Polyphase Transformer Arrangements with Reduced kVA Capacities for Harmonic Current Reduction in Rectifier-Type Utility Interface

Sewan Choi, *Member, IEEE*, Prasad N. Enjeti, *Senior Member, IEEE*, and Ira J. Pitel, *Senior Member, IEEE*

***Abstract*— In this paper polyphase transformer arrangements with reduced kVA capacities are presented for harmonic current reduction in high power diode rectifier-type utility interface systems. Based on the concept of an autotransformer, a 12-pulse rectifier system is realized with a resultant transformer kVA rating of 0.18P_o (pu). In this arrangement the 5, 7, 17, 19, etc. harmonics are absent from the utility input line current. In the second scheme an 18-pulse rectifier is realized with the kVA rating of 0.16P_o (pu) and the 5, 7, 11, 13, etc. harmonics are canceled in the utility line currents. Analytical design equations are presented to facilitate the design of system components. Simulation results verify the proposed concept, and experimental results are provided from a 208 V, 10 kVA 12-pulse rectifier system. The advantage of employing the proposed system for utility interface of rectifier/PWM-inverter motor drive systems is also explained.**

I. INTRODUCTION

LARGE HARMONICS, poor power factor, and high total harmonic distortion (THD) in the utility interface are common problems when nonlinear loads such as adjustable speed drives, power supplies, induction heating systems, UPS systems, and aircraft converter systems are connected to the electric utility. In several cases the interface to the electric utility is a three-phase uncontrolled diode bridge rectifier. Due to the nonlinear nature of the load, the input line currents have significant harmonics. For adjustable speed ac motor drive systems with no dc-link smoothing inductor, the discontinuous conduction of the diode rectifier results in a high THD and can lead to the malfunction of sensitive electronic equipment. The recommended practice, IEEE 519, has evolved to maintain utility power quality at acceptable levels [1].

Several methods have been proposed to overcome the presented problems [2]–[4]. One approach is to use a conventional 12-pulse converter which requires two six-pulse converters connected through Y-Δ and Y-Y isolation transformers as shown in Fig. 1 The operation of the conventional 12-pulse converter results in the absence of the fifth and seventh harmonics in the input utility line current, and the kVA rating of the transformer is 1.03P_o (pu) [4], [5].

In this paper new polyphase transformer arrangements with reduced kVA capacities are proposed to improve the quality of the utility line currents. The proposed approach is based on autotransformer arrangements between the utility and the diode bridge rectifiers so that the size (in kVA) of the transformer is reduced in comparison to the isolation transformer of the conventional 12-pulse converter. In the autotransformer, the windings are interconnected such that the kVA to be transmitted by the actual magnetic coupling is only a portion of the total kVA. The reduced kVA rating of transformer parts required in an autotransformer make it physically smaller, less costly, and higher efficiency than conventional transformers [6]. Fig. 2(a) shows the proposed 12-pulse diode rectifier system.

To ensure the independent operation of two rectifier groups, two interphase reactors, which are relatively small in size [0.066P_o (pu)], become necessary. With this arrangement the rectifier diodes conduct for 120° per cycle and the fifth and seventh harmonics are absent from the input line current. Further, the autotransformer arrangement also yields equal leakage reactance's in series with each line of the rectifier bridges, which contributes to equal current sharing.

The same concept can be extended to realize an 18-pulse system [Fig. 7(a)] in which the fifth, seventh, eleventh, and thirteenth harmonics in the utility input line currents are canceled with the kVA rating of 0.16P_o (pu). The proposed approaches are analyzed, and the kVA reduction in the new autotransformer is illustrated.

II. PROPOSED AUTOTRANSFORMER ARRANGEMENT FOR 12-PULSE DIODE RECTIFIER SYSTEM

Fig. 2(a) shows the 12-pulse configuration of the proposed approach to reduce the kVA rating of the transformer. The winding configuration of an interphase reactor is shown in Fig. 2(b). The diodes in each bridge rectifier conduct for 120° per cycle, and the rectifier input currents ($I_{a'}$, $I_{b'}$, $I_{c'}$ as well as $I_{a''}$, $I_{b''}$, and $I_{c''}$) consist of the six-pulse characteristic harmonics. The autotransformer bank between the utility and the rectifiers acts like a passive filter eliminating the fifth and seventh harmonics in the line current of the utility interface by introducing a 30° phase shift.

A. Delta-Type Autotransformer Connection

The vector diagram of the proposed delta-type autotransformer connection and the winding representation on a three-limb core are shown in Fig. 3(a) and (b), respectively. The necessary phase shift angle between $a'b'c'$ and $a''b''c''$ is 30°.

Manuscript received November 6, 1995; revised June 6, 1996.

The authors are with the Department of Electrical Engineering, Texas A&M University, College Station, TX 77843-3128 USA.

Publisher Item Identifier S 0885-8993(96)06861-5.

0885–8993/96$05.00 © 1996 IEEE

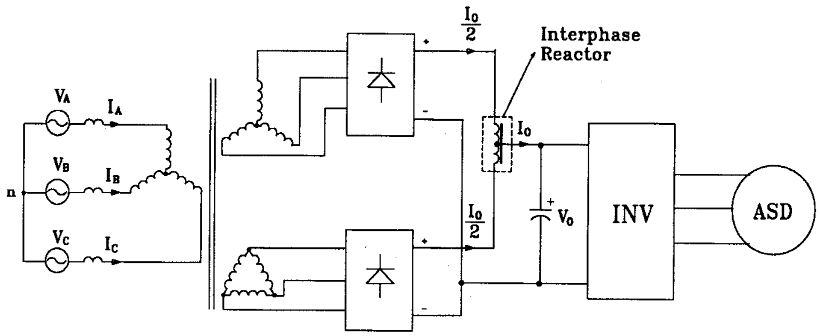
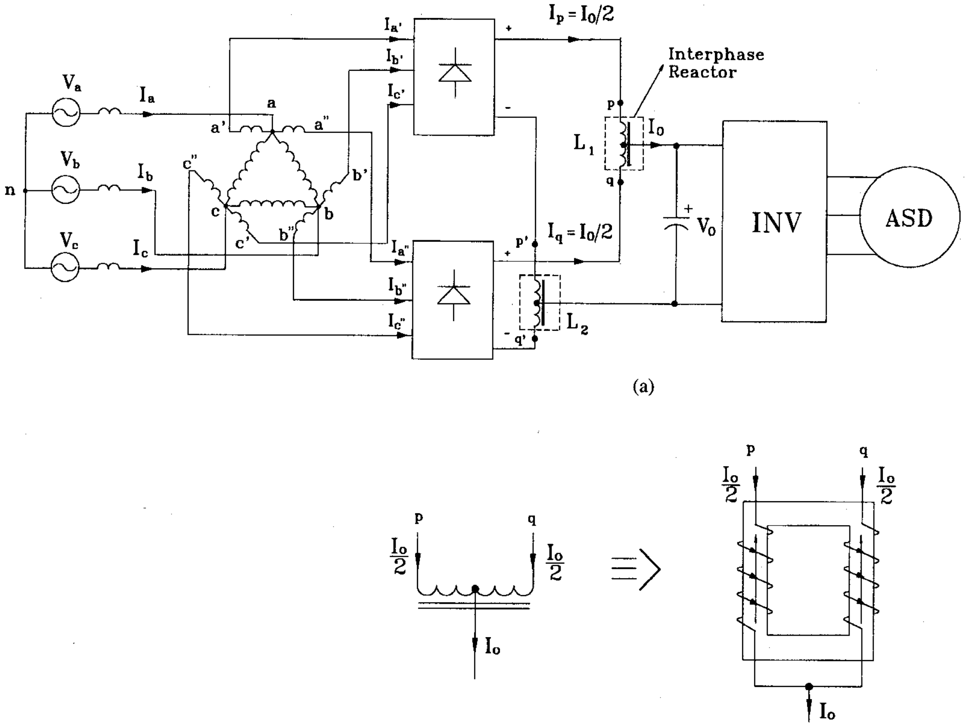


Fig. 1. Conventional 12-pulse converter (kVA $= 1.03P_o$).



(a)

(b)

Fig. 2. (a) Proposed 12-pulse approach employing the autotransformer with kVA rating of $0.18P_o$ (pu) and (b) winding configuration of interphase reactor.

Therefore, from Fig. 3(a) the length k_1 becomes

$$k_1 = 0.2679 \text{ (pu)}. \tag{1}$$

From limb one (1) of the three-limb core shown in Fig. 3(b), assuming $\sqrt{3}$ turns (pu) between terminals a and b, the MMF equation becomes

$$\sqrt{3} * I_1 = k_1(I_{c''} - I_{c'}). \tag{2}$$

Similarly, for core limbs two (2) and three (3), the magnetomotive (MMF) equations become

$$\sqrt{3} * I_2 = k_1(I_{a''} - I_{a'}) \tag{3}$$
$$\sqrt{3} * I_3 = k_1(I_{b''} - I_{b'}). \tag{4}$$

Input utility line current I_a can be expressed as

$$I_a = I_1 + I_{a'} + I_{a''} - I_3. \tag{5}$$

Then, from (2), (4), and (5) input current I_a becomes

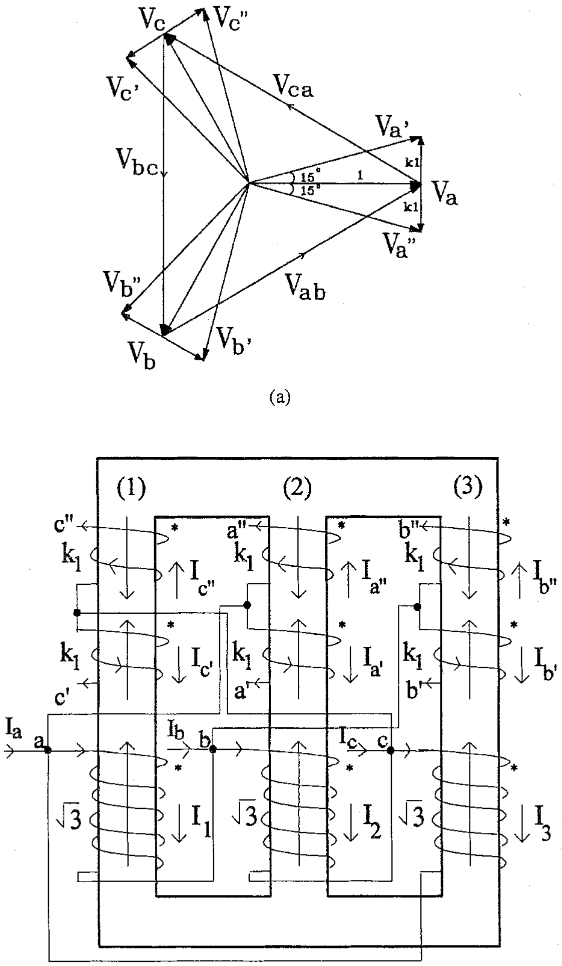
$$I_a = I_{a'} + I_{a''} + \frac{k_1}{\sqrt{3}}(I_{c''} - I_{b''} + I_{b'} - I_{c'}). \tag{6}$$

Similarly, input line currents I_b and I_c can be expressed as

$$I_b = I_{b'} + I_{b''} + \frac{k_1}{\sqrt{3}}(I_{a''} - I_{c''} + I_{c'} - I_{a'}) \tag{7}$$
$$I_c = I_{c'} + I_{c''} + \frac{k_1}{\sqrt{3}}(I_{b''} - I_{a''} + I_{a'} - I_{b'}). \tag{8}$$

B. Input Current Analysis

In this section the input line currents are analyzed and represented as a Fourier series. This facilitates evaluation of input current harmonics. Let the three-phase utility input



(a)

(b)

Fig. 3. (a) Vector diagram of the proposed autotransformer connection for 12-pulse operation and (b) autotransformer windings on a three limb core in Fig. 2(a).

voltages be

$$V_a = V_m \sin(\omega t) \tag{9}$$

$$V_b = V_m \sin\left(\omega t - \frac{2}{3}\pi\right) \tag{10}$$

$$V_c = V_m \sin\left(\omega t + \frac{2}{3}\pi\right). \tag{11}$$

Ignoring the source inductance's, two sets of the rectifier input voltages become

$$V_{a'} = V_m' \sin\left(\omega t + \frac{\pi}{12}\right) \tag{12}$$

$$V_{b'} = V_m' \sin\left(\omega t + \frac{\pi}{12} - \frac{2}{3}\pi\right) \tag{13}$$

$$V_{c'} = V_m' \sin\left(\omega t + \frac{\pi}{12} + \frac{2}{3}\pi\right) \tag{14}$$

and

$$V_{a''} = V_m' \sin\left(\omega t - \frac{\pi}{12}\right) \tag{15}$$

$$V_{b''} = V_m' \sin\left(\omega t - \frac{\pi}{12} - \frac{2}{3}\pi\right) \tag{16}$$

$$V_{c''} = V_m' \sin\left(\omega t - \frac{\pi}{12} + \frac{2}{3}\pi\right) \tag{17}$$

where

$$V_m' = \sqrt{1 + \left(\tan\frac{\pi}{12}\right)^2} V_m = 1.035 V_m. \tag{18}$$

Considering a highly inductive load current at the rectifier outputs, the rectifier input currents can be represented as [4]

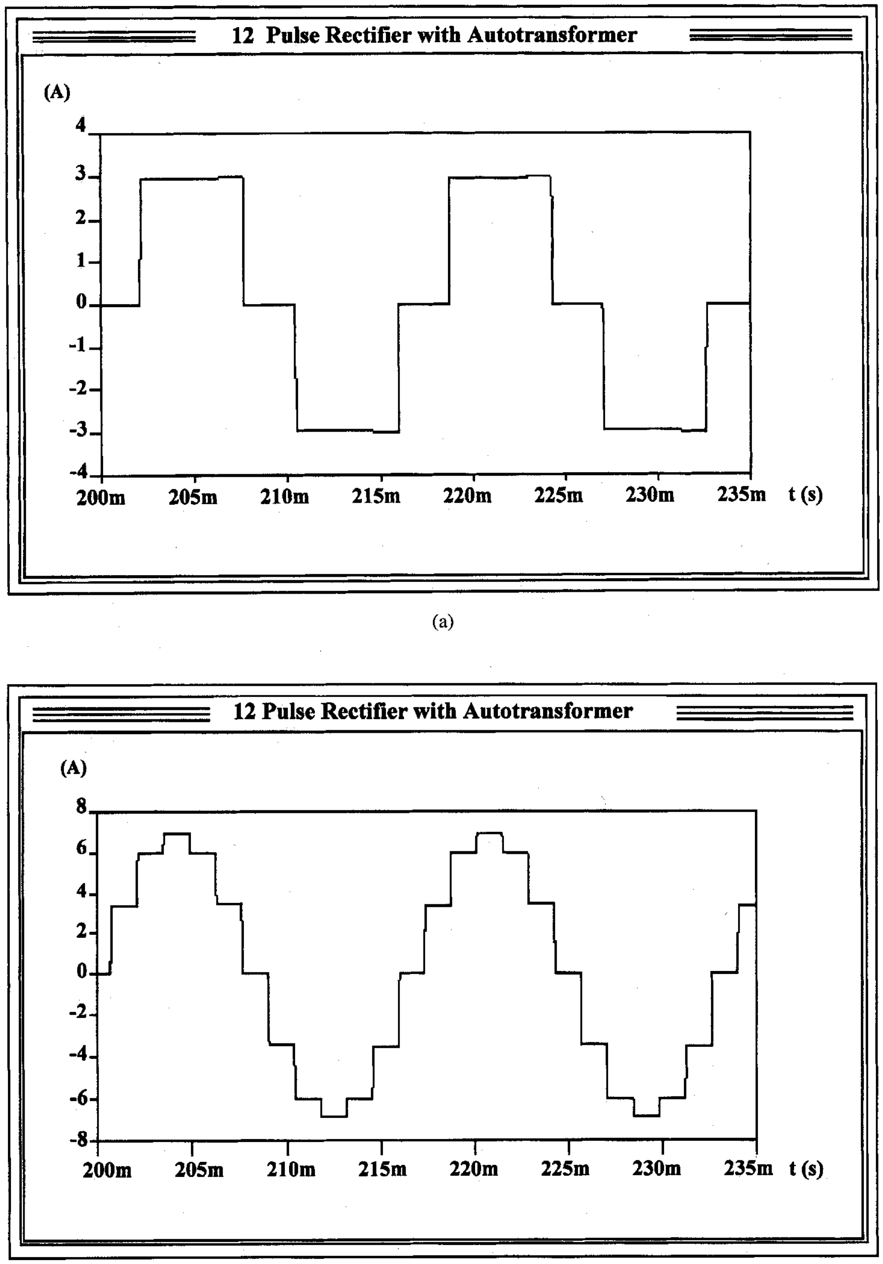
$$I_{a'} = \sum_{n=1,3,5\cdots}^{\infty} \left[\frac{4I_p}{n\pi} \cos\left(n\frac{\pi}{6}\right)\right] \sin n\left(\omega t + \frac{\pi}{12}\right) \tag{19}$$

$$I_{b'} = \sum_{n=1,3,5\cdots}^{\infty} \left[\frac{4I_p}{n\pi} \cos\left(n\frac{\pi}{6}\right)\right] \sin n\left(\omega t + \frac{\pi}{12} - \frac{2}{3}\pi\right) \tag{20}$$

$$I_{c'} = \sum_{n=1,3,5\cdots}^{\infty} \left[\frac{4I_p}{n\pi} \cos\left(n\frac{\pi}{6}\right)\right] \sin n\left(\omega t + \frac{\pi}{12} + \frac{2}{3}\pi\right) \tag{21}$$

$$I_{a''} = \sum_{n=1,3,5\cdots}^{\infty} \left[\frac{4I_q}{n\pi} \cos\left(n\frac{\pi}{6}\right)\right] \sin n\left(\omega t - \frac{\pi}{12}\right) \tag{22}$$

$$I_{b''} = \sum_{n=1,3,5\cdots}^{\infty} \left[\frac{4I_q}{n\pi} \cos\left(n\frac{\pi}{6}\right)\right] \sin n\left(\omega t - \frac{\pi}{12} - \frac{2}{3}\pi\right) \tag{23}$$



(a)

(b)

Fig. 4. (a) Rectifier input currents $I_{a'}$ and (b) utility line current I_a.

$$I_{c''} = \sum_{n=1,3,5\cdots}^{\infty} \left[\frac{4I_q}{n\pi}\cos\left(n\frac{\pi}{6}\right)\right]\sin n\left(\omega t - \frac{\pi}{12} + \frac{2}{3}\pi\right) \quad (24)$$

where I_p and I_q are the output current magnitudes of the two rectifiers, respectively.

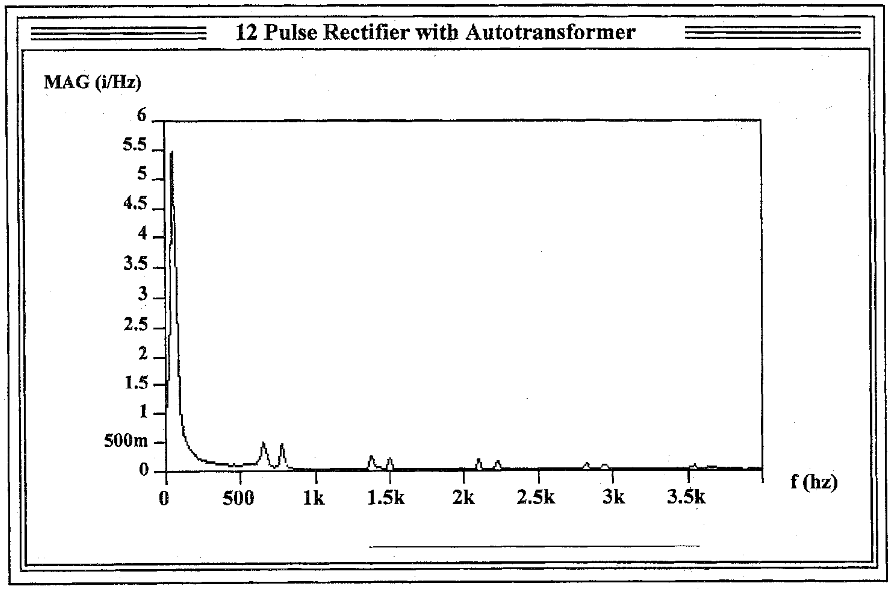
From (6) and (19) to (24), input line current I_a for the proposed 12-pulse system is shown to be

$$I_a = \sum_{n=1,3,5\cdots}^{\infty} \left[\frac{4}{n\pi}\cos\left(n\frac{\pi}{6}\right)\right] A_n \sin n(\omega t - \phi_n) \quad (25)$$

where

$$\begin{aligned} A_n &= \sqrt{(I_p + I_q)^2[d_n]^2 + (I_q - I_p)^2[n_n]^2} \\ \phi_n &= \tan^{-1}\left\{\frac{(I_p - I_q)n_n}{(I_p + I_q)d_n}\right\} \\ n_n &= \sin\left(\frac{n\pi}{12}\right) - \frac{2}{\sqrt{3}}k_1 \sin\left(\frac{2\pi n}{3}\right)\cos\left(\frac{n\pi}{12}\right) \\ d_n &= \cos\left(\frac{n\pi}{12}\right) + \frac{2}{\sqrt{3}}k_1 \sin\left(\frac{2\pi n}{3}\right)\sin\left(\frac{n\pi}{12}\right). \end{aligned} \quad (26)$$

Since $I_p = I_q = I_o/2$, substituting this into (26) yields $A_5 = 0$, $A_7 = 0$, $A_{17} = 0$, and $A_{19} = 0$. Therefore, the



(c)

Fig. 4. *(Continued.)* (c) Frequency spectrum of I_a for a highly inductive load.

utility input current harmonics consist only of the 12-pulse characteristic harmonics ($h = 12k \bullet 1, k = 1, 2, 3 \cdots$) and the fifth, seventh, seventeenth, and nineteenth, etc. harmonics are absent in utility input currents. From (26), it is also noted that the fundamental power factor is unity.

The proposed 12-pulse approach shown in Fig. 2(a) is simulated on SABER. Fig. 4(a) shows rectifier input currents $I_{a'}$ for a highly inductive load. Fig. 4(b) and (c) shows the utility line currents and the frequency spectrum of line current I_a. Note that the fifth and seventh harmonics are absent. The simulation results verify that the proposed 12-pulse system with the autotransformer arrangement eliminates the fifth and seventh harmonics in the input utility line.

C. Output Voltage Analysis

In this section output voltage V_o and voltages across the interphase reactors are calculated to facilitate the design of the autotransformer and the interphase reactor. For the sake of simplicity, the upper part of the two bridge rectifiers [Fig. 2(a)] connected to interphase reactor L_1 can be considered to be a midpoint converter as shown in Fig. 5(a). The Fourier series representation of voltages V_{pn}, V_{qn}, the voltages with respect to the neutral point n, can be obtained by

$$\begin{aligned} V_{pn} &= V_m' \frac{3}{\pi} \sin \frac{\pi}{3} \\ &\quad \times \left(1 - \sum_{3,6,9\cdots}^{\infty} \frac{2}{n^2 - 1} \cos \frac{n\pi}{3} \cos n\left(\omega t + \frac{\pi}{12}\right)\right) \end{aligned} \tag{27}$$

$$\begin{aligned} V_{qn} &= V_m' \frac{3}{\pi} \sin \frac{\pi}{3} \\ &\quad \times \left(1 - \sum_{3,6,9\cdots}^{\infty} \frac{2}{n^2 - 1} \cos \frac{n\pi}{3} \cos n\left(\omega t - \frac{\pi}{12}\right)\right). \end{aligned} \tag{28}$$

Then, the dc output voltage of the midpoint converter becomes

$$\begin{aligned} V_{o1} &= \frac{1}{2}(V_{pn,\mathrm{dc}} + V_{qn,\mathrm{dc}}) \\ &= 0.8270 V_m'. \end{aligned} \tag{29}$$

Similarly, the output voltage of the midpoint converter regarding the lower part of the two diode rectifiers, V_{o2}, becomes

$$V_{o2} = -0.8270 V_m'. \tag{30}$$

Therefore, the dc output voltage of the 12-pulse converter is

$$\begin{aligned} V_o &= V_{o1} - V_{o2} \\ &= 1.6540 V_m'. \end{aligned} \tag{31}$$

Also, voltage across interphase reactor L_1, V_{pq} becomes

$$\begin{aligned} V_{pq} &= V_{pn} - V_{qn} \\ &= V_m' \frac{12}{\pi} \sin \frac{\pi}{3} \sum_{3,6,9\cdots}^{\infty} \frac{1}{n^2 - 1} \cos \frac{n\pi}{3} \sin \frac{n\pi}{12} \sin n\omega t. \end{aligned} \tag{32}$$

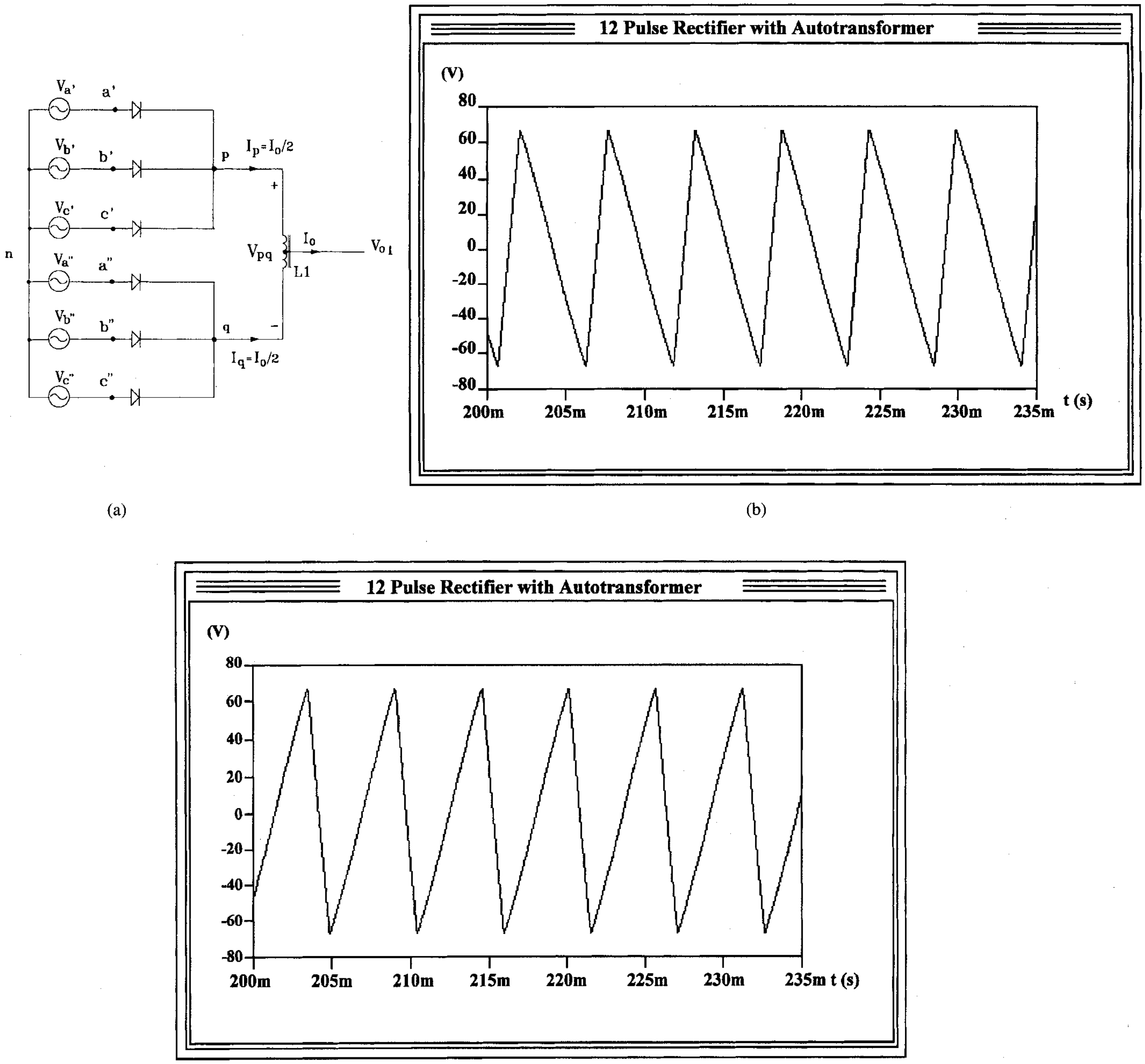
Fig. 5(b) and (c) shows voltages across interphase reactors L_1 and L_2, respectively. From (32) we see that the dominant frequency component of V_{pq} is the third harmonic and its magnitude for $n = 3$ is

$$|V_{pq,3}| = 0.2067 V_m. \tag{33}$$

Since the interphase reactor carries half of load current I_o, the interphase reactor ripple current is

$$\frac{|V_{pq,3}|}{3\omega L_1} = \frac{K_I I_o}{2} \tag{34}$$

where K_I is the desired percentage ripple of current $\frac{I_o}{2}$. Then, from (33) and (34), the inductance L_1 for the interphase reactor



(a)

(b)

(c)

Fig. 5. (a) Midpoint converter representation for the upper parts of the bridge rectifiers connected to interphase reactor L_1, (b) V_{pq}, voltage across interphase reactor L_1, and (c) $V_{p'q'}$, voltage across interphase reactor L_2.

becomes

$$L_1 = \frac{0.1165 V_{\mathrm{LL}}}{\omega K_I I_o} \tag{35}$$

where $V_{\mathrm{LL}} = \frac{\sqrt{3}}{\sqrt{2}} V_m$ is rms (root mean square) value of line-to-line input voltage. The inductance L_2 value is same as L_1 following the same procedure.

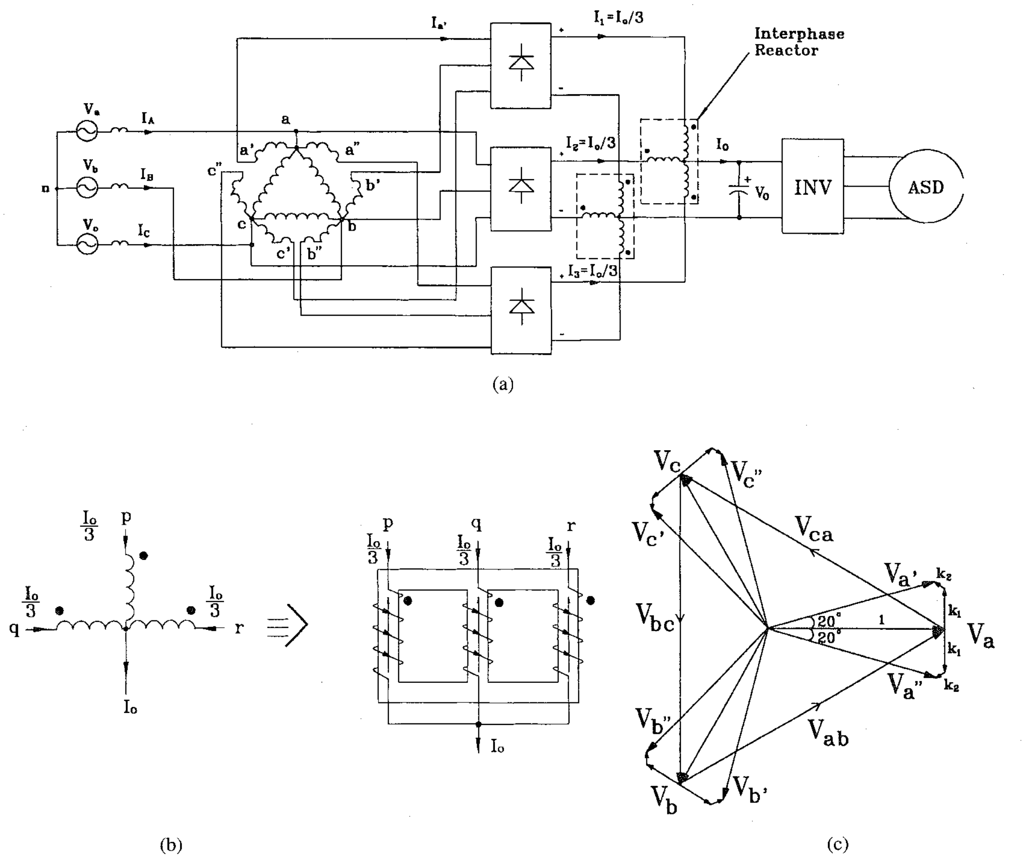
D. kVA Rating of the Polyphase Transformer and Interphase Reactor

The autotransformer utilized in the proposed 12-pulse approach [Figs. 2(a) and 3(a)] is designed such that the size (in kVA) of the transformer is minimized. Assuming the dc output current I_o is highly inductive, the rms value of the small winding currents is

$$\begin{aligned} |I_a'| &= \sqrt{\frac{2}{3}\frac{1}{2}} I_o \\ &= 0.4082 I_o. \end{aligned} \tag{36}$$

From (2) the rms value of the large winding currents is

$$\begin{aligned} |I_1| &= \frac{k_1}{\sqrt{3}} \sqrt{\frac{1}{3}\frac{1}{2}} I_o \\ &= 0.0446 I_o. \end{aligned} \tag{37}$$



(a)

(b)

(c)

Fig. 6. (a) Proposed 18-pulse system (kVA $= 0.16P_o$), (b) winding configuration of interphase reactor, and (c) vector diagram of the autotransformer connection.

The rms value of the small winding voltages is

$$\begin{aligned} |V'_{aa}| &= k_1 \frac{V_m}{\sqrt{2}} \\ &= 0.1895 V_m. \end{aligned} \tag{38}$$

Also, the rms value of the large winding voltages is

$$\begin{aligned} |V_{ab}| &= \sqrt{3} \frac{V_m}{\sqrt{2}} \\ &= 1.2247 V_m. \end{aligned} \tag{39}$$

Then the sum total volt-amp product of the autotransformer windings is

$$\begin{aligned} \mathrm{kVA_{tot}} &= 6|I'_a||V'_{aa}| + 3|I_1||V_{ab}| \\ &= 0.6280 I_o V_m. \end{aligned} \tag{40}$$

Hence, from (18) and (31) the equivalent kVA rating of the autotransformer is [4]

$$\begin{aligned} \mathrm{kVA_{eq}} &= \frac{1}{2} \mathrm{kVA_{tot}} \\ &= 0.1834 I_o V_o. \end{aligned} \tag{41}$$

Thus the proposed 12-pulse arrangement requires a transformer kVA of only 18% of the output kVA. This amounts to an 82% reduction in transformer kVA or relative size compared to the conventional 12-pulse scheme (Fig. 1). From (32) the rms value of V_{pq} can be computed as

$$\begin{aligned} V_{pq,\mathrm{rms}} &= 0.2185 V'_m \\ &= 0.1322 V_o. \end{aligned} \tag{42}$$

Since half of the load current flows through each limb of the interphase reactor, the kVA rating of the interphase reactor can be obtained by

$$\begin{aligned} \mathrm{kVA_{IR}} &= \frac{1}{2} V_{pq,\mathrm{rms}} I_o \\ &= 0.0661 V_o I_o \text{ (pu)}. \end{aligned} \tag{43}$$

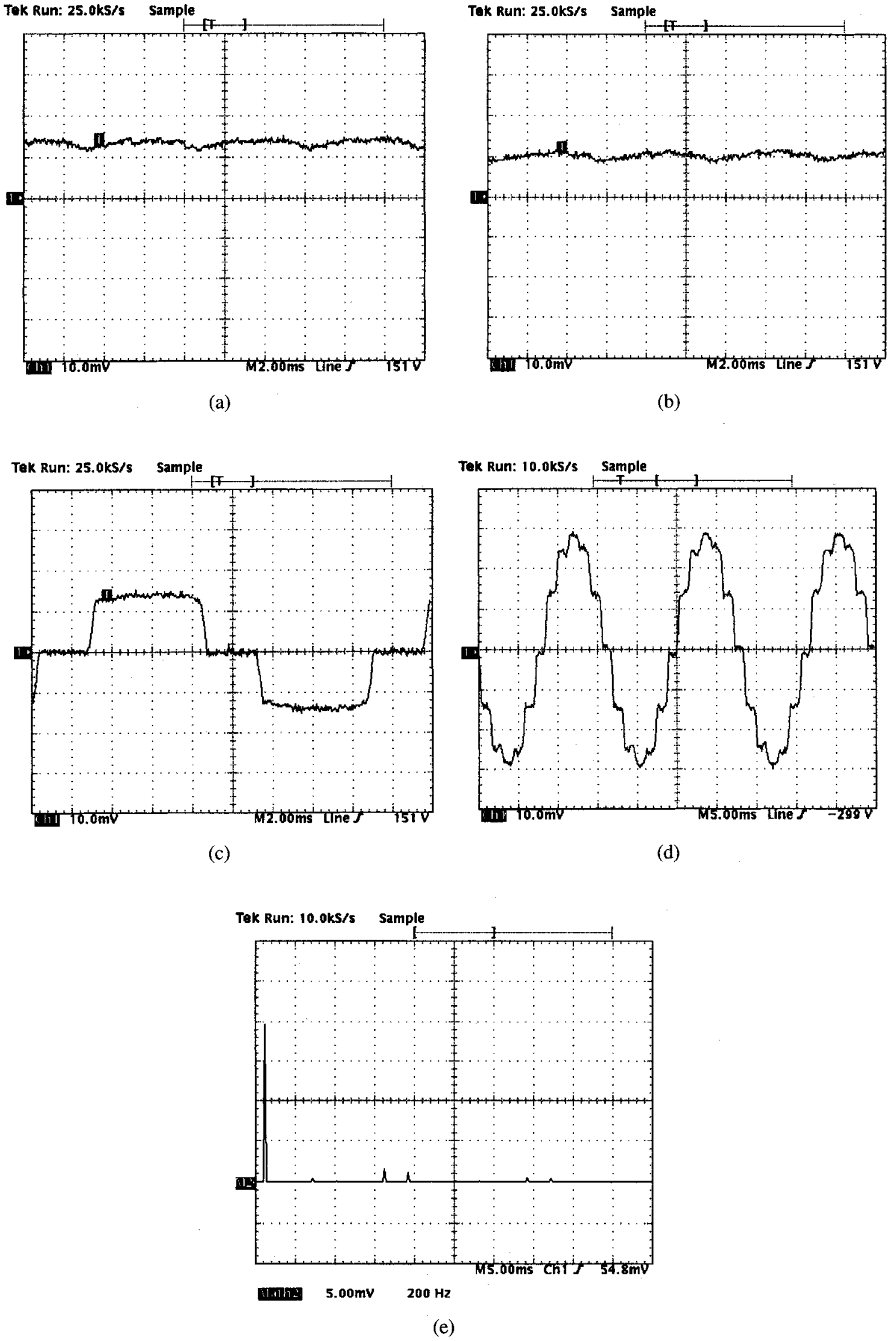
E. Design Example

Assuming the output current I_o as highly inductive and given output power $P_o = 10$ kVA, input line-to-line rms voltage $V_{\mathrm{LL}} = 208$ V, peak phase voltage V_m becomes

$$V_m = \frac{\sqrt{2}}{\sqrt{3}} V_{\mathrm{LL}} = 169.8 \text{ V}. \tag{44}$$

From (18) and (32), output voltage V_o becomes

$$V_o = 290.7 \text{ (V)}. \tag{45}$$



(a)

(b)

(c)

(d)

(e)

Fig. 7. Experimental results for a resistive load (5 A/Div.): (a) Rectifier-I output current I_{d1}, (b) Rectifier-II output current I_{d2}, (c) Rectifier-I input current I_{a1}, (d) input line current I_a, and (e) frequency spectrum of I_a.

Output current I_o becomes

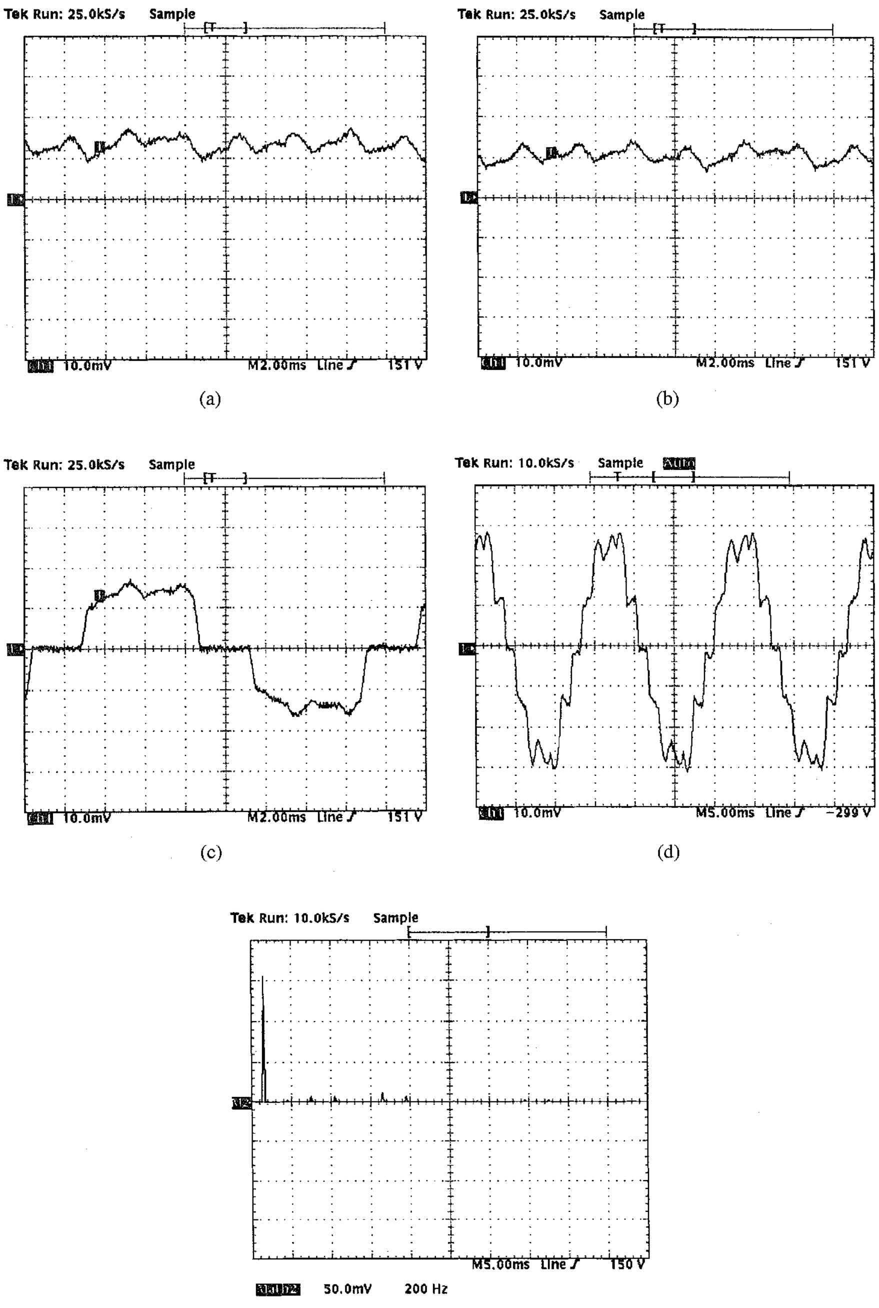
$$I_o = \frac{P_o}{V_o} = 34.4 \text{ A}. \tag{46}$$

Then, from (36)–(39) the rms values of the winding voltages and currents can be obtained by

$$\begin{aligned} |I'_a| &= 13.9 \text{ A} \\ |I_1| &= 1.53 \text{ A} \\ |V'_{aa}| &= 32.2 \text{ V} \\ |V_{ab}| &= 208.0 \text{ V}. \end{aligned} \tag{47}$$

Then, from (40) and (41) the equivalent kVA of the autotransformer becomes

$$\begin{aligned} \text{kVA}_{\text{eq}} &= \frac{1}{2} 3668 \text{ VA} \\ &= 1.834. \text{ kVA}. \end{aligned} \tag{48}$$



(a) (b) (c) (d) (e)

Fig. 8. Experimental results for a capacitive load (10 A/Div.): (a) Rectifier-I output current I_{d1}, (b) Rectifier-II output current I_{d2}, (c) Rectifier-I input current I_{a1}, (d) input line current I_a, and (e) frequency spectrum of I_a.

This illustrates that the required transformer kVA for the proposed 12-pulse scheme is 18% of the output kVA.

III. PROPOSED AUTOTRANSFORMER ARRANGEMENT FOR 18-PULSE DIODE RECTIFIERS

The concept of the proposed 12-pulse approach can be extended to the 18-pulse system employing three three-phase diode bridge rectifiers as shown in Fig. 6(a). Fig. 6(b) displays the practical winding configuration of an interphase reactor for the 18-pulse configuration. In this case, two sets of three-phase voltages are generated by the autotransformer bank, and the vector diagram of the delta-type autotransformer connection is shown in Fig. 6(c). The optimum phase shift angle for 18-pulse arrangements is 20°. From the vector diagram of Fig. 6(c), the lengths of the vectors k_1 and k_2 are determined to be 0.3072 (pu), and 0.0696 (pu), respectively. With the same method to Section II-D, the equivalent kVA rating of the autotransformer

TABLE I
SUMMARY OF PERFORMANCE OF THE PROPOSED SCHEMES

Type	kVA of the transformer	Harmonics eliminated	# of interphase reactor
Conventional 12-pulse	1.03 P_o	5,7,17,19 etc.	1 (two-limb)
Proposed 12-pulse	0.18 P_o	5,7,17,19 etc.	2 (two-limb)
Proposed 18-pulse	0.16 P_o	5,7,11,13th	2 (three-limb)

for the proposed 18-pulse scheme can be obtained by

$$\mathrm{kVA_{eq}} = 0.1675 I_o V_o. \tag{49}$$

The resultant utility line current harmonic profile indicates that the fifth, seventh, eleventh, and thirteenth harmonics are completely eliminated. Table I summarizes the performance of the proposed schemes.

IV. EXPERIMENTAL RESULTS OF THE PROPOSED 12-PULSE DIODE RECTIFIER SYSTEM

A 208-V, 10-kVA 12-pulse diode rectifier system employing the proposed autotransformer arrangements has been implemented in the "CLEAN" power converter laboratory of Texas A&M University. Experimental results on a resistive load as well as a capacitive load (R-C) emulating an adjustable speed ac drive (ASD) are discussed in this section. Rectifier-I output current I_{d1} and Rectifier-II output current I_{d2} for a resistive load are shown in Fig. 7(a) and (b), respectively. Note that I_{d1} and I_{d2} are almost identical in magnitude indicating equal current sharing and balanced 12-pulse operation. Fig. 7(c) shows Rectifier-I input current I_{a1} indicating 120° conduction of each diode. Fig. 7(d) and (e) shows input line current I_a and the frequency spectrum of I_a demonstrating the cancellation of 5, 7, 17, 19, etc. harmonics. Fig. 8 shows output currents I_{d1} and I_{d2}, rectifier input current I_{a1}, input line current I_a, and frequency spectrum of I_a for a capacitive load ($C = 5000\ \mu$F, $R = 14\ \Omega$) emulating an ASD application. Near equal current sharing and elimination of harmonics in the utility line currents is demonstrated. The experimental results verify the improved utility interface characteristics of the proposed 12-pulse system with the autotransformer arrangement.

V. CONCLUSION

In this paper polyphase transformer arrangements with reduced kVA capacities have been presented for harmonic current reduction in high power rectifier utility interface systems. It has been shown that 12-pulse operations can be realized with a transformer kVA of 0.18 (pu) of load kVA. This amounts to an 82% reduction in transformer kVA or relative size compared to a conventional 12-pulse approach. Further the autotransformer arrangement also yields equal current sharing of rectifier bridges The proposed 18-pulse approach employs a transformer of $0.16P_o$ (pu) kVA with further reduction in input current harmonics at the expense of complex hardware. The developed analytical equations facilitate the system design. Experimental results demonstrate the suitability of the proposed 12-pulse utility interface for medium and high power adjustable speed ac drive systems. Since the magnitude of the resulting dc-link voltage remains unaltered the proposed rectifier autotransformer arrangement is a viable candidate to retrofit six-pulse rectifier/PWM inverter ASD systems to reduce utility line current harmonics to comply with IEEE 519 limits.

REFERENCES

[1] *IEEE Recommended Practices for Power Systems Analysis.* New York: IEEE, 1992.

[2] S. Kim, P. Enjeti, P. Packebush, and I. Pitel, "A new approach to improve power factor and reduce harmonics in a three-phase diode rectifier type utility interface," *IEEE Trans. Ind. Applicat.*, vol. 30, no. 6, pp. 1557–1564, Nov./Dec. 1994.

[3] G. Oliver *et al.*, "Novel transformer connection to improve current sharing in high current DC rectifiers," in *IEEE IAS'93 Conf. Proc.*, 1993, pp. 986–992.

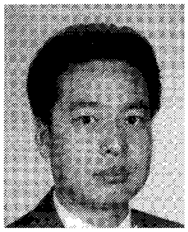
[4] G. Seguier, *Power Electronic Converters AC/DC Conversion.* New York: McGraw-Hill, 1986.

[5] S. Choi, "New multi-pulse diode rectifiers with reduced kVA capacities for harmonic current reduction in static power converter systems," Ph.D. dissertation, Texas A&M Univ., Dec. 1995.

[6] *Electrical Transmission and Distribution*, Westinghouse, pp. 116–120.

[7] E. Lowdon, *Practical Transformer Design Handbook.* Indianapolis, IN: Sams, 1980.

[8] C. Wm. T. McLyman, *Magnetic Core Selection for Transformers and Inductors.* New York: Marcel Dekker, 1982.



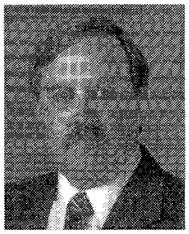
Sewan Choi (S'92–M'95) was born in Seoul, Korea, on March 3, 1963. He received the B.S. degree in electronic engineering in 1985 from Inha University in Incheon, Korea, and the M.S. and Ph.D. degrees in electrical engineering in 1992 and 1995, respectively, from Texas A&M University, College Station.

From 1985 to 1990, he was with Daewoo Heavy Industries, where he was involved in the development of several industrial controllers. He is currently a Senior Researcher working on the development of intelligent power modules in Samsung Electro-Mechanics, Suwon, Korea. His research interests include active power factor correction and the design and control of advanced power converters.

Prasad N. Enjeti (S'86–M'88–SM'95) received the B.E. degree from Hyderabad, India, in 1980, the M.Tech. degree from Indian Institute of Technology, Kanpur, in 1982, and the Ph.D. degree from Concordia University, Montreal, Canada, in 1987, all in electrical engineering.

He then joined the Electrical Engineering Department at Texas A&M University, College Station, where he is currently an Associate Professor. His current research interest include advance converters for power supplies and motor drives, power quality issues and active power filter development, utility interface issues and "clean" power converter designs, and electronic ballasts for fluorescent HID lamps.

Dr. Enjeti is Transactions Editor for the Industrial Power Converter Committee (IPCC) of the IEEE IAS and an Associate Editor for the IEEE TRANSACTIONS ON POWER ELECTRONICS. He was the recipient of the IEEE-IAS second best paper award in 1993 and second best transaction paper published in mid-year 1994 to mid-year 1995 in IEEE TRANSACTIONS ON INDUSTRIAL APPLICATIONS. He is a registered Professional Engineer in Texas.



Ira J. Pitel (M'73–SM'82) received the B.S. degree from Rutgers University, Piscataway, NJ, the M.S. degree from Bucknell University, Lewisburg, PA, and the Ph.D. degree from Carnegie-Mellon University, Pittsburgh, PA, in 1972, 1975, and 1978, respectively.

From 1973 to 1976, he worked for GTE Sylvania researching high-frequency ballasting techniques for gaseous discharge lamps. He joined Bell Laboratories in 1978 and Exxon Enterprises in 1979. He transferred to an Exxon subsidiary, Cornell-Dubilier Electronics, where he was Manager of Research and Development. In 1981, he founded Magna-Power Electronics, a contract research and development company specializing in the fields of power electronics and magnetics. In 1986, he joined Texas A&M University, College Station, as an Adjunct Associate Professor. His research interests are high-power ac to dc converters, static inverters, spacecraft power supplies, specialty lighting controls, and ac and dc drives. He holds 18 patents in the field of power electronics and has others pending.

Dr. Pitel is a member of Eta Kappu Nu and Tau Beta Pi and is Chairman of the Industrial Power Conversion Systems Department of the IAS-IEEE.