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New Pulse Multiplication Technique Basedon Six-Pulse Thyristor Converters forHigh-Power Applications

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Abstract

A new pulse multiplication technique based on six-pulse thyristor converters is proposed in this paper. With the pro-posed technique, 12-pulse, 18-pulse, and 24-pulse operations have been obtained both on the input current and on the output voltage. A control strategy over the whole range of phase angle is provided along with sophisticated input current and output voltage analysis. Experimental results from a laboratory prototype verify the pro-posed theory.

Index Terms: Harmonic, multipulse, pulse multiplication, thyristor.

I. INTRODUCTION

THE six-pulse thyristor converter rated up to several thou-sands of horsepower has been widely used as a front-end ac-to-dc power converter for dc drives or uninterruptible power systems (UPSs). The high contents of six-pulse related input current harmonics could couple into nearby telephone circuits and cause misoperation of protective relaying and circuit breakers. To avoid such undesirable harmonic effects, tuned passive filters have been employed on the ac side of the converter. However, passive filters generate their own harmonic problems, including delayed system response following distur-bances and suffer from the resonance problem with unknown system impedances. Active power filters could be a solution to these problems, but the initial cost of the equipment makes it difficult to put them into practical use, especially in high-powerapplications.

Multiple connection of thyristor bridges increases the pulse number of the converter and, therefore, reduces low-order harmonic contents without increasing high-order harmonics. With parallel or series connection of two bridges, the 12-pulse converter eliminates the fifth and seventh harmonics in the input current. In order to further increase the pulse number, multiple connection of bridges and the corresponding phase-shifting.

transformers are necessary, but this increases the cost and size of the equipment [1].

Several multipulse techniques based on parallel or series connection have been proposed [2]–[5]. A harmonic reduction technique has been proposed to utilize auxiliary thyristors connected to taps on the interphase transformer (IPT) of par-allel-connected thyristor converters [2]. A dc current reinjection technique, which multiplies the pulse number and eliminates harmonics based upon 12-pulse series-connected thyristor con-verters has been proposed for high-voltage applications such as HVdc conversion [3], [4]. The multipulse techniques based on the 12-pulse converter employ phase-shifting transformers to supply two sets of three-phase voltage displaced in phase by 30 [2]–[5] and an IPT in case of parallel connection to absorb the instantaneous voltage differences between the bridges [2]. Due to the unsymmetrical nature of the delta-wye winding of the phase-shifting transformer and phase unbalance of the two bridges, the average output voltages of the two bridges may be unequal, resulting in current unbalance between bridges and a severe saturation problem in the IPT circuit. This causes each bridge to operate in a discontinuous conduction mode in which each rectifier conducts only for 60 and carries the full-load current [6]. Unsymmetry of the delta-wye winding could be alleviated by a three-phase autotransformer or an extended-delta transformer configuration [5]. However, the firing angle imbalance of the two bridges to remedy the current unbalance could cause some undesirable effects, such as harmonic problems [6].In this paper, a new pulse multiplication technique based on six-pulse thyristor converters is proposed. With the proposed technique, 12-pulse, 18-pulse, and 24-pulse operations are ob-tained, both on the input current and on the output voltage. The proposed scheme exhibits the following advantages.

- There is no current unbalance unlike the 12-pulse-based multipulse converter.
- Phase-shifting transformers are not necessary. Instead, rel-atively low kilovoltampere transformers (around 50% of the input power) are employed.
- Output voltage ripples as well as input current harmonics are reduced with the proposed technique.
- Variation of source frequency and load does not affect the operation of the proposed scheme.
- The proposed approach can be considered as an add-on option.

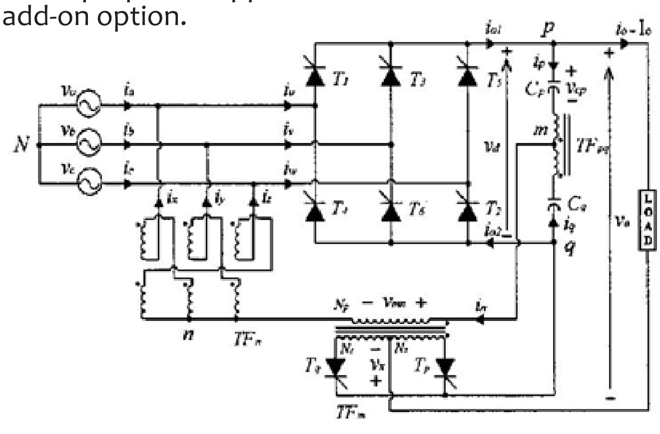

Fig. 1. Proposed 12-pulse converter.

A control strategy over the whole range of phase angle is pro-vided along with sophisticated input cur-rent and output voltage analysis. Experimental results from a 220 –V 3-kVA laboratory prototype are provid-ed.

II. PROPOSED 12-PULSE SCHEME

Fig. 1 shows the circuit topology of the proposed 12-pulse converter. The proposed scheme is based upon the six-pulse thyristor converter with additional circuitry to permit pulse multiplication. The additional circuitry consists of three parts: a voltage-dividing circuit, a current injection circuit, and a zigzag transformer. The voltage-dividing circuit includes two dc blocking capacitors C_p and C_q and a low-kilovoltampere transformer TF_{pq} operating at the ripple frequency which is 6 × the fundamental frequency. The zigzag transformer creates a neutral point " n" and equally distributes injected current i_n into three input phases. An injection transformer TF $_m$ is connected between the neutral point " n" of the zigzag transformer and the dc-link midpoint " m," and two auxiliary thyristors T_p and T_q inject a square-wave current on the primary side of the transformer TF $_m$.

Assuming negligible ripple voltages across the capacitors C_p and C_q due to large capacitances, voltage v_{mn} on the primary side of transformer TF $_m$ is given by

$$v_{mn} = v_{pn} - \frac{1}{2} v_d . \quad (1)$$

The waveform of voltage v_{mn} at phase angle $30_\circ$ is shown in Fig. 2, and its frequency is triple the fundamental frequency. Fig. 3 illustrates the operation of two auxiliary thyristors according to the commutation voltage v_{mn}. To assure natural commutation, thyristor T_p (T_q) is fired at an angle β_p (β_q), which is measured from the rising edge of voltage v_{mn}. Since thyristor T_p (T_q) is forward biased at this moment, it is turned on and carries output current I_o. This causes current $i_n = (N_s / N_p) I_o$ ($i_n = -(N_s / N_p) I_o$) to be induced on the primary winding of transformer TF $_m$. By the repeated firing of the two thyristors, the injected current i_n becomes square wave in shape as shown in Fig. 2. The current i_n is equally divided

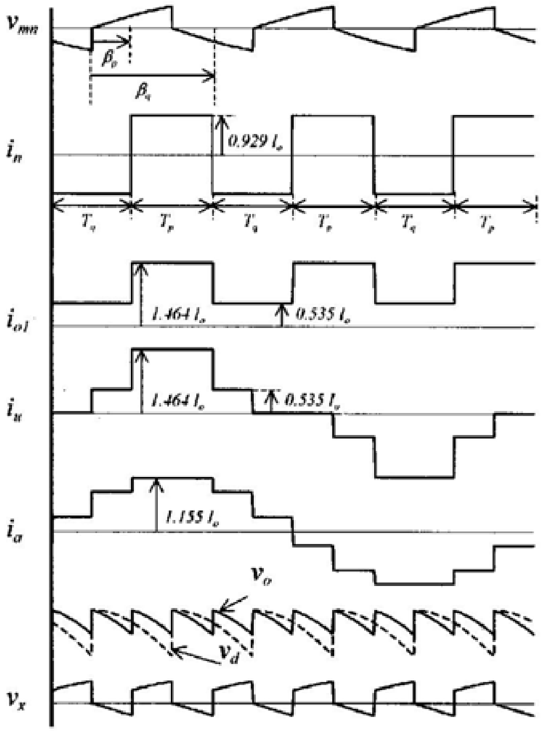

Fig. 2. Various waveforms ($N_s = N_p = 0{:}929$; $= 30$; $= 30$; $= 90$).

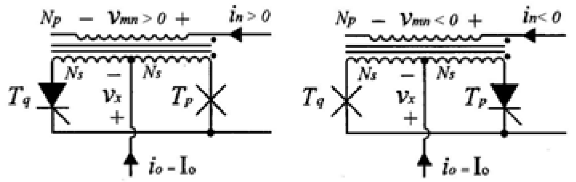

Fig. 3. Operation of the auxiliary circuit

into two currents i_p and i_q on the dc side and three currents i_x, i_y, and i_z on the ac side. That is,

$$i_p = i_q = \frac{i_n}{2} \quad (2)$$

$$i_x = i_y = i_z = \frac{i_n}{3} \quad (3)$$

Then, bridge output currents become

$$i_{o1} = I_o + \frac{i_n}{2} \quad i_{o2} = I_o - \frac{i_n}{2}. \quad (4)$$

Now, switching functions S_{a+} and S_{a-} for phase " a" are de-fined to relate bridge output currents to bridge input currents, as shown in Fig. 4. The switching functions for phases " b" and " c" can also be defined by

$$\begin{aligned} S_{b+} &= S_{a+} \angle -120^\circ \\ S_{b-} &= S_{a-} \angle -120^\circ \\ S_{c+} &= S_{a+} \angle +120^\circ \\ S_{c-} &= S_{a-} \angle +120^\circ . \end{aligned} \quad (5)$$

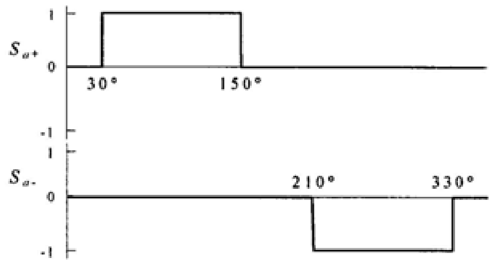

Fig. 4. Switching function S & S for phase " a."

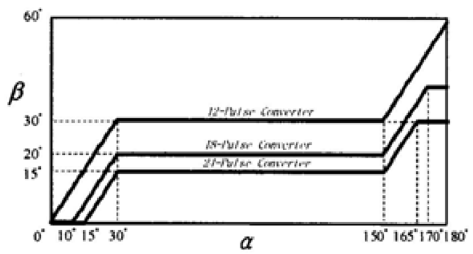

Fig. 5. Optimum firing angle versus phase angle .

Then, bridge input currents can be expressed in terms of bridge output currents and switching functions as

$$\begin{bmatrix} i_u \\ i_v \\ i_w \end{bmatrix} = \begin{bmatrix} S_{a+} \\ S_{b+} \\ S_{c+} \end{bmatrix} i_{o1} + \begin{bmatrix} S_{a-} \\ S_{b-} \\ S_{c-} \end{bmatrix} i_{o2} . \quad (6)$$

Due to equal distribution of current on the ac side, the input current becomes

$$\begin{aligned} i_a &= i_u - i_x = i_u - \frac{i_n}{3} \\ i_b &= i_v - i_y = i_v - \frac{i_n}{3} \\ i_c &= i_w - i_z = i_w - \frac{i_n}{3}. \end{aligned} \quad (7)$$

Finally, from (2)–(7), the input current can be obtained by

$$i_a = \frac{1}{6} i_n (3S_{a+} - 3S_{a-} - 2) + I_o (S_{a+} + S_{a-})$$
$$i_b = \frac{1}{6} i_n (3S_{b+} - 3S_{b-} - 2) + I_o (S_{b+} + S_{b-})$$
$$i_c = \frac{1}{6} i_n (3S_{c+} - 3S_{c-} - 2) + I_o (S_{c+} + S_{c-}). \quad (8)$$

It can easily be noticed from (8) that the input current waveform depends on the injected current i_n, that is, on turns ratio $K = N_s / N$ and on$_p$ firing$_q$ angles β and β. The optimum turns ratio has been found to be $K = 0.929$ The optimum firing angles $\beta (= \beta)$ and $\beta (= \beta + 60°)$ for the lowest input current total harmonic distortion (THD) have been obtained with respect to phase angle α and are shown in Fig. 5. With the optimum firing angle, the minimum THD of 14.19% has been obtained over the whole range of phase angle α between 0° and 180° as shown in Fig. 6. Various current wavefoms at phase angle $\alpha = 30°$ are shown in Fig. 2. Input current i_a is shown to have 12-pulse characteristics.

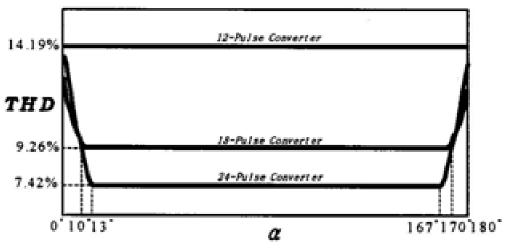

Fig. 6. Input current THD versus phase angle.

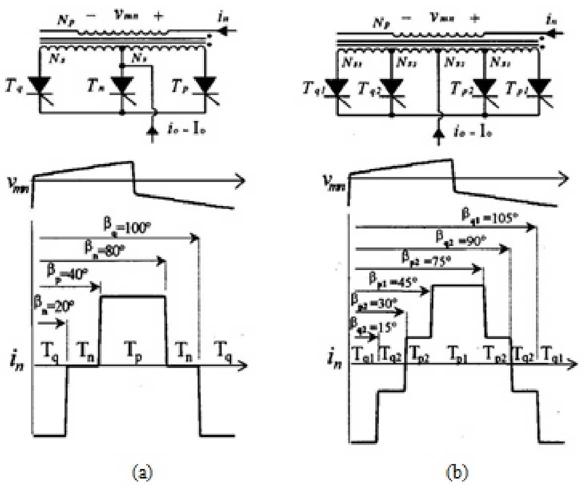

Fig. 7. Auxiliary circuit operation (= 30). (a) 18-pulse. (b) 24-pulse.

In the meanwhile, bridge output voltage is identical to the output voltage of the conventional six-pulse converter as shown in Fig. 2. On the other hand, the output voltage of the proposed scheme is given by

$$v_o = v_d + v_z. \quad (9)$$

Voltage v_z becomes $v_z = (N_s/N_p) v_{mn}$ with T_p turned on while it becomes $v_z = -(N_s/N_p) v_{mn}$ with turned on. Thus, voltage v_z is added to bridge output voltage v_d, resulting in output voltage improvement as shown in Fig. 2.

III. HIGHER PULSE OPERATION

The proposed 12-pulse approach is extended for higher pulse operations such as 18-pulse, 24-pulse, etc. For p-pulse operation, $(p/6)$ auxiliary thyristors are connected to taps on the secondary winding of transformer TF m as shown in Fig. 7. With appropriate firing of the auxiliary thyristors, the wavefoms of injected current i_n have three-level for 18-pulse operation and four-level for 24-pulse operation, respectively. This results in improvement in input currents and output voltages as shown in Fig. 8. To assure natural commutation, the firing order of auxiliary thyristors must be from left to right when voltage v_{mn} is positive, whereas it must be from right to left when v_{mn} is negative. Equations (1)–(9) derived in Section II are also valid for the higher pulse operation.

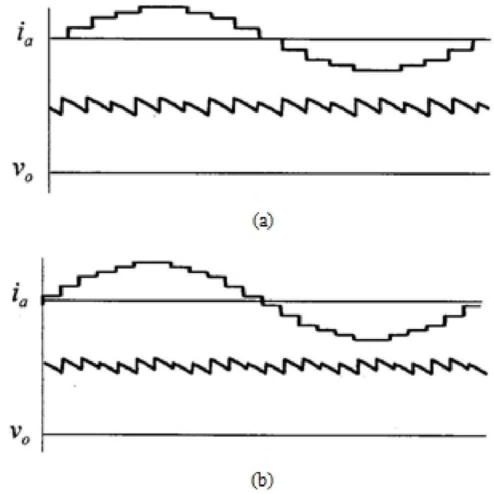

Fig. 8. Input current and output voltage waveforms (= 30). (a) 18-pulse. (b) 24-pulse.

TABLE I
CONTROL METHOD AND PERFORMANCE.

	12-Pulse converter	18-Pulse converter	24-Pulse converter
Turn ratio of TF_m	N_s/N_p=0.929	N_s/N_p=1.233	N_{s1}/N_p=1.383 N_{s2}/N_p=0.475
Optimum firing angle (See Fig. 5)	① $\beta_p=\beta$ ② $\beta_q=\beta+60°$	① $\beta_n=\beta$ ② $\beta_p=\beta+20°$ ③ $\beta_n=\beta+60°$ ④ $\beta_q=\beta+80°$	① $\beta_{q2}=\beta$ ② $\beta_{p2}=\beta+15°$ ③ $\beta_{p1}=\beta+30°$ ④ $\beta_{p2}=\beta+60°$ ⑤ $\beta_{q2}=\beta+75°$ ⑥ $\beta_{q1}=\beta+90°$
Firing order	T_q ⇄ T_p (① →, ② ←)	T_q ⇄ T_n ⇄ T_p (① ② →, ④ ③ ←)	T_{q1} ⇄ T_{q2} ⇄ T_{p2} ⇄ T_{p1} (① ② ③ →, ⑥ ⑤ ④ ←)
Input current THD	14.19%	9.26%	7.42%
Output Voltage RF (α=30°)	8.83%	6.43%	5.45%

Table I summarizes the optimum tap positions, the optimum firing angles, and the firing order of the auxiliary thyristors for the proposed pulse multiplication. It is noted that the degree of freedom of the optimum firing angles for each of the auxiliary thyristors is just one. Fig. 5 shows the optimum firing angles with respect to phase angle to achieve the minimum input current THD for 18-pulse and 24-pulse operation. Input current THDs with the proposed firing strategy are shown in Fig. 6. In the case of 18-pulse (24-pulse) operation, the input current THD for phase angle higher than 170 (167) and lower than 10 (13) rises since the auxiliary thyristors cannot be forward biased in this range.

TABLE II :TRANSFORMER VOLTAMPERE AND COMPONENT RATING (= 90).

			Conventional	Proposed		
			12-pulse converter	12-pulse converter	18-pulse converter	24-pulse converter
Phase Shift Transformer	Pri. Y	V_{rms}/V_{LL}	0.5773	-	-	-
		I_{rms}/I_o	0.8165	-	-	-
	Sec. Y	V_{rms}/V_{LL}	0.5773	-	-	-
		I_{rms}/I_o	0.4082	-	-	-
	Sec. Δ	V_{rms}/V_{LL}	1.0000	-	-	-
		I_{rms}/I_o	0.2357	-	-	-
	VA(%)		100.00	-	-	-
Transformer TF_n	V_{rms}/V_{LL}		-	0.3333	0.3333	0.3333
	I_{rms}/I_o		-	0.3096	0.3355	0.3427
	VA(%)		-	21.11	22.75	23.22
Transformer TF_{pq} or IPT	V_{rms}/V_{LL}		0.6861	0.2078	0.2078	0.2078
	I_{rms}/I_o		0.5000	0.4645	0.5019	0.5165
	VA(%)		24.25	6.60	7.09	7.28
Transformer TF_m	V_{rms}/V_{LL}		-	0.3899	0.3899	0.3899
	I_{rms}/I_o		-	0.9290	1.0070	1.0339
	VA(%)		-	24.77	26.70	27.35
Total VA (%)			124.25	52.48	56.54	57.85
Main Thyristor	V_{peak}/V_{LL}		1.4142	1.4142	1.4142	1.4142
	I_{peak}/I_o		0.5000	1.4645	1.6164	1.6915
	I_{rms}/I_o		0.2886	0.6384	0.6464	0.6499
Aux. Thyristor	V_{peak}/V_{LL}		-	0.2977	0.3892	0.4285
	I_{peak}/I_o		-	1.0000	1.0000	1.0000
	I_{rms}/I_o		-	0.7071	0.5773	0.5000
Capacitor	I_{rms}/I_o		-	0.4645	0.5019	0.5165
	Constant K_p		-	0.3600	0.3184	0.3602

The voltampere ratings of the transformers employed for the proposed pulse multiplication technique are calculated at $\alpha = 90°$ and listed in Table II.

The value "VA(%)" is determined by

$$\mathrm{VA}(\%) = \frac{\frac{1}{2}\sum V_{rms} I_{rms}}{\sqrt{3} V_{LL} I_a (= \text{Input VA})} \times 100 \qquad (10)$$

where I_a is the rms value of the input current. The total voltampere rating is simply the sum of each transformer voltampere, for example, it is 52.48% for the proposed 12-pulse operation.

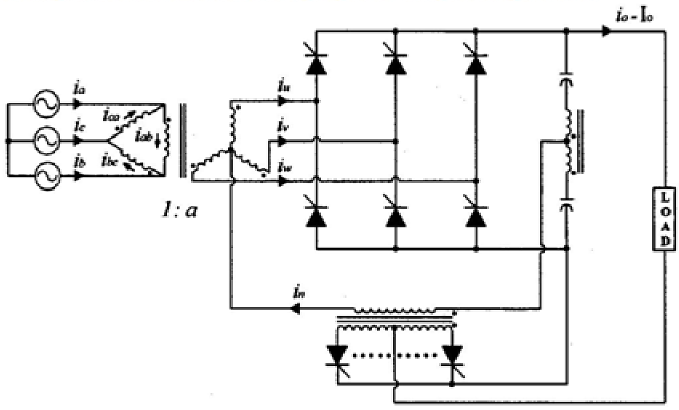

Fig. 9. Alternative scheme for isolation and/or voltage matching.

However, it should be noted that transformer TF_{pq} and transformer TF_m are physically smaller than might be expected because they operate at 360 and 180 Hz, respectively.

In the applications where the operating range of the phase angle is limited below or above 90 , the voltampere ratings of the transformers could be smaller than the listed value. Component ratings of the proposed schemes are also compared with those of the conventional 12-pulse converter. Note that the auxiliary thyristor has a small voltage rating compared to the main thyristor.

A large ripple in voltage $v_{cp}(v_{cq})$ due to small capacitance $C_p(C_q)$ distorts the commutation voltage v_{mn} , which may cause a commutation failure of the auxiliary thyristors. Therefore, capacitance $C_p(C_q)$ should be determined taking into account the permissible level of the ripple voltage. The capacitance can be determined by [4]

$$C_p = C_q = \frac{K_p}{K_v \omega V_{LL}} \qquad (11)$$

where K_v is the ripple factor and K_p is the capacitor constant according to the pulse number.

IV. ALTERNATIVE SCHEME

In some applications such as UPSs or static var compensators (SVCs) where voltage matching and/or isolation is needed, the zigzag transformer for equal distribution of the injected current can be omitted. Instead, the current is injected directly to the neutral of the delta-wye transformer as shown in Fig. 9. The op-erating principle of the alternative scheme shown in Fig. 9 is the same as the proposed scheme shown in Fig. 1. Bridge input cur-rent , and and injected current are identical for both schemes. Therefore, all the equations except (3), (7), and (8) in the previous section are also valid for the alternative scheme. Assuming that the turns ratio of the delta-wye transformer is , the current in the primary delta winding is expressed as

$$\begin{aligned} i_{ab} &= a \cdot i_u + \frac{1}{3} i_n \\ i_{bc} &= a \cdot i_v + \frac{1}{3} i_n \\ i_{ca} &= a \cdot i_w + \frac{1}{3} i_n . \end{aligned} \qquad (12)$$

TABLE III
VOLTAGE AND CURRENT RATING OF THE 1 Y TRANSFORMER.

		Conventional	Proposed		
		6-pulse converter	12-pulse converter	18-pulse converter	24-pulse converter
Pri. Δ	V_{rms}/V_{LL}	1	1	1	1
	I_{rms}/I_o	0.8165 a	0.8450 a	0.8504 a	0.8545 a
Sec. Y	V_{rms}/V_{LL}	a	a	a	a
	I_{rms}/I_o	0.8165	0.900	0.914	0.919

Then, the input current in terms of switching functions,and i_n I_o becomes

$$i_a = i_{ab} - i_{ca}$$
$$= a\left\{\frac{1}{2}i_n(S_{a+} - S_{b+} - S_{a-} + S_{b-}) + I_o(S_{a+} - S_{b+} + S_{a-} - S_{b-})\right\}. \quad (13)$$

It can easily be shown from (13) that the input current of the alternative scheme has the multipulse characteristics.

To accommodate the injected current i_n, the kilovoltampere rating of the $\Delta - Y$ transformer needs to be slightly increased. Table III shows the voltage and current rating of each winding of the transformer. Therefore, for the proposed 12-pulse, 18-pulse, and 24-pulse operation, the kilovoltampere rating of the $\Delta - Y$ transformer is increased 6.86%, 8.05%, and 8.42% compared to the conventional six-pulse operation.

VI. CONCLUSION

In this paper, a new pulse multiplication technique based upon the six-pulse thyristor converter has been introduced. The proposed scheme characterized in Fig. 1 does not necessitate phase-shifting transformers. Instead, transformers rated around 50% of the input power are employed. The proposed schemes also do not have the current unbalance problem unlike the multipulse technique based on parallel connection of bridges.

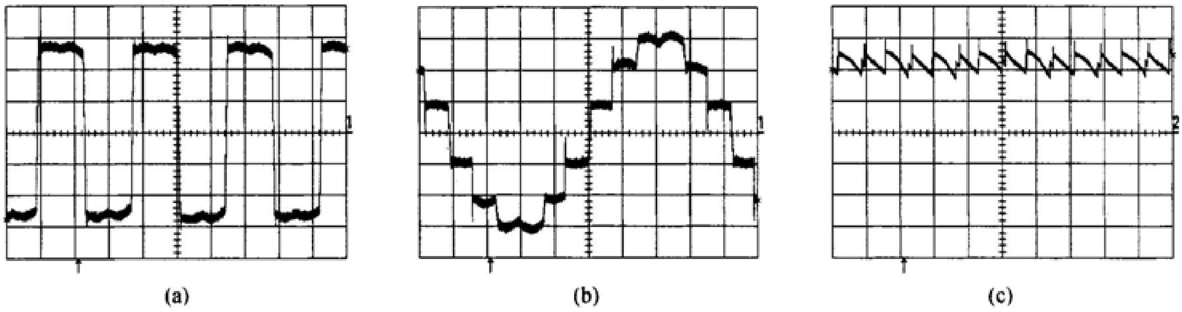

Fig. 11. Experimental waveforms (18-pulse). (a) Injected current i . (b) Input current i . (c) Output voltage v . Scaling: 2 A / div; 100 V/div; 2 ms/div.

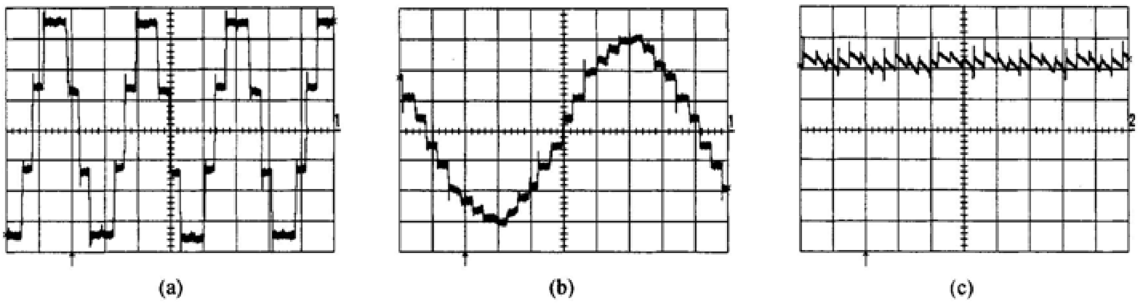

Fig. 12. Experimental waveforms (24-pulse). (a) Injected current i . (b) Input current i . (c) Output voltage v . Scaling: 2 / div; 100 V/div; 2 ms/div.div.

Optimum firing angles for minimum input current THD have been provided over the whole range of phase angle between 0 and 180 . Design parameters such as optimum tap positions of auxiliary thyristor and component ratings have been obtained. Further pulse multiplication such as 30-pulse, 36-pulse, etc., is possible with the proposed technique. The experimental results validated the proposed pulse multiplication technique.

REFERENCES

[1]R. Yacamini and J. C. de Oliveira, "Harmonics in multiple converter sys-tems: A generalized approach," Proc. IEEE, pt. B, vol. 127, pp. 96–106, Mar. 1980.

[2]S. Miyairi et al., "New method for reducing harmonics involved in input and output of rectifier with interphase transformer," IEEE Trans. Ind, Applicat., vol. IA-22, pp. 790–797, Sept./Oct. 1986.

[3]J. Arrillaga and M. Villablanca, "24-pulse HVDC conversion," Proc. Inst. Elect. Eng., pt. C, vol. 138, no. 1, pp. 57–64, Jan. 1991.

[4]S. Choi, J. Oh, and J. Cho, "Multi-pulse converters for high voltage and high power applications," in Proc. IPEMC 2000, Beijing, China, Aug. 2000, pp. 1019–1024.

[5]S. Choi, B. Lee, and P. Enjeti, "New 24-pulse diode rectifier systems for utility interface of high-power ac motor drives," IEEE Trans. Ind. Applicat., vol. 33, pp. 531–541, Mar./Apr. 1997.

[6]D. J. Perreault and J. G. Kassakian, "Effects of firing angle imbalance on 12-pulse rectifiers with interphase transformers," IEEE Trans. Power Electron., vol. 10, pp. 257–262, May 1995.