration to more electric technology, is creating concerns over system power quality. As a result, more stringent limits are being placed on load current harmonics.

One way of improving the input waveforms of 12-pulse rectifiers without incurring a significant weight penalty, and while retaining their inherent robustness is through the use of ripple injection techniques. These techniques were originally proposed for high-power applications such as HVDC transmission, and typically involve the addition of dc-side circuitry which modifies the rectifier output waveforms, usually through the injection of a harmonic frequency. The effective pulse number of the rectifier, at both input and output, is thereby increased, for example bestowing a 12-pulse rectifier with 24-pulse characteristics.

Advantages of the proposed system is that the injection techniques are presented in circuit allow the optimum injection waveform to be identified, which theoretically eliminates all the line current harmonics, No need for injection transformer and High frequency

of operation of the device enables high-quality input current which produces a meagre THD of 1.06%.

Generalized analyzes of injection techniques presented here give the optimum injection waveform which theoretically eliminates all the line current harmonics. The use of an optimum injection waveform in a rectifier system for aerospace applications, which consisted of a 12-pulse circuit and two interleaved dc-dc converters. PWM techniques were used to synthesize the optimum injection waveform.

This paper presents a ripple injection technique for a 12-pulse rectifier with series-connected diode bridges, which again uses the natural switching of the rectifier outputs. The circuit principally consists of a single active device that carries approximately 2.9% of the load current, and it potentially offers two important advantages over previous techniques: first there is no injection transformer, and second the active device may be operated with high-frequency, pulse-width modulation to produce high-quality input currents. Results are presented from a 4-kW Prototype to illustrate the circuit performance with 24-pulse operating modes. A line current THD of 1.06% is obtained using 24-pulse operating mode.

II. Rectifier Topology:

A. Proposed Rectifier:

The 24-pulse active injection topology (Fig. 4) consists of two six-pulse rectifiers connected in series on both the AC and dc sides; the series connection in the AC circuit being achieved through the star-delta transformer, which has a 1:1.73 ratio. The two bridge rectifiers are therefore assumed to be

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fed with almost sinusoidal currents of identical amplitude but phase shifted by 30° due to the transformer. The active injection circuit consists of four diodes, Db1 –Db4. And a single transistor that

together form a bidirectional switch between the center point of the two rectifiers M and the d-point of the dc-link, G.

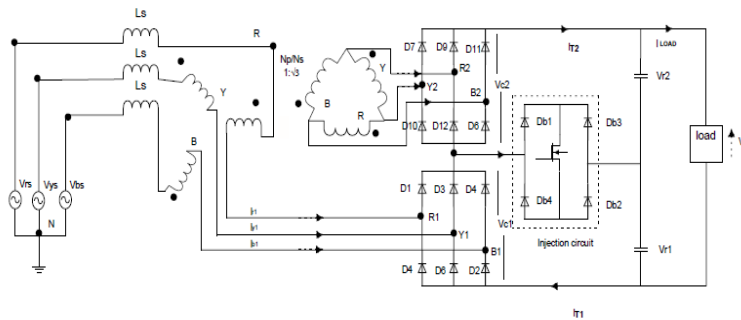


Fig. 1: proposed active injection.

B. Operation of the Active Injection Circuit:

The operation of the active injector and the switching of the rectifier output voltages are explained with reference to the equivalent circuits in Fig. 2 and the idealized waveforms in Fig. 3. The basic equivalent circuit in Fig. 2(a) shows the outputs of the rectifiers represented by current sources i_1 and i_2 which are equal to the full-wave-rectified rectifier input currents, and parallel diode paths which are termed bypass paths. The bypass diodes represent the possibility of both diodes in a bridge leg conducting simultaneously. The two current sources have standard six-pulse waveforms (Fig. 3) their mean values are identical, but the ripples are displaced by 30°.

The instantaneous difference between the current sources I_{diff} and the switching state of the active injector V_{gs} determine the configuration of the circuit. In this description, the transistor in the active injector operates at 12 times the AC supply frequency and the switching instants are assumed to be phase locked to the rectifier ripple currents. Initially in Fig. 3, the active injector is in the off state and the circuit is in configuration 1 [Fig.2 (b)] since the current i_1 is much greater than i_2 , resulting in the conduction of the bypass diode in parallel with the source.

The current, therefore, flows through the output, the difference current $I_{diff} = i_1 - i_2$ is positive and flows in the top bypass diode, clamping the voltage V_{o2} to zero and resulting in a voltage V_o of across the output of the bottom rectifier. Configuration 1 comes to an end when the injector is activated, and the circuit enters configuration 2 [Fig.2(c)].

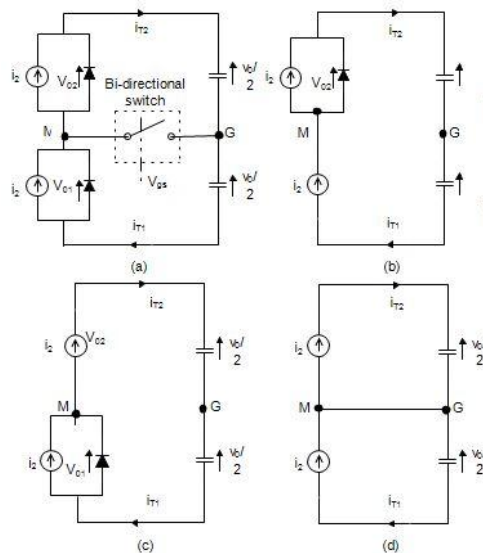


Fig. 2: Equivalent circuit and its configurations. (a) Equivalent circuit. (b) Configuration 1. (c) Configuration 2. (d) Configuration 3.

In configuration 2, the rectifier output voltages, V_{o1} , and V_{o2} are clamped to by the conducting switch and the split dc-link capacitors. The bypass diodes are reverse biased, and the current I_{diff} flows through the bidirectional switch. Initially in

configuration 2, I_{diff} is positive, and the odd injector diodes are conducting; however, as I_{diff} reverses, the even injector diodes are brought into conduction. The angular duration of configuration 2, denoted, is determined by the on time of the bidirectional switch.

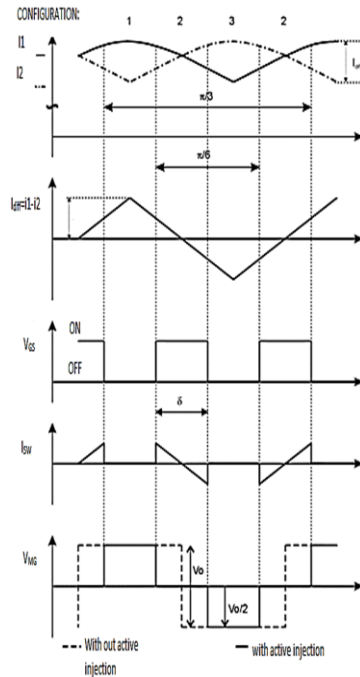


Fig. 3: Idealized waveforms of active injection circuit in 24-pulse mode.

Configuration 2 comes to an end when the active injector is switched off. The current I_{diff} is negative and, therefore, flows in the bottom bypass diode (Configuration 3) in Fig. 2(d), which is a mirror image of Configuration 1. The voltage V_{o1} is clamped to zero and V_{o2} equals the output voltage V_o . The circuit switches into Configuration 2 again when the active injector turns on, and the cycle ends when the active injector next turns off, returning the circuit to configuration one since I_{diff} is now positive. In Fig. 6 shows the current in the bidirectional switch, which is equal to when the switch is enabled and is otherwise zero.

The final waveform in Fig.3 is the voltage V_{MG} across the bidirectional switch, which is seen to be a quasi square wave at six times the supply frequency. The individual rectifier output voltages V_{o1} and V_{o2} are given By $V_o/2 + V_{MG}$.

III. 24-PULSE OPERATION

A. Production Of 24 Pulse Waveform:

Fig. 4 shows how the modification of the main rectifier output voltages to complementary stepped waveforms results in 24-pulse voltages at the right-hand side of the input inductors with respect to the

Supply neutral. For simplicity, Fig. four only shows the derivation of the V_{RN} waveform.

Fig. 4 shows the input voltages of the bottom rectifier with respect to the mid-point of the dc link

V_{R1g} , V_{Y1g} and V_{B1g} . The voltage depends on the direction of the line current i_{R1} ; when i_{R1} is negative, R1 is clamped to negative the rail of dc link, and V_{R1g} becomes $-V_o/2$. When i_{R1} is positive the R1 is connected to V_{o1} will switch between positive and negative $V_o/2$ and zero due to the action of bidirectional switch and reversal of the current difference I_{diff} . V_{Y1g} and V_{B1g} are similar in shape to V_{R1g} , but lag by 120 and 240, respectively. The rectifier input voltages may be referred to the supply neutral by subtracting the common mode voltage

$$\begin{bmatrix} v_{R1N} \\ v_{Y1N} \\ v_{B1N} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} v_{R1G} \\ v_{Y1G} \\ v_{B1G} \end{bmatrix} \quad (1)$$

V_{R1N} is the fourth waveform shown in Fig. 4. The input voltages to the top rectifier with respect to the mid-point of the dc link, V_{R2g} , V_{Y2g} and V_{B2g} have a similar waveform to V_{R1g} , V_{Y1g} and V_{B1g} except that the voltages will be clamped to $+V_o/2$ when the respective input current is positive and otherwise switch between positive and negative $V_o/2$ and zero. V_{RPrim} the phase primary voltage of the star-delta transformer is the seventh waveform in Fig. 4, and is calculated as

$$v_{RPrim} = \frac{1}{\sqrt{3}}(v_{R2N} - v_{B2N}). \quad (2)$$

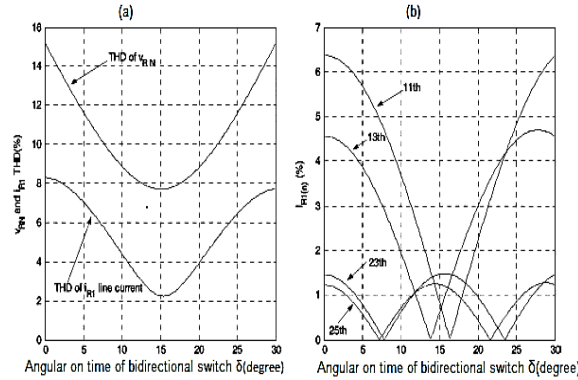


Fig. 5: (a) THD (%) of V_{RN} and i_{R1} versus the angular on-time of the bidirectional Switch. The THD of the line current is determined with $X_s=0.13$ p.u. (b) i_{R1} harmonics $n=11,13,23$ and 25 , $X_s=0.13$ pu.

Fig. 5: (b) shows the magnitude of the dominant low-order current harmonics in I_{R1} . Again calculated using (4), the analysis in Section 4.4 and a 0.13 p.u. Input reactance. The fifth and seventh harmonics are always absent, whereas the 11th and 13th harmonics are seen to be almost eliminated with $\delta=15$ degrees and the dominant harmonics are then the 23rd and 25th, confirming that with $\delta=15$ degrees, the circuit takes on the characteristics of a 24-pulse rectifier.

D. Calculation of Steady-State Conditions:

Since the equation (4) confirms that the waveform is in phase with the line current, as drawn in Fig. 4, then the power of the converter per phase may be represented by a fundamental frequency equivalent resistor R_{eq} such that

$$\frac{3V_{RN(1)}^2}{2R_{eq}} = \frac{V_O^2}{R_{Load}} \tag{5}$$

Where V_{IRN} is the fundamental component of V_{RN} . From (4), $V_{RN(1)} = 0.653V_o$ assuming δ takes its optimum value of 15 degrees, therefore from (5) $R_{eq} = 0.64 R_{load}$. To determine the steady state operating conditions, the line current is first calculated as follows:

$$I_{R1(1)} = \frac{V_{RS}}{\sqrt{R_{eq}^2 + X_s^2}} \tag{6}$$

Where V is the amplitude of the V_{RSN} source. The fundamental component of is then calculated as $V_{RN(1)} = I_{R1} * R_{eq}$ and finally the output voltage is calculated as $V_O = V_{RN(1)} / 0.653$.

The displacement angle ϕ between the supply voltage V_{RSN} and the line current I_{R1} may be determined from

$$\phi = \arctan\left(\frac{X_s}{R_{eq}}\right) \tag{7}$$

There are therefore conflicting demands on the choice of X_s , a small value is desirable to minimize the input displacement angle (7) and voltage regulation, whereas must be large to limit the magnitudes of the harmonic currents and the current THD. In addition, to ensure continuous conduction operation of the rectifiers, a minimum phase angle is required between the line-to-neutral supply voltage and the multilevel line-to-neutral voltage at the right-hand side of the line inductors, and this places another minimum limit on the size of X_s . A per unit line reactance of 0.13 was judged in this work to be a good compromise, providing an input displacement angle of 7.37 a line current THD of 2.29% and a power factor of 0.9914 with $\delta=15$ degree .

IV. Overview Of The Proposed System:

Architecture Parameter Specifications:

The system is operated with a 4 KVA prototype with separate line inductors as shown in fig 1. The simulation is executed in the Matlab 2012a version. The specifications of different parameters in the simulation circuit are described below in table II. Load for the given connection is assumed to be 20 ohm load.

Table II:

Parameters	specifications
Star delta transformer ratio	45:77
Input supply voltage	110
Input frequency range	400Hz- 800Hz
Source inductance per phase	480μH or 0.13 pu
Dc link capacitor	470μF

V. Simulation Results And Its Discussion:

A 400 -Hz, 115 -V supply is provided to the load as shown.. The fig 6 explains the line current I_R in reference to the load current I_{load} . Here the load

current is found to be dc with small ripple in the waveform as shown, and the input line current is shown with sinusoidal input current as shown in fig 16.

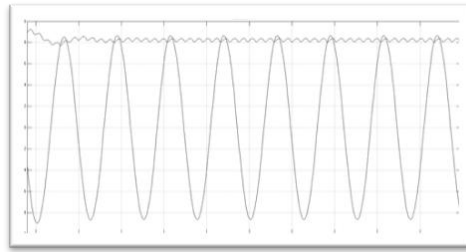


Fig. 6: Response of the line current i_{r1} , the load current I_{load} for 24 pulse operation.

The power analyzer measured the current THD to be 1.09% for current and voltage injection circuit and the angle of the line current at 6.75 degrees with

respect to the supply voltage. The power loss was 230 W, the efficiency 94.3%, and the power factor 0.993.

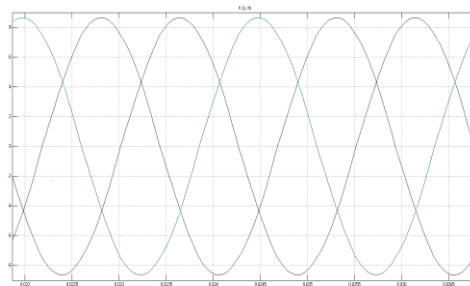


Fig. 7: Line currents waveforms for 24 pulse operation.

Fig. 8 shows a comparison of the normalized line current harmonics in the 24-pulse injection. The presence of very small third, fifth, and seventh harmonics was attributed to imperfect harmonic cancelation, principally caused by the small current drawn for the transformer excitation and core losses.

Fig. 8 shows that the 24-pulse injection virtually eliminates the 11th and 13th harmonics and also the 35th and 37th, but at the expense of an increase in the 23rd and 25th.

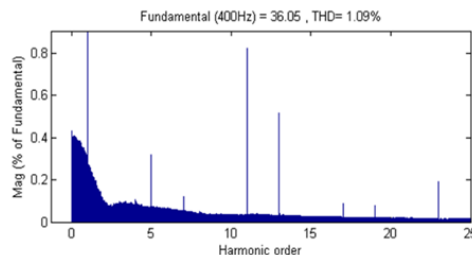


Fig. 8: Comparison of normalized line current harmonics for the 4-kW prototypes, 115-V, 400-Hz supply.

Conclusion:

The addition of a low-current, bidirectional switch between the two diode bridges and the midpoint of the dc link in a current fed, series-configured, 12-pulse rectifier allows the line current harmonics to be significantly reduced. The use of a 50% rated transformer makes the techniques particularly attractive for future aircraft equipment; however, the techniques are suitable for a wider range of applications. The bidirectional switch is operated with a fixed duty ratio of 50%, synchronized with the 12-pulse ripple resulting in input currents that are typical of a 24-pulse system. A line current THD of 1.09% was measured in the 4 kW, 400 Hz prototype.

Future research in this area could consider the development of robust synchronization techniques for the active injector, allowing rapid supply frequency variations to be tracked, which would be particularly important in aircraft systems. Also, the application of the bidirectional switch active injector to other multipulse rectifiers could be examined.

REFERENCES

Singh, B., G. Bhuvaneshwari, and V. Garg, 2006. "Harmonic mitigation using 12-pulse AC-DC converter in vector controlled induction motor drives," *IEEE Trans. Power Del.*, 21(3): 1483–1492.

Oguchi, K., G. Maeda, N. Hoshi and T. Kubata, 2001. "Coupling rectifier system with harmonic canceling reactors," *IEEE Ind. Appl. Mag.*, 7(4): 55–63.

Liu, Y.H., J. Arrillaga and N.R. Watson, 2003. "A new high pulse voltage sourced converter for HVDC transmission," *IEEE Trans. Power Del.*, 18(4): 1388–1393.

Singh, B., G. Bhuvaneswari, V. Grag and S. Gairola, 2006. "Pulse multiplication in ac-dc converters for harmonic mitigation in vector controlled induction motor drives," *IEEE Trans. Energy Conv.*, 21(2): 342–352.

Chivite-Zabalza, F.J., A.J. Forsyth and D.R. Trainer, 2006. "A simple, passive 24-pulse ac-dc converter with inherent load balancing," *IEEE Trans. Power Electron.*, 21(2): 430–439.