Abstract—In this paper, a comparative performance analysis of two-switch Pseudo-inverter and Full-bridge inverter for Off-Grid Photovoltaic (OGPV) system is presented using single 250W-PV module. The performance of Pseudo-inverter and conventional Full-bridge inverter in terms of total harmonic distortion of the output voltage and current are compared based on the internal control of the inverter (open loop control) using Bipolar and Unipolar Sinusoidal Pulse-Width Modulation (SPWM). The total harmonic distortion (THD) of the conventional Full-bridge inverter and Pseudo-inverter, before and after implementation of filtering components also being analyzed. The results show that the Unipolar Pseudo-inverter with filter significantly provide lowest THD which are (5.01% and 5.35%) compared to conventional Unipolar Full-bridge inverter (13.9% and 35.55%), for current harmonic and voltage harmonic, THDi and THDv respectively. All the analytical work was performed using MATLAB Simulink software.

Index Terms—Pseudo dc-link, inverter, Full-bridge, Microinverter, Voltage source inverter, Off-Grid Photovoltaic, Bipolar, Unipolar, PWM modulation.

I. INTRODUCTION

TREND of Photovoltaic (PV) installation in Malaysia is promising and the determination to drive the PV systems comes from the inverter technologies. Conventional Full-bridge inverter basically were used as unfolding circuit or integrated circuit in the AC Module topologies, either in dual-stage topologies [1–4], single-stage topologies [5–9] or pseudo dc-link topologies [10–13] as shown in Fig. 1. Energy from PV installed at small-scale rooftop is channelled to the household AC-powered appliance such as water pump. However, some power electronic components were required in between enabling the energy flows from PV to the household load. These power electronics role as power conversions (DC to DC, or DC to AC) and smooth the AC output (filter) before supplied to the AC-powered load.

DC-DC converter may have several topologies [3-4,6-8] to choose from based on the purposed served. Conventional boost converter or buck converter could be used for stabilizing and the same time increasing or decreasing the value of DC input respectively. Then, an inverter will be connected to transform

![Diagram](image-url)
There are two types of load when dealing with PV module; either can be connected to grid or specified load, also known as Grid-Connected PV (GCPV) or Off-Grid PV (OGPV) [27–31] respectively.

This study proposed to use single power switch during positive AC cycle and another power switch for negative AC cycle, transforming pseudo-wave DC input into AC output without the present of transformer. Higher number of power switches converting into more switching losses involve in the inverter conversion. Hence, this study with Pseudo-inverter comprise of total of two power switches is proposed. Different kinds of SPWM techniques (Bipolar and Unipolar) and the impact of the filtering components of the non-isolated Pseudo-inverter for OGPV application were being analyzed and compared to the conventional Full-bridge inverter. Finally the simulation results for a single-phase Pseudo-inverter using Bipolar and Unipolar SPWM techniques with and without filter components described are presented.

II. CONVENTIONAL FULL-BRIDGE INVERTER

General block diagram for GCPV or OGPV system can be illustrated as Fig. 2a, involving a PV-input, followed by DC-DC Converter, DC-AC Converter, and output.

Referring to Fig. 1a, input PV can be arranged in different configurations depending on the size of input voltage requirement; which known as central PV, string PV, multistring PV or micro PV (AC module) [14], [15], [32-33]. DC input from PV can be classified based on the waveform generated; a) direct-DC, b) pulsating-DC, or c) pseudo-DC [5-6] Fig. 2b illustrates the pseudo-waveform from the input PV current of the proposed Pseudo-inverter. The DC input can be increased or decreased with the connection of DC-DC converter.

The flaw from the conventional Full-bridge inverter yields square-wave AC (before filter) and modified AC sine-wave (after filter) with the presence of four power switches (two power switches during each conduction mode). Therefore, based on the hypothesis, that only one power switch active during each conduction mode (one switch active during positive cycle and another one power switch active during negative cycle), able to produce AC waveform from the pseudo-DC waveform, thus generates pure AC sine-wave after inverter and filter components. Pure AC sine-wave aims for lower harmonic content before entering the off-grid load, consequently reducing the harmness that could occur to the load itself.

Inverter output voltage generally can be controlled by these various methods [10], [13], [35–41]: a) external control of AC output voltage (Known as closed loop control or voltage feedback control), b) external control of DC input voltage, usually for Current-Source Inverter (CSI), and c) internal control of the inverter (open loop control).

III. PROPOSED TWO-SWITCH PSEUDO-INVERTER

Block diagram of the OGPV system as shown in Fig. 3, consisting single PV module, DC-link capacitor, proposed Pseudo-inverter, LC filter and RL load representation as off-grid load. Fig. 4 shows the proposed Pseudo-inverter which was used in this work, consisting only two power switches, S1 and S2, each of the switch operates during the conduction mode (either positive cycle or negative cycle). One of the power switch was placed for allowing the current to pass through the positive RL load, hence creating the positive output cycle. While another power switch was placed for allowing the current to pass through the negative RL load, hence creating negative output cycle. This proposed topology allow only one power switch conducted during the conduction mode, hence ideologically reduced the conduction loss from the conventional Full-bridge inverter that requires two active power switches during each conduction mode. Small R were placed to prevent from the short-circuited simulation.

![Block diagram of the proposed OGPV system.](image)

![Block diagram of the proposed Pseudo-inverter for OGPV system; a) without LCL filter and b) with LCL filter.](image)

Based on Fig. 4, proposed inverter with and without LC filter were represented for off-grid PV application. Duty cycle of the power switches each will be turn on for 50%. During positive half cycle, as power switch S1 turns on, the current flow from PV module to the positive RL load and complete the cycle to the negative PV module terminal through small resistance, R. For negative half cycle, as power switch S2 turns on, the current...
flow from PV module to the negative RL load and complete the
circuit to the positive PV module terminal through small
resistance, R. Hence generating AC waveform measured at the
RL load. LC filter are added to smooth-out the AC output
temperature, consequently reducing the harmonic content at the RL
load.

IV. SINUSOIDAL PULSE WIDTH MODULATION (SPWM)
TECHNIQUE

Specified duty cycle of the SPWM signal generating voltage
signal or gate pulses across the power switches allowing the
switch to be turns on and off based on the specified duty cycle.
SPWM were comparing two modulating signal; carrier signal
(triangle) and reference signal (sinusoidal), thus generating gate
pulses to the power switches. The frequency of the reference
signal was set at 50Hz which determines the proposed Pseudo-
inverter output frequency, while the amplitude of the reference
signal controls the modulation index and the RMS value of the
inverter output voltage. SPWM technique were chosen in this
paper because of the simple implementation using analogue
components or digital microcontroller.

A. Bipolar SPWM

The gate pulses from the Bipolar SPWM technique requires
one reference signal, one carrier signal. The carrier signal is
triangulate between 1, -1 and back to 1, while reference signal
is sinusoidal wave with amplitude equal to 1. These two signal
were compared generating one gate pulse, named as Vgs1 for
turning on and off the power switch, S1. Analogue NOT
component was required to generate gate pulse for the power
switch, S2. Fig. 5a shows Bipolar SPWM block diagram of
Simulink Model and aggregated gate signal for power switches,
Vgs1 and Vgs2, respectively. Based on the Fig. 5a, at time zero,
the power switch, S2 already being turn on and generate output
simultaneously. Bipolar SPWM caused both power switches,
S1 and S2 will be turn on and off during both positive and
negative cycle. It means, the power switches will always
operate through out the time period, thus increase the stress on
the power switches consequently reduce lifespan of the power
switches for a long operation.

B. Unipolar SPWM

The gate pulses from the Unipolar SPWM technique requires
two sinusoidal modulating waveform as reference signal and
one carrier signal. The carrier signal is triangulate between 1
and 0 while both of the sinusoidal waveforms with same
amplitude of 1, but 180° out of phase. These two sinusoidal
signal were compared with a triangular signal, generating two
gate pulses, named as Vgs1 and Vgs2 for turning on and off the
power switches, S1 and S2 respectively, without additional
analogue component. Fig. 5b SPWM block diagram of
Simulink Model and aggregated gate signal for power switches,
Vgs1 and Vgs2, respectively. Based on the Fig. 5b, both of power
switches, S1 and S2 were off few seconds before start to be

Fig. 5.Block diagram of the SPWM; a) Bipolar and b) Unipolar.
operated. Unipolar SPWM caused only one power switch to be turn on during half of the cycle, hence reducing the stress on the respective power switch consequently improve the lifespan of the power switches for a long operation. Vast advantage of using Unipolar SPWM which provide the balncking time or known as dead-time,

V. PROPOSED PSEUDO-INVERTER FOR OGPV SYSTEM WITH SPWM TECHNIQUE

The proposed topology converting the pseudo-based DC input into AC output, where the proposed Pseudo-inverter has been modulated using both Bipolar and Unipolar SPWM. Parameters used for the Simulink Model were tabulated in the Table 1. Power switches, S1 and S2 had the same duty cycle at 50%, carrier signal was set at 20kHz with modulation index, ma = 1. DC-link voltage was set in parallel to the PV module to provide constant DC voltage to the inverter as well as treating the inverter as voltage-source inverter (VSI). Proposed Pseudo-inverter and conventional Full-bridge inverter circuit were tested at irradiation, G=1000 W/m², with real environment at T =65ºC. The off-grid load is represented by using RL load and will be tested with and without low-pass filter, LfCf using Eq. 1. The proposed topology as shown in Fig. 6 will be compared to the conventional Full-bridge inverter in Fig. 7, both using Bipolar and Unipolar SPWM.

\[ L_f = \frac{1}{(2\pi f_o)^2 C_f} \]  

Where \( f_o \) is the resonant frequency, which normally set to 10% of the \( F_s \).

| Variable | Parameter | Value |
|----------|-----------|-------|
| PV Module | LUMOS LS250-60M | 250W |
|          | Parallel string, \( N_{PV\text{-parallel}} \) | 1 |
|          | Series string, \( N_{PV\text{-series}} \) | 1 |
| Vc       | DC-link capacitor | 100µF |
| Vmpp     | PV voltage at MPP | 30.1V |
| Voc      | PV voltage at Open Circuit | 37.3V |
| Imp      | PV current at MPP | 8.31A |
| Lfilter  | Lf | 3.165mH |
| Cfilter  | C | 2µF |
| RL       | RL load | 10Ω 5mH |
| R        | Small R | 5Ω |

TABLE II

| Filter | THDi (%) | THDv (%) | Fig. |
|--------|----------|----------|------|
| LC     | 1.08     | 1.45     | 8b   |
| LC     | 2.672    | 202.1    | 8c   |
| LC     | 0.68     | 1.754    | 8d   |
| LC     | 32.2     | 137.9    | 9a   |
| LC     | 29.08    | 33.4     | 9b   |
| LC     | 5.68     | 141.6    | 9c   |
| LC     | 5.995    | 5.685    | 9d   |

Fig. 6. Simulink Model of the proposed Pseudo-Inverter for Off-Grid PV system using; a) Bipolar SPWM and b) Unipolar SPWM.

Fig. 7. Simulink Model of the conventional Full-bridge Inverter for OGPV system using; a) Bipolar SPWM and b) Unipolar SPWM.
VI. RESULTS AND DISCUSSION

The proposed Pseudo-inverter with Bipolar and Unipolar SPWM are simulated using MATLAB Simulink with parameters as tabulated in Table I. Fig. 1b shows the desired DC current from the PV module in pseudo-wave shape pattern used in this work. The values of inverter output voltage and current have been set to make comparison for their performance. Output current and voltage waveform of both conventional Full-bridge inverter and proposed Pseudo-inverter with different modulation techniques and with or without filter connection which are depicted in Fig. 8 and Fig. 9 respectively.

Table II summarise the FFT analysis on the total harmonic distortion of the Bipolar and Unipolar SPWM for conventional Full-bridge inverter as well as the proposed Pseudo-inverter, with and without LC-filter component. The FFT analysis setting are: fundamental frequency equal to 50Hz, while the maximum frequency was set at 20kHz along across a time of period, $T=0.1s$ and the FFT analysis start time at $0.02s$, to give time for the system to settle down, as shown in Figure 10.

Referring to Fig. 8a and Fig. 8c, Bipolar SPWM technique produce inverter output voltage between $-V$ and $+V$ along the time period. It shows that by using Bipolar SPWM, the switching and operation mode of both power switches, $S1$ and $S2$ will be taken place in turns during both positive and negative cycle. Full-bridge inverter and Pseudo-inverter using Bipolar SPWM producing quite low THD, which are 1.93% and 2.672% respectively. However, Bipolar SPWM producing two-level output voltage ($+V$ and $-V$), does generating higher THD, in proposed Pseudo-inverter and conventional Full-bridge inverter which are are 104.2% and 202.1% respectively.

Previously in Fig. 5b, Unipolar SPWM allowing only one power switch to be operated during half cycle, while the other power switch is off, and vice versa. Hence, Unipolar SPWM producing three-level output voltage ($+V$, 0V and $-V$) due to the dead-time occurred from the carrier signal’s setting; which triangulate between $[1,0,1]$ consequently producing output waveform near to the sinusoidal shape and reducing the THD. This can be seen in Table II, where the proposed Unipolar Pseudo-inverter shown in Fig. 9c producing lower THDi compared to Bipolar Pseudo-inverter shown in Fig. 8c, where the THDi drop from 202.1% to 141.6% respectively. By comparing Unipolar of the inverters shown in Fig. 9c and Fig. 9a from Table II, the proposed Pseudo-inverter producing lower THDi which equal to 5.7% compared to the conventional Full-bridge inverter with THDi equal to 33.19%.

Low-pass filter was connected parallel to the off-grid load of both inverters. Referring to Fig. 8d and Fig. 8b from Table II, the proposed Bipolar Pseudo-inverter with LC-filter successfully producing AC waveform with THDi equal to 0.68% which are lower compared to conventional Bipolar Full-bridge inverter with THDi equal to 1.08%. However, Bipolar Pseudo-inverter with LC filter does have slightly higher THDv, but still in the acceptable values at 1.76%, compared to the conventional Full-bridge inverter at 1.45%.

The impact of the LC-filter on the Unipolar SPWM can be illustrated in Fig. 9d and Fig. 9b, where the proposed Unipolar Pseudo-inverter with LC filter successfully producing AC waveform with lowest THDi and THDv which are 5.1% and 5.69% respectively, comparing to the Unipolar Full-bridge inverter which are 29.08% and 33.4% respectively.

Last, based on Table II, the proposed Pseudo-inverter producing better THD performances by using Bipolar or Unipolar SPWM as shown in Fig. 8d and Fig. 9d compared to the conventional Full-bridge inverter as shown in Fig. 8b and Fig. 9b respectively.

These findings suggested that internal control of the inverter (open loop control) for this paper through Bipolar and Unipolar SPWM plus additional filter component able to generate inverter AC output, eventhough generates very low voltage range due to the single PV-input. The proposed Pseudo-inverter was planned for off-grid application where the output required is low. Hence, anything received by the PV input will be transformed into AC by the proposed Pseudo-inverter and transferred to the load directly, without storage unit nor connected to the national grid. However, more higher voltage range could be generated by inserting DC-DC converter as the
Fig. 8. Inverter Voltage and Current Output using Bipolar SPWM; a) Full-bridge Inverter without filter, b) Full-bridge Inverter without filter and c) Proposed Pseudo-Inverter without filter and d) Proposed Pseudo-Inverter with filter.

Fig. 9. Inverter Voltage and Current Output using Unipolar SPWM; a) Full-bridge Inverter without filter, b) Full-bridge Inverter with filter, c) Proposed Pseudo-Inverter without filter and d) Proposed Pseudo-Inverter with filter.

These results and discussions provide further support for the hypothesis earlier that only one power switch active during each conduction mode (one power switch active during half of the positive cycle and another one power switch active during half of the negative cycle), through open loop control of the Bipolar and Unipolar SPWM Pseudo-based inverter which able to transform DC waveform into AC waveform, moreover produce AC sine wave output with lowest THDi and THDv.
VII. CONCLUSION

The purpose of the study was to determine whether only one power switch can be activated during each conduction mode (where one power switch active 50% during the positive cycle, while another power switch active 50% during the negative cycle), thus transforming DC input into AC output through Pseudo-based inverter. The research has shown that controlling the proposed Pseudo-inverter through open-loop control using Bipolar SPWM successfully generating two-level voltage output (+V and -V) with 0.68% and 1.76% of THDv and THDi respectively. Additional, three-level voltage output (+V, 0V, and -V) was successfully generated by using open-loop control using Unipolar SPWM with 5.1% and 5.69% of THDi and THDv respectively. Based on the analysis conducted, it can clearly concluded that the proposed Pseudo-inverter with open loop control using Bipolar and Unipolar SPWM and installation of low-pass filter generating better THDv and THDi comparing to the conventional Full-bridge inverter.

ACKNOWLEDGEMENTS

This work was financially supported by the Ministry of Higher Education (MoHE), Malaysia. The authors also would like to acknowledge the Center for Robotics and Industrial Automation (CeRIA), Fakulti Kejuruteraan Elektrik, Universiti Teknikal Malaysia Melaka, 76100, Durian Tunngal, Melaka, Malaysia and Discipline of Electrical Power Engineering, School of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

REFERENCES

[1] Y. Fang and X. Ma, “A Novel PV Microinverter with Coupled Inductors and Double-Boost Topology,” IEEE Trans. Power Electron., vol. 25, no. 12, pp. 3139–3147, 2010.
[2] L. Chen, A. Amirzadian, Q. Zhang, N. Kutkut, and I. Batarseh, “Design and Implementation of Three-Phase Two-Stage Grid-Connected Module Integrated Converter,” IEEE Trans. Power Electron., vol. 29, no. 8, pp. 3881–3892, Aug. 2014.
[3] M. Kumar, M. Ashirvad, and Y. N. Babu, “An Integrated Boost-Sepic-Cuk DC-DC Converter with High Voltage Ratio and Reduced Input Current Ripple,” Energy Procedia, vol. 117, pp. 984–990, Jun. 2017.
[4] S. A. Khajehoddin, “Resonant Micro-Inverters for Single-Phase Grid-connected Photovoltaic Systems,” 2010.
[5] H. Krishnaswami, “Photovoltaic Microinverter using Single-Stage Isolated High-Frequency Link Series Resonant Topology,” in 2011 IEEE Energy Conversion Congress and Exposition, 2011, vol. 1, no. 1, pp. 495-500.
[6] N. Sukesh, M. Pahlevaninzechad, and P. K. Jain, “Analysis and Implementation of a Single-Stage Flyback PV Microinverter with Soft Switching,” IEEE Trans. Ind. Electron., vol. 61, no. 4, pp. 1819–1833, 2014.
[7] R. K. Surapaneni and A. K. Rathore, “A Single-Stage CCM Zeta Microinverter for Solar Photovoltaic AC Module,” 2015 IEEE Energy Convers. Congr. Expo. ECCE 2015, vol. 3, no. 4, pp. 892–900, 2015.
[8] D. Meneses, O. Garcia, P. Alou, J. A. Oliver, R. Prieto, and J. A. Cobos, “Single-stage grid-connected forward microinverter with constant off-time boundary mode control,” Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, pp. 568–574, 2012.
[9] M. Khalilian and P. Guglielmi, “Single-stage Grid-connected Flyback Inverter with Zero Current Switching for AC Module Application,” in IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics, 2016, pp. 2390–2395.
[10] R. Hernandez-Vidal, Q. Suritye, H. Renaudineau, S. Kourov, and B. Cabon, “Push-pull based pseudo DC-link PV microinverter,” Proc. IECON 2017 - 43rd Annu. Conf. IEEE Ind. Electron. Soc., vol. 2017-January, pp. 7843–7848, 2017.
[11] S. Pervez, M. U. Rehman, A. B. Asghar, and N. Zaffar, “A Novel Single-phase Soft switching Microinverter for Photovoltaic Applications,” in 2013 3rd International Conference on Electric Power and Energy Conversion Systems, EPEC 2013, 2013, pp. 1–5.
[12] C. Y. Yang et al., “A module-integrated isolated solar micro-inverter,” IEEE Int. Conf. Ind. Informatics, pp. 780–785, 2012.
[13] E. Fonkwe, J. Kirtley, and J. Elizondo, “Flyback micro-inverter with reactive power support capability,” 2016 IEEE 17th Work. Control Model. Power Electron. 17th Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, pp. 353–358, 2016.
[14] P. K. Sahu, a Mohanty, B. P. Gantila, and a K. Panda, “A multiphase interleaved boost converter for grid-connected PV system,” 2016 Int. Conf. Microelectron. Comput. Commun., pp. 1–6, 2016.
[15] R. Hasan, S. Mekhilaf, M. Nakaoka, and K. Nishida, “Soft-Switching Active-Clamp Flyback Microinverter for PV Applications,” in 2016 IEEE 2nd Annual Southern Power Electronics Conference, SPEC 2016, 2016, pp. 1–6.
[16] E. Kabalci, R. Bayindir, G. Gokkus, and Y. Kabalci, “Dual DC-DC converter and monitoring interface for asymmetrical string inverters,” 2015 Int. Conf. Renew. Energy Res. Appl. ICRERA 2015, vol. 5, pp. 1580–1585, 2016.
[17] Z. Ahmad and S. N. Singh, “Comparative Analysis of Single Phase Transformerless Inverter Topologies for Grid Connected PV System,” Sol. Energy, vol. 149, pp. 245–251, Jan. 2017.
[18] R. Hasan and S. Mekhilaf, “Highly Efficient Flyback Microinverter for Grid-connected Rooftop PV System,” Sol. Energy, vol. 146, pp. 511–522, Apr. 2017.
[19] S. R. Sundhini, G. Akalya, K. Aswini, K. Nandhini, M. V. Rajkumar, and B. Rajeshkumar, “A New Topology of H-bridge based Multilevel Inverter for PV System with Reduced Switches,” vol. 5, no. 4, pp. 60–68, 2017.
[20] S. Divya, K. Abarna, and M. Sasikumar, “PV Micro Inverter Topology using Soft Switching Half-Wave Cycloconverter,” in 2014 IEEE National Conference on Emerging Trends In New & Renewable Energy Sources And Energy Management (NCET NRES EM), 2014, pp. 148–152.
[21] A. Razi, M. N. Hidayat, and M. N. Seroji, “Microinverter Topology based Single-stage Grid-connected Photovoltaic System: A Review,” Indones. J. Electr. Eng. Comput. Sci., vol. 11, no. 2, pp. 645–651, 2018.
[22] A. Palanisamy et al., “A New Three-Level Three-Phase Boost PPM Inverter for PV applications,” in IEEE Energy Conversion Congress and Exposition (ECCE), 2018, pp. 791–796.
[23] D. L. Caiz, S. Kouro, F. Flores-Bahamonde, and R. Hernandez, “Unfolding PV Microinverter Current Control: Rectified Sinusoidal vs Sinusoidal Reference Waveform,” 2018 IEEE Int. Energy Convers. Congr. Expo. ECCE 2018, pp. 7094–7100, 2018.
[24] A. Razi, M. N. Hidayat, M. N. Seroji, and S. Z. Mohammad Noor, “A novel single-stage PWM microinverter topology using two-power switches,” Int. J. Power Electron. Drive Syst., vol. 11, no. 2, pp. 792–800, 2020.
[25] J. Doucet, D. Eggleston, and J. Shaw, “DC / AC Pure Sine Wave Inverter,” 2007.
[26] S. Sundar, “DESIGN OF A HIGHLY EFFICIENT PURE SINE WAVE INVERTER FOR PHOTOVOLTAIC APPLICATIONS,” Int. J. Pure Appl. Math., vol. 119, no. 6, pp. 4397–4403, 2018.
[27] I. R. Ibrahim, A. M. Omar, Z. Hussain, M. N. Mohd Hussain, and S. Z. Mohammad Noor, “Dual-Power PV-Grid Energy System - An Alternative to the Off-Grid PV Energy System,” Adv. Mater. Res., vol. 925, no. 2014, pp. 661–665, Jun. 2014.
[28] A. S. Mundada, Y. Nilsiam, and J. M. Pearce, “A Review of Technical Requirements for Plug-and-Play Solar Photovoltaic Microinverter Systems in the United States,” Sol. Energy, vol. 135, pp. 455–470, Oct. 2016.
[29] J. J. Shringija and V. Sivachidhanbaranathan, “PV Microinverter Topology based on Phase Shift Power Modulation Technique using Frequency Conversion Circuit,” in 2016 Second International Conference on Science Technology Engineering and Management.
[30] N. Sujitha, P. S. Subudhi, S. Krithiga, S. Angalaeswari, T. Deepa, and D. Subbulekshmi, “Grid tied PV system using modular multilevel inverter,” Int. J. Power Electron. Drive Syst., vol. 10, no. 4, pp. 2013–2020, 2019.

[31] S. Masoud Barakati and B. Wu, “A New Compact On and Off-grid Inverter for Photovoltaic Applications,” in 2017 40th International Conference on Telecommunications and Signal Processing (TSP), 2017, pp. 307–310.

[32] Z. Ahmad and S. N. Singh, “Improved modulation strategy for single phase grid connected transformerless PV inverter topologies with reactive power generation capability,” Sol. Energy, vol. 163, no. December 2017, pp. 356–375, 2018.

[33] Z. Zheng, “High Efficiency Single-stage Grid-tied PV Inverter for Renewable Energy System,” 2012.

[34] R. Hasan, S. Mekhilef, M. Seyedmahmoudian, and B. Horan, “Grid-Connected Isolated PV Microinverters: A Review,” Renew. Sustain. Energy Rev., vol. 67, pp. 1065–1080, Jan. 2017.

[35] D. Lopez-Caiza, F. Flores-Bahamonde, S. Kouro, V. Santana, N. Müller, and A. Chub, “Sliding mode based control of dual boost inverter for grid connection,” Energies, vol. 12, no. 22, pp. 1–15, 2019.

[36] S.-J. Yoon, T. Van Nguyen, and K.-H. Kim, “Current control of grid-connected inverter using integral sliding mode control and resonant compensation,” Int. J. Power Electron. Drive Syst., vol. 10, no. 2, pp. 1022–1033, 2019.

[37] B. K. Perera, P. Ciufo, and S. Perera, “Point of common coupling (PCC) voltage control of a grid-connected solar photovoltaic (PV) system,” IECON Proc. (Industrial Electron. Conf., no. Iecon, pp. 7475–7480, 2013.

[38] H. Athari, M. Niroomand, and M. Ataei, “Review and Classification of Control Systems in Grid-tied Inverters,” Renew. Sustain. Energy Rev., vol. 72, pp. 1167–1176, May 2017.

[39] G. D. U. Latha, S. S. S. Kinnera, and D. L. Priya, “Advances and Control Techniques in Grid Connected,” 2017.

[40] P. Monica and M. Kowsalya, “Control Strategies of Parallel Operated Inverters in Renewable Energy Application: A Review,” Renew. Sustain. Energy Rev., vol. 65, pp. 885–901, 2016.

[41] S. A. Khajehoddin, A. Bakhshai, and P. Jain, “A Novel Topology and Control Strategy for Maximum Power Point Trackers and Multi-String Grid-Connected PV Inverters,” in 2008 Twenty-Third Annual IEEE Applied Power Electronics Conference and Exposition, 2008, pp. 173–178.