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Three Phase Sinusoide Output Voltage of Multi Carrier for Nine Level Cascade H-Bridge Inverter with DC Fuel Cell

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***Abstract*— This paper discusses a cascade inverter 9 three-phase power system using a Cascade H Bridge inverter type with a DC Fuel Cell voltage source. The goal is to reduce the Total Harmonic Distrotion (THD) content in the output waveform in accordance with IEEE 519 standards below 5%. At each level the inverter is supplied by the fuel cell as a DC source and in series with the next level inverter circuit to get 9 output voltage levels. The switch performance of each level is controlled by PWM pulses at the level of different amplitudes but the same frequency. Unlike conventional approaches that rely solely on low-level inverters or fixed DC sources, this study proposes the implementation of a nine-level cascade H-Bridge inverter topology powered by a DC fuel cell with three-phase multi-carrier modulation technique to produce high-quality sinusoidal voltage. This system shows increased efficiency, harmonic reduction, and more optimal utilization of green energy. The simulation results show that when the system has not been installed with an LCL filter, the output voltage of each inverter is a 9-level step voltage with a harmonic content of 13.67%. However, after installing a low-pass filter, the THD can be reduced to 2.92%, making this system acceptable in an power system.This represents a new perspective from the research conducted.**

***Intisari*— Makalah ini membahas sistem daya tiga fasa inverter cascade 9 dengan menggunakan inverter Cascade tipe H Bridge dengan sumber tegangan DC Fuel Cell. Tujuannya adalah untuk mengurangi kandungan Total Harmonic Distribution (THD) pada bentuk gelombang keluaran sesuai dengan standar IEEE 519 di bawah 5%. Pada setiap level inverter disuplai oleh fuel cell sebagai sumber DC dan diseri dengan rangkaian inverter level berikutnya sehingga diperoleh 9 level tegangan keluaran. Kinerja sakelar setiap level dikontrol oleh pulsa PWM pada level amplitudo yang berbeda tetapi frekuensi yang sama. Tidak seperti pendekatan konvensional yang hanya mengandalkan inverter level rendah atau sumber DC tetap, penelitian ini mengusulkan implementasi topologi inverter cascade H-Bridge sembilan level yang ditenagai oleh fuel cell DC dengan teknik modulasi multi-carrier tiga fasa untuk menghasilkan tegangan sinusoidal berkualitas tinggi. Sistem ini menunjukkan peningkatan efisiensi, reduksi harmonisa, dan pemanfaatan energi hijau yang lebih optimal. Hasil simulasi menunjukkan bahwa ketika sistem tidak dipasangi filter LCL, tegangan keluaran masing-masing inverter adalah tegangan step 9 level dengan kandungan harmonik sebesar 13,67%. Namun, setelah pemasangan filter low-pass, THD dapat diturunkan menjadi 2,92%, dengan demikian sistem ini dapat diterima pada sebuah sistem tenaga. Hal ini merupakan perspektif baru dari penelitian yang dilakukan.**

***Kata Kunci* — Cascade H-Bridge Inverter; Fuel Cell; Multicarrier Frequency**

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I. INTRODUCTION

Electricity serves as a fundamental necessity for humans and plays a crucial role in human development [1]. The need for clean and eco-friendly energy sources is steadily rising in line with global awareness of the negative impacts of carbon emissions from conventional fossil fuel-based power plants. Generators are classified into two main types, namely AC generators and DC generators [2]

The demand for clean and environmentally friendly energy sources continues to increase in line with global awareness of the negative impacts of carbon emissions from conventional fossil fuel-based power plants. One promising solution is the utilization of *Fuel Cell* technology as an alternative energy source. *Fuel Cells* offer advantages such as high efficiency, low emissions, and the ability to generate electrical energy directly through electrochemical reactions without combustion processes. However, the output voltage of a *Fuel Cell* is direct current (DC) and tends to fluctuate, making it necessary to convert it into a stable, sinusoidal alternating current (AC) voltage suitable for power systems, particularly for three-phase applications.

In this context, multilevel inverters have emerged as a superior choice for DC to AC power conversion. Power electronics-based multilevel inverter circuits are expected to produce output voltages with minimal harmonic content. One of the most widely developed multilevel inverter architectures is the *cascaded H-bridge inverter*, which offers advantages in producing output voltages with low harmonic distortion, reduced voltage stress on power switches, and flexibility in integrating modular voltage sources. The output voltage waveform of a multilevel inverter is essentially the summation of voltage levels derived from discrete voltage sources, which can theoretically reach an infinite number of levels, resulting in output voltage total harmonic distortion (THD) approaching zero. This concept and innovation continue to evolve, especially for high-voltage applications, drive systems, VAR compensators, and renewable energy development [3].The use of a 9-level *cascaded inverter* enables the generation of a voltage waveform that closely approximates a sine wave, with a circuit complexity and component count that remains within tolerable limits. This makes it particularly suitable for processing the fluctuating voltage supplied by *Fuel Cells*. However, although multilevel inverters are capable of generating nearly sinusoidal output voltages, harmonic distortions cannot be completely eliminated. Therefore, power filters are required to further refine the output waveform. The LCL filter has become the preferred option in modern inverter

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systems due to its effectiveness in reducing high-frequency harmonics, along with its relatively compact size and low power losses. The integration of an LCL filter in a multilevel inverter system is crucial to ensuring power quality in accordance with grid standards and ensuring safety for connected loads.Based on the above background, this study focuses on the design and analysis of a three-phase sinusoidal voltage generation system using a 9-level *cascaded inverter* supplied by a *Fuel Cell* and equipped with an LCL filter. The objective of this study is to evaluate the system's performance in producing high-quality three-phase AC voltage with minimal harmonics and to assess the effectiveness of combining multilevel inverter technology with LCL filtering in *Fuel Cell*-based power conversion applications.

II. LITERATURE STUDY

II.1. Fuel Cell

Fuel cells efficiently convert the chemical energy of hydrogen or other fuels into electricity and are an important part of a comprehensive portfolio of solutions to achieve a sustainable and equitable clean energy future [3]. Fuel cells can be used for a wide range of applications across multiple sectors. (FC defined). Figure 1 is an illustration of the performance of a full cell where this module is an electrochemical process that produces electrical energy through the reaction between hydrogen(H_2) and oxygen(O_2) . In addition to hydrogen and oxygen, it can also use telephones, silicone rubber, nafion, platinum, graphite, carbon fiber and paper. There are several reaction processes in this event, namely the hydrogen oxidation reaction, the oxygen reduction reaction and the combined reaction of the entire process.

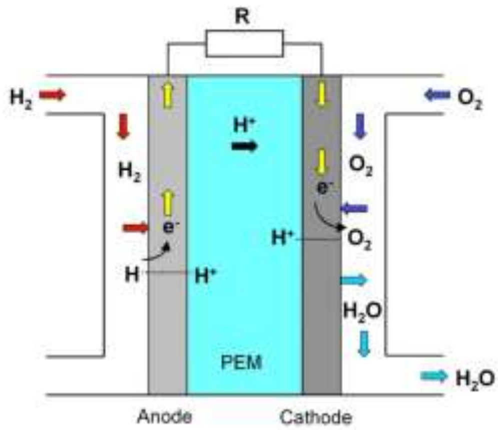

Fig.1 Fuel Cell Schematic
Source : https://grz-technologies.com/wiki/fuel-cell-technology/

Hydrogen oxidation process :

$$2H_2 \rightarrow 4H^+ + 4e^-$$

At the anode, hydrogen ($H2$) is split into hydrogen ions ($H+$) and electrons ($e-$). Meanwhile, at the cathode, the oxygen reduction process occurs) the chemical reaction is:

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

While the reaction is the whole process:

$$2H_2 + O_2 \rightarrow 2H_2O + energy \quad (1)$$

This reaction shows that fuel cells convert chemical energy from hydrogen and oxygen into electrical energy and water so that this power plant is free of pollutants and safe for the environment. Eenergy produced by each cell is obtained by the equation [4],[5]:

$$E_{cell} = E_{Nernst} - E_{act} - E_{con} - E_{ohm} \quad (2)$$

E_{Nernst} is the thermodynamic potential energy of the cell Eact is the activation voltage drop; Econ is the voltage concentration drop; Eohm is the ohmic voltage drop. activation voltage is obtained by the equation :

$$E_{act} = E_{act1} + E_{act2} \quad (3)$$

Where, *Eact1* is the voltage drop affected by temperature, while *Eact2* is the current affected by temperature. In this study, the type of fuel cell used is the 6 kW PEMFC (Proton Exchange Membrane Fuel Cell) type at 45 V which is an important cell type in the conversion of chemical energy into electrical energy[3]:

Fig. 2 describes the voltage and current characteristic curves of a fuel cell where there is a decrease in voltage against the increase in current flowing in the fuel at a constant temperature of 343 0K with different moisture content. This decrease is caused by the internal resistance of the fuel, the overproduction of oxygen in the oxygen reduction reaction, and the limitation of gas diffusion. The characteristic curve of PEMFC appears to be non-linear, so the power generated will be reached at a certain point, requiring an appropriate tracking method to determine the PEMFC output power and efficiency

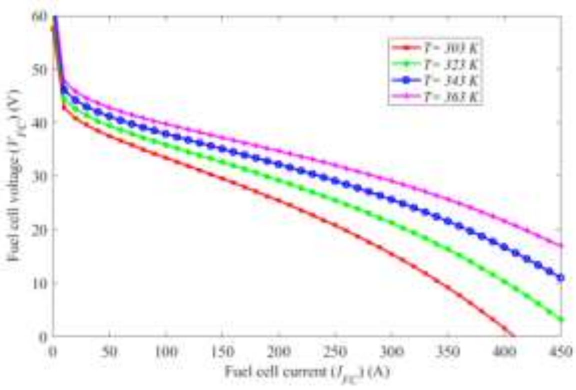

Fig. 2 Current and voltage relationship curve of fuel cell
Source : [6]

When the flowing current is small the efficiency is high, but when the current increases the efficiency goes down. In general, the characteristics of the fuel cell V-I curve can be concluded that the voltage will be high when the current is low, the voltage drop occurs when the current increases, the maximum power occurs at the balanced point between current and voltage, and the power will drop after passing that point. He also added that PEMFC is considered to be one of the most promising energy conversion technologies, which has advantages, among others PEMFC has high efficiency compared to conventional combustion engines, is able to work at low temperatures (60^0 to 80 °C), has high power density, can be placed in areas such as cars and portable power sources[7] . Some types, such as lithium-ion batteries (LIB), are prospective energy storage systems and dominate the energy market thanks to their low cost, high specific capacity and energy density, while still being able to meet the energy consumption needs of modern equipment [8].

Table 1. Technicl Specifications of 6 kW PEMPC at 45 V

Parameters	**Value**
Voltage at $[V\_(0A), V\_(1A)]$	65,63
Nominal operating point (I,V)	133.3,45
Maximum operating point (I,V)	225,37
Number of Cell	65
Nominal stack Efficiency (%)	55
Operating Temperature	65
Nominal air flow rate (Ipm)	300
Nominal supply pressure [Fuel (bar), Air (bar)]	(1.51,1)
Nominal composition (%) [H2 O2 H2O(Air)]	(99.95,21,1)

A maximum PEMFC (Proton Exchange Membrane Fuel Cell) current of 6 kW at 45 was achieved:

$$I = \frac{P}{V} = \frac{6{,}000}{45} = 133{,}33A$$

So, at 6 kW, a current of about 133 A is required.

II.2. Multilevel Inverter

Multilevel inverter (MLI) is a DC to AC converter in the form of voltage or current waves that have certain levels or levels. The goal is for the output wave (MLI) to approach or resemble a sinusoidal waveform [9] . The basic idea of MLI was first coined by Nabae in 1980 at the IEEE international conference on Transactions on Industry Application. There are 3 kinds of MLI topologies, among others [10][11]:

a. *Neutral Point Clamped - Diode Clamped Inverter (NPC-MLI)*

The Neutral Point Clamped Inverter (NPC-MLI), also known as the Diode Clamped Multilevel Inverter, refers to a multilevel inverter configuration that employs clamping diodes to produce multiple output voltage levels. The DC voltage is divided using capacitors, and then controlled by power switches and diodes to generate stepped AC voltages such as +Vdc/2, 0, and –Vdc/2 (in a 3-level configuration).NPC-MLI is widely used in medium-voltage applications due to its low harmonic distortion, reduced voltage stress on switches, and high efficiency. However, its main drawback is the increased circuit and control complexity as the number of levels increases.

b. *Flying Capacitor/Capacitor Clamped Inverter (FC-MLI)*

The Flying Capacitor Inverter (FC-MLI), also known as the Capacitor Clamped Multilevel Inverter, is a multilevel inverter topology that uses capacitors as clamping elements to generate multiple output voltage levels.Each voltage level is controlled by a combination of switches and flying capacitors, which store and release charge to produce stepped output voltages. Unlike the NPC-MLI, FC-MLI does not use clamping diodes but requires a large number of capacitors, especially for higher-level configurations.

c. *Cascaded H-Bridge Inverter (CHB-MLI).*

Cascaded H-Bridge Inverter (CHB-MLI) Represents a category of multilevel inverter designed to transform direct current (DC) energy into alternating current (AC) through producing several output voltage levels. This Cascaded H-Bridge configuration combines several H-Bridge inverter circuits in series to produce a smoother multilevel voltage, which in turn produces a more sinusoidal output wave and reduces harmonic distortion [12]. By connecting several H-Bridges in series, each H-Bridge will add one additional voltage level to the inverter output. For example, if one H-Bridge produces two voltage levels (positive and negative), two consecutive A single H-Bridge can generate four voltage levels, whereas three H-Bridges can create six levels, and so forth. The voltage output from each H-Bridge is managed through the regulation of its connected switches. This allows the inverter to select the required voltage at any point in time to achieve smoother AC output. By using multiple voltage levels, Cascaded H-Bridge Inverters can produce an output voltage waveform that is closer to a sinusoidal shape than traditional two-level inverters, reducing harmonic distortion and improving power quality. Cascaded H-Bridge Inverters are a very effective solution for large power applications, with high output quality and significant harmonic reduction, although they require a more complex design [13].

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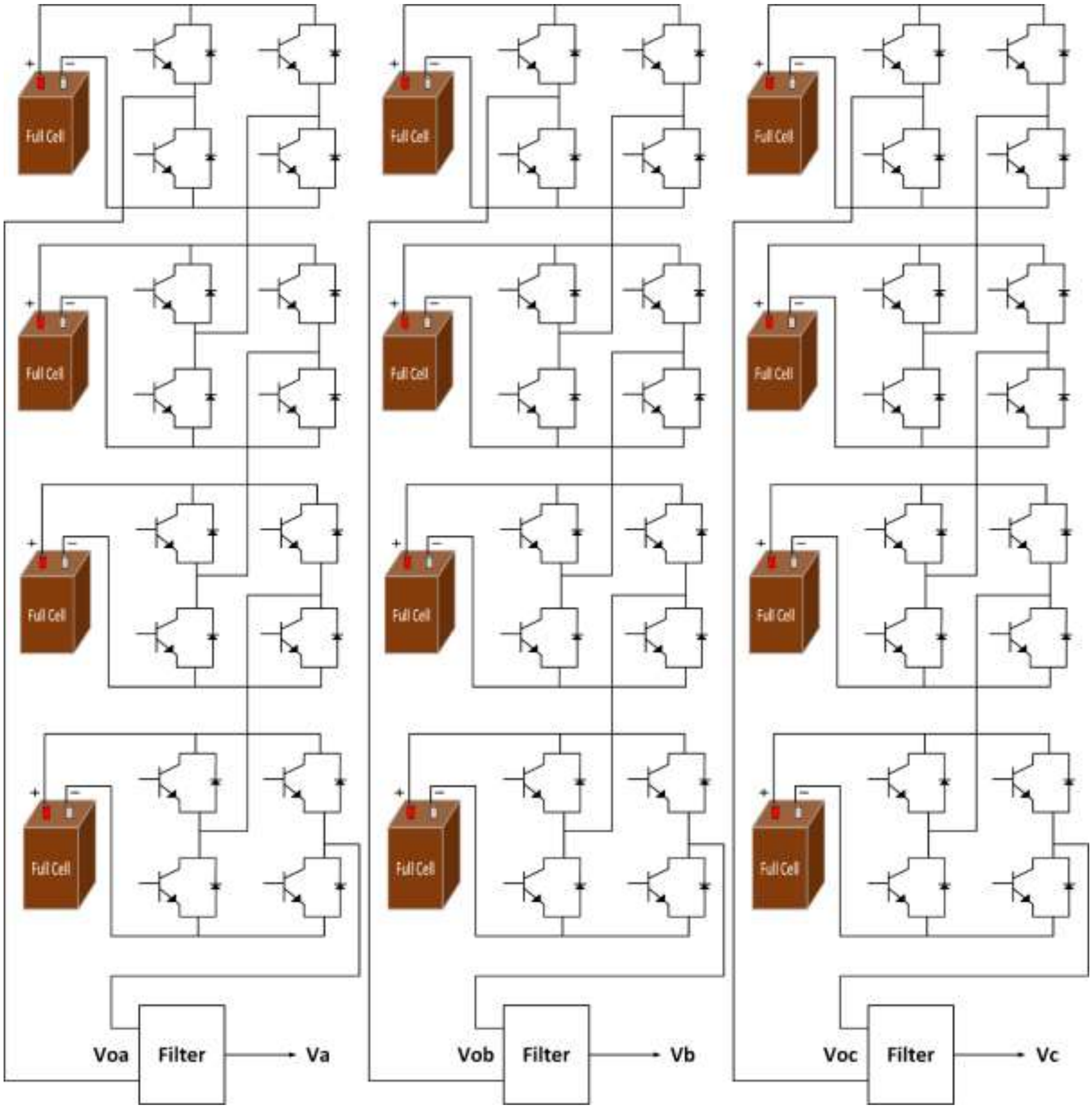

Fig. 3 Three Phase Nine level Cascade H-Bridge Inverter

Figure 3 is a 9-level inverter with a fuel cell as a DC voltage source. The design requires 12 DC fuel cells, 12 H-Bridge inverters arranged in series for each phase. output voltage of each phase is added a low pass filter to make the output voltage more sinusode with a small THD.

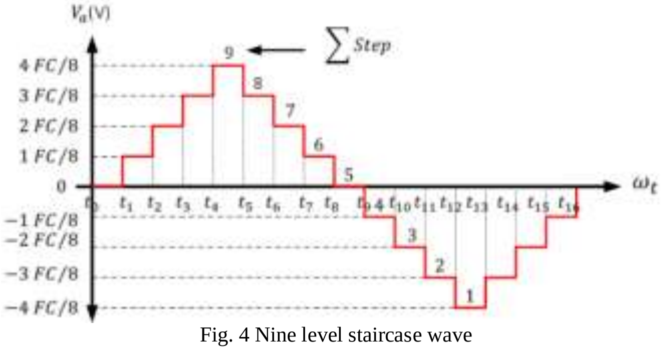

Fig. 4 Nine level staircase wave

Figure 4 explains that the inverter voltage waveform produces 9 different steps where the waveform resembles a staircase pattern up and down. If you consider the output voltage waveform of the inverter phase a has an amplitude of 1 Vpp then for the increase of each level (level 1 to level 9) of the multilevel inverter is 1/8 FC where FC is the fuel cell voltage). In the system design, one fuel cell has an output voltage of 65 V so that if there are 4 fuel cells arranged in series, the output voltage of the 9-level inverter will have a level of 65x4 = 260 Vpp. The single-phase 9-level MLI output voltage equation is a series of ladder functions which in 1 cycle of the foor function wave|f(x)| can be written as follows :

$$V(a) = \begin{cases} \frac{4.5}{B}\omega t, if\ 0 \le \omega t \le B\ , & B = \frac{1}{2}(t_4 + t_5) \\ -\frac{A}{B}\omega t + 9A, if\ B \le \omega t \le C, & C = \frac{1}{2}(t_{12} + t_{13}) \\ \frac{A}{B}\omega t - 13.5, & if\ C \le \omega t \le \frac{1}{2}(t_{16} + t_{17}) \end{cases}$$

The equation can be solved

$$V(a) = \sum_{n=0}^{\infty} \left(a_n \cos\left(\frac{n\pi}{L}\omega t\right) + b_n \cos\left(\frac{n\pi}{L}\omega t\right) \right) \quad (4)$$

$$a_0 = \frac{1}{2L}\int_{-L}^{L} V(a)d(\omega t)$$

$$a_n = \frac{1}{L}\int_{-L}^{L} V(a)\cos\left(\frac{n\pi}{L}\omega t\right) d(\omega t)$$

$$b_n = \frac{1}{L}\int_{-L}^{L} V(a)\sin\left(\frac{n\pi}{L}\omega t\right) d(\omega t)$$

$$\text{where } L = \frac{t_{16}}{2}$$

II.2.PWM Generation

PWM (Pulse Width Modulation) pulse generation is a method used to build signals that have high and low or 0 and 1 conditions with adjustable pulse widths called duty cycles . PWM performance by turning on and off signals with high frequency. This PWM is used as a gate turn-on signal control for each inverter switch. Figure 5 is a PWM pulse generator circuit using a comparator. The working principle is to compare the carrier signal (triangle wave) [14] (fc = 1 kHz) Vc 1 V and the modulation signal (fm = 50 Hz) Vm 3.9 V. Thus the amplitude ratio index value (ma) by $m_a = \frac{V_m}{V_c} = \frac{1}{3.9} =$ 0,256 the modulation index is $m_f = \frac{f_m}{f_c} = \frac{50}{1000} = 0.05$. The amplitude of the carrier signal is set at a level of 1 Volt which is placed at each level while the amplitude of the modulation signal is 3.9 Volts. The PWM pulses obtained are shown in the fig.5. There are three PWM switching techniques that are often used in controlling multilevel inverter switches including *Carrier-Based* PWM, *Selective Harmonic Elimination*, and *Space Vector* PWM [15] . all three are developments of PWM strategies for two or more levels. *Types of Carrier-based* PWM include *Subharmonic* PWM, *Switching Frequency Optimal* PWM, and *Multicarrier* PWM. Multicarrier switching method, the waveform in the form of triangular waves is more than one and depends on the number of inverter levels. In general, this multi-carrier method is divided into two namely Phase- Shift PWM (PS-PWM), and Level-Shifted PWM (LS-PWM). The PS-PWM method has a number of triangular waves of m + 1 where the phase shift is 360^0/m or 180^0/m. While in LS-PWM the number of triangular waves is m- 1 built in stages.

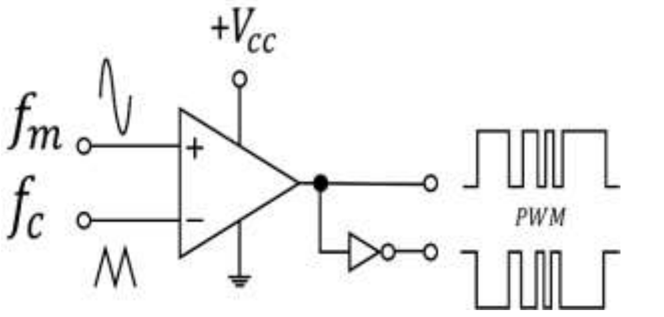

Figure 5. PWM pulse generation

II.2.1.Total Harmonic Distortion

THD is used to assess the extent to which the output voltage resembles a sinusoidal reference or measures the conformity of the output voltage waveform to its fundamental waveform. THD is calculated by taking the square root of the total sum of the squares of all harmonic components above the fundamental, then dividing the result by the RMS value of the fundamental component. The formula for determining THD is shown as follows [16].

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \quad (5)$$

Where *V*1 represents RMS value of fundamental component and *Vn* represents rms value of nth harmonic component. Harmonics that occur in an ideal power system are below 5%. If the THDi or THDv levels are below 5% then no overheating occurs transformer so it doesn't need one decrease in transformer power capacity. but if it exceeds these standards then it is necessary to reduce the transformer capacity [17].

III. RESEARCH METHOD

This research aims to develop and analyze a simulation modeling of a three-phase sinusoidal output voltage generating system using Multi Carrier PWM control on a nine-level cascade H-Bridge inverter, with a power source from a DC fuel cell and an LCL filter to reduce the harmonic content or Total Harmonic Distortion. (THD). To achieve this goal, the research method will be implemented in several stages which include model design, simulation, results analysis, and system performance evaluation. The following is the research flow in the form of a flow chart regarding the design of the system being built**.**

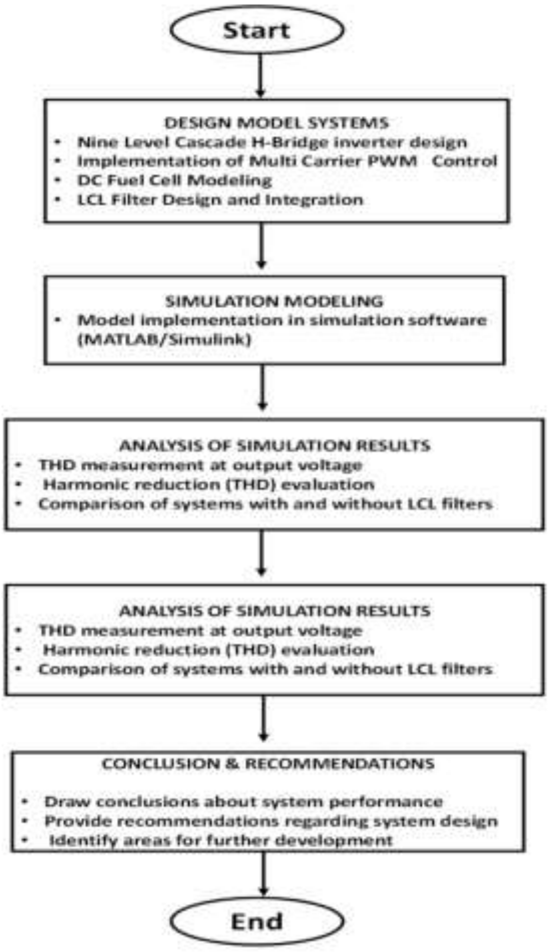

Fig..6 Flowchart diagram system

Figure 6 are explanation of system workflow

1. System Model Design: Starting with designing a nine-level cascade H-Bridge inverter model, Multi Carrier PWM control, and LCL filter to reduce harmonics. In addition, a DC fuel cell model as a power source will also be prepared.
2. Simulation Modeling: The model that has been designed is then implemented in simulation software (MATLAB/Simulink) to test system performance.
3. Analysis of Simulation Results: Simulation results are analyzed with a focus on measuring Total Harmonic Distortion (THD), reducing harmonics with the LCL filter.
4. System Performance Evaluation: Evaluation is carried out to assess the quality of the sinusoidal output voltage and the effectiveness of harmonic reduction (THD) carried out by the Multi Carrier PWM control and LCL filter.
5. Drawing Conclusions and Recommendations: Based on the results of the analysis, conclusions will be drawn regarding the effectiveness of the system and recommendations for design improvements and further development.

IV. RESULTS AND DISCUSSION

IV.1.Design Model System Analyze

The modeling of a 9 level inverter system equipped with an LCL filter is shown in fig. 7 for phase A, while phases B and C have the same technical parameters and design, the difference lies in the pulse control system for turning on each inverter switch. The ignition pulses in phases B and C are built with a phase difference of 120^0. Each phase contains 4 Fuel Cells, 4 H Bridge Inverters and LCL filters. Table 2 explains the technical parameters of the elements and components of each phase

Table 2. Parameter Info Design System

Element/Component	Information
H Bride Inverter	4 (16 IGBT Semiconductor as Switch)
Fuel Cell	4 PMFC 6 kW 45 V
Li	10 mH
Lo	10 mH
C	63.3 mF
Rd	0.54 ohm

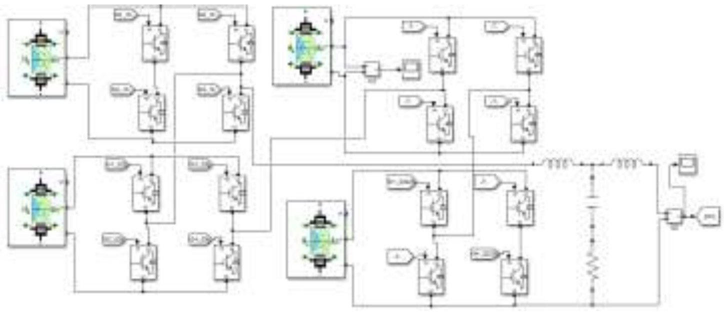

Fig. 7 Nine Level H Bridge Inverter Phase A

IV.2. Simulation Modeling

Analysis of Pulse generation using the Level Shited Multicarrier Base PWM Method

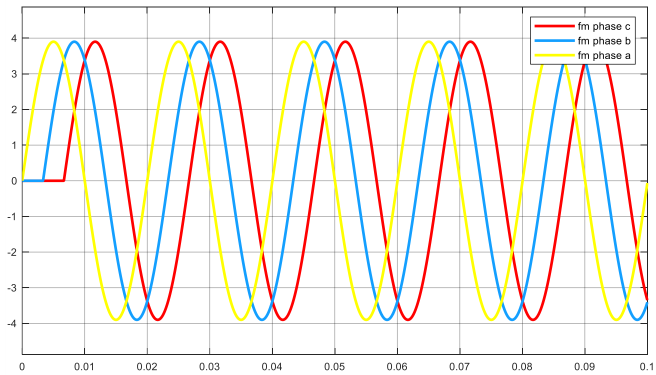

Fig. 8 Three sinusoidal modulated signals

Fig. 8 is a three-phase abc carrier wave that differs from phase 1200 with an amplitude of 3.93 V.

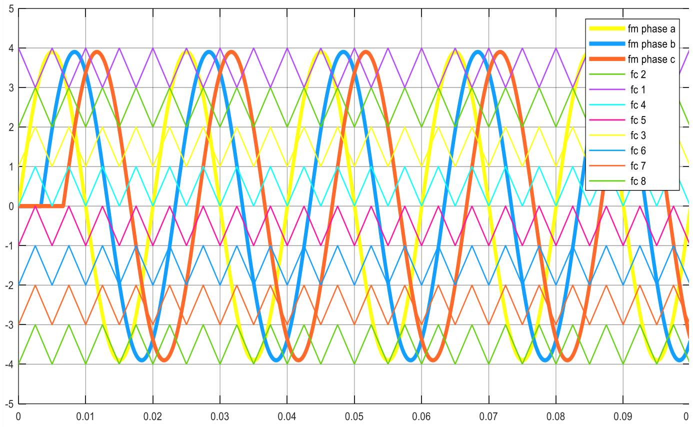

Fig. 9 Level Shifted Multicarrier Modulation

Fig. 9 is the modulation waveform type (Level Shifted Modulation) and carrier in the abc three phase inverter circuit. There are 8 voltage levels and each level is modulated with a triangular signal of frequency 1 kz amplitude 1 V. Observation of the simulation results of generating ignition pulses using the multicarrier level shifted PWM method for each switch has an amplitude of 1 V (T_1 and T_2) frequency of 1 kHz with a phase difference of 180^0 for each pair of switches.

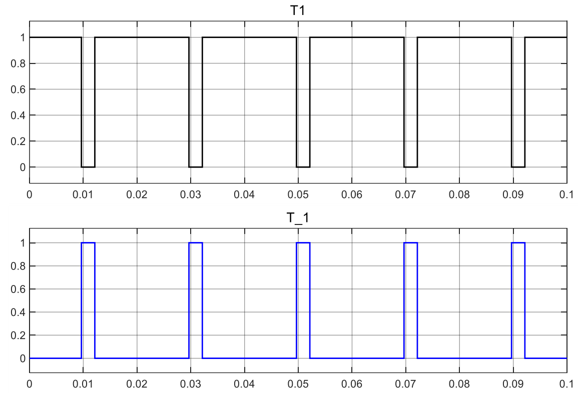

Fig. 10 PWM pulses for switch startup

Fig. 10 firing pulse shapes for each pair of switches. T1 is the trigger pulse for one pair of switches while T_1 is the negation of the T1 waveform for other switches. The number of switches in the 9-level H-Bridge inverter cascade circuit is 16, so it requires a total of 8 T pulses and 8 complementary pulses (T_1).

Analysis of 9-level inverter output waveform

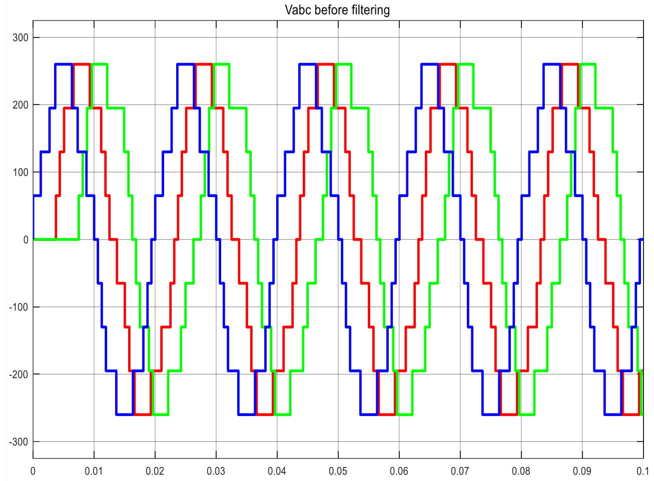

Fig. 11 Voltage of three-phase 9-level inverter

Fig.11 explains that the output voltage of the three-phase inverter before filtering is a 9-level ladder wave that differs from phase 120^0 frequency 50 Hz with an amplitude of 260 Vpp. This voltage is close to a sinusoidal function but still contains a large THD of 13.67%. The three-phase 9-level output wave equation can be defined $Vabc$.

$$V_a = 260\ sin\omega t \quad (6)$$

$$V_b = 260\sin(\omega t - 120^0) \quad (7)$$

$$V_c = 260\sin(\omega t + 120^0) \quad (8)$$

Where the values of Va, Vb, and Vc can be determined by (4).

Total harmonic distortion analysis of the inverter output voltage wave before filtering

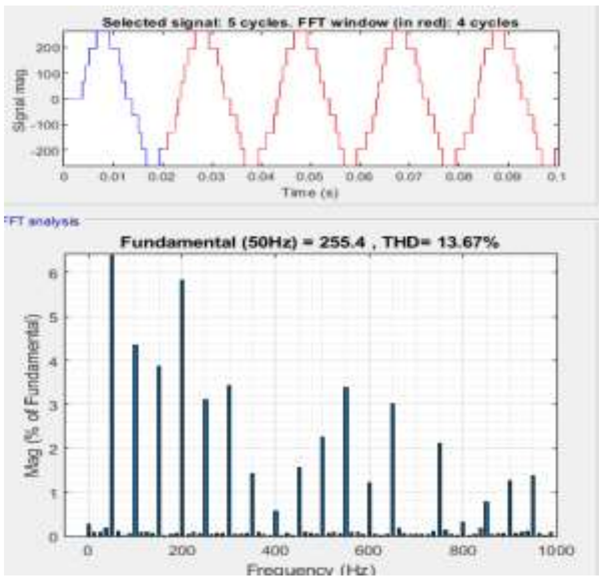

Fig. 12. THD value of the inverter before filtering

Fig.10 is the THD value of the inverter output voltage waveform before filtering by 13.67%. This value is caused by the performance of the inverter switch on each phase. It appears

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that the largest sequence of disturbances occurs at frequencies of 200 Hz, 100 Hz, 150 Hz, 300 Hz, 550 Hz and so on. For this reason, a filter is needed that is able to reduce the value of harmonics to be even smaller.

IV.3.LCL Filter Analysis

MLI 9 level has an output voltage that contains a large enough ripple or harmonic so that a filter is needed which is useful for smoothing the output waveform to approach sinusoidal and reduce the THD (Total Harmonic Distortion) value. LCL filters offer the advantage of lower cost as well as faster dynamic response, as they allow the use of smaller inductors In comparison to L-filters, however, being a third-order system, the LCL filter can cause oscillations. Therefore, the damping method is applied for system stability [18].

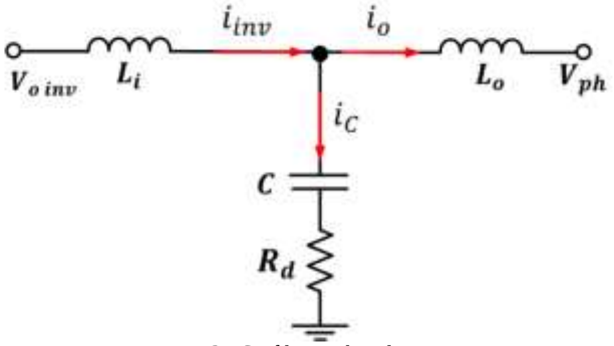

Fig. 13 LCL filter with R damping

Figue13 is an LCL passive filter that is used to eliminate inverter waveform defects so that the expected inverter voltage waveform becomes sinusoidal. There are four elements in this LCL filter, namely Li (inductor on the inverter side), capacitor C, inductor Lo (inductor on the phase voltage side (output)), and Rd is a damping resistor or resonance damping of the LCL filter[19] [20].

The value of each component can be determined:

$$L_i = \frac{V_{oinv}}{2\lambda_{C\_L_i} f_{sw} i_{inv}} \quad (9)$$

Where$Vinv$ is the inverter output voltage,fsw is the switching frequency,$iinv$ the rms current at ,$Li\lambda C\_Li$ the ripple value that occurs in the flowing current.

$$\text{Current } i_{inv} = \sqrt{\left(2\pi f_o C.V_{ph}\right)^2 + i_o^2} \quad (10)$$

$$L_o = \frac{1}{L_i C (2\pi f_h)^2 - 1} x \left(L_i + \frac{V_{oinv}}{2\pi f_h \lambda_h i_0}\right) \quad (11)$$

The parameterfh is the dominant harmonic frequency.

Rated capacitor

$$C = \lambda_C \frac{P_0}{2\pi f_{ph} V_{ph}^2} \quad (12)$$

The quantityfph is the phase voltage frequency,Vph is the phase voltage or voltage after the filter. The value ofRd is determined from its resonance frequency where the resonance frequency is equal to

$$\omega_{resonansi} = 2\pi f_{resonansi} = \sqrt{\frac{L_i + L_o}{L_i L_o C}}$$

$$f_{resonansi} = \frac{1}{2\pi} x \frac{L_i + L_o}{L_i L_o C}$$

So that R damping

$$R_d = \frac{1}{2\pi f_{resonansi} C} \quad (13)$$

In this study the value of Li= Lo = 10 mH and C = 63.3 mF, Rd = 0.54 ohms.

To eliminate the magnitude of interference, a filter is needed which aims to make the inverter waveform smoother and closer to sinusoidal.

Analysis of the inverter output voltage waveform after filtering

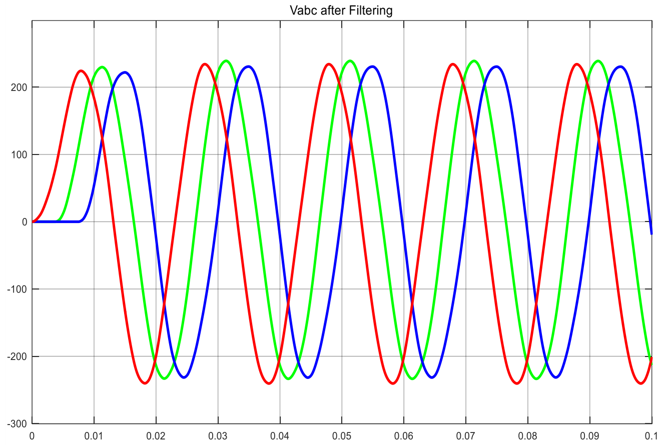

Fig. 14 Inverter waveform after filtering.

Figure 14 is the inverter voltage vabc after filtering and it appears that the three-phase waveform is smooth and close to sinusoidal with a reduced THD content of 2.92%. The amplitude of the wave drops by 230 V this occurs due to the voltage drop in the RC low pass filter circuit which is considered a load by the inverter. This THD value is already below 5% so it is feasible to use as a power system.

IV.4. Analysis of the total harmonic distortion of the inverter output voltage wave after filtering

Figure 15 shows the THD value of the inverter circuit after the filter is installed at 2.92%. The frequency of interference that still appears occurs at a frequency of 100 Hz or second order. To get a smaller THD value by increasing the number of levels that are even greater, namely 11, 13, 15 and so on, but it requires additional circuits and more complex controls.

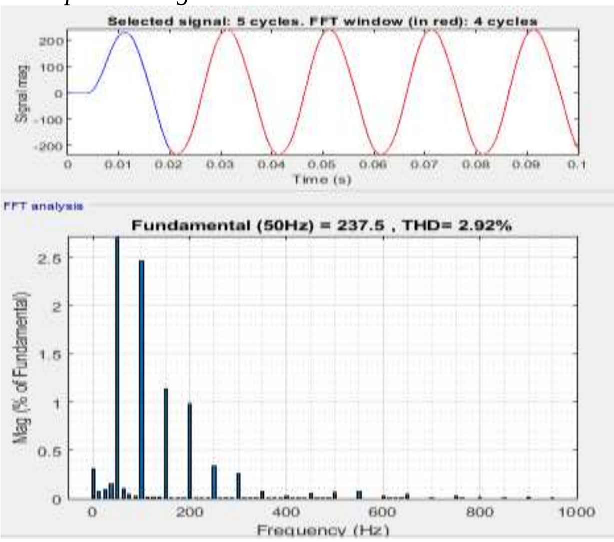

Fig.15 THD value after filtering

V. CONCLUSIONS

A 9-level three-phase inverter circuit can be formed by arranging 4 H-Bridge switches in series or cascade. The DC source voltage using the Fuel Cell power plant at each level is 65 V DC. The inverter output voltage level is at 3 level modes, namely the zero level, which is a condition where there is no output voltage at level 5, levels 6 to 9 are voltages on a positive cycle gradually increasing and levels 4 to 1 are voltages on a negative cycle and gradually decreasing. The cascade H-bridge inverter switch control uses the Level Shifted PWM method with the aim that the amplitude of the carrier frequency is specifically at a certain level. The simulation results show that the inverter voltage waveform is a nine-level DC voltage at different levels that resembles a sinusoidal wave. The THD value of the output voltage before filtering is 13.67% which shows that the harmonic content of the voltage is still high. After the filter is installed, the THD value drops to 2.92%, indicating that the inverter output voltage is close to sinusoidal and according to the IEEE 519 standard, this voltage is suitable for supplying energy needs to the load.

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