iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 11 **Issue:** IX **Month of publication:** September 2023

**DOI:** https://doi.org/10.22214/ijraset.2023.55624

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538*
*Volume 11 Issue IX Sep 2023- Available at www.ijraset.com*

# Comparative Study on Analysis of Losses and Leakage Current for Transformer-less Inverters for PV Applications: A Review

Mohammed Imran[1], Manjula Mane[2]
*Electrical Engineering Department, UCOE, Osmania University, Hyderabad, India*

***Abstract: The reduction in the Common Mode Voltage (CMV) and thermal losses in semiconductors play a crucial role in designing of a new transformer-less inverter topologies for solar powered applications. The galvanic isolation and the leakage current problem due to non-availability of transformer can be addressed either by providing additional switches on the dc side or on the ac side, but this results in more number of semiconductor devices being added into the conduction paths which are switched according to the desired output requirements which further results in high conduction and switching losses indirectly effecting the efficiency of the transformer-less inverters. Hence it is important to study the existing topologies in view of the total losses, CMV and leakage current parameters together. In this review paper H5, H6 and HERIC transformer-less inverter configurations in terms of CMV, Leakage current, Conduction and Switching losses as total losses have been analyzed using PSIM2022.2 simulation software package with the availability of the thermal module. The study of total losses with CMV and leakage current will help in noting the drawbacks of the topologies discussed in this paper.***
***Keywords: Common Mode Voltage (CMV), Differential Mode Voltage (DMV), Leakage current ($I_{Leakage}$)***

## I. INTRODUCTION

### *A. Transformer-less PV Inverter*

Single phase transformer-less inverters are becoming more and more common for solar power applications due to their Lower cost, compact size and improved efficiency, As shown in the Fig.1 the transformer used in the PV system is removed in order to lower the price, size, losses, and weight and to improve its efficiency. As a result of this idea, numerous transformer-free PV inverter topologies have been created. The PV inverter is more cost-effective and efficient because the transformer has been removed.
The transformer's removal from the system, however, causes the galvanic isolation between the grid and the PV source to be lost. Because of this, the leakage current starts circulating in the PV system. The resonant path of parasitic elements is triggered by the Common Mode Voltage (CMV) developed in the circuit. This causes flow of high leakage currents.

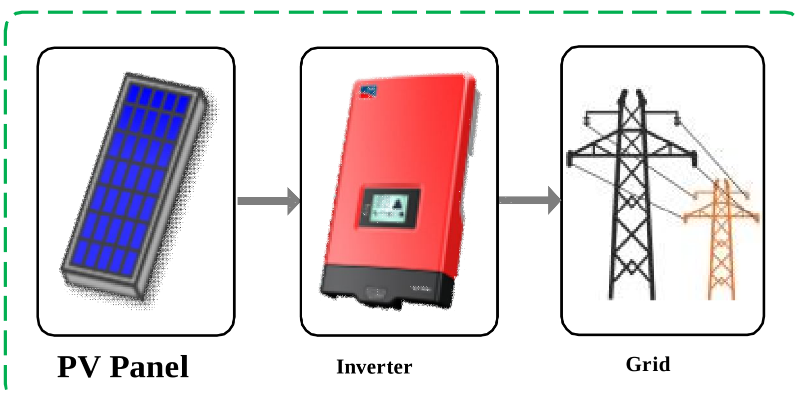



Fig. 1. The block diagram of transformer-less PV inverter topology.

As per VDE0126-1-1 German standards the value of leakage current for single phase transformer-less inverter PV grid connected systems should be less than 100mA.

### B. *CMV Analysis*

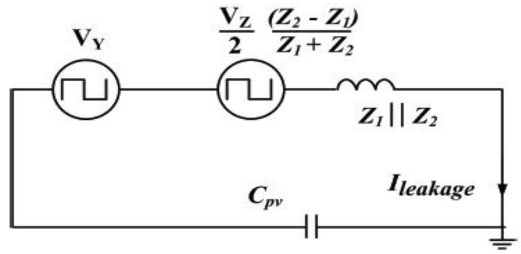



Fig.2. Common mode modelling of singe phase transformer-less Inverter topology

The voltages $V_Y$ (or $V_{CM}$) and $V_Z$ (or $V_{DM}$) act as a forcing function for the direction of the leakage current, as shown in Fig. 2. So, if the aforementioned forcing functions can be made either of the following, the flow of leakage current will be minimized or eliminated: Since the impedance provided by $C_{PV}$ is very high at low frequencies, the $V_Y$ and $V_Z$ should be (a) zero, (b) constant dc, or (c) consisting only of reduced or low frequency components.

## II. H5 TOPOLOGY

1) *Mode-1:* During the positive half cycle for Mode-1, S5, S1 and S4 are switched at switching frequency, S3, S2 are not turned ON. The path of the current is from switch S5 to S1 via power grid and then to the switch S4 to connect PV voltage to the grid.

Here $V_{AO}= V_{PV}$, $V_{BO}=0$, also $V_{DM}=+V_{PV}$, thus, the average of leg Voltages (CMV) and difference in leg Voltages (DMV) can be written as

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(V_{PV} + 0)}{2} = \frac{V_{PV}}{2} = 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - 0 = V_{PV}$$

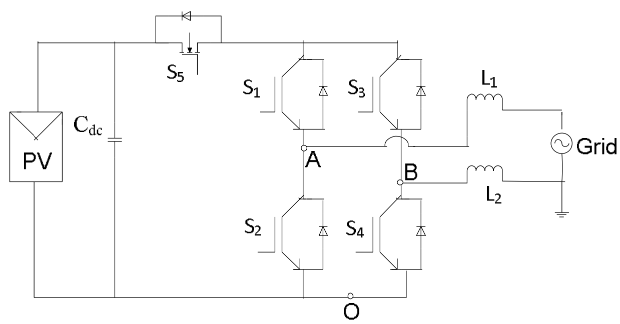



Fig.3. H5 topology

2) *Mode-2:* During this mode, diode D3 is conducting and While switches S2, S4, and S5 are all off, switch S1 is turned on. The path of the current is from first inductor to power grid to inductor to diode D3 and then to the switch S1 to connect PV to the grid. Due to freewheeling mode of operation $V_{AO}$ is floating and is not constant, thus Common Mode Voltage CMV cannot be constant.

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(\sim V_{PV} + 0)}{2} = \frac{\sim V_{PV}}{2} =\sim 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - V_{PV} = 0$$

3) *Mode-3:* During the negative half cycle for Mode-3, S5, S2, S3 are switched at switching frequency ($f_s$), whereas other switches are kept OFF. The current flows through S5 to S3 to inductor L2 to grid to inductor L1 and then to the switch S2 to connect PV voltage to the grid.

Here $V_{AO}$= 0, $V_{BO}$= $V_{PV}$, also $V_{DM}$=-$V_{PV}$, thus, the average of leg Voltages (CMV) and difference in leg Voltages (DMV) can be written as

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(0 + V_{PV})}{2} = \frac{V_{PV}}{2} = 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = 0 - V_{PV} = -V_{PV}$$

4) *Mode-4:* During this mode, diode D1 is conducting and switch S3 is ON whereas all other switches are turned OFF. The current freewheels from inductor (L2) to grid to inductor (L1) to diode D1 and then to the switch S3 to connect PV to the grid. Due to freewheeling mode of operation $V_{BO}$ is floating and is not constant, thus Common Mode Voltage CMV cannot be constant.

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(\ 0 + \sim V_{PV})}{2} = \frac{\sim V_{PV}}{2} = \sim 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - V_{PV} = 0$$

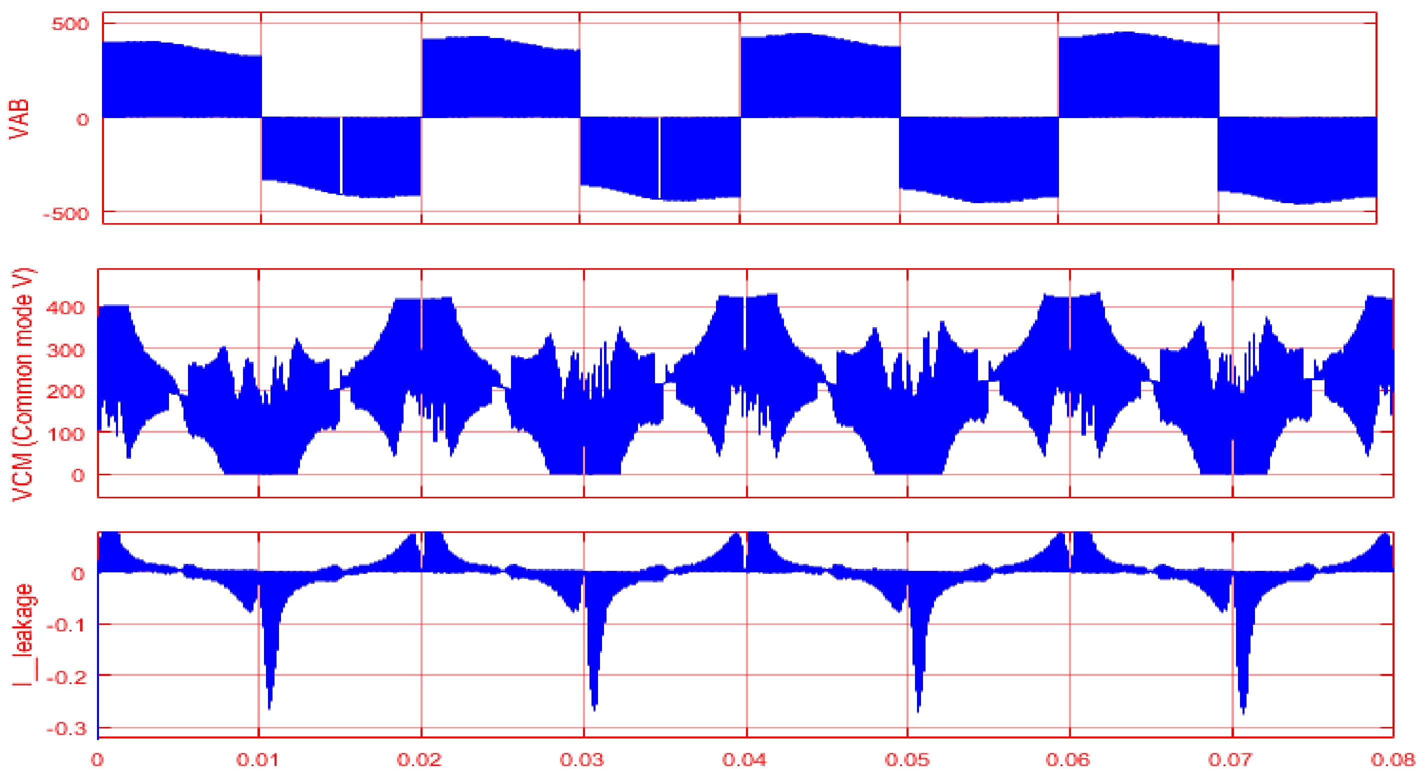



Fig.4. $V_{CM}$, $V_{DM}$ and leakage current output waveforms for H5 topology

Table I Total Loss in H5 topology

| Topology | S1 | S2 | S3 | S4 | S5 | Total loss |
|---|---|---|---|---|---|---|
| H5 | 1.99W | 1.99W | 1.99W | 1.99W | 2W | 10.0W |

Clearly CMV is not constant in freewheeling modes of operation of H6 topology and results in total loss of 10 watts including both conduction and switching losses and leakage current ($I_{Leakage}$) is not completely mitigated.

## III.H6 TOPOLOGY

1) *Mode-1:* During the positive half cycle for Mode-1, S1 and S6 are ON, S5 and S4 are switched at high switching frequency, S3, S2 are not turned on. The path of the current is from switch S5 to S1 tofirst inductor to power grid to inductor to then to the switch S4 to S6 to connect PV voltage to the grid.

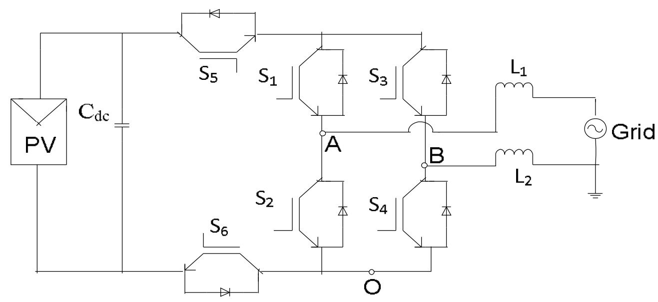



Fig5**.** H6 topology

Here $V_{AO}= V_{PV}$, $V_{BO}=0$, also $V_{DM}=+V_{PV}$, thus, the average of leg Voltages (CMV) and difference in leg Voltages (DMV) can be written as

$$V_{CM} = \frac{V_{AO}+V_{BO}}{2} = \frac{(V_{PV}+0)}{2} = \frac{V_{PV}}{2} = 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - 0 = V_{PV}.$$

2) *Mode-2:* During this mode, diode D3 is conducting and switch S1 is ON whereas all other switches are not turned on. The path of the current is from first inductor to power grid to inductor to diode D3 and then to the switch S1 to connect PV to the grid. Due to freewheeling mode of operation $V_{AO}$ is floating and is not constant, thus Common Mode Voltage CMV cannot be constant.

$$V_{CM} = \frac{V_{AO}+V_{BO}}{2} = \frac{(\ \sim V_{PV}+0)}{2} = \frac{\sim V_{PV}}{2} =\sim 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - V_{PV} = 0$$

3) *Mode-3:* During the negative half cycle for Mode-3, S5 and S2 are ON, S3, S6 are switched ON at high frequency, whereas other switches are OFF. The current flows through switch S5 to S3 to inductor L2 to grid to inductor L1 and then to the switch S2 to S6 to connect PV voltage to the grid.

Here $V_{AO}= 0$, $V_{BO}= V_{PV}$, also $V_{DM}=-V_{PV}$, thus, the average of leg Voltages (CMV) and difference in leg Voltages (DMV) can be written as

$$V_{CM} = \frac{V_{AO}+V_{BO}}{2} = \frac{(0+V_{PV})}{2} = \frac{V_{PV}}{2} = 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = 0 - V_{PV} = -V_{PV}$$

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue IX Sep 2023- Available at www.ijraset.com

4) *Mode-4:* During this mode, diode D1 is conducting and switch S3 is ON whereas all other switches are not turned on. The current freewheels from inductor (L2) to grid to inductor (L1) to diode D1 and then to the switch S3 to connect PV to the grid. Due to freewheeling mode of operation $V_{BO}$ is floating and is not constant, thus Common Mode Voltage CMV cannot be constant.

$$V_{CM} = \frac{V_{AO} + V_{BO}}{2} = \frac{(0 + \sim V_{PV})}{2} = \frac{\sim V_{PV}}{2} = \sim 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - V_{PV} = 0$$

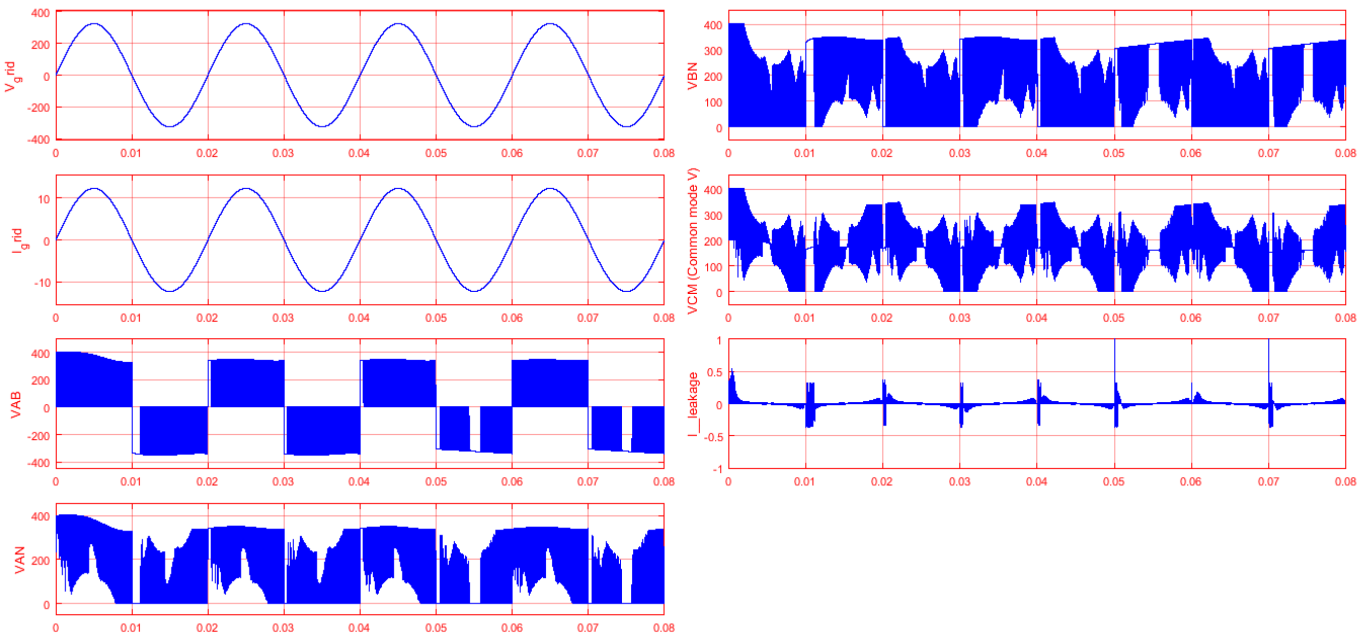



Fig.6. $V_{CM}$, $V_{DM}$ and leakage current output waveforms for H6 topology

Table II. Total Loss in H6 topology

| Topology | S1 | S2 | S3 | S4 | S5 | S6 | Total loss |
|---|---|---|---|---|---|---|---|
| H6 | 1.99W | 1.99W | 1.99W | 1.99W | 2W | 2W | 12.0W |

Clearly CMV is not constant in freewheeling modes of operation of H6 topology and results in total loss of 12 watts including both conduction and switching losses and leakage current ($I_{Leakage}$) is not completely mitigated.

## IV. HERIC TOPOLOGY

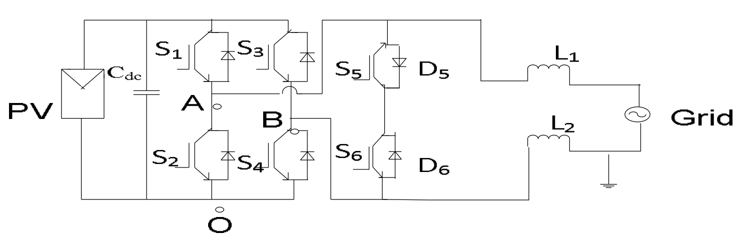



Fig.7. HERIC topology

1) *Mode-1:* During the positive half cycle for Mode-1, S1 and S4 are switched at switching frequency, S3, S2 and S6 are OFF. The path of the current is from switch S1 to first inductor to power grid to inductor to then to the switch S4 to connect PV voltage to the grid. Here $V_{AO}= V_{PV}$, $V_{BO}=0$, also $V_{DM}=+V_{PV}$, thus, the average of leg Voltages (CMV) and difference in leg Voltages (DMV) can be written as

$$V_{CM} = \frac{V_{AO}+V_{BO}}{2} = \frac{(V_{PV}+0)}{2} = \frac{V_{PV}}{2} = 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - 0 = V_{PV}$$

2) *Mode-2:* During this mode, diode D6 is conducting and switch S5 is ON whereas all other switches S2, S3, and S4 are not turned on. The path of the current is from first inductor to power grid to inductor to diode D6 and then to the switch S5 to connect PV to the grid. Due to freewheeling mode of operation $V_{AO}$ is floating and is not constant, thus Common Mode Voltage CMV cannot be constant.

$$V_{CM} = \frac{V_{AO}+V_{BO}}{2} = \frac{(\sim V_{PV}+0)}{2} = \frac{\sim V_{PV}}{2} =\sim 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - V_{PV} = 0$$

3) *Mode-3:* During the negative half cycle for Mode-3, S2, S3 are switched at switching frequency. S1, S4, S5 are not turned on. The current flows through S3 to inductor L2 to grid to inductor L1 and then to the switch S2 to connect PV voltage to the grid.

Here $V_{AO}= 0$, $V_{BO}= V_{PV}$, also $V_{DM}=-V_{PV}$, thus, the average of leg Voltages (CMV) and difference in leg Voltages (DMV) can be written as

$$V_{CM} = \frac{V_{AO}+V_{BO}}{2} = \frac{(0+V_{PV})}{2} = \frac{V_{PV}}{2} = 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = 0 - V_{PV} = -V_{PV}$$

4) *Mode-4:* During this mode, diode D5 is conducting and switch S6 is ON whereas all other switches are not turned on. The current freewheels from inductor (L2) to grid to inductor (L1) to diode D5 and then to the switch S6 to connect PV to the grid. Due to freewheeling mode of operation $V_{BO}$ is floating and is not constant, thus Common Mode Voltage CMV cannot be constant.

$$V_{CM} = \frac{V_{AO}+V_{BO}}{2} = \frac{(0+\sim V_{PV})}{2} = \frac{\sim V_{PV}}{2} =\sim 0.5\ V_{PV}$$

$$V_{DM} = V_{AO} - V_{BO} = V_{PV} - V_{PV} = 0$$

Table III. Total Loss in HERIC topology

| Topology | S1 | S2 | S3 | S4 | S5 | S6 | Total loss |
|---|---|---|---|---|---|---|---|
| HERIC | 1.99W | 1.99W | 1.99W | 1.99W | 1.515W | 1.515W | 11.0W |

*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538*
*Volume 11 Issue IX Sep 2023- Available at www.ijraset.com*

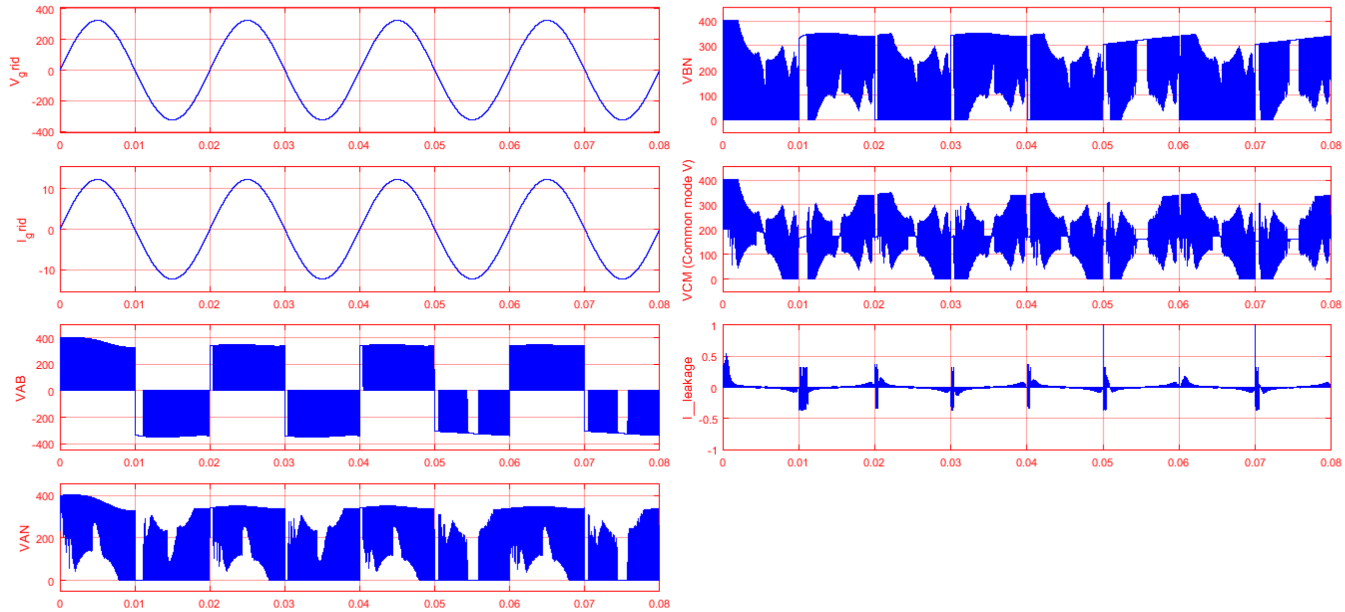



Fig.8. $V_{CM}$, $V_{DM}$ and leakage current output waveforms for HERIC topology

Clearly CMV is not constant in all modes of operation of HERIC topology but this topology results in reduced total losses compared with H6 topology as both HERIC and H6 have same number of switches but still leakage current ($I_{Leakage}$) is not completely mitigated.

## V. CONCLUSIONS

These days transformer-less PV connected grid inverters are often used at a single phase beside the three phase level. Computation of losses, efficiency with constant or reduced CMV is required to overcome the cost and to achieve this good efficient inverter with minimum leakage current topology is required.

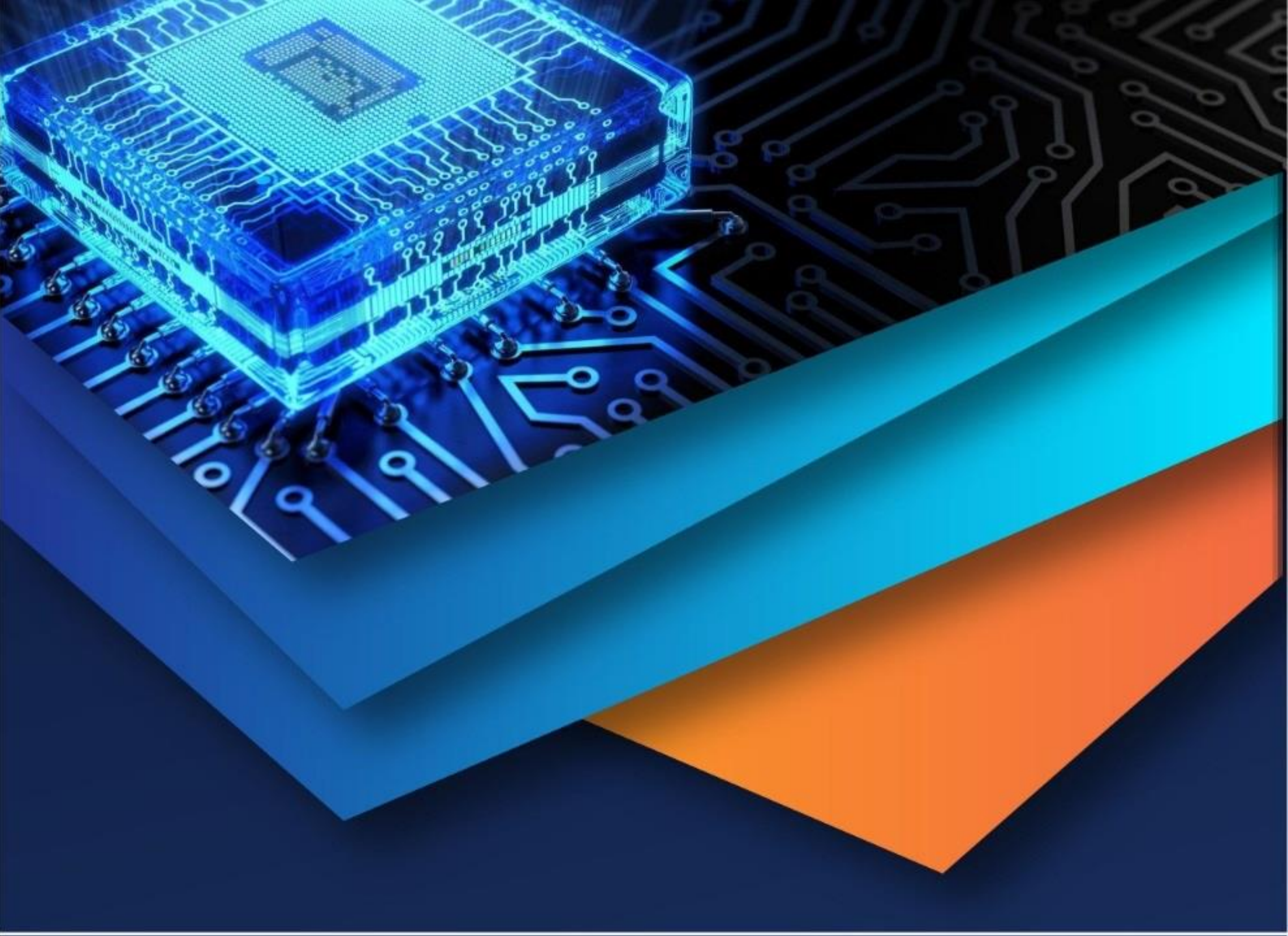
H5, H6 and HERIC transformer-less PV-inverter configurations in terms of average leg voltage, Leakage current, total losses have been evaluated using PSIM2022.2 simulation software package with the help of its thermal module.

## REFERENCES

[1] Zameer 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, 2017.

[2] G. Vazquez, TamasKrekes, Alejandro Rolan, Daniel Aguilar, Alvaro Luna and Gustavo Azevedo, "Losses and CMV Evaluation in Transformerless Grid-connected PV Topologies," ISIE 2009 (IEEE International Symposium on Industrial Electronics),2009.

[3] Zameer Ahmad and S. N. Singh, "Improved modulation strategy for single phase grid connected transformerless PV inverter topologies with reactive power generation capability",Solar Energy, 2018.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY