Reduction of Harmonic Current Using 12-Pulse AC/DC Power Conversion System with Delta Modulated PWM Trapezoidal Voltage

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Abstract

This work involves the design and improvement of a 12-pulse ac/dc power conversion system circuit with trapezoidal voltage by delta modulated PWM inverters to reduce harmonic current. The process can be divided into three stages. The first stage encompasses design and experiment of delta modulated PWM. The design circuit has RC hysteresis as a component. In addition, signal PWM harmonics can be controlled by adjusting RC hysteresis to eliminate harmonics. Even though this is similar to standard PWM Inverter, the delta modulated is very economical compared to a standard type. The second stage concerns the design of 6-pulse ac/dc power conversion system with trapezoidal voltage source. As a result, this can reduce current harmonic at the order 5 th, 7 th, 11 th, and 13 th with design and implementation trapezoidal voltage. The experiment shows that trapezoidal voltage can reduce total harmonic current distortion (THDi) by 15.60%. The final stage concerns the design and simulation by computer of 12-pulse converter system circuit which is a combination of the first two stages integratied with design and improvement of 12-pulse converter connected to the secondary winding of Δ/Δ/Y transformer. Applying trapezoidal voltage improves input current waveform from the transformer. This can reduce total harmonic current distortion (THDi) by 14%, at harmonic spectrum order 11^{th}, 13^{th}, 23^{rd}, 25^{th},, 35^{th}, 37^{th}, 47^{th} and 49^{th}, of 12-pulse converter to be nearly sine wave form. Furthermore, another benefit is that the system is designed such that it works similar to a UPS, and thus can account for electricity drop.

Keywords: Trapezoidal Voltage, 12-pulse-converter, Delta Modulated PWM Inverter, harmonic Current.

1. Introduction

Static pulse-width-modulated (PWM) inverters are frequently found in variable-speed ac motor drives. Several modulation strategies have been developed. One of the most widely used, due to its simplicity, is the sinusoidal modulation [1]. Having many reported cases, harmonic current is greatly found in industrial factories. This indicates problems in the power quality of electricity used. Power loss in electric generators, power loss in transmission line systems and power loss in transformers as well as electromagnetic interference (EMI), is produced as a result of harmonic current arising from installed devices such as power converters, power inverters, electroplating equipincnt, welding machines, and induction furnaces. These devices normally contain power electronics such as power diode-rectifiers used to convert alternating current (AC) to direct current (DC), which produce harmonic current at the order 5 th, 7 th, 11 th, and 13 th, respectively. The number of uses of such devices increase according to factories' technological advancements.

Concerning harmonic current problem in Thailand, the electricity committee has considered power quality as an important part of the electricity system. Electric Generating Authority of Thailand (EGAT), Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA) have installed inductors and capacitors as a detuned filter. It is found that harmonic current is not totally taken out from the system.

One alternative method to reduce harmonic current that can perform betters than detuned filters is to improve a 6-pulse converter to be a 12-pulse ac/dc power conversion system [2] as seen in Fig.1. Application of an active filter is proposed by [3] via current compensation. To make input current primary transformer more nearly a sine wave form, this paper introduces the trapezoidal voltage application for 12-pulse converter to reduce harmonic current.

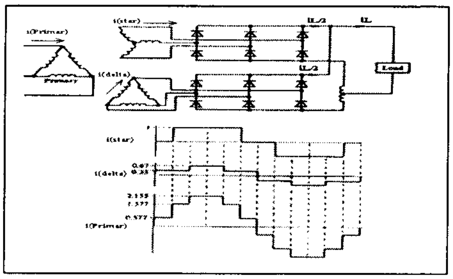


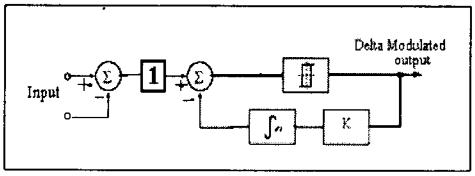
Fig.1 Conventional 12-pulse power conversion

2. Delta modulation PWM: primary concept

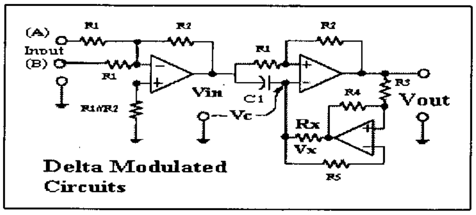
Delta modulation (DM) offers the opportunity of on-line harmonic minimization of pulse width modulated (PWM) inverter. Fig.2a shows delta modulation PWM block diagram, corresponding to delta-modulated circuits, Fig.2b which consists of a quantizer-comparator and integrator. The integrator performs the function of input signal estimation from the output signal [4]. The output signal PWM is obtained, Fig.2c and Fig.2d, having frequency switching (f_m) for input signal (when using Rx = 130 kΩ and C1= 0.045 μF). Experimental results of Vin (Vm.sin ωt) and Vout (delta modulate PWM) follows the expression:

$$f_m = (Ix/4\Delta VxC_1)[1-(\omega V_m C_1/I)^2\cos^2\omega t] \quad \textbf{(1)}$$

f_m = Output frequency switching (Hz)
ΔVx = Hysteresis voltage (V)
V_m = Command input voltage (V)
Ix = Current through capacitor (A) = V_x/R_x



(a)



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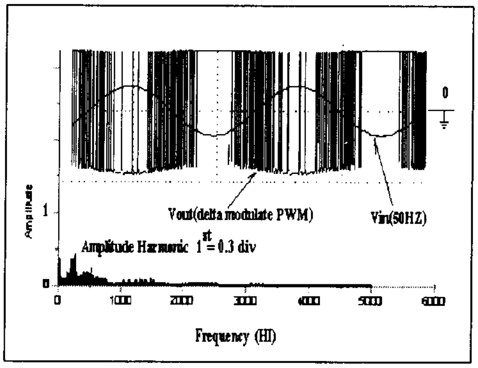

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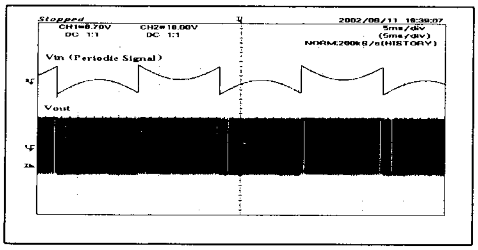


(d)

Fig.2 Delta modulation PWM (a) block diagram (b) circuit system (c) output signal delta modulation PWM when having sinusoidal wave input (d) output signal delta modulation PWM when having periodic wave input

3. Technical design of source of trapezoidal voltage

Signal-mixing technique between sine wave and trapezoidal wave is performed and the result is a periodic waveform. However, when the utility power system recovers from the interruption, the command to the inverter is replaced with the wave-shaping voltages to be trapezoidal waves. Equation (2) is followed and corresponds to the block diagram (Fig. 3). Fig.4 reveals experimental signal mixing of the block diagram when applied with equal amplitudes.

$$F[trap(\omega t)] = f[\sin(\omega t)] - f[Periodic(\omega t)] \quad (2)$$

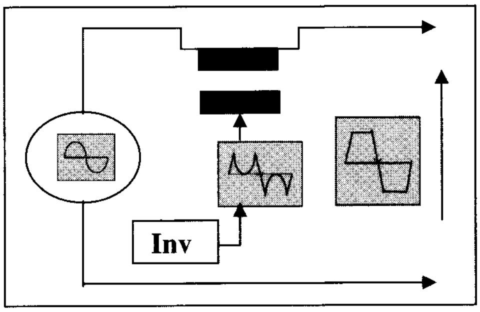


Fig. 3 Signal mixing of the block diagram

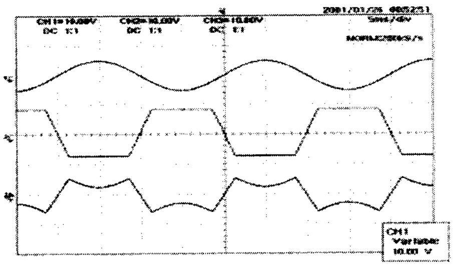
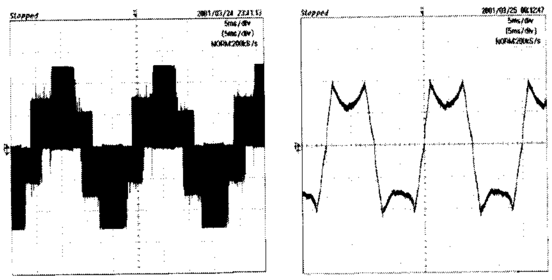


Fig.4 Experimental waveform Input-Output signal mixing

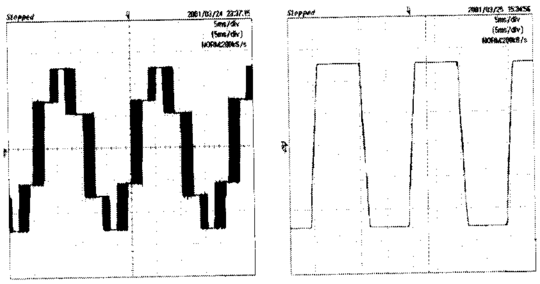
4. Testing inverter having trapezoidal voltage

Trapezoidal voltage is generated by inverter circuit system that contains sine-voltage signal sensor, and phase lock loop (PLL). Under normal state, PLL is employed to synchronize the wave-shaping voltage with the utility sinusoidal voltage. With freely run PLL, the output is consecutively 50Hz trapezoidal voltage. Notably, delta modulated PWM is operated when command input comes from Fig.3. PWM is then connected to a power drive circuit as given in Fig.5 and Fig.6.



(a) (b)

Fig.5 Experimental waveform Periodic voltage (a) before and (b) after filtered



(a) (b)

Fig.6 Experimental waveform Trapezoidal voltage (a) before and (b) after filtered

5. Comparing harmonic current for 6-pulse ac/dc power conversion.

Experimental testing under the same load having capacity 250VA, the comparison can therefore be made between using sine wave voltage source (Fig.7) and trapezoidal voltage source (Fig.9). From trial experiments, it is found that the best trapezoidal voltage source should have 1ms rising time and 1ms falling time with 30 degrees delay offset between phase-to-phase as shown in Fig.9. The main reason for such condition is that the input 6-pulse converter current will be nearly a sine wave form. Further, this causes total harmonic current distortion (%THDi) to be reduced by 15.6% (compare Fig.8 and Fig.10).

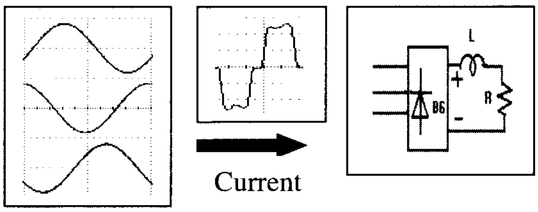


Fig. 7 Input current when using sine wave voltage source

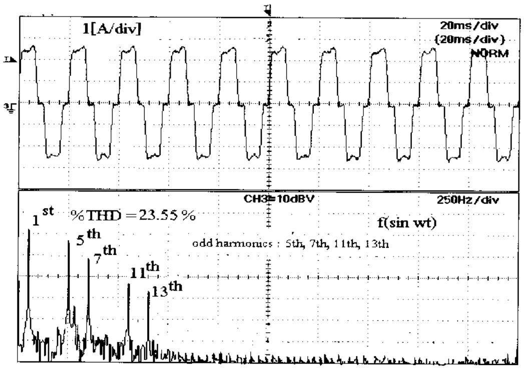


Fig. 8 Experimental Spectrum that generates harmonic current when using sine wave voltage source

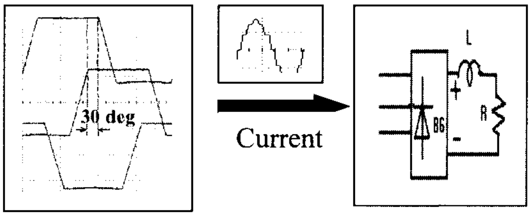


Fig. 9 Input current when using trapezoidal voltage

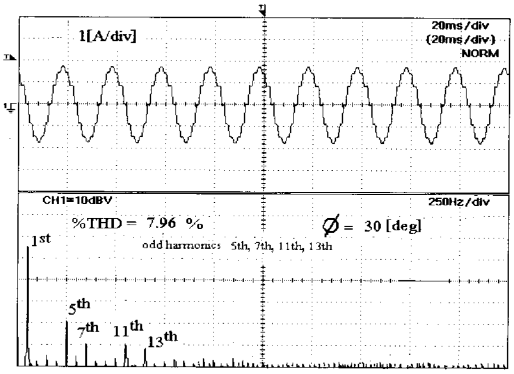


Fig. 10 Experimental Spectrum that generates harmonic current when using trapezoidal voltage source

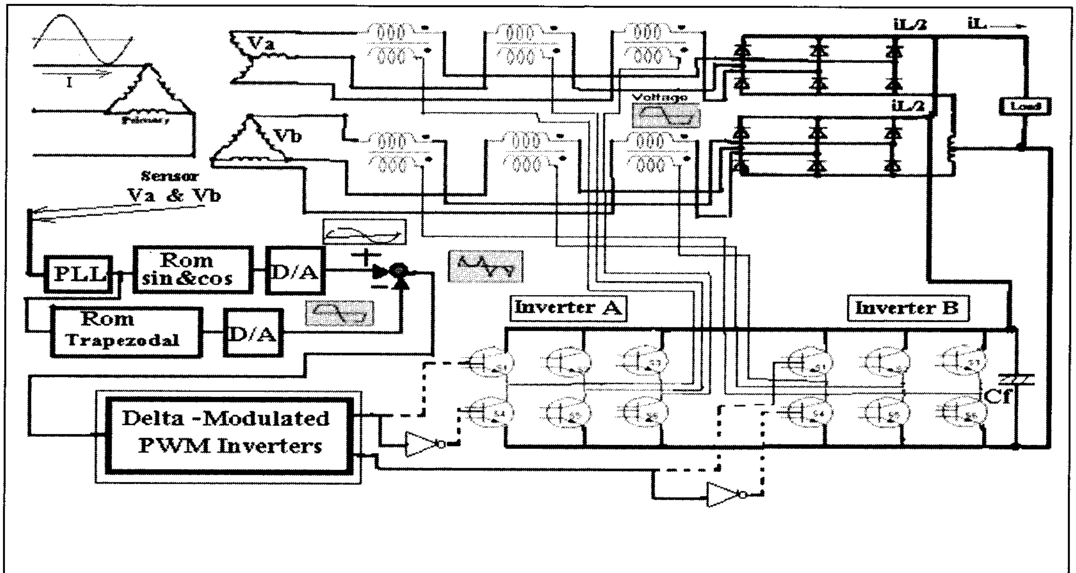


Fig.11 12-Pulse ac/dc power conversion system with applied trapezoidal voltage source system

6. 12-Pulse ac/dc power conversion system with applied trapezoidal voltage

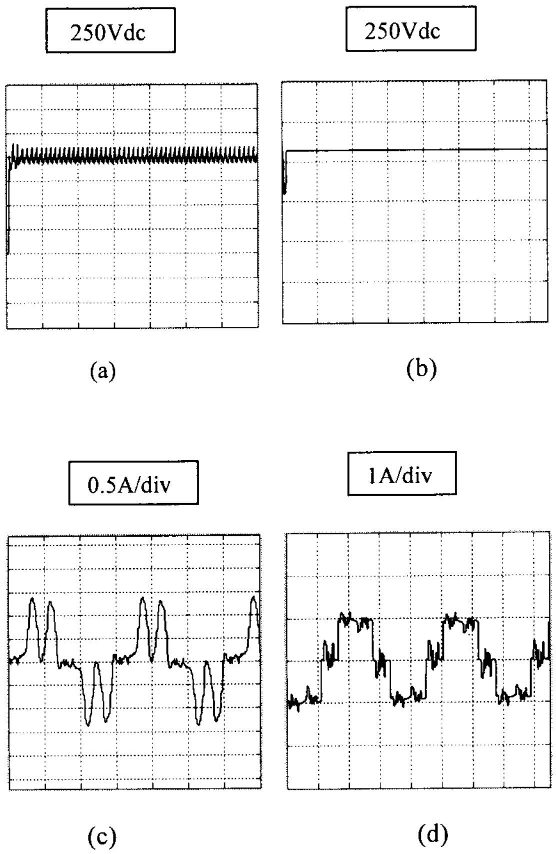
The ac supply is from a transformer having two secondaries. star-connected and delta-connected. In this manner, the three-phase voltage supplying the two bridges is displaced by a phase angle of 30 degree. Hence the two six-pulse output are symmetrically displaced to give an overall twelve-pulse output [3]. It has been known that total harmonic current distortion from 12-pulse converter is better than that from 6-pulse converter. When trapezoidal voltage is applied, total harmonic current distortion is further improved as shown in the diagram (Fig.11). It consists of a combination of a double-series diode rectifier rated at 250VA and Delta modulation PWM inverter with a peak voltage and current rating of 250VA. A clear advantage is from using DC link from output DC voltage of 12-pulse ac/dc power conversion system (double-series diode rectifiers) the dc terminal of the diode rectifiers and the applied trapezoidal voltage from a common dc bus equipped with an electrolytic capacitor[3]. The ac terminal of each Delta modulation PWM inverter is connected in series with a power line of Δ/Δ/Y transformer.

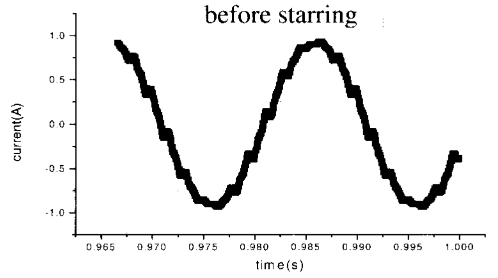
7. Computer Simulation of 12-pulse ac/dc power converter system with applied trapezoidal voltage

This study uses the computer program MatLab SimuLink to simulate Fig.11. A comparison study was conducted between a conventional 12-pulse converter and a 12-pulse power converter with applied trapezoidal voltage. From Fig.12, it is learnt that input current primary transformer is nearly sine wave form Fig.12(e), against Fig.12(g). From this experiment, relevant parameters are given in Table 1.

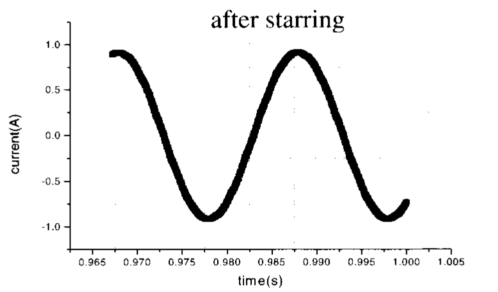
Table 1. Parameters of the 12-pulse ac/dc power converter system with applied trapezoidal voltage

Transformer: 1kVA,50Hz,Δ/Δ/Y,380/220/220V	
Δ-Pri:R1(pu),L1(pu):	0.0025pu,0.08pu
Δ-Sec:R2(pu),L2(pu):	0.0025pu,0.08pu
Y-Sec:R3(pu),L3(pu):	0.0025pu,0.08pu
Ratio series transformer: (a=1:1)	
R-L Load:	250ohm,100mH
Sw-frequency-delta-modulation(fsw): 10kHz	
IGBT devices:[Fall time Tf (1μs)and tail time Tt(2μs)] Snubber-circuit: (Rs=100Ω),(Cs=1μf)	
LC-Filter: 300μH,20μF	
DC Bus Output voltage: 250Vdc	

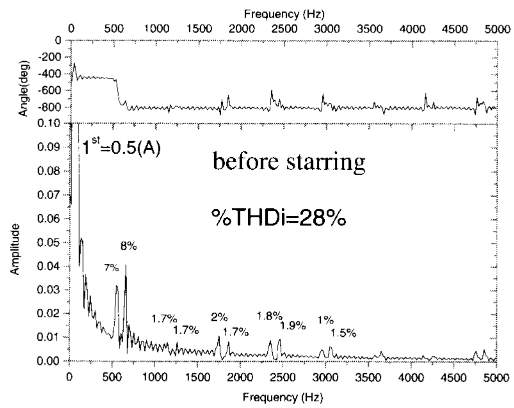




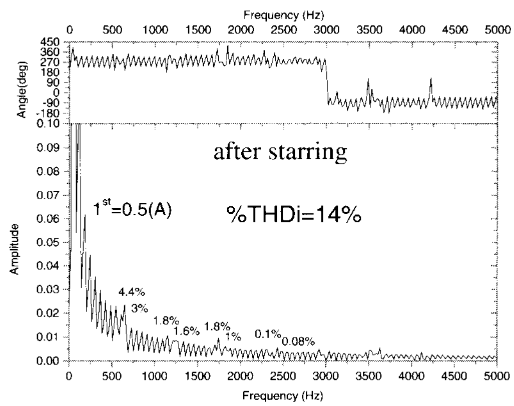
(e)



(f)



(g)



(h)

Fig. 12 Simulation result: waveform (a) before starring DC-Bus output-voltage(50V/div) (b) after starring DC-Bus output-voltage (100V/div) (c) before starring the output-current secondary winding (0.5A/div) (d) after staring the output-current secondary winding (1A/div) (e) before starring current into primary winding (f) after starring current into primary winding (g) Spectrum that generates harmonic current when using sine wave voltage source (h) Spectrum that generates harmonic current when using trapezoidal voltage source

Software ORIGIN^{TM} 5.0 (Microcal) is used to plot simulation results for data analysis and technical graphics. DC bus output voltage (Fig.12(a)) has a ripple factor of about four percent. After applied trapezoidal voltage source, the ripple factor is reduced to almost zero percent (Fig.12(b)). This increases the efficiency of the power converter system. Current waveform outputs from secondary winding transformer is displayed in Fig. 12(c). The shape is very far from a sine wave form. Trapezoidal voltage source is applied and the output current waveform Fig. 12(d) is greatly improved. In a similar way, trapezoidal voltage source applied to power converter system helps to improve input current waveform from primary winding in Fig. 12(e) to Fig. 12(f). A comparison can easily be seen from the figures. This simulation of total harmonic current distortion (THDi) can be reduced by 14 percent (comparing Fig. 12(g) and Fig. 12(h)) at harmonic spectrum order 11^{th}, 13^{th}, 23^{th}, 25^{th},, 35^{th}, 37^{th}, 47^{th} and 49^{th}.

8. Concluding Remarks

The experimental study involves with design, testing, and simulation of a 12-Pulse ac/dc Power Conversion system with applied trapezoidal voltage. Study conclusions and remarks can be summarized as follows:

1. Delta modulated PWM circuit from 12-pulse converter with applied trapezoidal voltage helps cost savings.

2. With applied trapezoidal voltage source to 6-pulse converter, total harmonic current distortion can be reduced by 15.6%. From Fig.8 and Fig.10, the best trapezoidal voltage source should have 1ms. rising time and falling time with 30 degrees delay offset between phase-to-phase.

3. From simulation, by applying trapezoidal voltage, a 12-pulse converter can decrease the total harmonic current distortion (%THDi) by 14%. This process can be repeated to get even lower total harmonic current distortion, i.e. 12-pulse converter to 24-pulse converter.

4. Size of capacitor filter output DC voltage is smaller because trapezoidal voltage helps to lessen percent ripple factor (Fig.12(b)).

5. A 12-pulse converter is very beneficial when line voltage from transmission line is interrupted. The reason is from signal-mixing as previously discussed (Fig.3).

9. Acknowledgements

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10. References:

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