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Comparison and Analysis of H5 and OH5 Transformerless Inverters in terms of Leakage Current and THD

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Abstract: *The importance of solar power is increasing day by day due to scarcity of fossil fuels. Solar power can be used with off grid or on grid. Grid connected system is most reliable than off grid. Transformer can be used with grid connected system, but cost, weight increases and efficiency decreases. Transformerless inverter can solve this issue. But more leakage current flows throughtransformerless inverter. THD is another concern for transformerless inverter system.Advanced topologies can alleviate these issues. Topologies based on three techniques named decoupling technique, mid-point clamping technique and solidly clamping technique have been utilized in the literature to solve these problems.In this paper, two well-known topologies H5 and OH5, first one from decoupling technique, second one from mid-point clamping technique have been extensively analyzed for open loop and closed loop condition. In the open loop condition, resistive load has been used for analysis and comparison. The 230V ac grid has been used as load for analyzing and comparing the topologies in the closed loop condition. Besides it, their strengths and weakness have been highlighted in terms of THD and leakage current.Finally, the best one among two well known topologies has been identified in terms of leakage current and as well as in terms of THD. All the validations done through MATLAB/Simulink.*

Keywords: *decoupling, grid-connected, leakage current, mid-point clamping, transformerless inverter and THD.*

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I. INTRODUCTION:

Solar Power is one of the most expanding energy sources all over the world. The best advantages are its availability and environment friendliness nature. The other advantages are better performances and reduced weight. But it is heavily dependent on solar irradiances and temperature. Suitable MPPT technique can minimize these problems. This power can be used in two ways- one is off grid and other is grid connected systems. The connection of grid connected systems is much more than off grid systems[1]. The grid connection can be used in two ways. One is with the help of transformer and other is without the help of transformer. When transformer is used, then there creates a galvanic isolation between grid and solar panels and thereby ensures more safety. But the weight and cost are increased and efficiency is decreased. If the transformer is eliminated from the system that is called transformerless inverter system can enhance the efficiency and can reduce the cost and weight[2]–[5]. But due to absence of galvanic isolation, more leakage current flows through grid and solar panels can hamper the safety matters[6]–[9].

Advanced topology can reduce the leakage current and thereby maintain the safety issue. Some topologiesin the literature have been proposed based on decoupling technique[10]–[15] to reduce the leakage current. Besides it, some researchers have proposed many topologies based on mid-point clamping[16]–[19] and solidly clamping[20]–[22] technique. An extensive review has been done in [23].

As the neutral point clamping technique is complex, so the two well-known topologies one (H5) from decoupling group and other (OH5) from mid-point clamping technique have been selected for extensive analysis and comparison. H5 and OH5 topologies are analyzed with open loop condition (with resistive load) and closed loop condition (with grid).The merits and demerits based on leakage current and THD are provided for the proper selection of best topology.

The remainder of the paper is as follows: section II provides the basics of leakage current and THD. The circuit structure, operating modes and pulse generation process are shown in section III, section IV and section V respectively. Section VI describes the simulation results for open loop and closed loop condition. The comparison and analysis between H5 and OH5 are shown in section VII. Finally, section VIII concludes the paper.

II. LEAKAGE CURRENT ISSUE AND THD:

A current flow through the grid and parasitic capacitors of PV panels is the leakage current. The leakage current (I_{LC}) flowing path is shown in Figure 1. From Figure 2, it is clear that the leakage current is the effect of total common mode voltage (V_{tCM}).

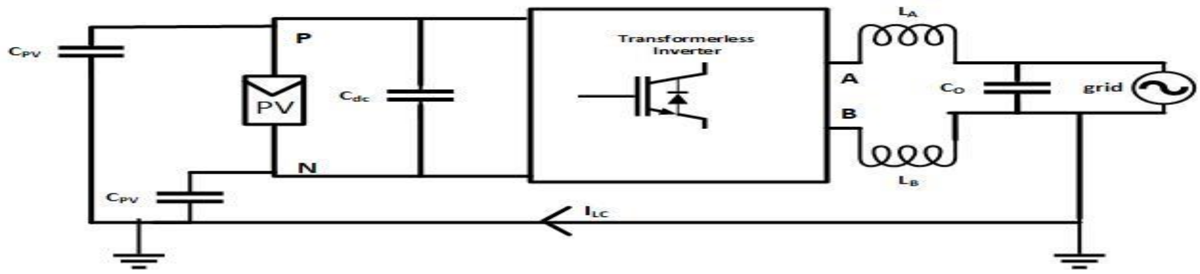

Figure 1: Leakage current flowing path in transformerless inverter

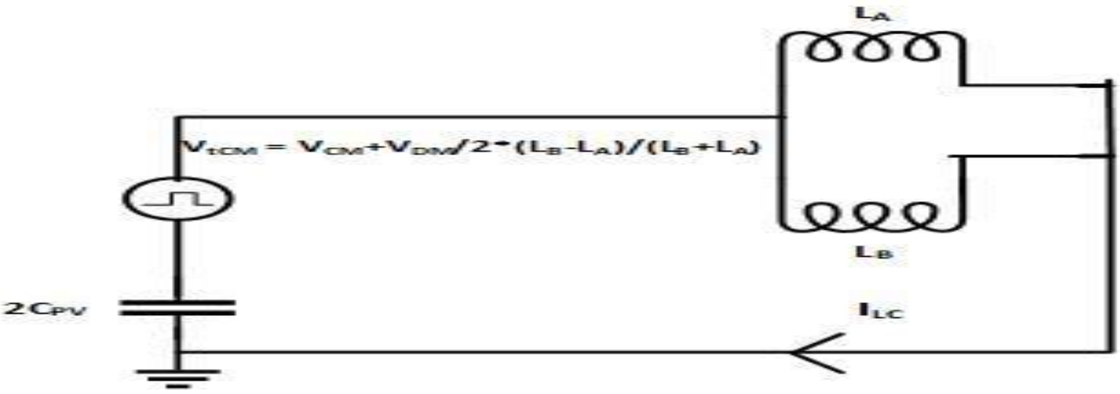

Figure 2: Final model of leakage current flowing path of transformerless inverter

The common mode voltage V_{CM} and differential mode voltage V_{DM} can be defined as[24],

$$V_{CM} = \frac{V_{AN} + V_{BN}}{2} \quad (1)$$

$$V_{DM} = V_{AN} - V_{BN} \quad (2)$$

Rearranging (1) and (2), V_{AN} and V_{BN} can be expressed in terms of V_{CM} and V_{DM},

$$V_{AN} = V_{CM} + \frac{V_{DM}}{2} \quad (3)$$

$$V_{BN} = V_{CM} - \frac{V_{DM}}{2} \quad (4)$$

Now, if the two sources are converter into a single sources of V_{tCM} , then, the total common mode voltage,

$$V_{tCM} = V_{CM} + \frac{V_{DM}}{2}\frac{L_B - L_A}{L_A + L_B} \quad (5)$$

Where, L_A and L_B are the filter inductors connected to the A and B terminals of the inverter respectively.
If L_A=L_B, then the equation (5) becomes

$$V_{tCM} = V_{CM} = \frac{V_{AN} + V_{BN}}{2} \quad (6)$$

THD is the total harmonic distortion of the sinusoidal voltage or current. It can be defined as:

$$THD = \frac{\sqrt{\sum_2^N {V_N}^2}}{V_1} \quad (7)$$

In this paper, the filter is designed as L_A=L_B and up to 20th harmonic value is considered for THD calculation.

III. CIRCUIT STRUCTURE:

A. H5:

The circuit structure of H5 topology is shown in Figure 2. H5 topology is firstly proposed by [10]. In [25], a new modulation scheme of H5 is developed. It is one of the best topology based on zero state decoupling technique. It consists of five switches. S5 is utilized for disconnecting the solar power from the grid during zero state and it is called freewheeling mode. Only one dclink capacitor is used for controlling the input voltage ripple to the acceptable limit. The full bridge consists of switches S1 to S4 is extended with S5 to make the structure of it.

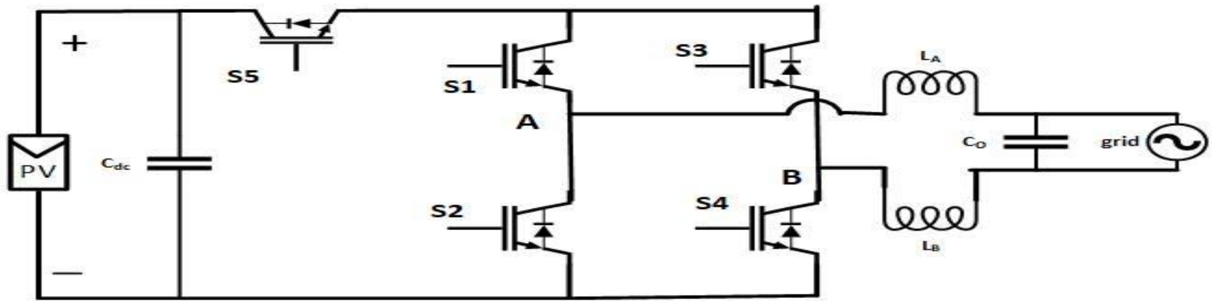

Figure 3: Circuit structure of H5 topology

B.OH5:

The circuit structure of OH5 topology is shown in Figure 3. This topology is proposed by [16]. It is one of the best topologies based on mid-point clamping technique. Six switches have been used here. This topology is constructed by modifying H5 topology. S6 switch is employed to clamp the mid-point capacitor voltage during zero state. Two capacitors have been utilized to control the input voltage ripple and divide the input voltage.

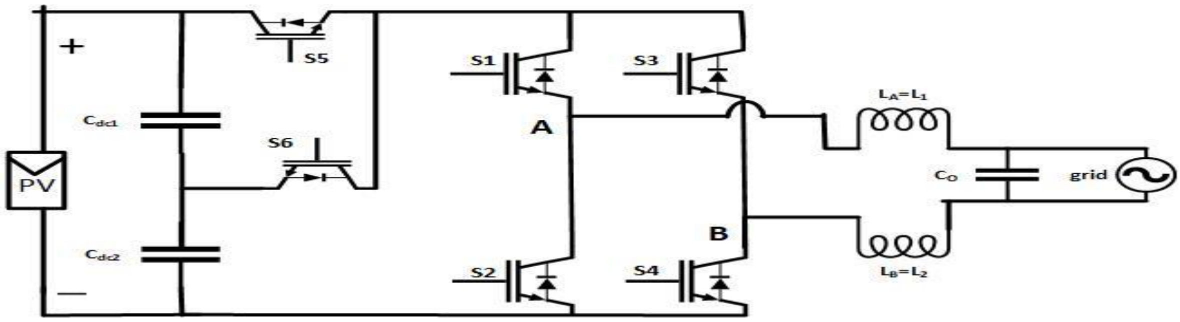

Figure 4: Circuit structure of OH5 topology

IV. OPERATING MODES:

A. H5:

There are four operating modes of H5 topology. When the switch S5 is in the on state during positive half cycle is called as positive half cycle active mode and it is shown in Figure 5. During positive half cycle when S5 is in the off state is termed as positive half cycle freewheeling mode and it is shown in Figure 6. Similarly, during negative half cycle, when S5 is on then it is termed as the negative half cycle active mode and it is depicted in Figure 7. When S5 is off during negative half cycle is called negative half cycle freewheeling mode and it is shown in Figure 8. The inactive devices of every mode of operations are unhighlighted in the figures.

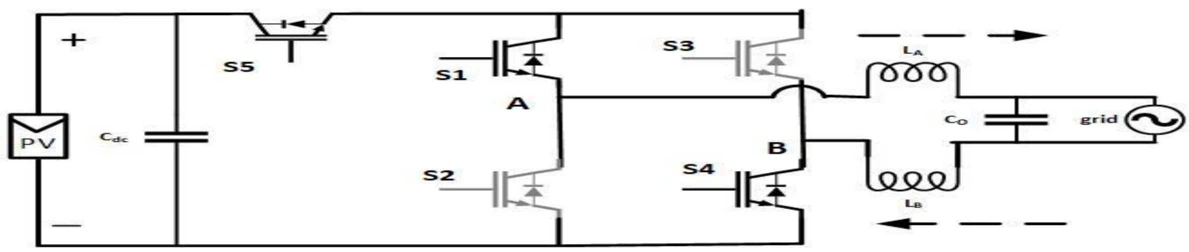

Figure 5: Positive half cycle active mode of H5 topology

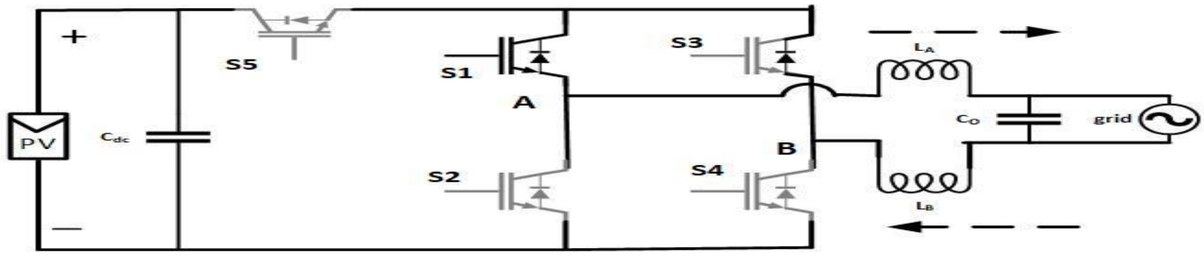

Figure 6: Positive half cycle freewheeling mode of H5 topology

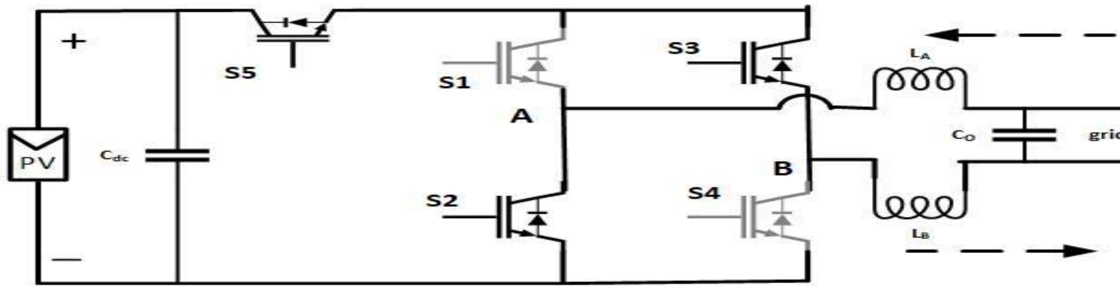

Figure 7: Negative half cycle active mode of H5 topology

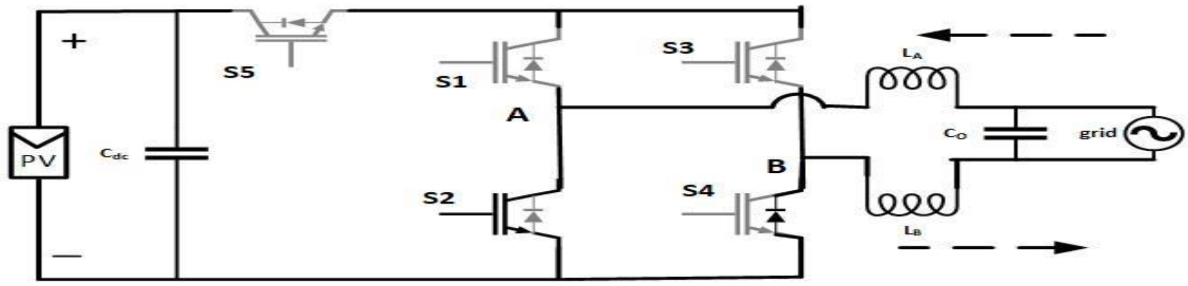

Figure 8: Negative half cycle freewheeling mode of H5 topology

B.OH5:

There are four operating modes of OH5 topology. When the switch S5 is in the on state during positive half cycle is called as positive half cycle active mode and it is shown in Figure 9. During positive half cycle when S5 is in the off state is termed as positive half cycle freewheeling mode and it is shown in Figure 10. Similarly, during negative half cycle, when S5 is on then it is termed as the negative half cycle active mode and it is depicted in Figure 11. When S5 is off during negative half cycle is called negative half cycle freewheeling mode and it is shown in Figure 12. The inactive devices of every mode of operations are unhighlighted in the figures.

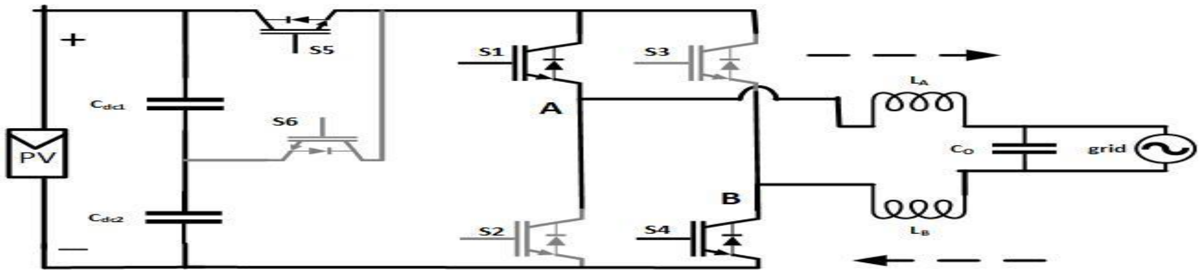

Figure 9: Positive half cycle active mode of OH5 topology

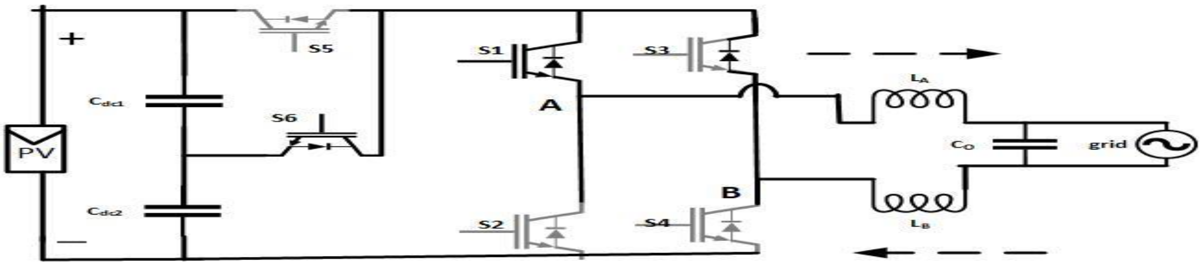

Figure 10: Positive half cycle freewheeling mode of OH5 topology

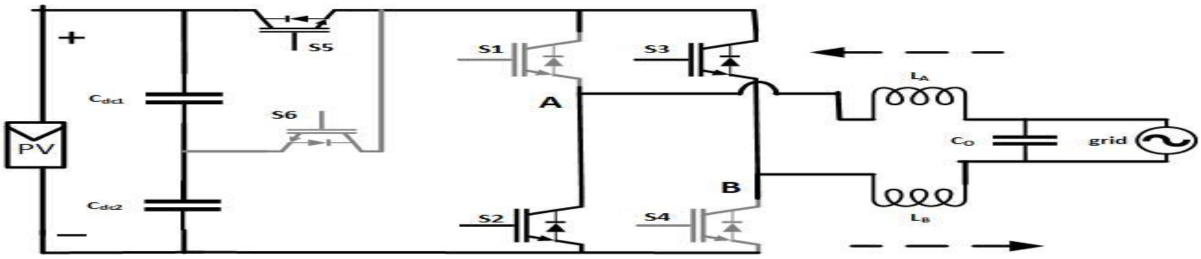

Figure 11: Negative half cycle active mode of OH5 topology

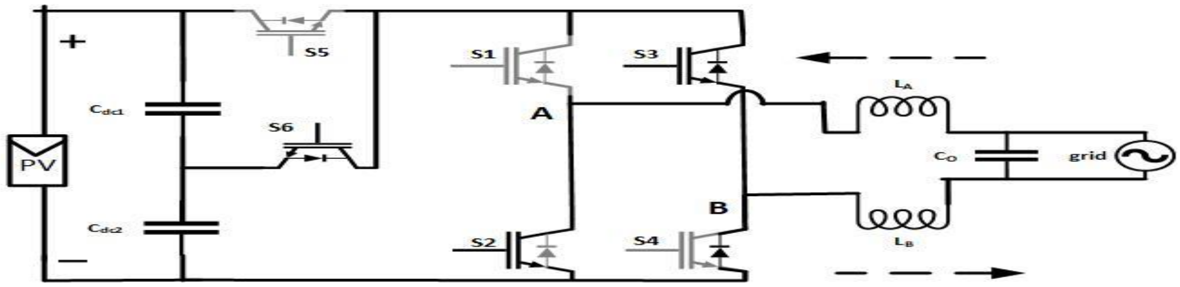

Figure 12: Negative half cycle freewheeling mode of OH5 topology

V: PULSE GENERATION PROCESS:

A. H5:

The pulse generation process of H5 topology is depicted in Figure 13. Switch S1 and switch S3 are operated on grid frequency and other two switches of the full bridge section are operated on switching frequency for half cycle operation. S5 is operated on switching frequency with full cycle operation.

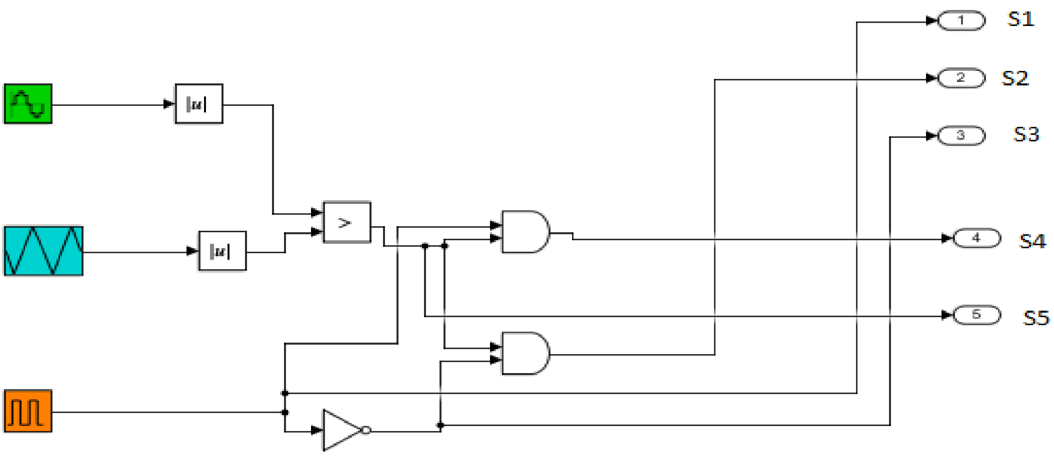

Figure 13: Pulse generation process of H5 topology

B.OH5:

The pulse generation process of OH5 topology is shown in Figure 14. S2 and S4 are operated on switching frequency for half cycle period on alternate manner. S1 and S3 are operated on switching frequency on zero state for half cycle period and on grid frequency for other half cycle. S1 and S3 also operated on alternate manner. S5 is operated on switching frequency on active state for whole cycle. S6 is employed to clamp the mid-point voltage on zero state.

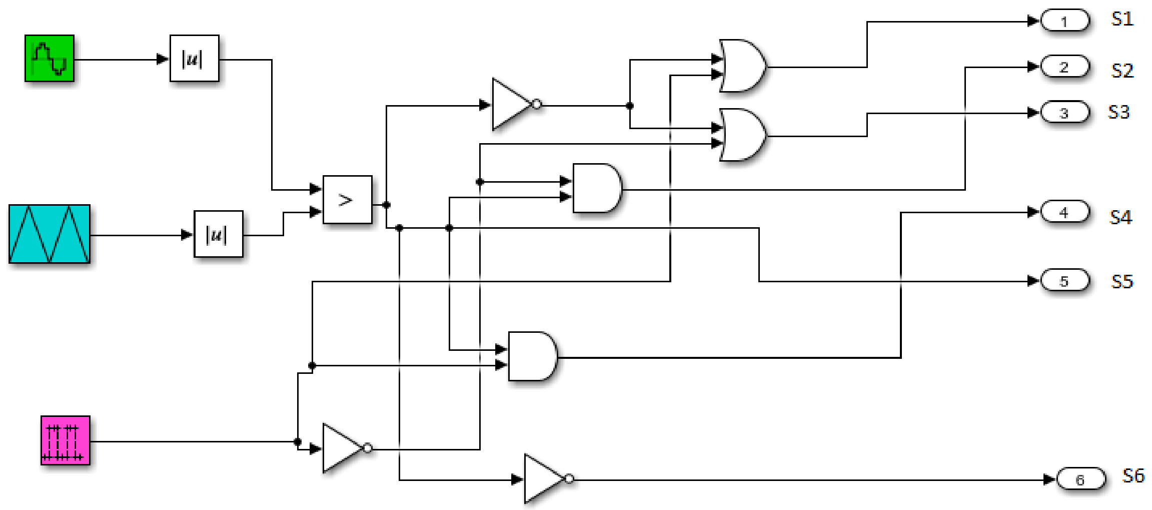

Figure 14: Pulse generation process of OH5 topology

VI: SIMULATION RESULTS

All the simulations have been performed with MATLAB/Simulink environment. Because it is powerful tool for power electronics model design and also for real time applications [26].

A. OPEN LOOP:

The simulations for open loop condition of H5 and OH5 have been carried out based on the simulation parameters provided in Table 1. The solar panel is replaced by a dc source. Resistive load has been used for open loop condition.

Table I: Simulation parameters for open loop

Parameters	***value***
AC Output Voltage	230 V
Line Frequency	50 Hz
AC Output Current	4.34 A
DC Input Voltage	400 V
Output Load	53 Ω
Rated Power	1000 W
Switching Frequency	16 KHz
DC Bus Capacitor ($C_{dc}=C_{dc1}/2=C_{dc2}/2$)	400 μF
Filter Capacitor, C_o	2.2 μF
Filter Inductor, $L_1= L_2$	3 mH
Parasitic Capacitor, $C_{PV}=C_{PV1}=C_{PV2}$	75 nF

i. H5:

The common mode behavior of H5 topology id depicted in Figure 15. From this figure, the total common mode voltage is not constant for whole period but it is close to 200V for most of the time. So, the rms value of leakage current is small but peak value of leakage current is comparatively high as 150 mA. The output voltage and current is shown in Figure 16. It is pure sinusoidal with very small THD.

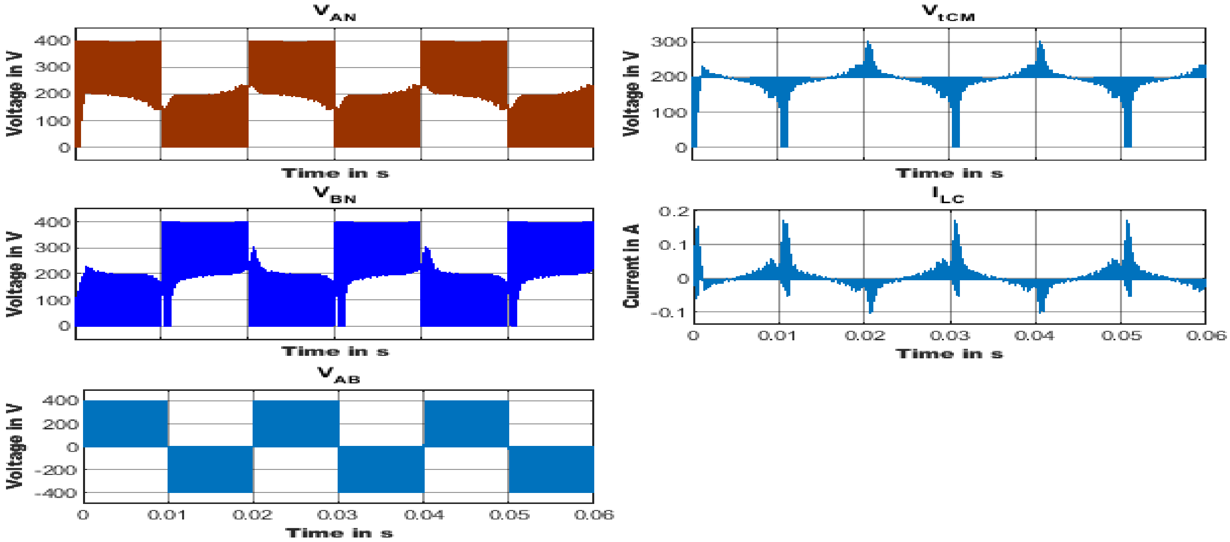

Figure 15: Common mode behavior of H5 topology for open loop

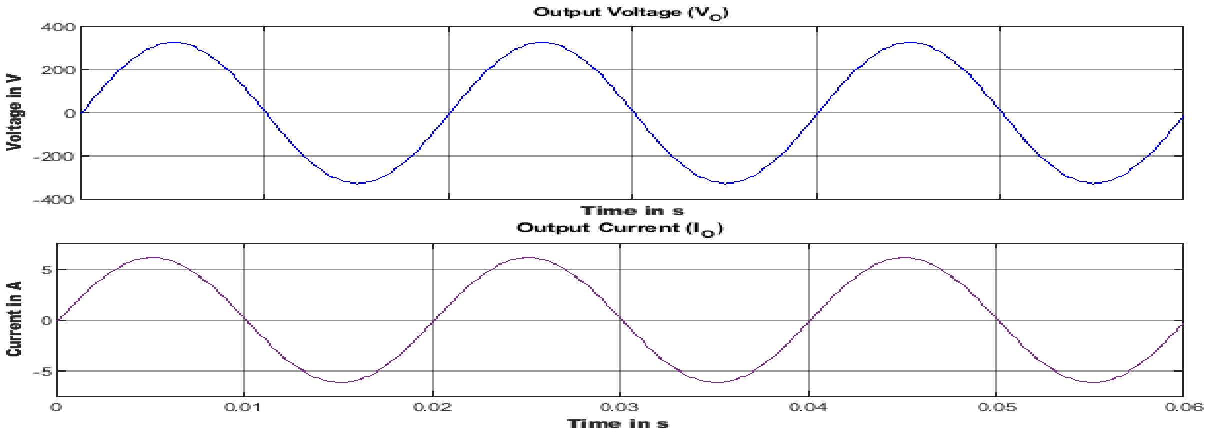

Figure 16: Output voltage and output current of H5 topology for open loop

ii. OH5:

The common mode behavior of OH5 topology id depicted in Figure 17. From this figure, the total common mode voltage is about constant to 200V for whole period. So, the rms value of leakage current is very small but peak value of leakage current is comparativelylow. The output voltage and current is shown in Figure 16. It is pure sinusoidal with small THD.

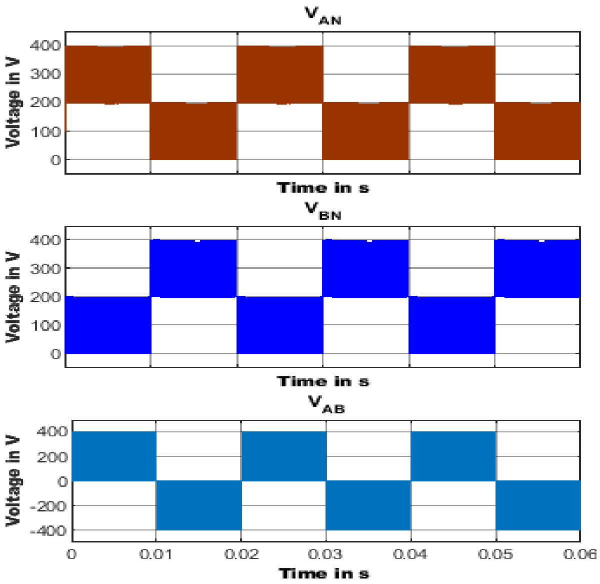

Figure 17: Common mode behavior of OH5 topology for open loop

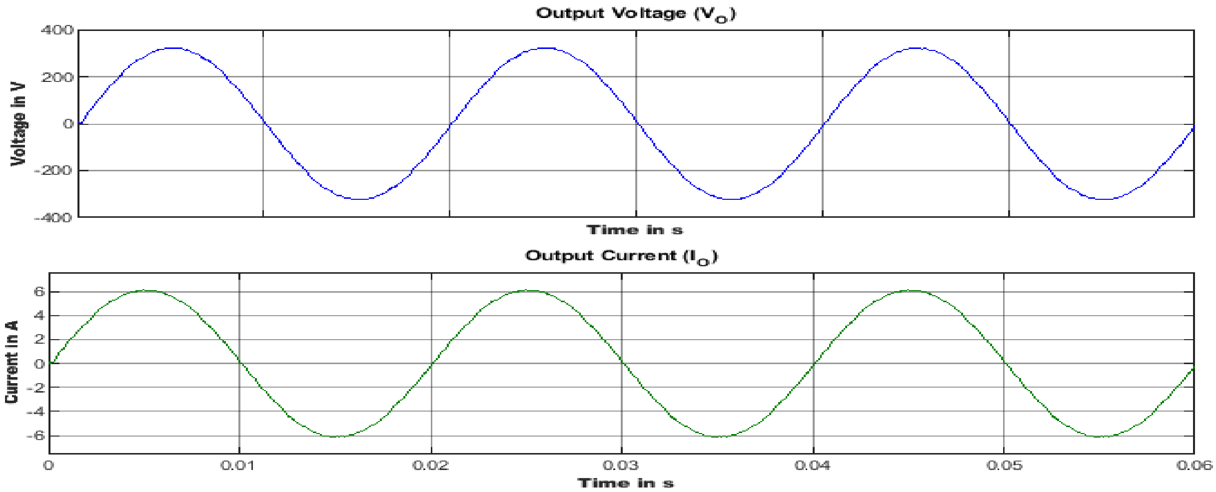

Figure 18: Output voltage and output current of OH5 topology for open loop

B. CLOSED LOOP:

The simulations for closed loop condition of H5 and OH5 have been carried out based on the simulation parameters provided in Table 2. The solar panel is replaced by a dc source. 230V ac grid has been used for closed loop condition as load.

Table II: Simulation parameters for closed loop

Parameters	value
AC Output Voltage	230 V
Line Frequency	50 Hz
AC Output Current	4.34 A and 8.68A
DC Input Voltage	400 V
Output Load	230V GRID
Rated Power	1000 W and 2000W
Switching Frequency	16 KHz
DC Bus Capacitor ($C_{dc}=C_{dc1}/2=C_{dc2}/2$)	400 µF
Filter Capacitor, C_o	2.2 µF
Filter Inductor, $L_1= L_2$	3 mH
Parasitic Capacitor, $C_{PV}=C_{PV1}=C_{PV2}$	75 nf
K_P	9
K_I	0.04

i. H5:

The common mode behavior of H5 topology is shown in Figure 19. It is about similar result that is got for open loop condition. The output static performance of H5 topology for closed loop with 1KW fixed active power is depicted in Figure 20. The closed loop current control system accurately tracks the reference power. The output dynamic performance of H5 topology for closed loop from 2KW to 1KW active power switching is shown in Figure 21. Here the PI controller of the closed loop control can track the output power changing.

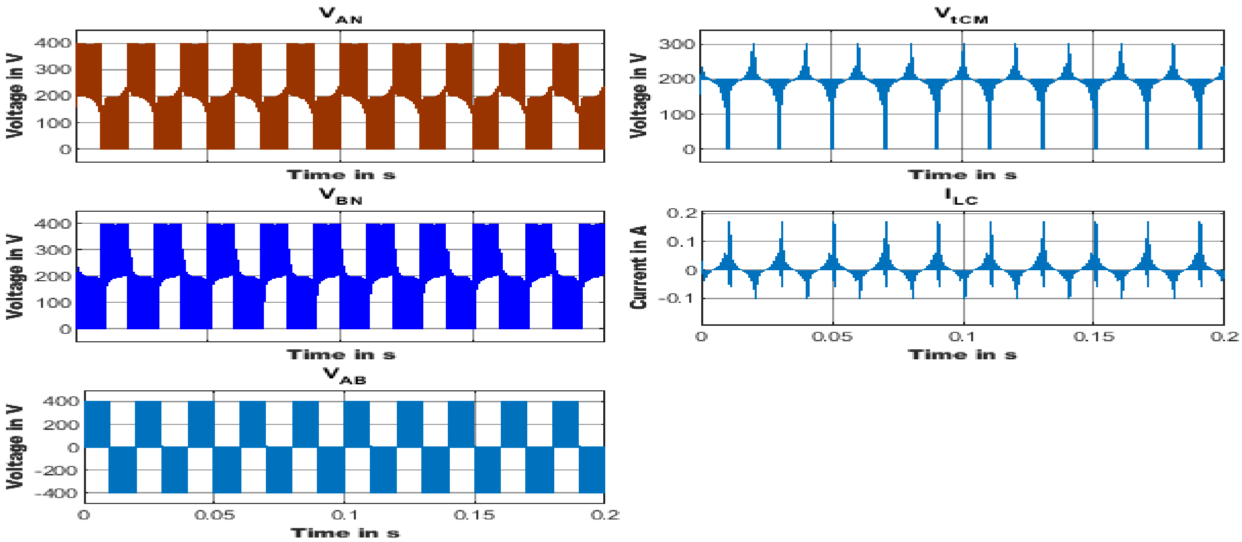

Figure 19: Common mode behavior of H5 topology for closed loop

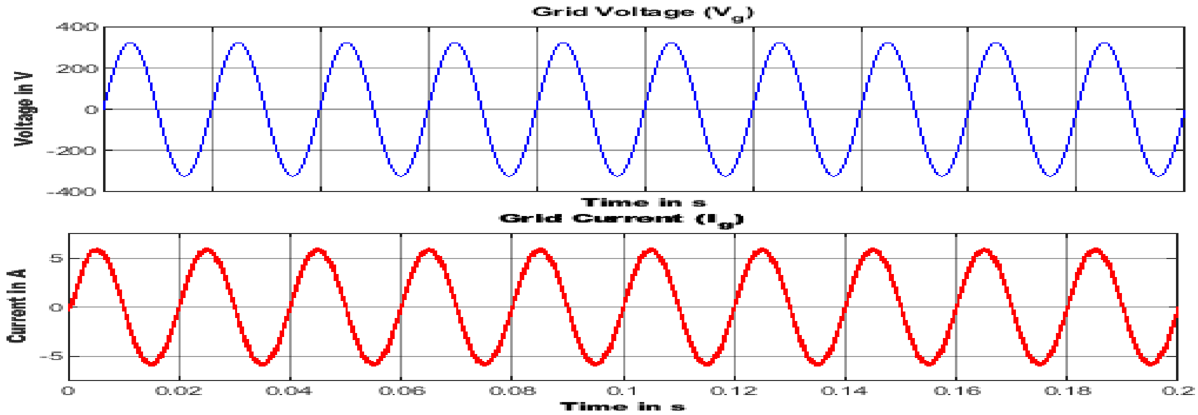

Figure 20: Output static performance of H5 topology for closed loop with 1KW fixed active power

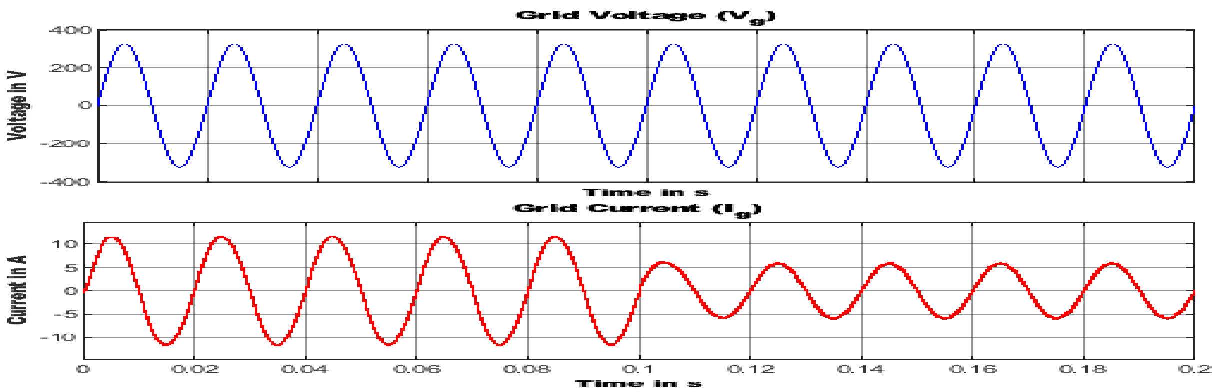

Figure 21: Output dynamic performance of H5 topology for closed loop from 2KW to 1KW active power switching

ii. OH5:

The common mode behavior of OH5 topology is shown in Figure 22. It is about similar result that is got for open loop condition. The output static performance of OH5 topology for closed loop with 1KW fixed active power is depicted in Figure 23. The closed loop current control system accurately tracks the reference power. The output dynamic performance of OH5 topology for closed loop from 2KW to 1KW active power switching is shown in Figure 24. Here the PI controller of the closed loop control can track the output power changing.

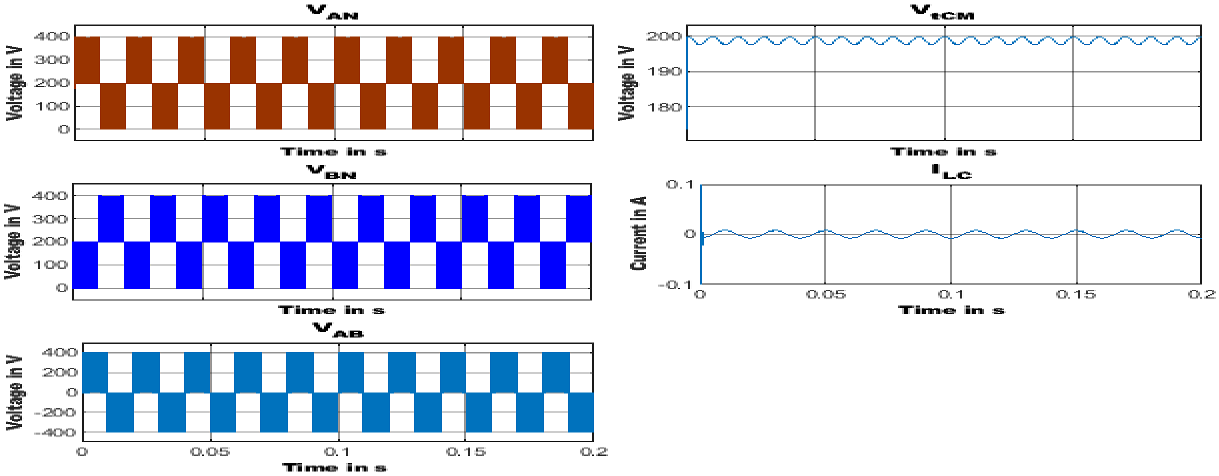

Figure 22: Common mode behavior of OH5 topology for closed loop

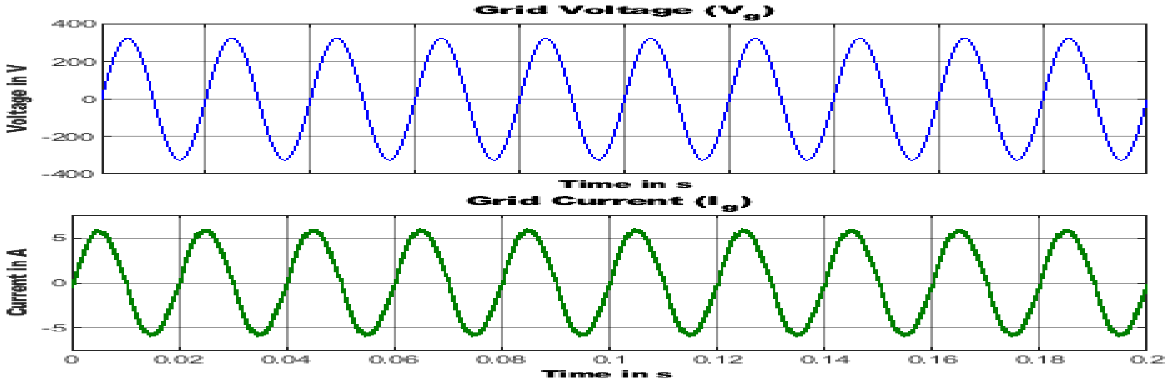

Figure 23: Output static performance of OH5 topology for closed loop with 1KW fixed active power

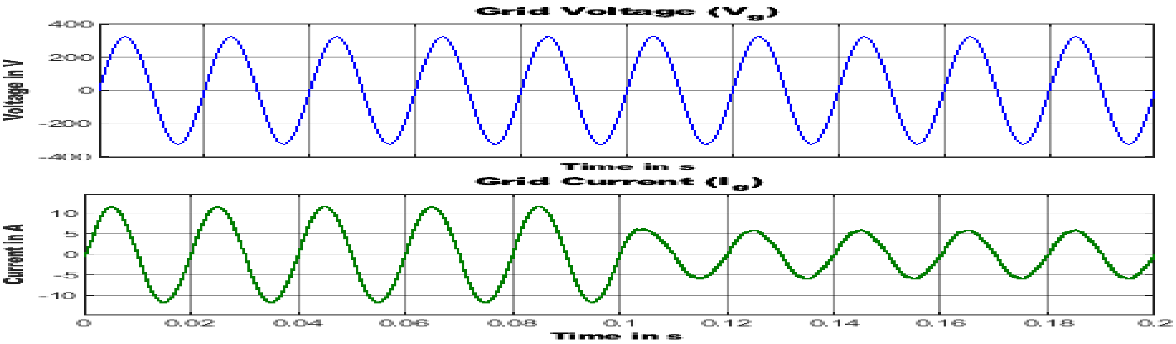

Figure 24: Output dynamic performance of OH5 topology for closed loop from 2KW to 1KW active power switching

VII. COMPARISON AND ANALYSIS:

The detailed results of H5 and OH5 topology are shown in Table 3. For open loop condition, the rms value of leakage current for H5 topology is 12.59 mA whereas it is only 6.89 mA for OH5 topology. The voltage THD and current THD of H5 topology is 0.53% whereas it is 0.74% for OH5 topology. Here, the voltage THD and current THD is same because of resistive load.

Table III: Comparison between H5 and OH5 topology

Condition	*Topology Name*	*Leakage Current (mA)*	*Voltage THD (%)*	*Current THD (%)*
Open Loop	*H5*	12.59	0.53	0.53
	OH5	6.89	0.74	0.74
Closed Loop	*H5*	12.55	0.02	1.96
	OH5	5.42	0.02	3.45

For closed loop condition, the rms value of leakage current for H5 topology is 12.55 mA whereas it is only 5.42 mA for OH5 topology. The grid voltage THD is same for both topology under closed loop condition due to use the grid as the load and it is only .02%. The grid current THD of OH5 topology under closed loop is 3.45% whereas it is only 1.96% for H5 topology.

VIII. CONCLUSION

In this paper, two best topologies, one from decoupling and other from mid-point clamping technique, have been selected for analysis and comparison. Both H5 and OH5 have been fulfilled the THD requirement of IEEE standard as below 5%. The VDE0126-1-1 standard for leakage current has been maintained by the topologies. After the critical analysis, it can be concluded that H5 topology is well suited where THD is the main concern whereas OH5 can be 1st choice where very low leakage current is required. Authors hope that this research would be helpful for researchers, engineers and academicians.

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