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Analysis of the Different Transformerless PV Inverter Topologies

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ABSTRACT

The transformer-less PV inverter network topology that is offered for the single-phase inverter system is what we are anticipating in this research. utilizing the PV grid-connected apparatus. This paper investigates the terminal voltage of the most widely used PV inverter network topology that is reported in the works. A comparison is made between the topologies. The offered analysis makes use of the switching function concept about the switch configuration. Switching functions allow the analysis to consider the outcome of the switching approach or the pulse-width variation technique arranged in the terminal voltage of the evaluated configuration. the topologies that use PWM and SPWM for the switches' gate operation, the switches that are employed in the topology, the applications of filters, and the schematic diagram-based method for reducing leakage current. It gives complete information on the high-frequency changes in the terminal voltage for the designated switching approach and explains how switching events impact the voltage at the terminal.

KEYWORDS: PWM ,SPWM, PVGrid

1. INTRODUCTION

As we move from one generation to the next, our population grows, and so does our demand for energy resources. We have many types of natural resources such as petroleum and gases firewood etc. Still, with them, we are also having renewable energy as the replacement, as conventional sources of energy create pollution. They are also on the verge of extinction as the increase in demand. They are limited sources of energy they can't replenish themselves but renewable energy can replenish itself and its nonpolluting when used. We have many types of sustainable energy sources like solar, hydro, and wind. We can say that solar energy [1–3] is the best of them because it has low maintenance, and can be installed anywhere we have efficient sunlight. The ultimate source of energy that can be easily converted is the sun, which is also responsible for the existence of life on Earth. To use the energy from the sun, we have developed solar panels. When solar panels[4] generate energy, they produce a DC, but we use AC in our daily lives.

Therefore, we need a device that can efficiently convert DC to AC. The devices we Inverters and their topologies are used in the conversion of DC to AC. play a crucial role in efficient output and the reduction of conduction losses in an inverter. Here, we are going to study some latest Topologies for PV inverters based on the switching characteristics with the mode of working. the types of inverter we are going to study in this paper are known as hybrid inverters as they don't use a transformer for the galvanic isolation and they are in continuous development[5] .as they don't use a transformer, they are comparatively low in price, weight and the logistics will be easy for it they will have an extended life expense as the point of losses are reduced enormously when we remove a transformer from the system and we have less loss in the semiconductors. the problems we face on removing the transformer are the safety measures and the high THD[6–10] in the output which can be compensated with the help of proper grounding of the inverter and the appropriate filter arrangements. We use MOSFETs and IGBTs [11]

2. INVERTER SWITCHING TOPOLOGIES

A. **Unipolar PWM** *[8]*

An inverter transforms direct current (DC) into alternating current (AC). Here, a popular method for A full bridge is a crucial part of power electronics. regulating the inverter's output waveform is pulse width modulation or PWM. The unipolar technique is one particular PWM [8]method that modifies only one half-cycle within the AC waveform. The entire bridge inverter is constructed of four switches placed in a bridge pattern. By carefully manipulating these switches, it can create an alternating current channel from a direct current source. PWM is used to accurately control the AC output; one such technique is unipolar PWM. The AC waveform is only modulated for one half-cycle by unipolar PWM. This usually entails changing the pulse width while maintaining the integrity of the negative half-cycle in the positive half-cycle. By comparing a triangular carrier wave with a reference signal typically a sinusoidal waveform that represents the intended output the modulation process is accomplished. In a complete bridge inverter, monopolar pulse width modulation is implemented by comparing the carrier wave and reference signal during the positive half-cycle. The comparison's outcome establishes the pulse width, which regulates the related switches opening and closing. Following that the switches are controlled by the PWM signal, which affects the output of the voltage at the start of the half-cycle.

There are benefits of unipolar PWM in terms of efficiency and simplicity. Compared to bipolar PWM, it modulates just one half-cycle, which reduces the complexity of the control circuitry. In some cases, this might result in lower costs and more dependability. The effect of unipolar PWM on harmonic content is one important feature. Compared to bipolar PWM, it might introduce greater harmonic distortion because it only modulates one half-cycle. This trade-off is frequently justified, nevertheless, in situations where simplicity and economy of design take precedence over the requirement for exceptionally low harmonic distortion. Additionally, the unipolar PWM method is essential for lowering electromagnetic interference, eliminating common-mode voltage, and improving overall inverter performance. The steady and effective AC output is facilitated by the controlled switching that occurs in the course of the positive half-cycle.

The voltage generated by the inverter when using the unipolar PWM technique has three levels: 0, Vpv, and -Vpv. For the full-bridge inverter to 6+generate three levels at the output terminals, the S1, S2, S3, and S4 switches are required. There is no restriction on how the switch matches (S1, S2) and (S3, S4) are worked. The many methods by which the full-span inverter with unipolar PWM operates. When switches S1 and S4 are turned ON, the inverter output voltage changes to Vpv. Along these lines, when the S2 and S3 switches are activated, the inverter yield voltage arrives at −Vpv. Either the base switches pair (S2 and S4) or the top switches pair (S1 and S3) are activated at the zero-voltage level. Thus, the current that results from the inverter openly streams through either the top or base arrangement of switches and has three levels (Vpv, 0, and −Vpv) while utilizing the unipolar PWM approach. The S1, S2, S3, and S4 switches are utilized by the full-span inverter to create three levels at the result terminals. [12]

Thus, the terminal voltage Vag expression is

$$Vag = 0.5Vgnd + 0.5Vs$$

The voltage of 0 terminal voltage expression is

$$Vag = \infty$$

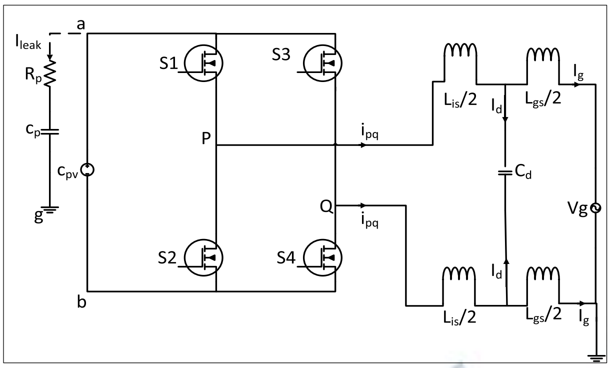

Figure 1 unipolar PWM

B. Bipolar PWM technique[12]

To convert DC (direct current) to AC (alternating current), a complete bridge inverter is an essential part of power electronics. It is made up of four switches set up in a bridge arrangement. Pulse Width Modulation is a frequently used technique for controlling the output waveform (PWM). The modulation method in bipolar PWM[12] entails altering the AC waveform's positive and negative half-cycles. By flipping the switches in diagonal pairs, the full bridge inverter generates an alternate channel for the current. Through this procedure, a DC source can produce an AC output. However, PWM is used to regulate the properties of the output waveform. Particularly, bipolar PWM modifies both AC cycle halves. The width of the pulses in the positive and negative half-cycles is separately varied during the modulation process. Exact control over the output voltage, frequency, and harmonic content is made possible by this flexibility. The modulating signal and triangular carrier are contrasted waves for both the positive and negative half-cycles to achieve bipolar PWM in a full bridge inverter. Upon comparison, pulse-width modulated signals are produced for every half-cycle. The output voltage is determined by these modulated signals, which regulate the appropriate switches' opening and shutting.

In terms of efficiency and output quality, bipolar PWM has benefits. It allows for improved harmonic control and reduced total harmonic distortion (THD) in the output waveform by individually modulating the positive and negative half-cycles. This is critical for applications like motor drives and renewable energy systems that need a clean, precise AC output. Additionally, the bipolar PWM approach lowers electromagnetic interference, minimizes common-mode voltage, and enhances the inverter's overall performance. Effective power management and optimal voltage regulation are made possible by the exact control over the pulse width. In summary, the flexibility of separately modulating positive and negative half-cycles is combined with the switching capabilities in a complete bridge inverter of the bridge structure that uses bipolar PWM. This leads to a high-performing AC output that is more efficient, has a lower common-mode voltage, and a better harmonic content. Applications for this technology can be found in many different domains, such as industrial motor drives and renewable energy systems, where there is a critical need for dependable and superior AC power.

The schematic diagram for a full-bridge inverter remains unchanged. Unlike unipolar PWM, bipolar PWM allows the inverter's output voltage to have two levels (Vpv and −Vpv). Bipolar PWM is utilized in the two working modes of the full-bridge inverter. When the S1 and S4 switches are in operation, the inverter output voltage changes to Vpv. Comparatively, As a result, when switches S2 and S4 are activated, the inverter output voltage rises to −Vpv. The bipolar PWM full-bridge inverter technology's voltage output, terminal voltage, and gate pulse waveforms. The bipolar PWM technique uses a single reference wave and a single carrier wave. When the magnitude of the reference wave is higher than that of the carrier wave, the switch pair (S1 and S4) is engaged.

The other switch pair (S2 and S3) is engaged if not. The output voltage of the inverter varies between Vpv and −Vpv values during the whole grid voltage cycle. Further insight into this is provided by the output voltage waveform. The lack of a 0 state within the bipolar PWM approach prevents the switches (S1 and S3) or (S2 and S4) in pairs from being switched ON simultaneously. Consequently, switch S1 or switch S3 is switched ON for the duration of the output voltage cycle.[12]

In the bipolar PWM technique due to the absence of 0 state the terminal voltage Vag expression as,

$$V_{ag} = 0.5V_{gnd} + 0.5V_s$$

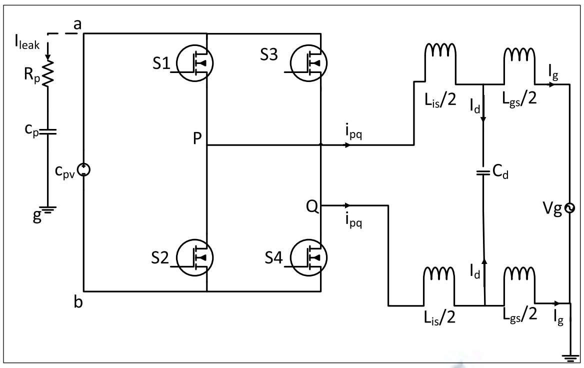

Figure 2 Bipolar PWM

C.H5 Inverter topology[9]

Grid-connected H5 Inverter topology has 5 switches (S1-S5), S5 is used as an additional switch. An LCL filter connects H5 inverters to a grid to the PV array. The H5 Inverter produces three different output voltage levels, which are Vpv (positive state), 0 state, and -Vpv (negative state). The switch S5 is employed in the freewheeling condition to segregate the PV array and grid (it is also called 0 state).

When the S1, S4, and S5 switches are turned on, the positive level is obtained and current flows through the PV array to switch S5, S1, and S4 to the grid, when the S2, S3, and S5 switches are turned on the negative level is obtained and current flow through the PV array to switch S5, S2, and S3 to the grid, when the switch S5 is OFF and either switch S2 and S4 is ON or switch S1 and S3 is ON 0 level is obtained. For the output current of the inverter to freewheel and no current flow from the PV array to the grid.[12]

Now the obtaining ab positive voltage level Vpv & negative voltage -Vpv The terminal voltage expression's magnitude is

$$Vag = 0.5Vgnd + 0.5Vs$$

The terminal voltage expression's magnitude at 0 voltage level is

$$Vag = \infty$$

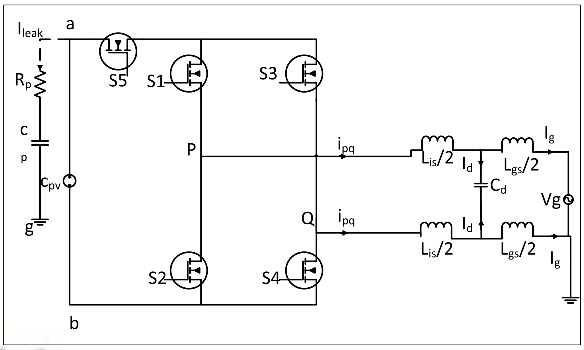

Figure 3 H5 inverter

D. H6 Inverter [6]

Grid-connected photovoltaic (PV) systems are seeing an increase in usage. The best solution is a non-isolated inverter, which is both affordable and extremely efficient. Safety and power quality issues plague these inverters. An excellent balance between cost, complexity, and efficiency can be found in traditional full-bridge inverters. Problems are caused by parasitic capacitors between the ground and the PV array. Partial capacitance and dangerous current are decreased by grounding a photovoltaic array. Topologies for inverters that are safe from leakage currents include half bridge and neutral-point clamped. H4 topology and PWM methods are being improved. A new, highly efficient transformer-less inverter with a hybrid modulation technique is suggested. Analytical theory is supported by experimental data. For grid-tied photovoltaic systems, transformer-less inverters are utilized because of their low cost and excellent efficiency. Low leakage current H6 transformer-less inverter topologies are suggested. Power losses and expenses for the H5, HERIC, and H6 topologies are compared. According to experimental findings, the H6 topology is more efficient than the H5 topology. The paper describes a MOSFET-based high-efficiency inverter for photovoltaic applications. The suggested H6-type arrangement provides a low ground leakage current and good efficiency. Split capacitors are not required, and there is little output ac-current distortion. PWM scheme, bootstrap power supply, and detailed power stage working principles are explained. The experimental results demonstrate the resolution of the ground leakage and MOSFET body diode problems. reached 98.1% efficiency for the European Union and 98.3% efficiency at maximum.[12] Six switches are employed in the H6 inverter topology (S1-S6). Additionally, the H6 inverter provides three voltage levels: 0 and -Vpv. A positive level is obtained when the switches pair (S1, S4, and S5) are turned on, and a negative level is obtained when the switches pair (S2 and S6) are switched on. Now the resulting expression is given by

$$Vag = 0.5Vgnd + 0.5Vs$$

And at Zero voltage can be obtained by ON the switching pair S1 and S3 therefore the expression is

$$Vag = \infty$$

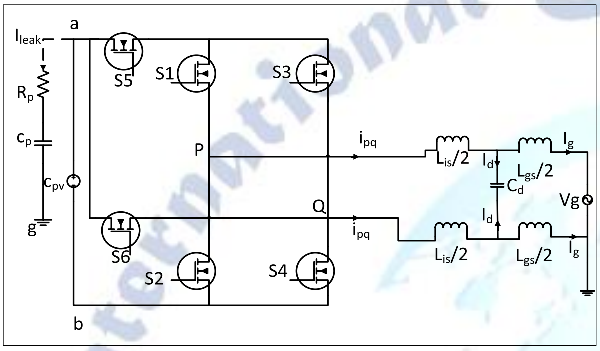

Figure 4 H6 inverter

E. Transformer-less H6 Inverter [11]

An LCL filter is used to link the inverter structure schematically to the grid. The six switches in the provided inverter architecture are S1–S6. Three output voltage levels are also produced by the specified inverter configuration method of operation of the given inverter at voltage stages Vpv, 0, and −Vpv. Following the activation of switches S1, S4, and S6, the voltage level 'Vpv' is determined. Similarly, the voltage stages -Vpv is attained if the S2, S3, and S5 switches are turned on. When there is no voltage, the network current is freewheeling between switches S5 and S6. S5 and S6 switches continue to operate and remain in the on state during a half-cycle of the grid voltage. They also function at a high frequency through the opposing half-cycle switching frequency. In the absence of voltage, the network inductor current ipq freely flows over switches S5 and S6. The remaining S1–S4 switches are not in use while the voltage is at zero. Turning off switches S1–S4 separates the PV array from the network. As a result, the inverter design in question minimizes PV systems' leakage current by utilizing the AC decoupling methodology. Fig. 7c displays the output voltage, terminal voltage, and pulse-generating waveforms for the specified inverter. For the specified inverter, two carrier waves that have been level-shifted by one volt and one reference wave are required. When the reference wave's magnitude exceeds that of the higher carrier wave, the switches turn on for S1, S4, and S6. Similarly, the switches S2, S3, and S5 are activated when the orientation wave's magnitude is lower than the lowest carrier waves. During the grid's positive half-cycle, the inverter's output voltage varies between Vpv and 0. Similar to the grid voltage, the inverter output fluctuates between 0 and −Vpv throughout the negative half cycle. [12]

And the expression for terminal voltage Vag is

$$Vag = 0.5Vgnd + 0.5Vs$$

The terminal voltage at the zero-voltage level can be expressed as

$$Vag = \infty$$

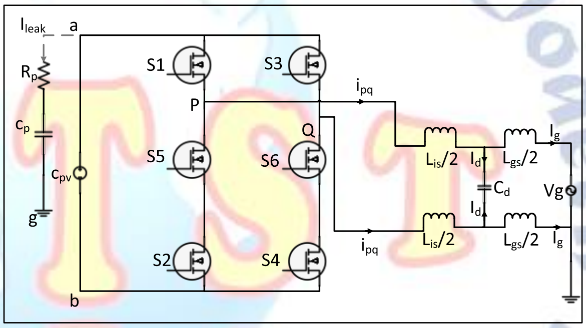

Figure 5 Transformer-less H6 inverter

F. High-efficiency H6 Inverter [4]

The grid is connected to the topology of the inverters via an LCL sludge. In this topology, six switches (S1 through S6) and two diodes (D1 and D2) make up. likewise, this inverter topology produces three situations of affair voltage. The operation modes of this inverter for the voltage situations are Vpv, 0, and -Vpv. The voltage position Vpv is attained when the S1, S4, and S5 switches are activated. also, the voltage position- Vpv is attained when the S2, Sw3, and Sw6 switches are activated. In the 0-voltage setting, the grid current is freewheeling through switches S5 and S6. During the grid voltage's +ve and -ve half cycles, the switches S5 and S6 are activated, independently.

The network inductor current ipq freewheels over the switches Sw5 and Sw6 in the case of zero voltage. The switches Sw1- Sw4 are turned OFF at the 0-voltage position, performing in insulation of the grid and PV array. Thus, this inverter topology utilizes AC divorcing method to reduce PV systems' leakage current. Two carrier swells and one reference surge are needed for this inverter, which is position-shifted by 1V. Whenever the upper carrier surge is exceeded by the amount of the reference surge, the switches S1, S4, and S5 become active. Also, if the reference surge's size is less than the nethermost carrier surge, the switches S2, S3, and S6 are activated, the voltage of the inverter fluctuates between Vpv and 0. In addition, the inverter affair voltage fluctuates between 0 and -Vpv during the grid voltage's negative half cycle. [11]

Since the high-efficiency H6 inverter provides three output voltage levels as well, the expression is

$Vag = 0.5Vgnd + 0.5Vs$

And the expression for 0 voltage level is

$Vag = \infty$

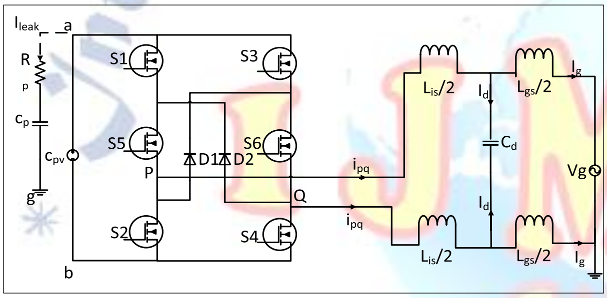

Figure 6 High-efficiency H6 inverter

G. HERIC Inverter [5]

The paper discusses the modulation strategy for AVC-HERIC inverters in PV systems. The modulation scheme ensures bidirectional current flow and infusion of reactive power. The suggested modulation makes up for restrictions on minimum pulse width and dead time. The efficiency of the suggested modulation is confirmed by experiments and simulations. A promising modulation technique for PV systems that are compatible with the grid. Design of efficient solar inverter for grid-connected photovoltaic system. Two-stage topology without galvanic isolation for single-phase inverter linked to the grid. DC to AC conversion is accomplished by a DC/DC boost converter with MPPT control. HERIC inverter is used for higher efficiency in converting DC to AC.

It adopts conventional UP-PWM for positive power and a specific modulation scheme for negative power. The proposed scheme also introduces modified dead time at zero-crossing sites for UP-PWM. Experiments and simulations conducted on a 4-kW HERIC inverter system confirm the scheme's efficacy. The design of a HERIC inverter for photovoltaic systems is covered in the paper. To guarantee correct operation, a hardware-in-the-loop (HIL) simulation is utilized. The algorithm is executed by the TMS320F28335 chip. The HERIC inverter offers high efficiency and safety without a transformer. The process can be applied to design high-power, high-efficiency converters.

[12] The H-bridge inverter of the HERIC inverter topology is connected to the bi-directional switches SW5 and SW6. As a result, during the positive and negative half cycles, Sw5 and Sw6 turned on, and the terminal voltage Vag expression is

$Vag = 0.5Vgnd + 0.5Vs$

When the voltage is zero, only switches Sw1 and S3 are turned ON remaining switches are turned OFF therefore terminal voltage expression is

$Vag = \infty$

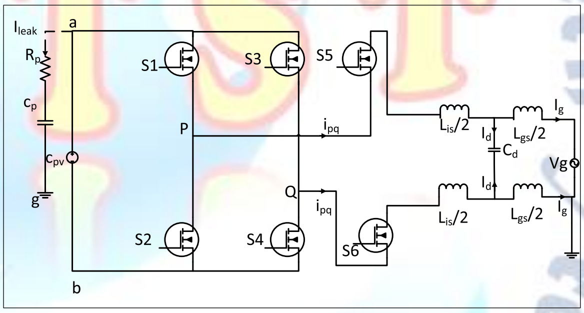

Figure 7 Heric inverter

H. NPC Full Bridge Inverter[10]

An LCL filter connects the neutral point clamped full bride inverter to the grid. A neutral point inverter is suitable for 3-4 KV. In NPC topology three voltage levels allow for the line to neutral waveform.

It consists of eight switches (S1-S8), In NPC the input PV array is two capacitors which are split into two balanced halves. These clamps give the output a freewheeling path. Three output voltage levels are produced by the neutral point clamped inverter, which are positive level (Vpv), 0 level, and negative level (-Vpv). When the Turn on the switches S1, S2, S5, and S6. The voltage level Vpv is obtained and current flow from the PV array to S1, S2, S5, and S6 are switched to the grid. When the switches S3 and S4 are turned ON the voltage level - Vpv is obtained and current flows from the PV array to switch S3, and S4 to the grid. The voltage level drops to zero when switches S2, S5, S7, and S8 are turned on, and no current flows from the PV array to the grid. This aids in clamping the voltage at the terminal.[12]

Consequently, after analyzing both positive and negative terminal voltage, the terminal voltage output expressions are

$$Vag = 0.5Vgnd + 0.5Vs$$

And for the analysis of the 0 voltage level terminal voltage expression is

$$Vag = \infty$$

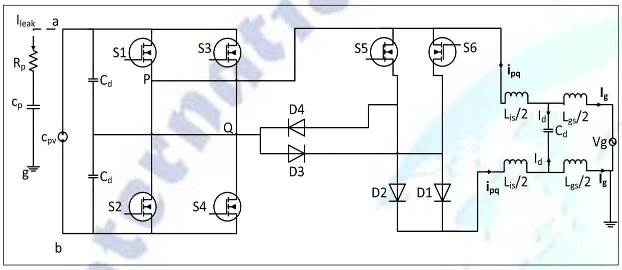

Figure 8 NPC full Bridge inverter

I. Quasi unipolar SPWM [9]

This paper presents a detailed analysis of a unique inverter topology intended to link photovoltaic (PV) installations to the grid: a quasi-unipolar SPWM full-ground transformer-less PV grid-connected inverter with continuous common-mode voltage. The grid is connected to the inverter topology through an LCL circuit, which filters high-frequency harmonic currents and lowers the common-mode voltage.

Four diodes, D1 and D4, an H-ground inverter, AC-bypass switches S5 and S6, and the switches S1 through S4 compose the inverter topology. An AC voltage that can be sent into the grid is created by the H-ground inverter from the DC voltage produced by the PV array. Inverter input PV voltage is divided in half by the use of two equal-value capacitors. This equalizes the voltage across the PV array and lowers the common-mode voltage. Three voltage conditions are produced by the inverter topology: Vpv, 0, and -Vpv. By activating switches S2 and S3, it is feasible to attain the -Vpv voltage point. Activating switches S1 and S4 results in the Vpv voltage position. When the voltage is zero, the grid inductor current freely flows through AC-bypass switches S5 and S6. During this voltage position, all of the H-ground switches are turned off, insulating the PV array and the grid. This lowers the leakage current and raises the inverter's efficiency. The two carrier swells required by the inverter are position-shifted by 1V to generate the AC voltage. A sinusoidal waveform is used to generate the carrier swells, and it is compared to a reference waveform. The switches S1 and S4 are activated when the reference swell's amplitude is less than the upper carrier swell; similarly, the switches S2 and S3 are activated when the reference swell's magnitude is less than the lowest carrier swell. When the reference swell's magnitude is between the two carrier swells, the voltage position is zero. During the negative half-cycle of the grid voltage, the switches S2 and S3 operate at an advanced switching frequency, and during the positive half-cycle, the switches S1 and S4 do the same.

The inverter voltage fluctuates between the Vpv and 0 voltage points during the positive half-cycle of the grid voltage. In addition, during the grid voltage's negative half-cycle, the inverter voltage varies between the 0 and -Vpv voltage points. In the article, the terminal voltage is extensively derived, contributing to a deeper comprehension of the inverter topology and its modes of operation. For grid-connected PV systems that maintain a constant common-mode voltage, the inverter topology that has been given is all things considered, an efficient and effective solution. The inverter's efficacy and dependability are increased by lowering the common mode voltage and leakage current through the application of LCL sludge and the NPC technique. The thorough examination and derivation of the inverter topology and its modes of operation provide invaluable knowledge for PV system design and optimization [9].

When the pair switches S1-S4 and S2-S3 are in the active state, they are switched on, indicating that the switching status for these switches is

$$Vag = 0.5Vgnd + 0.5Vs$$

When all switches are turned off, the switches S5 and S6 pair is switched ON, and the outcome is

$$Vag = 0.5Vgnd + 0.5Vs$$

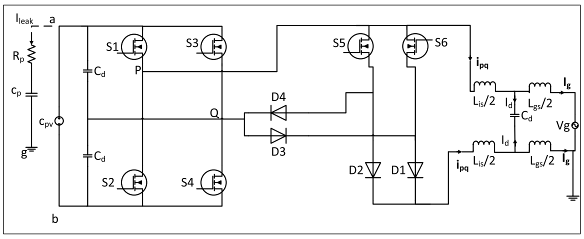

Figure 9 Quasi unipolar transformer-less inverter

J. Comparison

The fundamental topologies of transformer-less PV inverters have been outlined and compared in this research. This study explains the specifics of how the fundamental transformer-less PV inverter topologies operate. By applying the switching function approach, the terminal voltage equations for any PV inverter design may be found. Considering variables such as switching and conduction losses, the number of switches used, and the THD of the grid current, a comparison of the PV inverter topologies is also offered.

This study concludes with the following points:

1. Bipolar PWM technology and inverter topology produce the least amount of leakage current in full-bridge inverters, according to Zhang et al. and Xiao et al.
2. The maximum leakage current is found in full-bridge inverters using the unipolar PWM method.
3. A constant connection exists between the source and the grid. whether using bipolar or unipolar PWM full-bridge inverter systems.
4. In comparison to other topologies presented, the efficiency of the HERIC inverter architecture is high.
5. Islam et al. and Ji et al. H5, H6, and inverter designs require a switch on the bus (DC decoupling) to isolate the PV array from the grid.
6. The grid current THD of the bipolar PWM full-bridge inverter is extremely high in comparison to other topologies.
7. HERIC employs inverter switches and AC-by-pass (AC decoupling) to disconnect the PV array and the grid when in the zero condition.

3. DISCUSSION

We have discussed the different types of inverter topologies and the mode of their actions, the areas they can be used, and how they perform their switching. It gives us ideas about the techniques we can use in inverter topologies. What are the instruments that we can use in our inverters for switching actions. This paper has discussed the importance of filters in the inverters and the area of improvement in the inverter topologies. It has discussed the difficulties we face while we design an inverter without a transformer and according to our needs which we can use in our designed system.

4. CONCLUSION

It can be concluded from the paper that the different topologies use a three-level operation and Vpv,0,-Vpv respectively and they use SPWM and PWM for the gate value parameters in all the inverters we have used LCL filter and they use similar switches like MOSFETs and IGBTs. the paper gives a brief overview of the topologies presented in the papers. And gives the featured study of the topologies.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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