TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 5691 - 5697

The Effect of Modulation Index in THD of Transformer less Inverter

[1] Alawi Al-hasani, [2] M. Abouelela, [3] Saad Alghuwainem, [4] Abdullah M. Al-Shaalan, [5] Yahya Bakhuraisa

[1] MSc. Student, [2] Professor, [3] Professor, [4] Professor, [5] MSc. Student Electrical Engineering Department, King Saud University, Saudi Arabia

[1] alwimohsen@gmail.com, [2] mabouelela@ksu.edu.sa, [3]saadalgh@ksu.edu.sa, [4]shaalan@ksu.edu.sa, [5] ybakhuraisa@gmail.com

Article Info
Volume 82
Page Number: 5691 - 5697
Publication Issue:
January-February 2020

Article History
***Article Received**: 18 May 2019*
***Revised**: 14 July 2019*
***Accepted**: 22 December 2019*
***Publication**: 27 January 2020*

Abstract:
Due to the fast increase of photovoltaic (PV) adoption and utilization, their efficiency and power quality become of great importance. The grid connected inverter is a basic part in grid tied solar system. The inverter design has to keep the total harmonic distortion (THD) under permissible and tolerable limits. In this work, several techniques have been suggested and employed to mitigate the effects of the THD in the inverter output. These techniques are based on using both the sinusoidal pulse width modulation (SPWM) while varying the amplitude modulation index (Ma) for controlling THD. The full bridge and H5 transformerless topologies has been simulated at different modulation index Ma using MATLAB Simulink. The simulation shows that H5 topology has a lower THD than the unipolar inverter. Also, the results verified that the best performance of the two topologies occurs at Ma = 1.02.

Keywords: *Power Inverter, PV system, Sinusoidal PWM, Total Harmonic Distortion (THD).*

I. INTRODUCTION

In recent years, there are immense endeavours on the renewable energy sources particularly in photovoltaic (PV) power system generation due to their low maintenance cost, the availability of abundant sun light and the increase of the fuel cost [1], [2]. Fig. 1 shows a PV grid connected system. As illustrated power inverter plays an essential role in the grid connected photovoltaic power generation. So, power electronics engineers have focused their attention to the inverters that resulting an improvement to the overall system performance.

Earlier, there was a transformer-based inverter which is considered to be an expensive, large size, heavy weight and low efficiency [3]. Since the PV industry is highly driven by efficiency, there are many efforts that have been spent to develop the other type of inverter that is called “transformerless” inverter with improved characteristics rather than the previous one such as efficiency, reliability, reasonable size and lower cost [3].

To reduce the current harmonics of inverters, one of the most popular methods is to increase the inductance in the filters, but it implies higher size and cost. To overcome this problem, the switching frequency may be increased. However, this may result in higher switching loss. This paper discusses different types of transformerless

January - February 2020
ISSN: 0193 - 4120 Page No. 5691 - 5697

topologies while focusing on improving the system performance by reducing and mitigating the harmonic distortion while the modulation index (Ma) changing. H4&H5 transformerless topologies

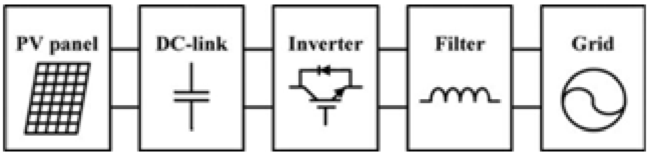


Fig. 1. *Overall system structure of grid tied PV system*

have been designed and tested with different modulation index by MATLAB Simulink program and the results are discussed and displayed below.

II. HARMONICS IN POWER SYSTEM

In electrical Power engineering, the systems must be designed to be operated at fundamental frequencies either 50 Hz or 60 Hz. However, in power system network there are certain types of loads called nonlinear loads that produce currents and voltages with frequencies that are integer multiples of the 50 Hz or 60 Hz fundamental frequency. These multiples frequencies create several problems in power system such as “power system harmonics” [4]. Therefore, it is important to gauge the total effect of these harmonics.

Nowadays, grid connected inverters used in PV power systems installations can be considered as a source of harmonics [5]. Due to the variation of the switching frequency, this grid tied inverter will inject harmonic distortion to the grid side according to switching frequency of the PWM that applied to the inverter which has side effects at the grid side. Once these distortions are entered into the power network, the power losses of the system will be increased. Moreover, the efficiency will be reduced. In addition, miss-operation of protection devices due to electromagnetic interference [6].

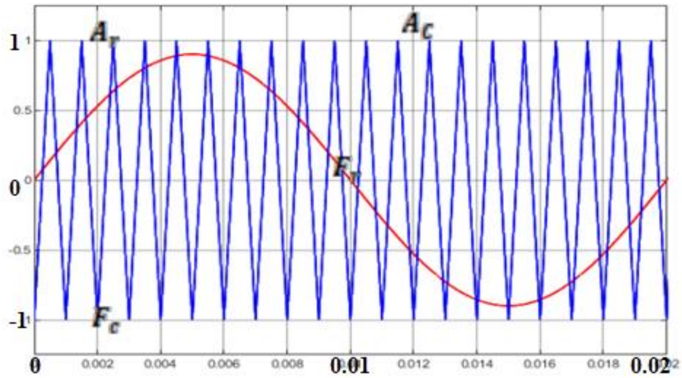


Fig. 2. *SPWM comparison between reference signaland triangular signal*

Total harmonic distortion (THD) is an improper and undesirable phenomenon in electric systems operation and it must be mitigated or reduced as much as possible. Lower THD in power systems resulted an improved power factor that will increase the overall system efficiency as well. High levels of total harmonic distortion index THD has negative effect in system equipment such as in the transformer, capacitor, motor operation or generator heating, disoperation of electronic equipment [7].

Therefore, the IEEE and the IEC standards suggested a limit for the harmonic generated by Photovoltaic (PV) Systems for the current total harmonic distortion (THD) factor [8]. The IEEE 929 and IEC 61727 standards specified 4% limitation for these old harmonics at range of 3rd to 9th and less than 3% for harmonics between 11th to 15th [9], [10].

Fourier series [4] can be used for mathematically describe the harmonics existed in a given waveform. If the waveform is T-periodic and continuous, then the waveform can be written as given by equation (1).

The sequence of Fourier coefficients (ak and bk) is called the spectrum of the function x(t). THD is an index that gives indication of the harmonic distortion. It could be defined as: the ratio of the summation of the squared of the magnitude of all

January - February 2020
ISSN: 0193 - 4120 Page No. 5691 - 5697

harmonic components to the squared of the magnitude fundamental frequency.

III. SINUSOIDAL PULSE WIDTH MODULATION

The conventional Sinusoidal Pulse Width Modulation (SPWM) is the most commonly operated to control inverter switches. This SPWM has a sine wave reference and the traditional triangular carrier is as illustrated in Fig. 2. In grid connected inverter, the sinusoidal signal that come from grid voltage is compared to the triangular carrier signal to give the proper gate signal to power switches of this inverter [11]. The reference frequency controls the frequency of the output voltage and current of inverter whereas, the gate pulses PWM frequency is controlled by the carrier frequency. Equation (2) gives the definition of both Ma (the amplitude modulation index) and Mf (frequency modulation index). From Fig. 2, we may conclude that (Ma) and (Mf) affect the total harmonic distortion of the inverter [12].

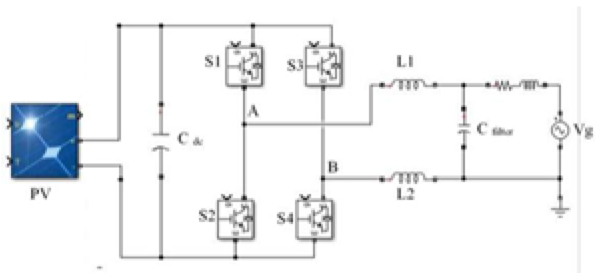


Fig. 3. *Structure of Full Bridge (H4) grid-tied inverter*

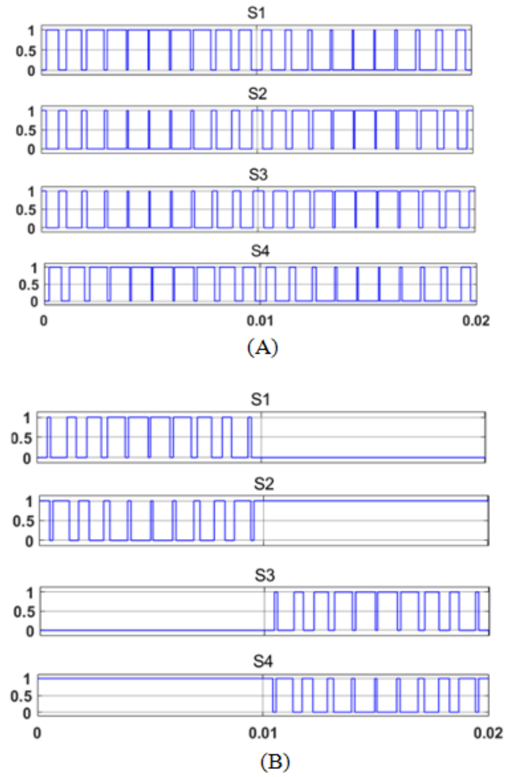


Fig. 4. *SPWM of Full bridge (A) Bipolar (B) Unipolar*

$$M_a = \frac{A_r}{A_c}, M_f = \frac{F_c}{F_r} \quad (2)$$

IV. INVERTER TOPOLOGIES UNDER TEST H4&H5

A. Full-bridge inverter (H4)

the structure of Full bridge (H4) PV inverters mainly contains four switches connected as as illustrated in Fig. 3, that can be controlled either by bipolar pulse width modulation (PWM) scheme or unipolar PWM. The total harmonic distortion characteristics, power quality and output efficiency depends on the PWM scheme used [13].

In bipolar PWM, switches S1 and S3 are complementary controlled with modulation frequency. Similarly, switches S2 and S4 are also oppositely controlled with the frequency of the triangular carrier signal. Fig. 4 (A) illustrates bipolar

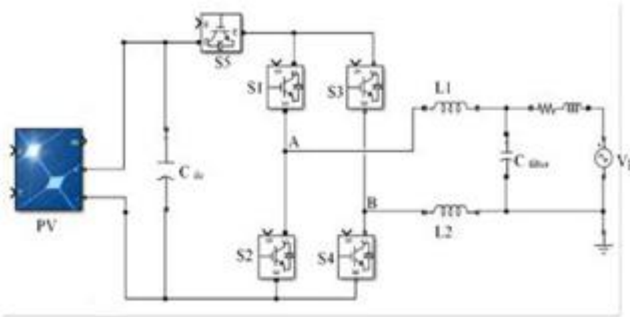


Fig. 5.*Structure of grid-tied H5 inverter*

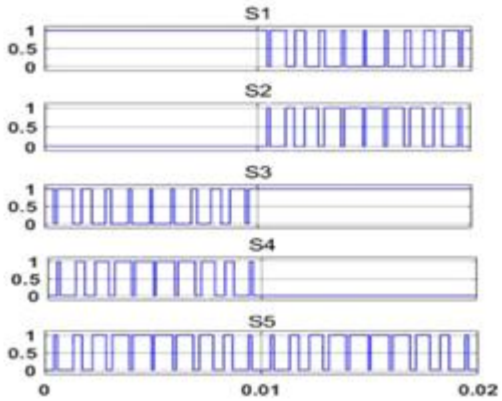
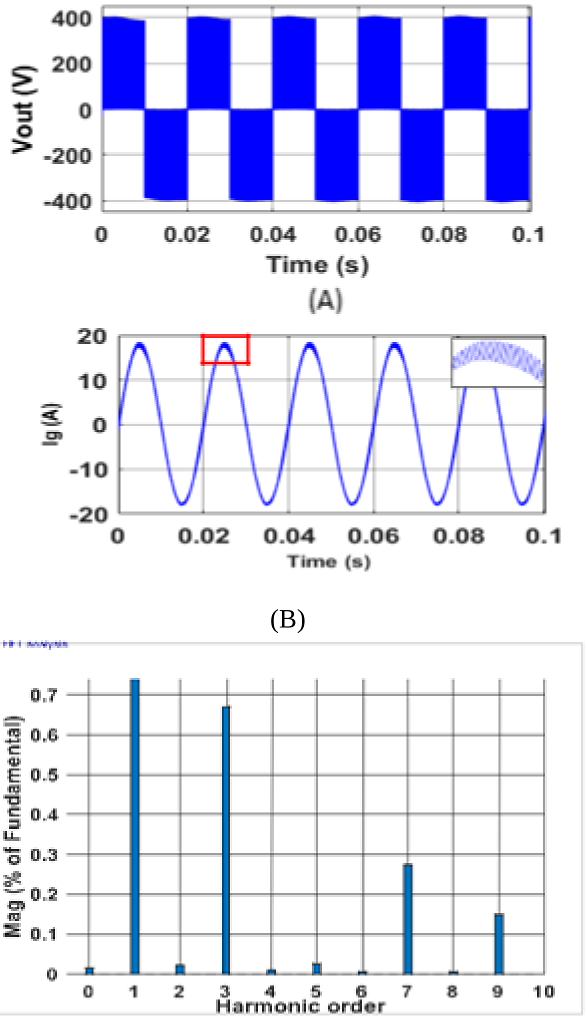


Fig. 6.*PWM of H5 topology*

PWM, where it can be seen from the Fig. that (S1-S4) and (S2-S3) are synchronized with modulation frequency [14]. As a result of bipolar modulation, the inverter output will have two level (+VPV, -VPV). This may cause high core losses due to the high current ripple across the filter inductors (L1, L2). Consequently, this may lead to a reduction in the inverter efficiency and an increase in the THD of its output [15].

Whereas, the unipolar PWM the switches will be controlled either with modulation frequency or grid reference voltage frequency according to the reference polarity as shown in Fig. 4 (B). S1 and S2 are complementary switched



(C)

Fig. 7. *Full bridge unipolar (A) output voltage (B) outputcurrent after filter (C) FTT analysis*

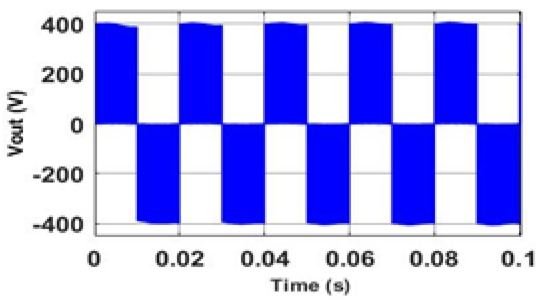
with carrier wave frequency in positive grid voltage and with reference frequency in negative grid reference. Whilst, the switches S3 and S4 are commutated with grid frequency in positive reference cycle. However, they commutate with modulation frequency in negative voltage cycle [13]. With this PWM modulation scheme, the output voltage will be three level (+VPV,0, -VPV). This will improve the overall efficiency due to lower core loses compared with the bipolar inverters. The output current ripple is lowered and THD is reduced [15].

January - February 2020
ISSN: 0193 - 4120 Page No. 5691 - 5697

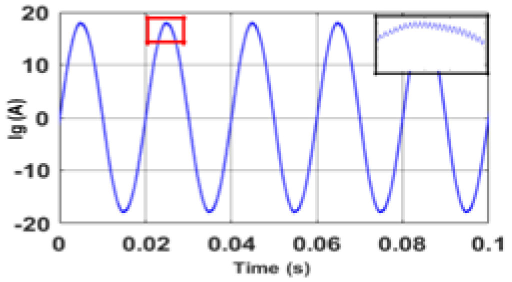
B. H5 topology

Fig. 5 introduces H5 inverter topology that mainly consists of an extra switch which is connected to full bridge in positive bus of the DC-link. This inverter topology was first invented by SMA solar technology, which is become one of the world's top producers of PV application such as inverter [13]- [17].

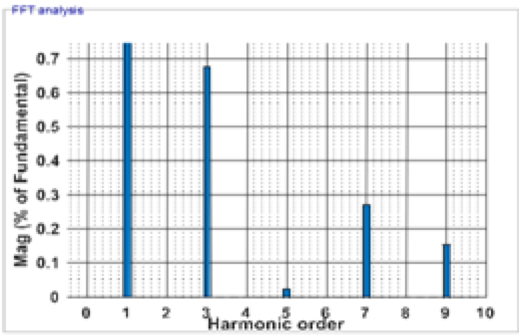
As shown in Fig. 6, the switches are operated independently with carrier or grid voltage reference frequency according to voltage polarity. The sinusoidal PWM was applied to control the five switches. If the reference signal is greater than zero (positive), the switch S1 become ON and the switch S2 is not operated. The switches S3 and S4 are controlled oppositely with the modulation frequency kHz. However, the switch S5 operated as same as



(A)



(B)



(C)

Fig. 8. *H5 topology (A) output voltage (B) outputcurrent after filter (C) FTT analysis*

S4. In negative grid voltage reference, the switch S3 is become ON for this half period and the switch S4 is not operated. The switches S1 and S2 are switched complementally with carrier signal frequency. Whereas, S5 worked similar to the PWM of switch S2. [14].

Same as unipolar modulation, the output voltage of H5 topology has three levels, namely, (+VPV,0, -VPV). The current ripple is low and the total harmonic distortion will be lower than the full bridge topology. However, the losses will be more than the unipolar case since there is one additional switch that the output current will flow through it in the active mode. The leakage current performance will be improved due to the reason that S5 is being OFF in a freewheeling mode.

V. SIMULATION RESULTS

the overall PV system operation and performance of transformerless grid tied PV inverters topologies such as (H4&H5) have been designed and verified by Simulink software and the simulation results discussed below. The THD has been calculated for several values of ma in the range 0.8< Ma< 1.2.

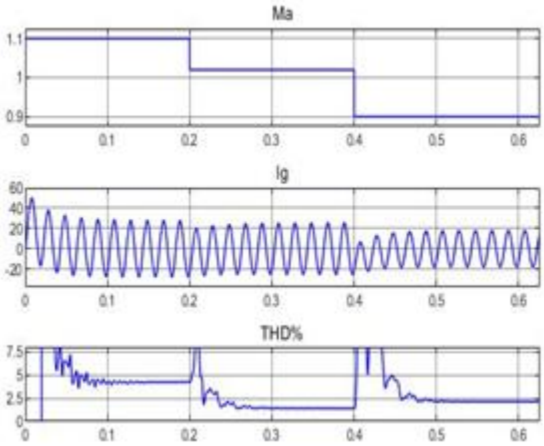


Fig. 9. *performance of changing Main THD of Ig*

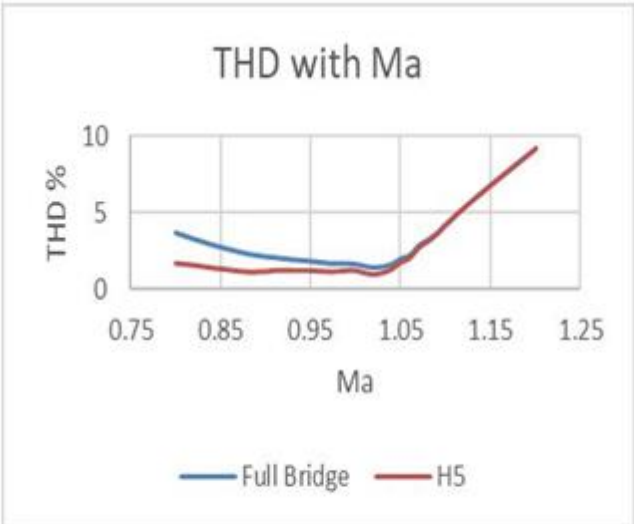


Fig. 7 (A) shows the output voltage of H4 inverter with unipolar PWM where it can be seen that the voltage has three levels as mentioned above. In addition, there is a little bit ripple in output current as illustrated in Fig. 7 (B). It can be noticed that the importance of LCL filter to decrease the distortion of the output and improving the shape of the signal to be sinusoidal.

To analyze the THD index, FFT Fast Fourier Transformation is implemented to the inverter voltage and current output waves as shown in Fig. 7 (C) where it can be noticed that the amplitude of the 3rd harmonic is less than 0.7% RMS of the fundamental 50 Hz and the THD is at 2.12%.

As full bridge unipolar inverter, H5 topology has three level voltage before filter as shown in Fig. 8 (A). However, the current ripple of the output reduced compared to the unipolar topology due to the mission of S5 that disconnect the DC side in freewheeling mode as illustrated in Fig. 8 (B). Therefore, the THD will be lower than unipolar technique as displayed in Fig. 8 (C).

Fig. 8 (C) displays the FFT of the grid current to analyze THD of H5 topology with Ma=0.9 and switching frequency 10 kHz. It can be seen that 3rd harmonic has the largest magnitude with 0.68% of the fundamental frequency.

Figs. (9-10) shows how the changing in Ma will affect the THD of Ig. From Fig. 10, it can be concluded that H5 has better effect than the full bridge unipolar topology because its low THD index. The variation of Ma within the interval [0.8, 1.2] to obtain the proper value of Ma that gives the lowest THD is displayed in Fig. 10.

VI. CONCLUSION

In this paper, a transformerless full bridge unipolar and H5 inverter topologies based on SPWM are designed and tested by MATLAB Simulink program, in order to verify the effect of varying the modulation index ma in THD. From the above results, it can be noticed that H4 and H5 topologies have three level voltage out. However, it can be verified that the output current of H5 has low current ripple with less THD compared with the full bridge unipolar. finally, it can be concluded that H5 inverter has better performance than full bridge. Also, the lowest THD index of the two topologies gave an amplitude modulation index to be around 1.02.

REFERENCES

[1] V. Sonti, S. Jain, and S. Bhattacharya, "Analysis of the modulation strategy for the minimization of the leakage current in the PV grid-connected cascaded multilevel inverter," IEEE Trans. On

TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 5691 - 5697

Power Electronics, vol. 32, no. 2, pp. 1156-1169, Feb. 2017.

[2] K.-Y. Chen, Z. Chen, Y.-L. Xie, and X.-k. Mao, "Low switching loss and harmonics PWM for three-phase grid-connected PV inverter," in 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017-ECCE Asia), 2017, pp. 1457-1461: IEEE.

[3] E. Z. Bighash, S. M. Sadeghzadeh, E. Ebrahimzadeh, and F. Blaabjerg, "High quality model predictive control for single phase grid-connected photovoltaic inverters," Electric Power Systems Research, vol. 158, pp. 115-125, May 2018.

[4] E. H. Mayoral, M. A. H. López, E. R. Hernández, H. J. C. Marrero, J. R. D. Portela, and V. I. M. Oliva, "Fourier Analysis for Harmonic Signals in Electrical Power Systems," in Fourier Transforms-High-tech Application and Current Trends: IntechOpen, 2017 pp. 43-66.

[5] H. Cangi and S. Adak, "Analysis of solar inverter THD according to PWM's carrier frequency," in 2015 International Conference on Renewable Energy Research and Applications (ICRERA), 2015, pp. 194-198: IEEE.

[6] J. Xian, H. Zhang, and L. Tan, "Decouple control strategy of three-phase grid-connected inverter with LCL filter," in 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA), 2018, pp. 238-242: IEEE

[7] D. Kumar and F. Zare, "Harmonic analysis of grid connected power electronic systems in low voltage distribution networks," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 4, no. 1, pp. 70-79, March 2016.

[8] D. Zammit, C. S. Staines, and M. Apap, "Reduction of Current Harmonics in Grid-Connected PV Inverters using Harmonic Compensation-Conforming to IEEE and IEC Standards," international conference Europe and the Mediterranean Towards a Sustainable Built Environment, Malta, 2016.

[9] A. Agrawal and D. K. Singh, "Harmonic Impact of Grid Connected Photovoltaic System on Low Voltage Power System," in 2018 3rd International Conference for Convergence in Technology (I2CT), 2018, pp. 1-5: IEEE.

[10] Y.-K. Wu, J.-H. Lin, and H.-J. Lin, "Standards and guidelines for grid-connected photovoltaic generation systems: A review and comparison," IEEE Trans. On Industry Applications, vol. 53, no. 4, pp. 3205-3216, July- Aug. 2017.

[11] S. A. Barge and S. R. Jagtap, "Harmonic Analysis of Sinusoidal Pulse Width Modulation," International Journal of Advanced Electrical and Electronics Engineering (IJAEEE) Journal, vol. 2, no. 5, pp. 13-16, 2013.

[12] S. N. Adithya and R. R. S,"Study of multilevel sinusoidal PWM methods for cascaded h-bridge multilevel inverters," in 2014 IEEE 2nd International Conference on Electrical Energy Systems (ICEES), 2014, pp. 249-254: IEEE.

[13] W. J. Cha, K. T. Kim, Y. W. Cho, S. H. Lee, and B. H. Kwon, "Evaluation and analysis of transformerless photovoltaic inverter topology for efficiency improvement and reduction of leakage current," IET Power Electronics, vol. 8, no. 2, pp. 255-267, Feb. 2015.

[14] Z. Ahmad and S. N. Singh, "Comparative analysis of single phase transformerless inverter topologies for grid connected PV system," Solar Energy, vol. 149, pp. 245-271, June 2017.

[15] Z. Liao, C. Cao, and D. Qiu, "Analysis on topology derivation of single-phase transformerless photovoltaic grid-connect inverters," Optik, vol. 182, pp. 50-57, April 2019.

[16] M. Islam, S. Mekhilef and M. Hasan,"Single phase transformerless inverter topologies for grid-tied photovoltaic system: A review," Renewable and Sustainable Energy Reviews, vol. 45, pp. 69-86, May 2015.

[17] M. A. Khan, A. Haque, and K. Bharath, "Control and Stability Analysis of H5 Transformerless Inverter Topology," in 2018 International Conference on Computing, Power and Communication Technologies (GUCON), 2018, pp. 310-315: IEEE