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A New Modulation Technique for A Three-Cell Single-Phase CHB Inverter with Un-Equal DC-Link Voltage for Improving Output Voltage Quality

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***Abstract*—This paper investigates a new modulation technique for a three-cell single-phase CHB (Cascaded H-Bridge) inverter with un-equal DC link voltage. The proposed PWM technique is verified using Matlab/Simulink. The applied DC-link voltages of inverter are 6 V, 12 V and 24 V respectively (DC-link voltage ratio of 1: 2: 4). The result is compared with the CHB inverter with equal DC-link voltage (using DC-link voltage of 12 Volt). The simulation results show that the output voltage using DC-link voltage ratio of 1: 2: 4 produces 15 levels DC voltage, while equal DC-link can only generate a 7 voltage levels. As the number of level in the output voltage increases, the quality of the voltage improves significantly. This is indicated by the reduction of THD percentage from 13.22 % to 5.265 % that can be seen from the harmonics spectrum of the three-cell CHB inverter using conventional and new PWM. The harmonics spectrum also shown that the output voltage of the three-cell CHB inverter using new PWM is almost free from harmonics, while using the conventional PWM, the 3rd, 5th and 7th harmonics and some higher harmonics are still appeared. Another indicator is carried out by comparing the percentage of low order harmonics content up to the 19th harmonic (950 Hz) of the output voltage. It is noted that there is a significant reduction of the low order harmonics from 3.25 % to 0.518 % achieved using the new PWM method. To sum up, the new modulation technique enables the inverter to produce better output voltage quality.**

***Keywords*—Three-cell single-phase CHB inverter, DC-link voltage ratio, output voltage quality**

I. Introduction

Technical problems are often encountered in a solar panel system while delivering power to supply ac loads through the inverter as the converter from dc to ac power. First, inverter output voltage contains high harmonics that makes the output power is not high (low efficiency). Voltage with high harmonic value will also accelerate damage to transformers and other equipment [1-3]. Second, to produce an inverter output voltage with good voltage quality, a large number of switches are required. This requires a more complicated modulation technique and also a large capacity microcontroller to generate pulses for the switches. Microcontrollers with large capacity are relatively more expensive [4-5].

H-bridge inverter is one of the best inverter topologies for solar panel system [6-7]. H-bridge inverter has a simple structure and can be arranged cascade with other inverters called cascaded H-Bridge (CHB) inverter to be able to produce voltage with better quality. The voltage generated by this inverter depends on the modulation technique used. Modulation techniques can generally be grouped into modulation techniques with high switching speeds such as the Sin-PWM method and the space vector PWM method or modulation techniques with low switching speeds such as the 180 degree conduction technique or the staircase waveform technique [8].

Another alternative is to combine the two modulation techniques with different frequency bases called mixed or hybrid modulation techniques [9]. In addition, Selective Harmonics Elimination (SHE) modulation techniques can also be used and combined with other modulation techniques [10]. Improving inverter performance are also done by modifying the inverter structure in order to produce better quality of the output voltage and reducing the number of switches and other components used. Research with regard to modulation techniques and improvements to the CHB inverter structure has continued to develop in recent years. One of the structures developed is the single phase CHB inverter using 3 cells, 12 switches.

Ko, et al [11] investigated that controlling the inverter using Discontinuous Sin-PWM (DSPWM) modulation technique can increase the reliability of the inverter in producing 7 levels of voltage. This is indicated by the decrease of temperature on the IGBT component and diode hence increase the economical life of the component. Atkar, et al [12] compared the performance of the inverter to produce 7 levels of voltage using multi-carrier sin-PWM method and its variation. Simulation results show that hybrid method can improve the output voltage with relatively low THD value. Negash and Manthati [13], investigated that the use of SHE modulation method can produce 7 levels of voltage with highest quality compared to the variant multi-carrier modulation method (IPD, POD and APOD).

This study presents an improved modulation technique for the inverter. This is done by varying the DC-link voltage ratio of the three cells of the inverter. This modulation technique can increase the level of output voltage produced by the inverter compared with the level voltage produced by the above mentioned researches (7 levels). Higher number of voltage levels will make the waveform of output voltage nearer to sinusoidal waveform and increase the quality of the output voltage.

II. METHODOLOGY

A. Cascaded H-Bridge (CHB) multilevel inverter

Cascaded H-Bridge is a multilevel inverter uses only capacitors and switches. A pair of capacitors and switches makes a combination called the Bridge (H-Bridge), each Bridge or a cell has separated input DC voltage. This kind of multilevel inverter has the advantages that it requires fewer components than diode-clamped and flying-capacitor multilevel inverters.

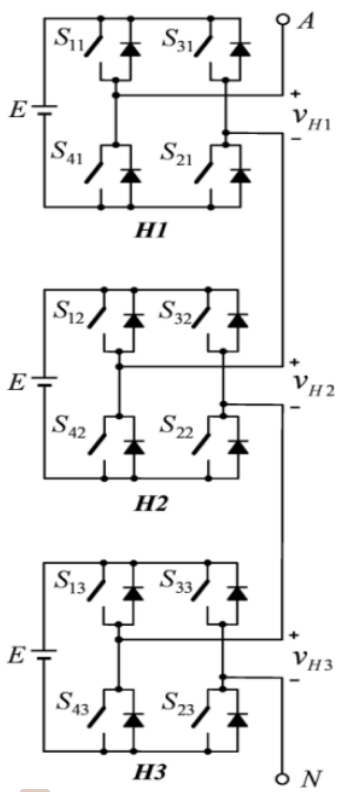

Fig. 1. Three Cells Single-phase Cascaded H-bridge (CHB) multilevel inverter

B. Modulation Technique

The simplest modulation technique for the Cascaded H-Bridge multilevel inverter is a 180° conduction method in which each switch is conducted (ON) at half the positive cycle and not conducted (OFF) in the next half cycle. By shifting the phase angle of ignition of the inverter arm "a" and the inverter arm "b" in each inverter cell it will produce different output voltage form as shown in 2nd to 4th row of Figure 2. The output voltage waveforms of the inverter are shown in 1st row of Figure 2. It is composed by 7 DC voltage levels ie {- 1, - 2, -3, 0, +3 , +2, +1} V dc because each cell uses a separate DC symmetrical link voltage of 1 V dc, or with a ratio equal to 1: 1: 1.

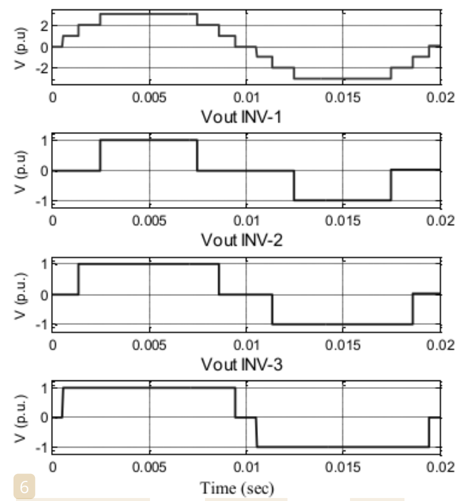

Fig. 2. The output voltage waves of each cell and the inverter output voltage using using DC-link voltage ratio of 1: 1: 1 modulation techniques

The number of levels in the output voltage of the Cascaded H-Bridge multilevel inverter can be multiplied by varying the DC-link voltage ratio from 1: 1: 1 to 1: 2: 4. In the DC-link voltage ratio of 1: 2: 4, each inverter cell can produce three voltage levels ie {+1, 0, -1} V dc, {+2, 0, -2} V dc, {+ 4, 0, -4} V dc. The resulting voltage generated by the inverter is a 15 levels output voltage {± 7, ± 6, ± 5, ± 4, ± 3, ± 2, ± 1, 0} V dc as a combination of voltages generated by the three cells as shown in Figure 3.

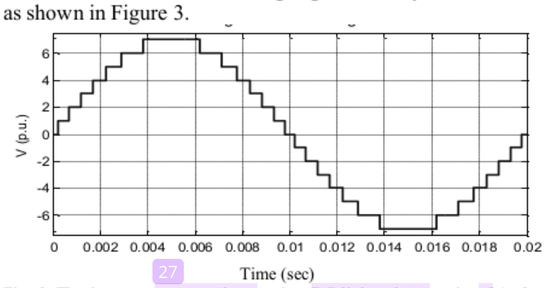

Fig. 3 The inverter output voltage using DC-link voltage ratio of 1: 2: 4 modulation techniques

III. SIMULATIONS AND RESULTS

A. Simulation circuit

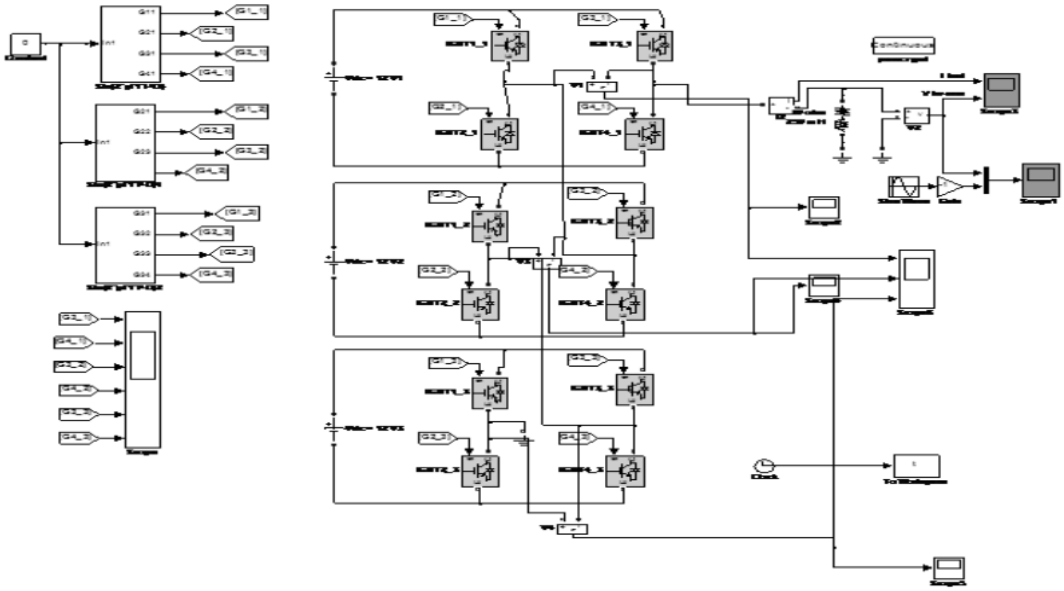

Fig. 4. Three-cells CHB inverter circuit modeled using MATLAB/Simulink

Fig. 4. shows the overall simulation circuit using MATLAB/Simulink software. The circuit working principle is that a reference voltage (v_m) is compared with four triangular signals or carrier signals (v_{cr}) to produce four kinds of pulse signals. The four pulse signals are the input for electronic switches at the upper position of each inverter cell. The electronic switches at the lower position of each inverter cell get the inverse of the four pulse signals for the input. It aims to set the on and off states for each switch to avoid short circuit.

B. Simulation Results

Fig. 5 (a) shows the new PWM signals of upper switches of the three-cell CHB inverter. It can be seen that the first legs of each sell of CHB inverter operates in 180° conduction mode while the second legs operates 15 time, 7 times and 3 times faster than the first legs of cell1, cell2 and cell3 respectively. As a comparison, the gating signals of the upper switches of the conventional 3-cells CHB is shown in the Fig. 5 (b). It is clearly shown that all switches operate in similar manner where only switched ON/OFF once per period.

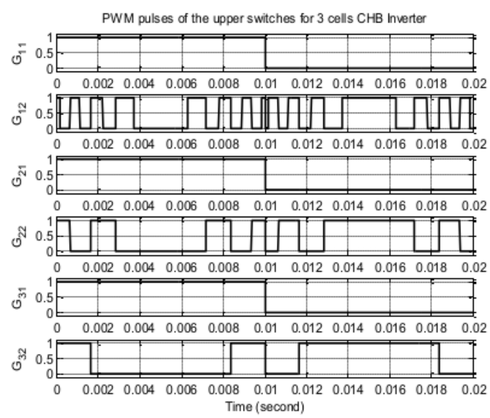

Fig 5 (a) New PWM signals for the upper switches of three-cell CHB inverter

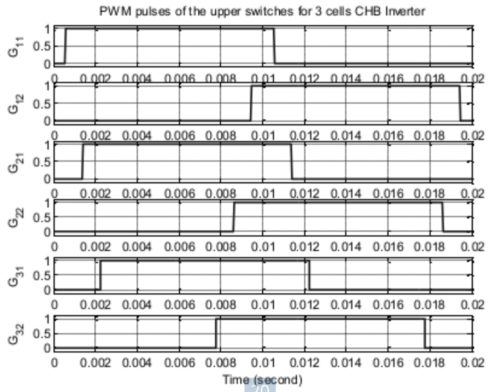

Fig 5 (b) Conventional PWM signals for the three-cell CHB inverter

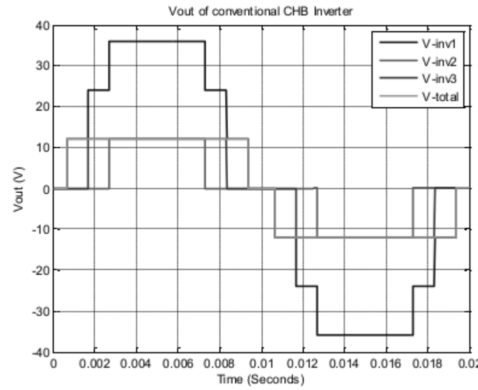

Fig. 6 (b) Output voltage of the three-cell CHB inverter using conventional PWM

Fig. 6 (a) shows the output voltage of the CHB inverter using the new PWM along with the output voltage of the individual cell of inverter. It is shown that the output voltage of inverter is a sum of the individual output of the cell1, cell2 and cell3. It consists of 15 levels DC voltage i.e 0 V, ± 6 V, ±12 V, ±18 V, ± 24 V, ± 30 V, ± 36 V, ±42 V. While Fig. 6 (b) shows the output voltage of the 3-cell CHB inverter with equal DC-link voltage using the conventional PWM. It is shown that the voltage consists of 7 levels DC voltage i.e 0 V, ±12 V, ± 24 V, ± 36 V.

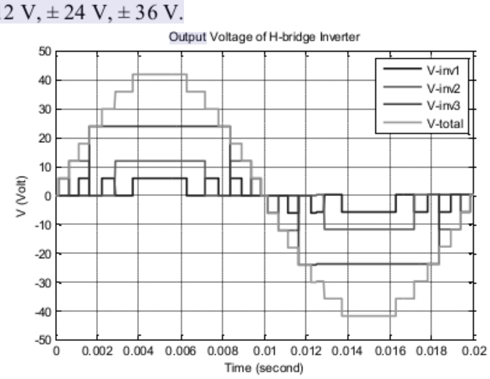

Fig. 6 (a) Output voltage of the three-cell CHB inverter using new PWM

As the number of level in the output voltage increases, the quality of the voltage improves significantly. Improvement of the voltage quality is indicated by the reduction of THD percentage from 13.22 % to 5.265 % that can be seen from the harmonics spectrum of the three-cell CHB inverter using conventional and new PWM as shown in Fig 7 (a) and (b) respectively. The harmonics spectrum also shown that the output voltage of the three-cell CHB inverter using new PWM is almost free from harmonics. While using the conventional PWM, the three-cell CHB produces7 level output voltage with the 3rd, 5th and 7th harmonics and some higher harmonics are still appeared.

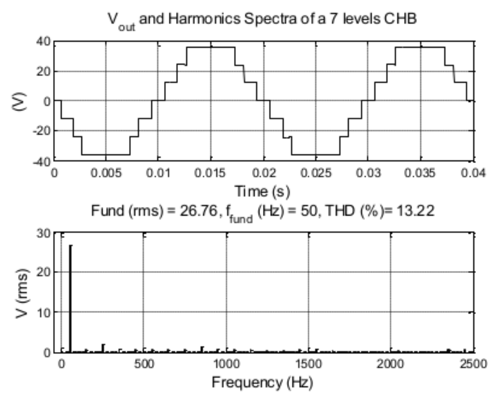

Fig. 7 (a) Harmonics Spectrum of the three-cell CHB inverter using conventional PWM

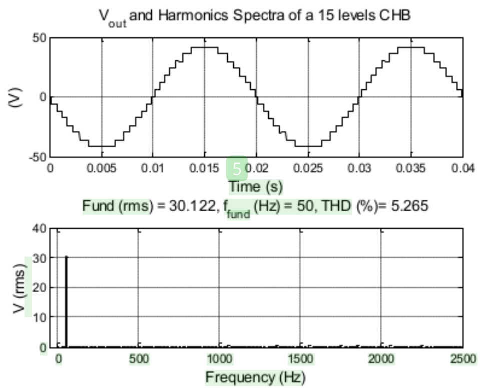

Fig. 7 (b) Harmonics Spectrum of the three-cell CHB inverter using new PWM

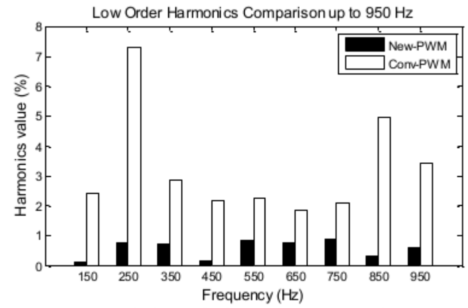

Fig. 8. Comparison of the low order harmonics content of the two PWM methods

Another indicator to reveal the voltage quality improvement of the inverter using the proposed PWM technique is carried out by comparing the percentage of low order harmonics content of the output voltage as shown in Table 1 and Fig. 8. It is obvious that a significant reduction of the low order harmonics is achieved using the new PWM method. This average value of the low order harmonics using the new PWM method is less than 1 % while using the conventional PWM method is more then 3 %. The detail of the comparison reveal in Table 1. It is noted that the reduction of average percentage of low harmonic content of CHB inverter output voltage up to 19 th harmonic (950 Hz) is from 3.25 % to 0.518 %.

TABLE I. LOW HARMONIC CONTENT OF CHB INVERTER OUTPUT VOLTAGE

Frequency (Hz)	Conventional PWM (%)	New PWM (%)
150	2.42	0.11
250	7.32	0.76
350	2.87	0.73
450	2.20	0.19
550	2.25	0.84
650	1.83	0.76
750	2.10	0.88
850	4.97	0.31
950	3.43	0.60
Average	**3.25**	**0.518**

IV. CONCLUSIONS

This paper investigates a new modulation technique for a three-cell single-phase CHB (Cascaded H-Bridge) inverter using un-equal DC link voltage. The results show that the new modulation technique enables the inverter to produce better output voltage quality compared with using conventional PWM (equal DC link voltage). This is indicated by:

1. The output voltage level is improved from 7 levels to 15 levels DC voltage.
2. The THD percentage of output voltage is reduced from 13.22 % to 5.265 % (almost 5% as THD percentage acceptable standard by IEEE).
3. The output voltage using the new PWM is almost free from harmonics. While using the conventional PWM, the 3rd, 5th and 7th harmonics and some higher harmonics are still appeared.
4. The average percentage of output voltage low harmonic content up to 19 th harmonic (950 Hz) is reduced from 3.25 % to 0.518 %.

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