A Wide Input Range Active Multi-pulse Rectifier
For Utility Interface Of Power Electronic Converters

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Abstract

In this paper, a wide input range active multi-pulse rectifier for utility interface of power electronic converters is proposed. The scheme combines multi-pulse method using a Y-Δ transformer and boost rectifier modules. A current control scheme for the rectifier modules is proposed to achieve sinusoidal line currents in the utility input over a wide input range of input voltage and output load conditions. A design example is included for a 208V to 460V input, 700V_{dc}, 10kW output rectifier system. Simulation results are shown.

I. Introduction

The usage of 3-phase nonlinear loads such as adjustable speed drives (ASD) and power converters for telecommunications and data processing systems is increasing. Due to the nature of the loads, the input line currents have significant harmonics. To maintain utility power quality at acceptable levels, new harmonic limits for these equipments are detailed in IEC 61000-3-4 and IEEE 519.

Three-phase line-to-line voltage ranges from a nominal 208V_{rms} to a nominal 480V_{rms}. Three-phase PWM rectifier circuits can be used for a wide input voltage range, but most of them are unable to handle it effectively. Three single-phase power factor correction (PFC) circuits connected across a three-phase system provide simple control, but interaction among the phases requires special consideration for low frequency line current components in the DC side. Another approach is to use multi-pulse method. Even though this approach has several advantages such as no active control and no additional EMI, parallel operation comprising of several six-pulse rectifiers may suffer from imbalance operation due to impedance mismatch and pre-existing voltage distortion, resulting in saturation at interface reactor.

This paper proposes a wide input range active multi-pulse rectifier for utility interface using boost converters to shape the input current to sinusoidal waveform.

The advantages of the proposed approaches are;

(i) Sinusoidal input current for a wide range of utility input voltage and output load conditions
(ii) Regulated DC link voltage over wide input voltage range and load changes
(iii) Improved ride-through capability for voltage sags.
(iv) Smaller size and weight of magnetic component.
(v) Imbalanced operation is minimized by current sharing among the boost rectifier modules.

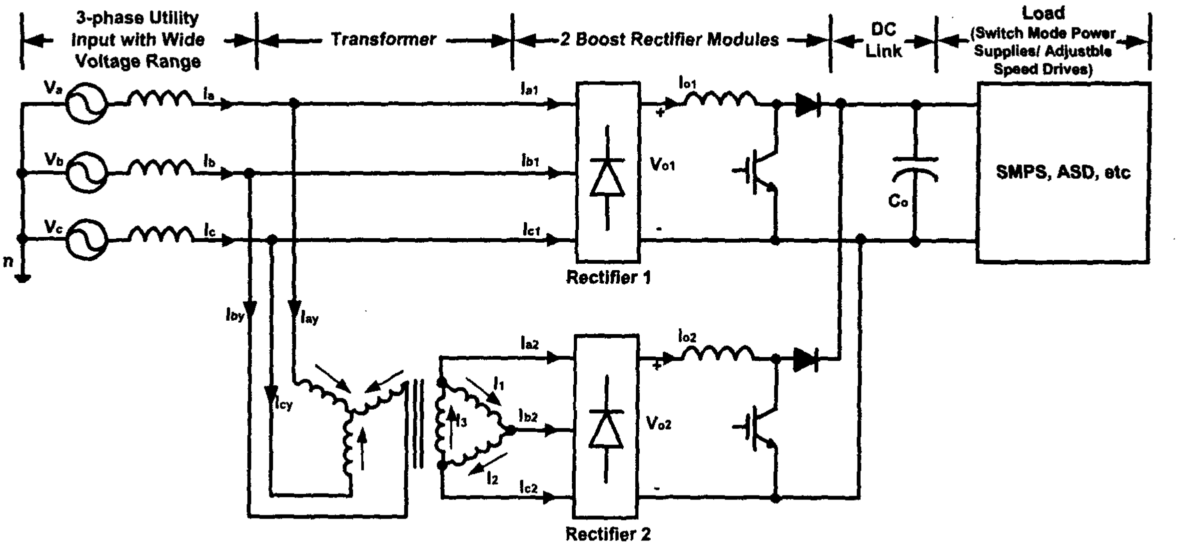


Fig. 1 Proposed wide input range active multi-pulse active rectifier system

II. Proposed System

Fig. 1 (a) shows the proposed wide input range active multi-pulse active rectifier system. The Y-Δ transformer generates 30° phase shift. Two boost rectifier stages are connected to each rectified three-phase output (Fig. 1 (a)).

A. Analysis

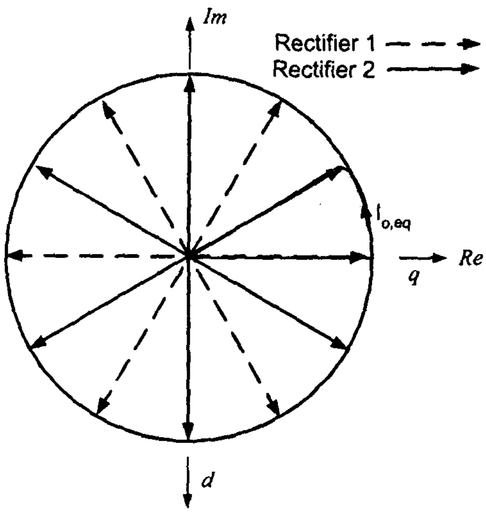
The diode switching vector of Rectifier 1 and Rectifier 2 for the proposed system can be expressed in the dashed and solid line in space vector plane as in Fig. 2 (a). Outside circle represents reference current $I_{o,eq}$ trajectory. Since the adjacent two vectors are available and can be manipulated, the input current can be shaped. In the gray area, the currents at each boost rectifier can be calculated using the relationship of I_{o1} and I_{o2} (Fig. 2 (b)).

$$I_{o1} = 2I_{o,eq}\sin(\theta) \tag{1}$$

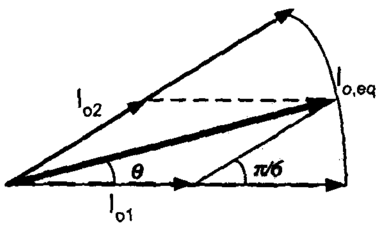
$$I_{o2} = 2I_{o,eq}\sin\left(\frac{\pi}{6}-\theta\right) \qquad 0 \le \theta \le \frac{\pi}{6} \tag{2}$$

where

$$I_{o,eq} = \frac{P_o}{V_{rec}} \text{ and } V_{rec}=1.35V_{LL} \tag{3}$$



(a) Diode switching vectors in the proposed system



(b) Relationship of each output current

Fig. 2. Output current calculation

The next sector can be calculated by similar way.

Fig. 3 shows the output voltages and currents at each rectifier for one cycle. If the output currents I_{o1} and I_{o2} are shaped as Fig. 3, the input currents can be sinusoidal.

One pulse of Fig. 3 is shown in Fig. 4. Since input power and output power is the same, minimum DC link voltage can be calculated.

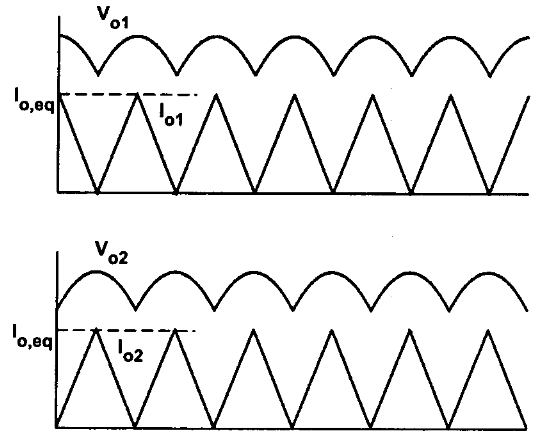


Fig. 3. Output currents at each boost rectifier modules.

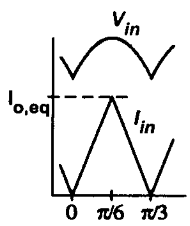


Fig. 4. Rectifier output voltage and current

$$\int_0^{\frac{\pi}{3}} v_{in} i_{in} d(\omega t) = V_o\left(\frac{I_{o,eq}}{2}\right) \tag{4}$$

From Eq. (4), minimum DC link voltage is

$$V_o > \frac{\pi}{3}\sqrt{2}V_{LL}(=1.48V_{LL}) \tag{5}$$

The rectifier input currents can be written in terms of switching functions and rectifier output currents [2].

$$\begin{bmatrix} I_{a1} \\ I_{b1} \\ I_{c1} \end{bmatrix} = \begin{bmatrix} S_{a1} \\ S_{b1} \\ S_{c1} \end{bmatrix} I_{o1} \tag{6}$$

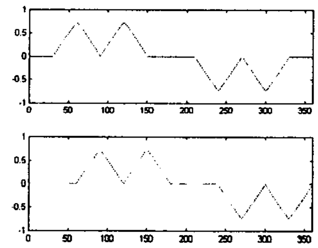
$$\begin{bmatrix} I_{a2} \\ I_{b2} \\ I_{c2} \end{bmatrix} = \begin{bmatrix} S_{a2} \\ S_{b2} \\ S_{c2} \end{bmatrix} I_{o2} \tag{7}$$

The currents in the transformer can be expressed as below.

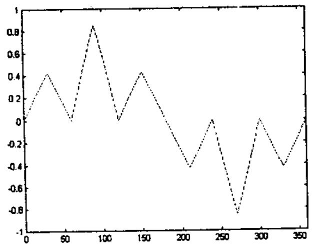
$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} I_{a2} - I_{b2} \\ I_{b2} - I_{c2} \\ I_{c2} - I_{a2} \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} I_{ay} \\ I_{by} \\ I_{cy} \end{bmatrix} = \sqrt{3}\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} \tag{9}$$

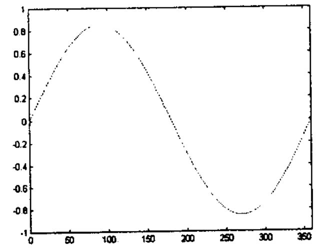
The waveforms of I_{a1}, I_{a2}, I_{ay} and I_a are shown in Fig. 5.



(a) I_{a1} and I_{a2}



(b) I_{ay}



(c) Ia

Fig. 5. Current waveforms

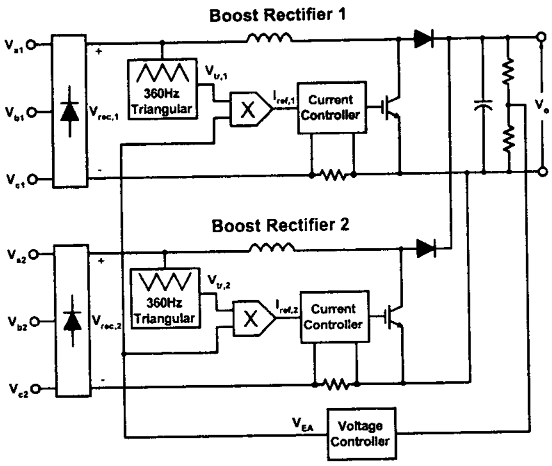


Fig. 6. Control block diagram of the system

B. Control Scheme

Fig. 6 shows the control block for the system. Since the resultant output currents, I_{o1} and I_{o2} are similar to triangular waveform, 360Hz triangular voltage $v_{tr,i}$ is generated in synchronization with the rectified output voltage $v_{rec,i}$ ($i=1, 2$).

The rectified input current $I_{rec,i}$ and the current reference $I_{ref,i}$ can be represented as below.

$$I_{rec,i} = K_s I_{ref,i} \qquad i=1,2 \qquad (10)$$

$$I_{ref,i} = K_M K_{tr} V_{EA} \qquad (11)$$

where K_s; power stage gain
K_M; multiplier gain
K_{tr}; triangular generator gain
V_{EA}; voltage error amplifier output

From Eqs. (10) and (11), the rectified current $I_{rec,i}$ is proportional to the reciprocal of $V_{rec,i}$. Therefore, the input power P_i is

$$P_i = V_{rec,i} I_{rec,i} = K_s K_M K_{tr} V_{EA} V_{rec,i} \qquad i=1, 2 \qquad (12)$$

When the RMS rectified voltages are the same, each boost rectifier module draws the same power.

C. Transformer rating

From Fig. 4, the RMS value of rectified current is

$$I_{rec,i} = 0.5882 I_{o,eq} \qquad i=1,2 \qquad (13)$$

The RMS currents through the secondary winding can be calculated by Eqs. (6) and (7).

$$I_1 = 0.2776 I_{o,eq} \qquad (14)$$

The currents I_2 and I_3 have the same RMS value as I_1. Since the output voltage of the transformer is V_{LL}, the VA rating is

$$VA_{TR} = 0.6169 P_o \qquad (15)$$

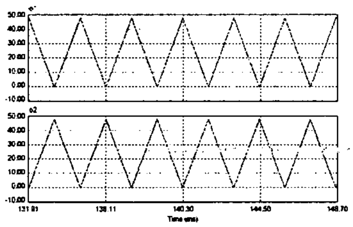
3. Design Example and Simulation

Table 1 summarizes the volt-ampere rating of the auto-transformer.

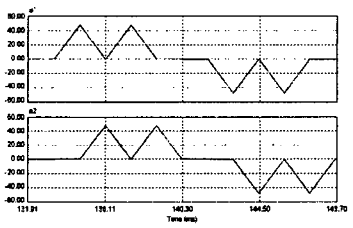
Table 1. VA rating of the auto-transformer (rms value)

Primary winding current	I_{ay}	$0.4808\ I_{o,eq}$
Secondary winding current	I_1	$0.2776\ I_{o,eq}$
Primary winding voltage	V_a	$0.4277\ V_{rec}$
Secondary winding voltage	V_{LL}	$0.7407\ V_{rec}$
Transformer VA rating	VA_{TR}	$0.6169\ P_o$

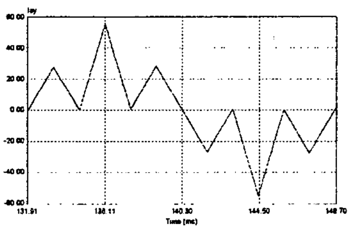
The system is simulated at $208V_{LL}$ and $460V_{LL}$, 10kVA load. The output voltage is set to 700V. Fig. 7 (a), (b), (c) and (d) show the current at $208V_{LL}$ Input. The same waveforms are shown at $460V_{LL}$ input (Fig. 7 (e), (f), (g) and (h)). They demonstrate sinusoidal utility input current waveforms.



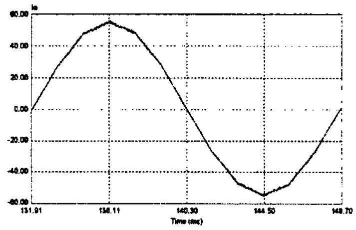
(a) I_{o1} and I_{o2} currents ($208V_{LL}$)



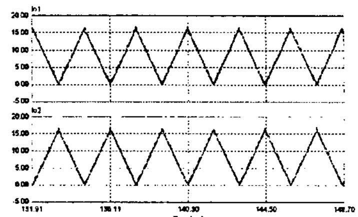
(b) I_{a1} and I_{a2} currents ($208V_{LL}$)



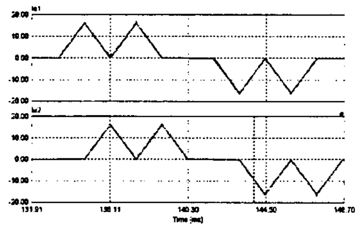
(c) I_{ay} current ($208V_{LL}$)



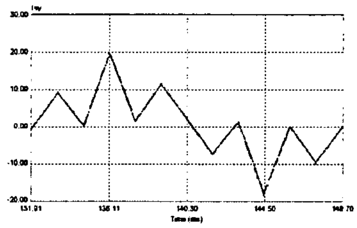
(d) I_a current ($208V_{LL}$)



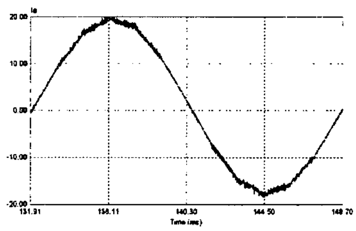
(e) I_{o1} and I_{o2} currents ($460V_{LL}$)



(f) I_{a1} and I_{a2} currents ($460V_{LL}$)



(g) I_{ay} current ($460V_{LL}$)



(h) I_a current ($460V_{LL}$)

Fig. 7. Simulated waveforms

4. Conclusion

A new active multi-pulse rectifier for wide-range input voltages has been presented. A Y-Δ transformer and boost rectifier modules provide sinusoidal input current over wide utility input voltages and output load conditions. Simulation results verify the proposed system.

References

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