PERFORMANCE INVESTIGATION OF ASYMMETRIC MULTILEVEL INVERTER WITH REDUCED SWITCH COUNT FOR FUEL CELLS

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ABSTRACT

This paper investigates the performance of Asymmetric Multilevel Inverter (AMLI) with reduced number of switches for fuel cell applications. The proposed topology generates fifteen-level output with improved spectral quality of the output. Moreover, a novel hybrid modulation strategy based on Variable Amplitude Phase Opposition Disposition (VAPOD) technique is implemented. The proposed topology is powered by PEM fuel cell source which is modeled in MATLAB. The performance parameters such as Total Harmonic Distortion (THD), Weighted THD (WTHD), Harmonic Spread Factor (HSF) and Distortion Factor (DF) are computed to verify the performance of the proposed topology. Circuit simulation studies are carried out in MATLAB/SIMULINK software and the results are verified.

KEYWORDS

AMLI, POD, FPWM, PEMFC, Charge double layer

I. INTRODUCTION

Multilevel inverter produces stepped waveforms which are widely employed for renewable energy sources. The output stepped waveform which is nearly sinusoidal has reduced ripple content, low total harmonic distortions and low voltage stress across the individual switches. This paper mainly focuses on asymmetric multilevel inverter (AMLI) with minimum number of switches for producing 15- level output with fuel cell as the source. AMLI is selected over the symmetric one based on the number of switches needed to produce 15 level voltage waveform. In AMLI, the magnitude of voltage sources is unequal whereas in SMLI, the voltage sources are equal. The desired output voltage levels are obtained by giving proper switching sequence to the gate driver circuits. In the proposed AMLI, Proton Exchange Membrane Fuel Cell (PEMFC) is used as the source as it is a clean source of energy. This study mainly discusses about the performance investigation of AMLI for fuel cell applications. The basic methods of hybrid modulation technique are demonstrated in the reference [1].For this investigation, POD based hybrid modulation technique is developed and analyzed. The theoretical analysis of the performance parameters for VAPOD technique is computed.

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II. BASIC OPERATION OF AMLI

AMLI produces increased number of levels for the equal number of components when compared with symmetric multilevel inverter and conventional multilevel inverter. In this paper, binary configuration of voltage sources is used which is determined by geometric progression with the power of two [2]. Figure 1 shows the structure of the proposed AMLI which includes asymmetric inverter basic unit followed by a full bridge inverter. By using three sources and seven switches, fifteen- level output voltage waveform is achieved. The basic structure of the proposed MLI is shown in Fig.1. In general, 'n' switches are required to produce 2n+1 level. The proposed asymmetric multilevel inverter consists of seven switches and voltage sources of $V_1 = V_{dc}$, $V_2 = V_{dc}/2$, $V_3 = V_{dc}/4$ (V_1=6V,V_2=12V,V_3=24V) which is shown in the figure 1.The overall output voltage depends on the conduction of three switches $S_{1,}$ S_2 and $S_{3.}$. For generating output voltage levels, two switches must be turned ON in full bridge inverter unit, one from upper switches and other from lower switches The difference between values of sources improves performance of multilevel inverter and enhances the number of levels.

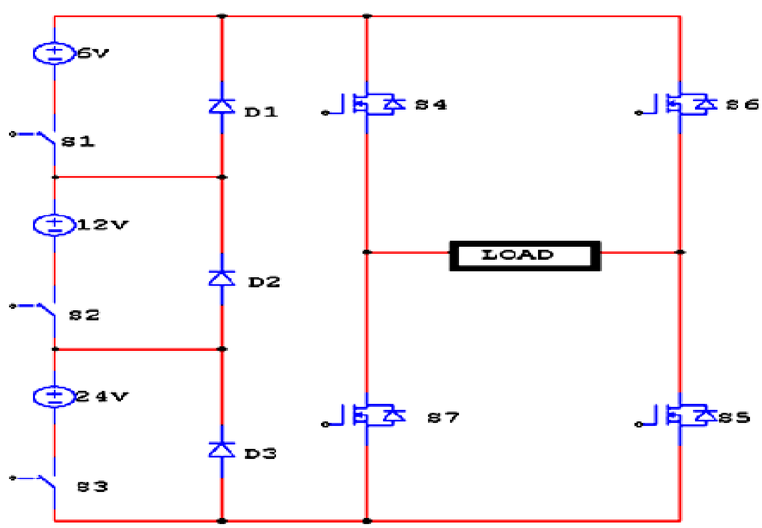


Figure1: Asymmetric Multilevel Inverter

TABLE 1: CONDUCTION STATE OF AMLI

Switches							**Output Voltage**
S1	S2	S3	S4	S5	S6	S7	V0
1	0	0	1	1	0	0	6
0	1	0	1	1	0	0	12
1	1	0	1	1	0	0	18
0	0	1	1	1	0	0	24
1	0	1	1	1	0	0	30
0	1	1	1	1	0	0	36
1	1	1	1	1	0	0	42
0	0	0	0	1	1	0	0
1	0	0	0	0	1	1	-6
0	1	0	0	0	1	1	-12
1	1	0	0	0	1	1	-18
0	0	1	0	0	1	1	-24
1	0	1	0	0	1	1	-30
0	1	1	0	0	1	1	-36
1	1	1	0	0	1	1	-42

In this topology, number of power electronic devices, and number of levels for proposed asymmetric multilevel inverter are formulated as

$$V_{omax}= (2^{n-1})*V_1 \qquad (1)$$

$$N_{IGBT}=n+4 \qquad (2)$$

$$N_{Level}=2^{(n+1)} -1 \qquad (3)$$

where n represents the number of voltage sources used in asymmetric multilevel inverter.

III MODULATION STRATEGIES FOR AMLI

In order to obtain a better output voltage spectral quality, a suitable modulation technique must be employed for the proposed MLI. Different modulation algorithms are discussed in the literature, but this paper proposes a novel hybrid modulation technique as it reduces switching losses and harmonic contents in the output.

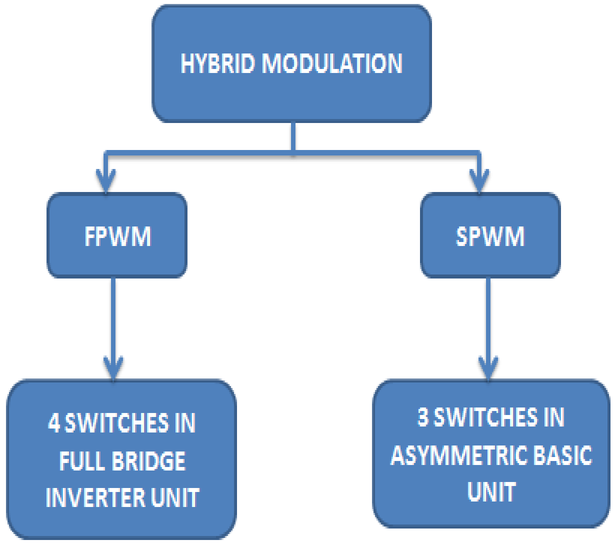


Figure 2. Block diagram of Hybrid PWM Modulation

In hybrid, the PWM employed is PODPWM [1] as it gives better output voltage waveform with reduced THD of 13.13% when compared with different hybrid modulation technique for the proposed asymmetric multilevel inverter.

IV POD BASED HYBRID MODULATION TECHNIQUE

In AMLI, FPWM is used for full bridge inverter switches and four carriers based on POD technique are used for asymmetric basic unit switches. For reducing THD, the POD based modulation technique is used. This improved performance of POD based PWM technique is used for controlling and reducing harmonics of output voltage. The various topologies of POD based hybrid modulation technique are

- ✓ Variable Amplitude POD
- ✓ Variable Amplitude Carrier Overlapping POD
- ✓ Variable Frequency POD
- ✓ Inverter Sine POD

These multicarrier arrangements for POD based hybrid modulation have amplitude modulation of 0.9 and frequency modulation of 63.

A. Variable Amplitude Carrier Overlapping POD

In variable amplitude carrier overlapping POD PWM, several overlapping carriers with single modulating signal are used [3]. For a fifteen level inverter, four carriers with the same frequency f_c and different peak-to-peak amplitude A_c are disposed such that the bands they occupy overlap each other. The reference wave has the amplitude Am and frequency fm and it is centered in the middle of the carrier signals. The amplitude modulation index is given by

$$m_a = \frac{A_m}{(\frac{m}{4})A_c} \qquad (4)$$

Figure 3 shows the multicarrier arrangements of Variable Amplitude Carrier Overlapping PWM method. In this strategy, two groups are opposite in phase with each other while keeping in phase within the group.

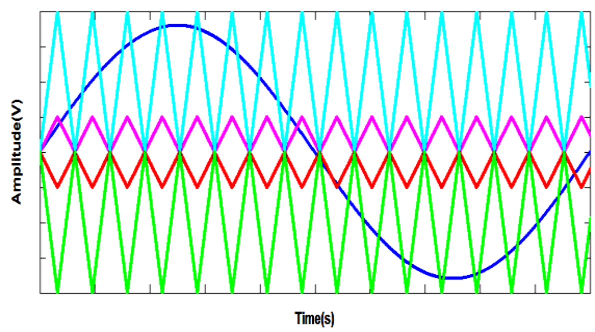


Figure 3: VACO POD PWM

B. Variable Frequency POD PWM

Variable Frequency POD (VFPOD) PWM is used where to equalize the number of switching for all the switches. By using constant frequency carriers, the number of switching of the upper and lower switches is higher than the intermediate switches. Figure 4 shows the multicarrier arrangements of VF POD [4-6]. To overcome this, VFPOD PWM is used in which the frequency of the carrier is increased properly to balance the number of switching for all the switches.

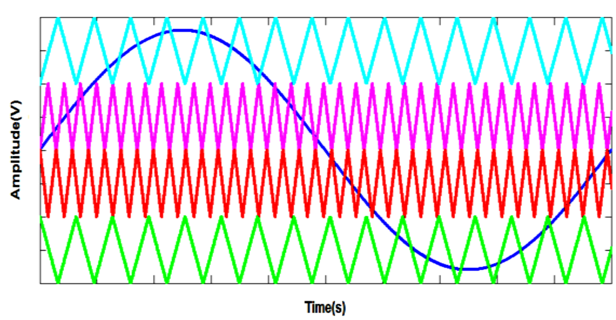


Figure 4: VF POD PWM

C. Inverted Sine POD PWM

Inverted Sine POD (ISPOD) PWM is different from other PWM technique by using inverted sine as the carrier signal instead of triangular signal. It compares inverted sine carrier signals with sinusoidal modulating signal [7]. For fifteen level AMLI, four ISPOD carriers are used as shown in the figure 5. By using ISPOD PWM, the spectral quality is improved when the amplitude of the modulating signal is greater than the carrier signal.

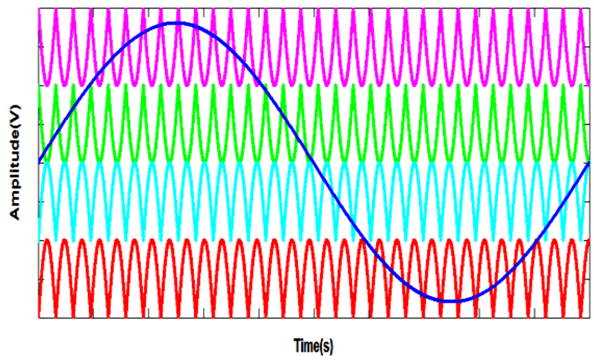


Figure 5: IS POD PWM

D. Variable Amplitude POD

In VAPOD technique, four triangular carriers are compared with sinusoidal modulating signal. Here, two carriers are of same amplitude and other two carriers have same amplitude but different and unequal from the previously discussed two carriers. Figure 6 shows four carriers based on VAPOD used for AMLI with single modulating signal. For this VAPOD hybrid modulation technique, the third harmonic distortion level is reduced due to this varying amplitude of the carrier signal. AMLI generates output voltage with reduced harmonic contents.

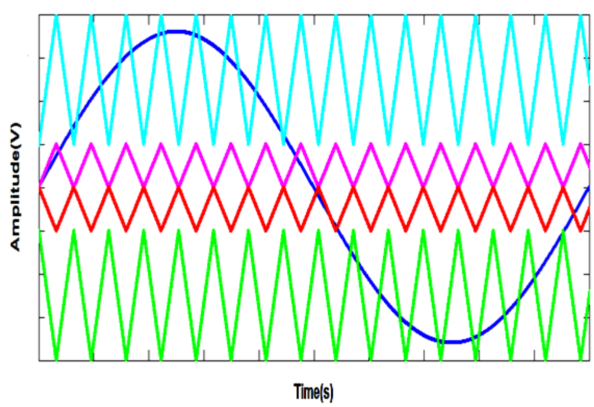


Figure 6: VA POD PWM

V. POLARIZATION CHARACTERISTICS OF PEMFC

Based on low working temperature, compactness and safe operational modes, PEMFC is considered compared to various types of fuel cell. In PEMFC, the hydrogen and the oxygen are used as the reactants and the protons and electrons are separated from hydrogen [8-9]. The protons are transported to the cathode side where oxygen is present through the polymer and electrons are transported to the load for conduction outside the electrode. The output of the PEMFC depends on the activation loss, concentration loss and ohmic loss.

$$H_2 \rightarrow H^+ + e^- \quad (5)$$

$$H^+ + O_2 \rightarrow H_2O \quad (6)$$

$$V_{FC} = E_{Nerst} - V_{act} - V_{ohm} - V_{conc} \quad (7)$$

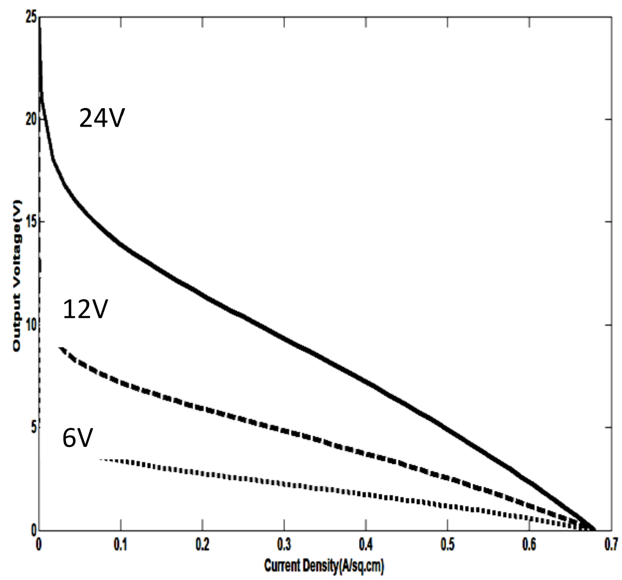


Figure 7: PEM fuel cell output voltages

The charge double layer in PEMFC will take responsible for sudden increase in current and exponential decrease in voltage during sudden change in load [10]. For producing 6V, 12V and 24V, 10, 20, 40 cells are connected in series respectively. Figure 7 shows the voltage produced by PEMFC which is used as the sources for AMLI.

VI SIMULATION RESULTS

To obtain the fifteen level output voltage waveform, the proposed AMLI is simulated using MATLAB/SIMULINK. The simulink model for interface of PEMFC and AMLI with VAPOD PWM technique is shown in the figure 8. The sources are given by PEM fuel cell.

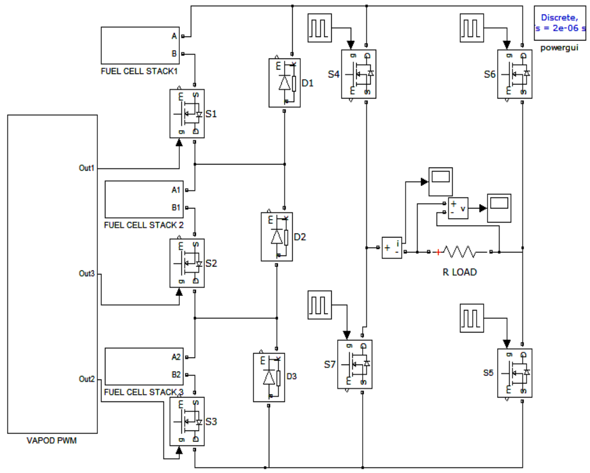


Figure 8: Simulink model for interface of PEMFC and AMLI

Figure 9 shows the pulse generation for AMLI by hybrid modulation technique. FPWM technique for four switches in full bridge inverter unit and VAPOD PWM technique for three switches in asymmetric basic unit.

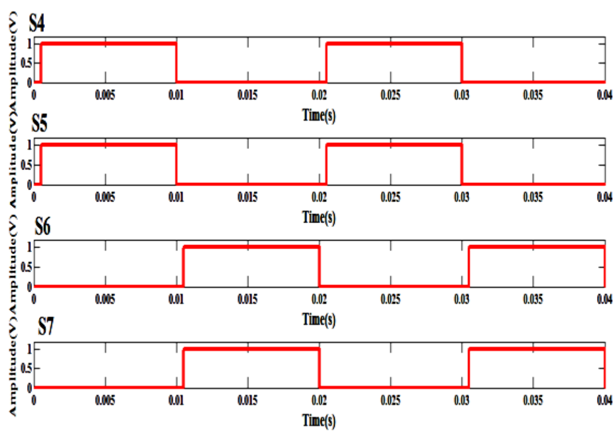
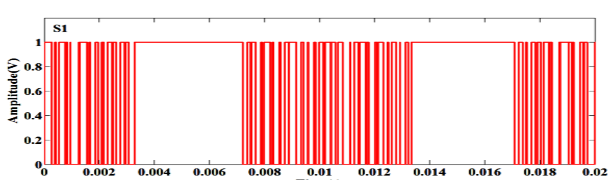


Figure 9(a): Gate pulses for Full bridge inverter unit switches



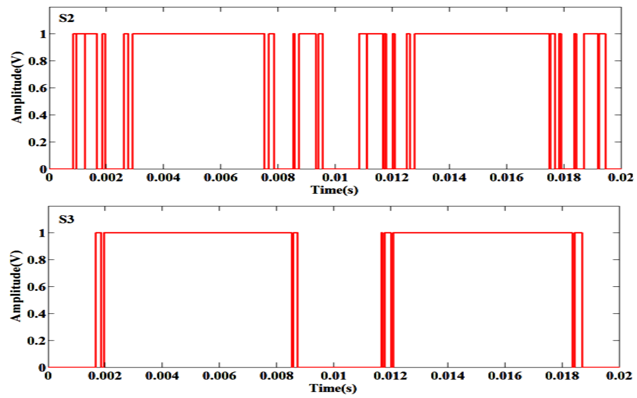


Figure 9(b): Gate pulses for Asymmetric basic unit switches

By using the proper switching sequence for all the switches in the proposed inverter, the 15 level output is produced from 3 sources and 7 switches. Figure 10 shows the results of AMLI and its THD analysis is shown in the figure 11. VAPOD PWM with THD of 9.92% is best suited for the this multilevel inverter.

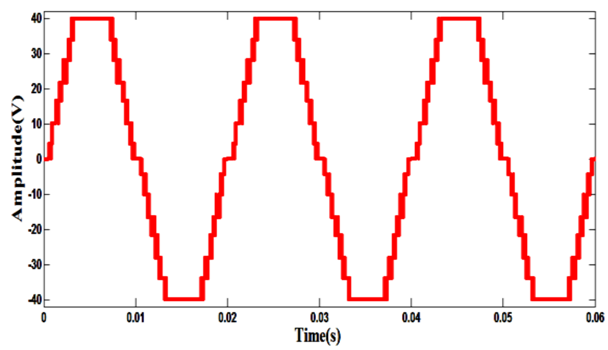


Figure 10: Simulation Results of 15 level AMLI

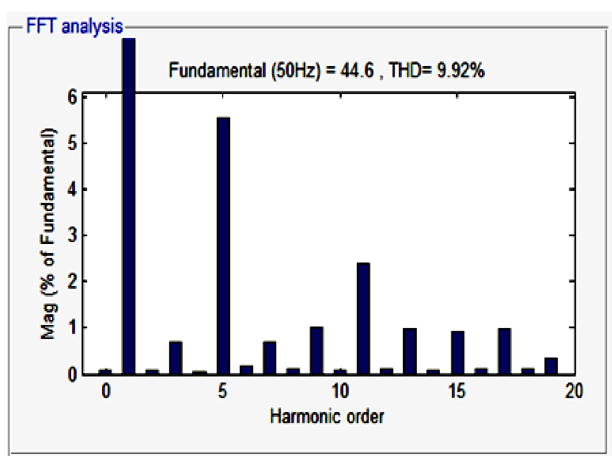


Figure 11: FFT analysis of VAPOD PWM

TABLE 2: COMPARISON OF POD BASED PWM TECHNIQUE

POD based Hybrid Modulation Technique	Total Harmonic Distortion
VAPOD	9.92%
VACOPOD	11.09%
VFPOD	11.14%
ISPOD	10.34%

By comparing the THD values of various POD based PWM technique as in table 2, Variable Amplitude POD produces better output with reduced 9.92% THD.

VII PERFORMANCE PARAMETERS FOR THE PROPOSED AMLI

Based on the comparison of THD, VAPOD PWM which has minimum harmonic content is suitable for the proposed AMLI and this topology is further analyzed for computing the performance parameters such as

- Weighted THD
- Harmonic Spread Factor
- Distortion Factor

A. Weighted THD

The weighted total harmonic distortion is normally used to assess the quality of output of the AMLI with variable amplitude POD PWM technique. It gives the measure of the harmonic pollution for components in each order as its weight factor. From the mathematical analysis, AMLI output has minimum WTHD which is below 5%. The expression for WTHD is

$$WTHD = \frac{\sqrt{\sum_{n=2}^{\infty}\left(\frac{V_n}{n}\right)^2}}{V_1} \qquad (8)$$

V_1 – Fundamental voltage, V_n – total Harmonics voltage and n – number of harmonics

B. Harmonic Spread Factor

The quality indicator, harmonic spread factor (HSF) is used for evaluating the harmonic spread effect of VAPOD PWM technique. The expression for HSF is

$$HSF=\sqrt{\frac{1}{N}\sum_{j=2}^{N}\left(H_{j}-H_{0}\right)^{2}} \qquad (9)$$

Hj = Value of jth harmonic & H0 = Average value of all N Harmonics

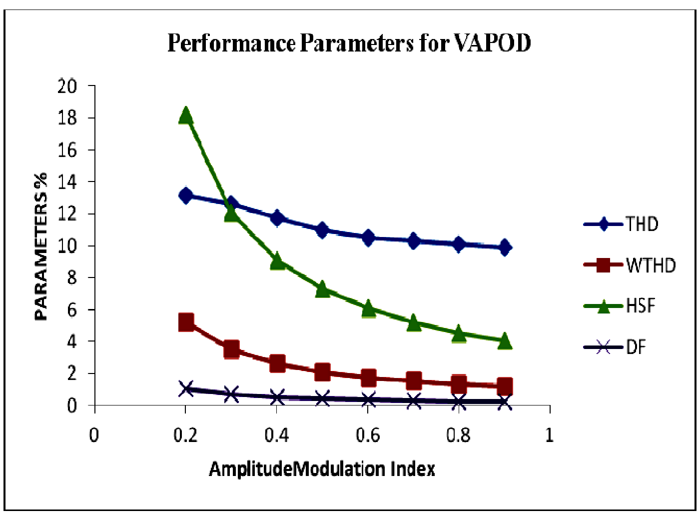
C. Distortion Factor

Distortion factor (DF) is used to measure the intensity of the non linear distortion of the VAPOD PWM technique. The mathematical expression for DF is

$$D.F=\frac{1}{V_{1}}\left[\sum_{n=2,3,....}^{\infty}\left(\frac{V_{n}}{n^{2}}\right)^{2}\right]^{1/2} \qquad (10)$$

V – Fundamental voltage, V_{on} – total Harmonics voltage and n – number of harmonics

From the comparison based on THD_v(%) values ass hown in Figure 12, variable amplitude PODPWM is the best one with minimum harmonic content. The values in results of performance analysis are below 5% as per the standard. The performance parameters for such VAPOD are shown in the table: 3.



Figure; 12 Performance parameters for VAPOD

Table 3: Performance Parameters for VAPOD

Parameters	Calculated Values
THD	9.92%
WTHD	1.174%
DF	0.238%
HSF	4.05%

For VAPOD, the amplitude modulation index (m_a) 0.9 is selected based on the comparison of THD, WTHD, HSF and DF values for various m_a from the graph 1.

VIII CONCLUSION

In this paper, a new hybrid modulation technique is recommended for AMLI for producing fifteen level output voltage waveform. From the analysis, it is found that VAPOD hybrid modulation provides a reduced THD compared to the conventional methods. Moreover, harmonic spread factor is also less for the proposed topology and hence AMLI with VAPOD is a suitable candidate for fuel cell applications.

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