A Comparative Study of PWM Control Techniques for Multilevel Cascaded Inverter

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Abstract - The emergence of multilevel converters has been in increase since the last decade. These new types of converters are suitable for high voltage and high power application due to their ability to synthesize waveforms with better harmonic spectrum. Numerous topologies have been introduced and widely studied for utility and drive applications. Amongst these topologies, the multilevel cascaded inverter was introduced in Static Var compensation and drive systems. This paper investigates several control techniques applied to the Multilevel Cascaded Inverter in order to ensure an efficient voltage utilization and better harmonic spectrum. Computer simulation results with Matlab will be presented and discussed together with a comparative study of the different control techniques of multilevel cascaded inverter.

I. INTRODUCTION

Recently, for high power application multilevel inverter are widely used such as in static var compensators, drives, and active power filters [1]. The topologies of multilevel inverters are classified into three types the flying capacitor inverter, the diode clamped inverter and the cascaded H-bridge inverter[1], [2]. Amongst these inverters, the flying capacitor has the disadvantage that each capacitor must be charged with different voltage as the voltage level increases. And up to three level, the diode clamped inverter needs a supplementary circuit for capacitor voltage balancing [3], the number of clamping diode and the difficulty of the disposition between the DC link capacitor and the devices increase as the voltage level increases.
Despite the need of separate DC sources , the unbalance DC link voltage problem do not occur in multilevel cascaded inverter [1]. This paper will investigate several control techniques applied to the multilevel cascaded inverter in order to ensure an efficient voltage utilization and better harmonic spectrum. Computer simulation results with Matlab will be presented and discussed together with a comparative study of the different control techniques of multilevel cascaded inverter.

II. MODELING OF MULTILEVEL CASCADED INVERTER

Fig. 1 shows the power circuit of 11 level cascaded inverter composed of five full bridge inverters connected in series on each phase.

For each full bridge inverter the output voltage is given by :

$$V_{oi} = V_{dc}\left(S_{1i} - S_{2i}\right) \qquad (1)$$

And the input dc current is :

$$I_{dci} = I_a\left(S_{1i} - S_{2i}\right) \qquad (2)$$

$i = 1 \ldots 5$ (number of full bridge inverters employed).
I_a is the output current of the cascaded inverter.
S_{1i} *and* S_{2i} are the upper switch of each full bridge inverter.
Now the output voltage of each phase of the multilevel cascaded inverter is given by :

$$V_{on} = \sum_{i=1}^{n} V_{oi} \qquad (3)$$

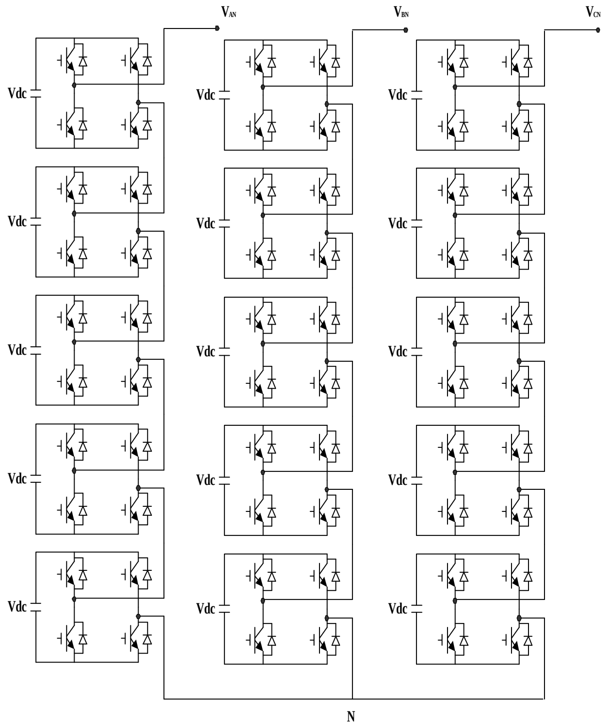

Fig. 1 Power circuit of 11 level cascaded inverter

III. CONTROL TECHNIQUES OF MULTILEVEL CASCADED INVERTER

3.1 Shift PWM technique

This technique uses a number of wave carriers equal to the number of full bridge inverters employed in cascaded inverter structure shifted by 1/(5.fc), where 1/fc is the period of carrier reference [4].
In this technique the frequency modulation index is always multiple of three to have a symmetry in the output voltages.
Fig. 2 shows The SPWM technique for 11 level cascaded inverter and the output voltage is depicted in Fig. 3.
Fig. 4 shows the output voltage spectrum of 11 level cacaded inverter for different frequency modulation index m_f.
In three phase system the frequency modulation index is defined as follows :

$$m_f = \frac{f_c}{f_s} \qquad (4)$$

With $m_f = 3, 6, 9, \ldots$

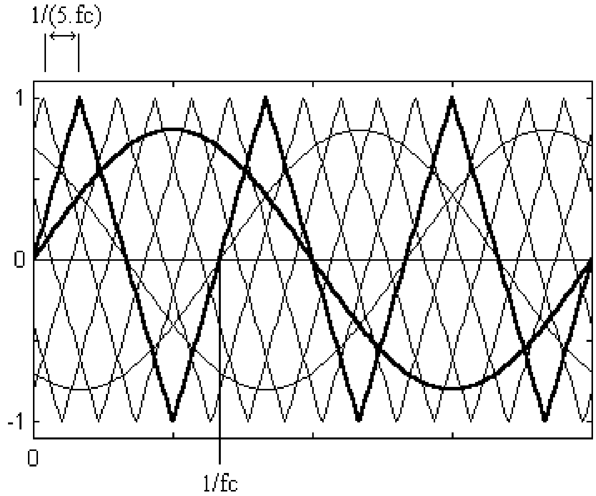

Fig. 2 11 level cascaded inverter shift PWM technique for $m_f = 3$

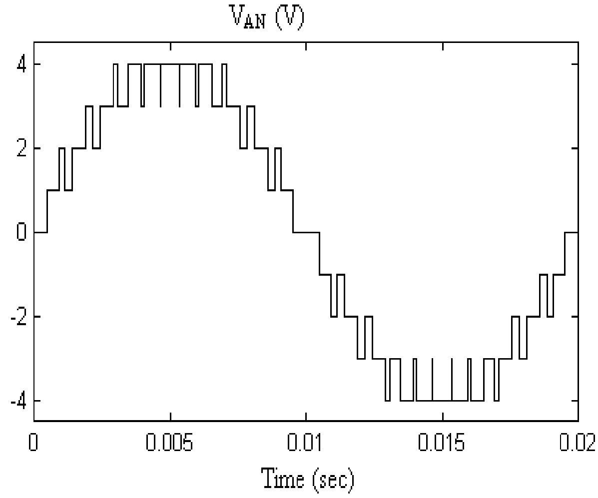

Fig. 3 Line to neutral output votage of 11 level cascaded inverter

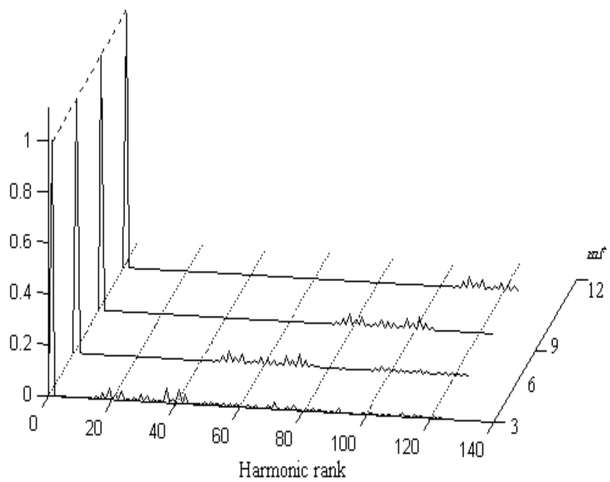

Fig. 4 Output voltage spectrum of 11 level cascaded inverter for $m_f = 3, 6, 9, 12$

3.2 Sinusoidal Natural PWM (SNPWM) technique

Sinusoidal pulse width modulation is one of the primitive technique which was expanded to the multilevel cascaded inverter as shown in Fig. 5.
Fig. 6 shows the output voltage with SNPWM technique for $m_f=3$ and $n=5$

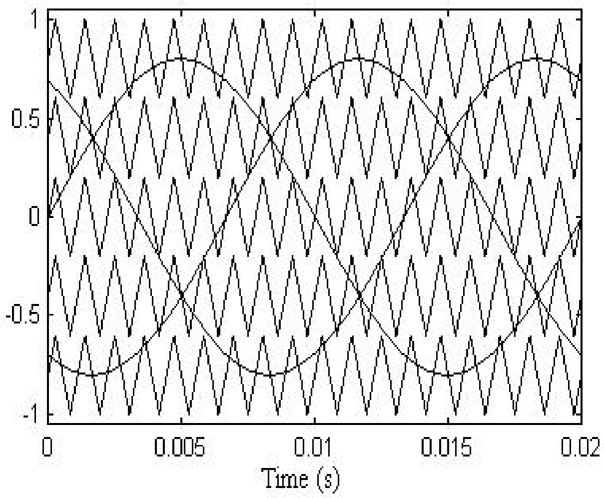

Fig. 5 References and carriers waves for 11 level cascaded inverter.

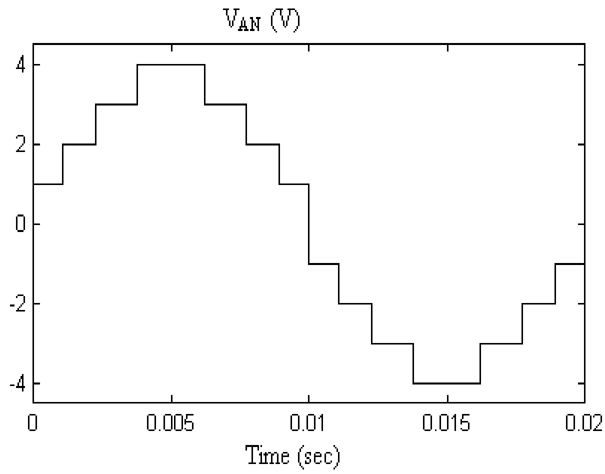

Fig. 6 Line to neutral output votage of 11 level cacaded inverter.

Fig. 7 shows that for the same m_f , the output voltage spectrum of SPWM technique is better than that of SNPWM technique. The SNPWM can be used for very high power application which needs low stress on power devices as IGBTs.

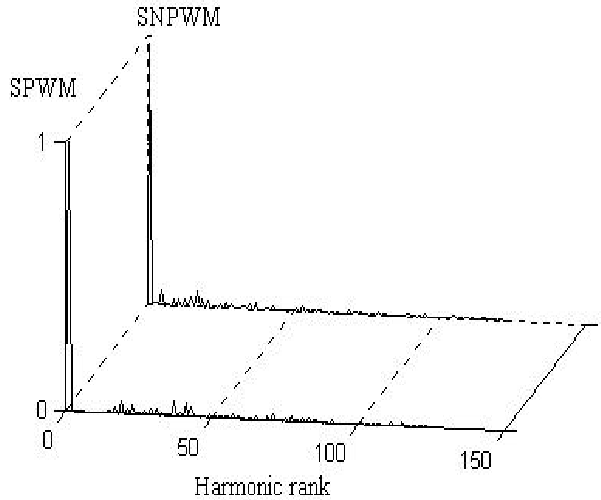

Fig. 7 Output voltage spectrum of both PWM technique for $m_f = 3$.

3.3 Programmed PWM technique

Programmed PWM technique allows the elimination of selected number of harmonics. This method is used because it optimises a particular objective function such as to obtain minimum losses, reduced torque pulsations, selective elimination harmonics, and therefore is the most effective means of obtaining high performance results.
With the equal amplitude of all dc sources, the expression of the amplitude of the fundamental and all harmonics contents are given by :

$$H_n(a)=\frac{4Vdc}{np}\sum_{k=1}^{m}\cos(na_k) \quad \text{for odd } n \quad (5)$$

$$H_n(a)=0 \quad \text{for even } n \quad (6)$$

Where :

Vdc : is the dc voltage supply
m : is the number of dc source and α_k is the optimized harmonic switching angles.

The low-order surplus harmonics must be eliminated, therefore equation (5) shows that m-1 odd harmonics and m-1 non triplen odd harmonics can be eliminated.
The parameters of the programmed PWM can be found by the resolution of the set of nonlinear equations given by equations (5) and (6).
Table.1 gives the switching angles of the programmed PWM for different modulation index (MI).

Table.1 Switching angles

MI	α1	α2	α3	α4	α5
0.5	36.68	50.19	65.39	82.69	91.25
0.6	35.34	46.95	58.57	72.61	87.83
0.7	34.37	44.62	54.14	65.37	77.91
0.8	22.34	39.27	52.68	59.31	70.96

Fig. 8 shows the output voltage with Programmed PWM technique for MI=0.5, and Fig. 9 ilustrates the output line to line voltage spectrum for the same MI.

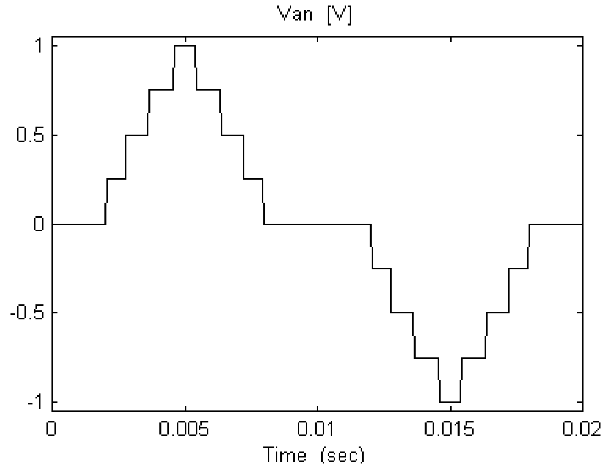

Fig. 8 Line to neutral output votage of 11 level cacaded inverter for *MI=0.5*.

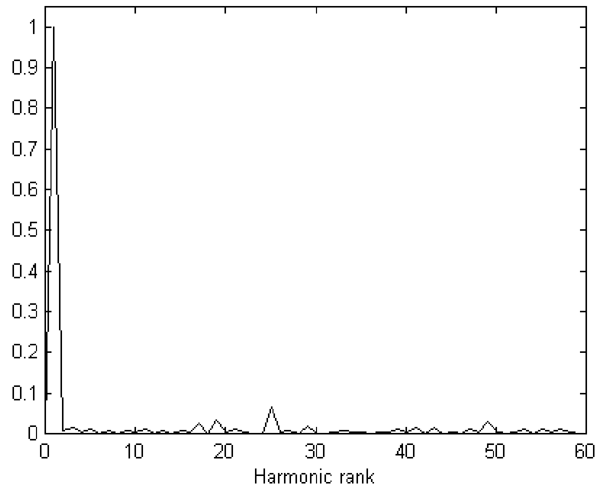

Fig. 9 Output line to line voltage spectrum of 11 level cascaded inverter for *MI=0.5*

This control technique of multilevel cascaded inverter gives good performances and the output voltage spectrum is better when the number of full bridge inverter used increases.

IV. CONCLUSION

This paper has investigated the performance of each technique in terms of output voltage spectrum with low frequency. It is possible to obtain a satisfactory spectral performance with relatively low switching frequency. It can be seen that the SNPWM technique gives poor output voltage spectrum than the SPWM technique, but the programmed PWM is the best one for many applications that need high dynamic performance in high power application. Finally, comparative simulation analysis between the different multilevel cascaded inverter control techniques are given.

V. REFERENCES

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