Improved Switching Frequency in Delta Modulated Inverter for UPS Applications

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Abstract:The concept and results of a simple constant switching frequency delta modulation scheme suitable for DC-AC power conversion in uninterruptable power supply (UPS) applications are presented. Unlike the traditional delta modulation scheme, the scheme has a well defined harmonic spectrum, resulting in a simple filter design and reduced radio interference.

Keywords: Delta modulation, Uninterruptible Power Supplies ,DC-AC Power conversion ,Radio interference.

1. INTRODUCTION

Uninterruptible Power Supplies(UPS's) are used to interface critical loads such as computers and communication systems to the utility system. The output voltage of the UPS inverter is required to be sinusoidal with minimum total harmonic distortion. This is usually achieved by employing of pulse-width modulation(PWM) scheme and a second-order filter at the output of the inverter. One way of achieving a "clean"sinusoidal load voltage is by using a delta pulse width modulation scheme[1]-[2], which possess such advantage as the inherent *V/f* feature and attenuation of lower order harmonics. In [2], the reported hysteresis band modulation is implemented only in a single-phase PWM inverter. Then in [3] three-phase implementation was carried out with outline of an analytical approach for hysteresis band modulation in static inverter applications.

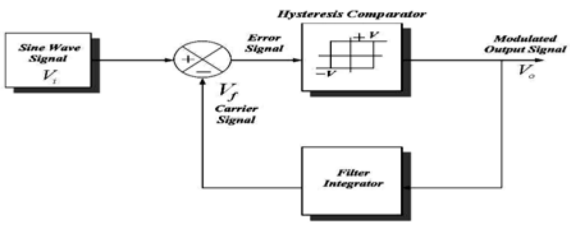
However, the problem in fixed hysteresis band delta modulation technique is a variation of switching frequency over the fundamental period of the modulation signal. This causes more subharmonics and higher the load current ripple when comparing to the fixed PWM switching frequency. For UPS applications, the output filter has to be designed to copy with a broad band harmonic. However, attempts have been made to develops adaptive hysteresis band and synchronization techniques for these PWM inverters [4],[5].

The synchronized hysteresis modulation technique by adding synchronizing pulses to the error signal of feedback loop of the hysteresis modulator in order to fix the switching frequency. The technique allows the solution to the unbalance voltages in three-phase systems. However, the circuitry is very complex, loss the commutation cycles during slope transition and loss of synchronism following order to slope transition. Also, the voltage gain is low.

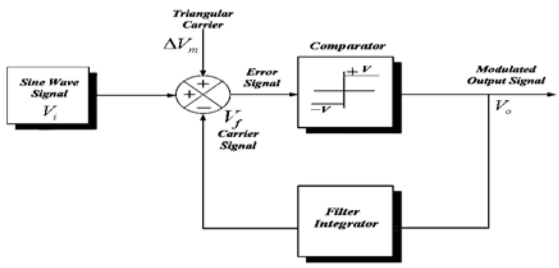
With the proposed technique, a simple constant switching frequency delta modulator by adding a triangular wave to the sinusoidal reference and forcing the carrier signal output to follow the sum of these two signals is proposed in this paper.

2. PRINCIPLES

The block diagram of a conventional delta modulator [DM] is shown in Fig.1(a). Two basic components of the modulator are the hysteresis comparator and the filter integrator. For inverter operation the input to the modulator is a sine wave to produce an error signal. The error signal is quantized by the hysteresis comparator producing the modulated output which is the switching signal for the inverter.



(1a)



(1b)

Fig.1. Block diagram of existing delta modulator. (1a) Conventional DM (1b) Proposed DM.

The block diagram of the new scheme is shown in Fig.1(b). The problem of variable switching frequency is solved by introducing a triangular carrier is inserted into the conventional block diagram of the DM. To control the switching frequency constant, the proposed modulator operates by forcing the carrier signal (V_f) to follow a reference sinusoidal signal with a superimposed carrier ($V_i + \Delta V_m$). Switching angles are obtained by intersecting the reference signal, consisting of a sinusoidal signal with superimposed triangular carrier ($V_i + \Delta V_m$). Switching angles are obtained by intersecting the reference signal, consisting of a sinusoidal signal with superimposed triangular carrier ($V_i + \Delta V_m$), and of a carrier signal, representing the estimated load current. As a result, the PWM switching frequency to be constant for all PWM pulses as shows in Fig. 2.(a),(b). Therefore, the modulator operates in a manner comparable to hysteresis control, with the hysteresis band imposed ΔV_m . However, the switching frequency is also fixed by the frequency of ΔV_m which the lead to constant switching frequency operation, unlike the hysteresis bang-bang control. In Fig.2, the operation of the modulator is illustrated for various modulation indices at chosen base frequency($f_s = 50$ Hz). Fig.2.(c),(d). Shows the simulation results of control signal and DM-PWM pattern for vary modulation indices. Modulated reference ($V_i + \Delta V_m$) and indeterminate states should be avoided. This requires that, in terms of magnitudes, the following condition apply at all times

$$\text{slope } (V_f) < \text{slope } (V_i + \Delta V_m) \qquad (1)$$

This ensures that intersections will always exist to generate the PWM pattern for output voltage, for which in order for the modulating scheme to operate properly multiple crossings betw carrier signal (V_f) andthe modulated

In order for the modulating scheme to operate properly multiple crossings between the carrier signal and the

$$\text{slope}\,(V_f) = \pm \frac{1}{RC} V_{ol} \qquad (2)$$

where V_{ol} is the output voltage level of the modulator. The minimum value of the slope for the waveform ($V_i + \Delta V_m$) is

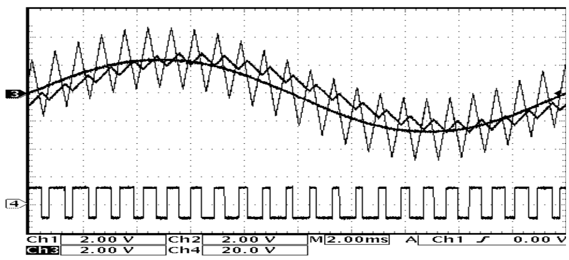
$$\text{min slope } (V_i + \Delta V_m) = \text{slope } (\Delta V_m) - \text{slope } (V_i)$$

$$= 4 f_m \Delta V_m - 2\pi f_s V_s \qquad (3)$$

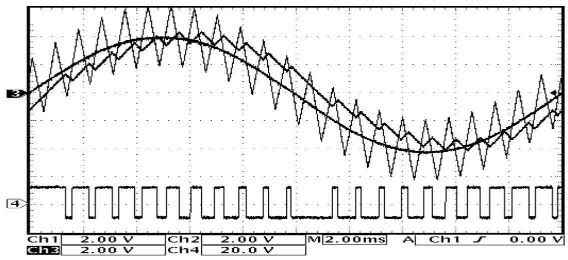
Combining (1),(2) and (3) yields the following relation:

$$\Delta V_m f_m \geq 0.25 \left[\frac{1}{RC} V_{ol} + 2\pi f_s V_s \right] \qquad (4)$$

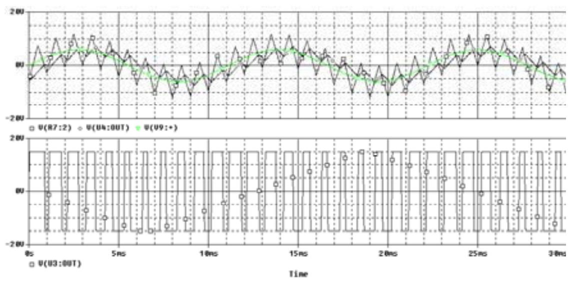
where V_s and f_s are the maximum amplitudes for control signals and base frequency respectively.



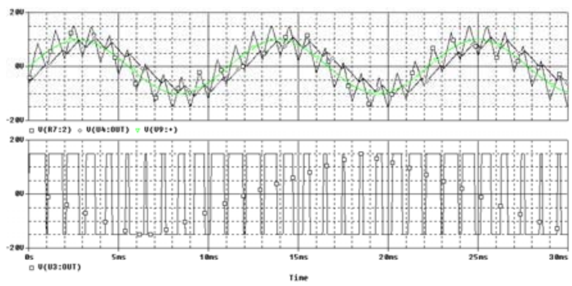
(2a)



(2b)



(2c)



(2d)

Fig.2. Control signal and DM-PWM pattern for vary modulation indices at base frequency (f_s) of 50Hz, (a) *M*=0.6 (b) *M*=0.8 ; ΔV_m =.5V , f_m =1KHz and RC = 2.65 ms.

3. EXPERIMENTALS

In order to verify the feasibility and performance of the modulator, the proposed DM modulator was tested on a 1-ϕ IGBT full bridge inverter having dc link voltage V_{dc}=100V as shown in Fig.3. The load consists of inductance of 15 mH, and a resistor of 8 Ω in series connection. The fundamental frequency is 50 Hz. The maximum switching frequency for fixed hysteresis band is the same as for the proposed delta modulation of 1 KHz. This value is chosen in order to observe clearly different performance for both technique.

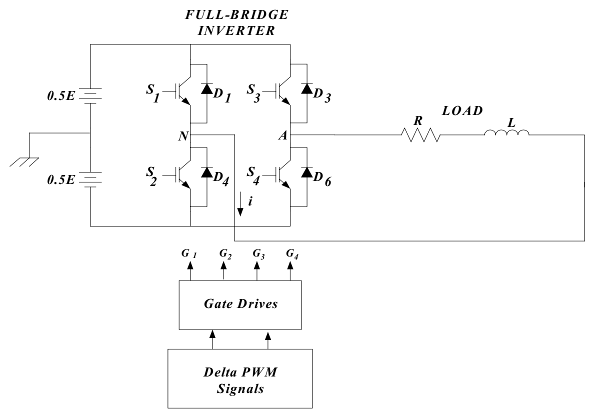
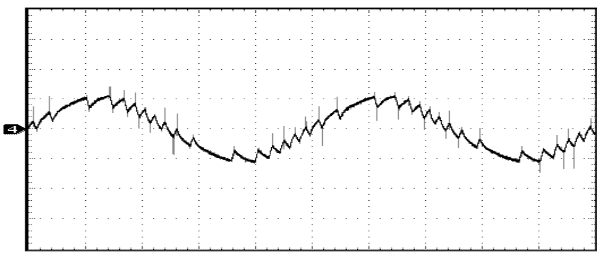
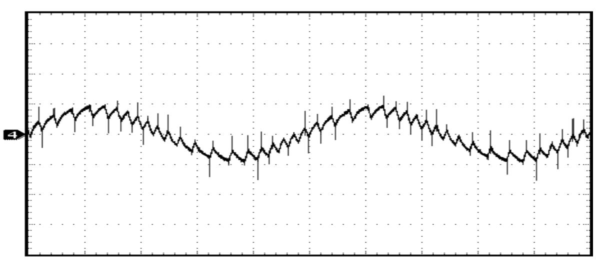


Fig.3. Full-bridge PWMinverter

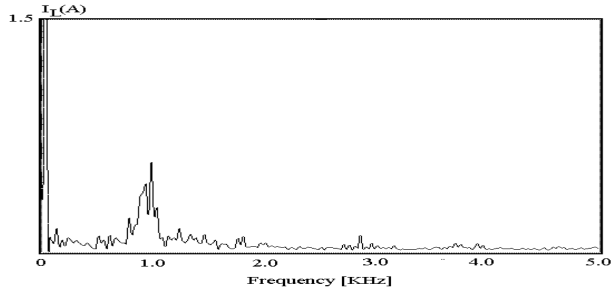


(4a)

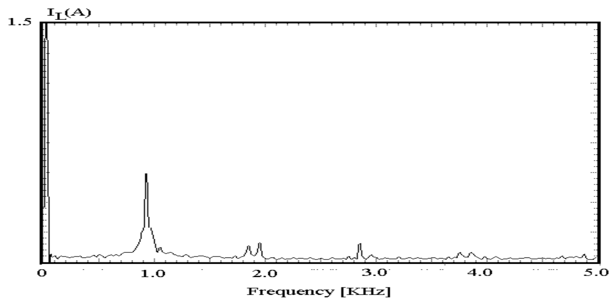


(4b)

Fig. 4. Experimental waveform of the output current of delta modulation technique (4a)Conventional DM (4b) Proposed DM



(5a)



(5b)

Fig.5. Frequency spectrum of output current (5a)Corresponding harmonic current spectra of conventional DM, (5b)Corresponding harmonic current spectra of proposed DM

Fig.4(a) and 5(a), for conventional DM, shows the load current waveform and corresponding current spectra for experiments. The percentage of THD of load current is approximately 44.17 %.

Fig.4(b) and 5(b), for proposed DM, shows the load current and corresponding harmonic current spectra. Clearly, this proposed technique give smaller load current ripple when compared to conventional delta modulator. The percentage of THD of load current is approximately 30.15 % which is significantly less than that of the conventional DM technique.

Fig.6(a) show the comparative THD of the output voltages between both scheme with a given *LC* filter and switching. At low modulation index, %THD for both scheme are not of significant difference whilst at higher modulation index, the proposed scheme offers the considerably less a percentage of THD.

This can reduce the size of the filters. Cleary, at higher modulation index, a conventional DM gives lager a percentage of THD and tend to increase in THD. This results from the existence of the lower switching frequency of PWM pulse; and eventually transition into square wave operation mode for a very high modulation index.

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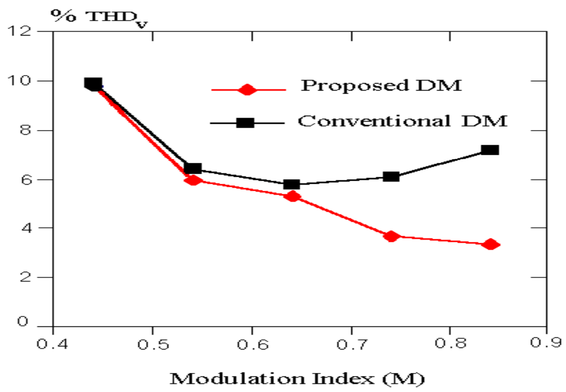
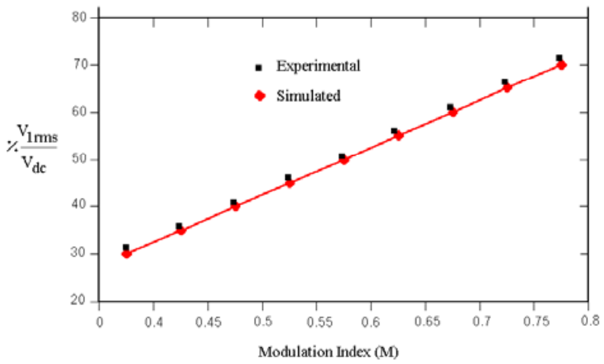
Fig.6(b), illustrate the relationship between modulation index and rms fundamental output voltage relative to dc voltage. The experimental and simulated results are in a good agreement. This has proved effective for designed circuit. From Fig.6(b), it is clear that the linearly proportional of fundamental output voltage to modulation index and the modulation index is linearly proportional to reference voltage as shown in [6]. This is a good advantage for closed loop control of output voltage.



(6a)



(6b)

Fig.6(a). A comparative of percentage of total harmonic distortion between conventional DM and proposed DM.

Fig.6(b). A variation of rms fundamental voltage with modulation index for proposed DM.

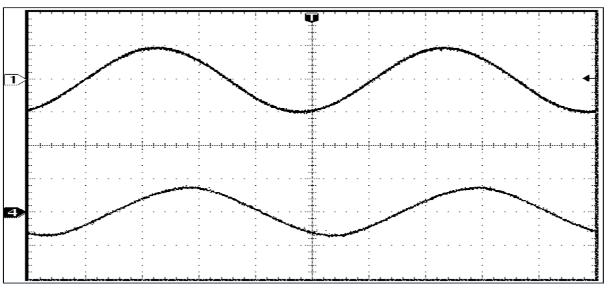


Fig.7. Experimental results of proposed delta modulation technique.
:filtered output voltage waveform (Upper trace)
:filtered output current waveform (Lower trace)

Fig.7 illustrates inverter output voltage and load current with appropriate filter. The %THD of load voltage is approximately 4.1%. This figure demonstrates the effectiveness of the proposed DM in producing near sinusoidal quality load voltage and currents for UPS applications. Experimental results confirming the feasibility of the proposed modulator.

4. CONCLUSION

The proposed delta modulation technique offers the following advantage that make it attractive for UPS applications:

(1) fixed switching frequency.

(2) very simple circuit implementations.

(3) the harmonic content of the inverter output voltage can be controlled using the modulator parameters, and

(4) it provides a simple means where by the output voltage can be regulated.

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