MINIMIZATION OF SWITCHING LOSSES WITH DIFFERENT SINGLE PHASE INVERTER TOPOLOGIES FOR ON GRID SOLAR SYSTEM.

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Abstract-
When compared to transformer-based inverters, residential grid-connected PV systems using single phase inverters are most desirable. The main limitations of transformer-based inverters include reactive power injection, high efficiency, leakage current issues, and power quality. These are the key concerns that need to be taken into account when using grid-connected power. Transformer-less inverters now compete on a level playing field with wide-band gap (WBG) devices in low load applications. In this paper, the various full-bridge grid connected solar inverter are described with the types. To analyze and contrast the power losses for the period of the turn-on and turn-off processes, a hybrid modulation method was used. This purpose which provide a comprehensive and perceptive overview on reduction of switching losses by adopting different types of inverter.

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I. INTRODUCTION

One of the most efficient, accessible and commonly used renewable energy sources is solar photovoltaic (PV). The initial investment of the solar system is constantly decreasing because to technological advances in material science and manufacturing method, making it the most affordable energy sources for widespread implantation in the future. Many countries (including India, the United States, France, Italy, Spain, Germany, China, and the United Kingdom) have already begun to reap the benefits of this system's widespread adoption and integration into the power grid. Referring to the 2022e fiscal year report of the International Energy Agency photovoltaic power systems Program (IEA-PVPS), the worldwide annual solar energy market reached 175GW in 2021. The solar market grew despite the epidemic that the world was dealing with entering its second year and the end of year disruptions in possibly could have hit 200 GW without these limitation.

Based to a recent research, 24 IEA-PVPS nations attained 264 GW PV installation. The cumulative installed PV capacity of the top IEA-PVPS nations from 2012 to 2021 is depicted in Fig. 1. From the graph, it can see that the photovoltaic industry is growing rapidly, currently five leading countries like China, USA, Japan and India are the biggest installation capacity counties in recent years.

In order to meet the large scale integration of photovoltaic, PV Inverters play a critical role in converting and transmitting solar energy into electricity grids and power consumers. On the basis of their production energy scale, PV inverters may be classified in three categories: Central inverter for photovoltaic installations [4]. For medium and high power application String inverter is utilizes (for offices or industrial PV power systems), module level or micro inverter (for residential PV systems). Low, medium power solar photovoltaic systems have been preferred and are able to be installed on rooftops or walls while PV installations require a large area for installation [5].

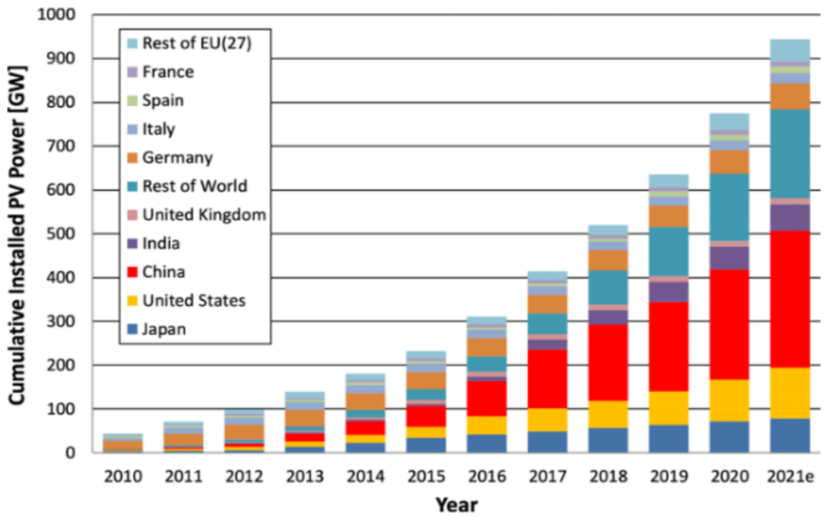


Fig 1.a. According to IEA-PVPS reports, Top PV installation countries from 2012 to 2021e[1]

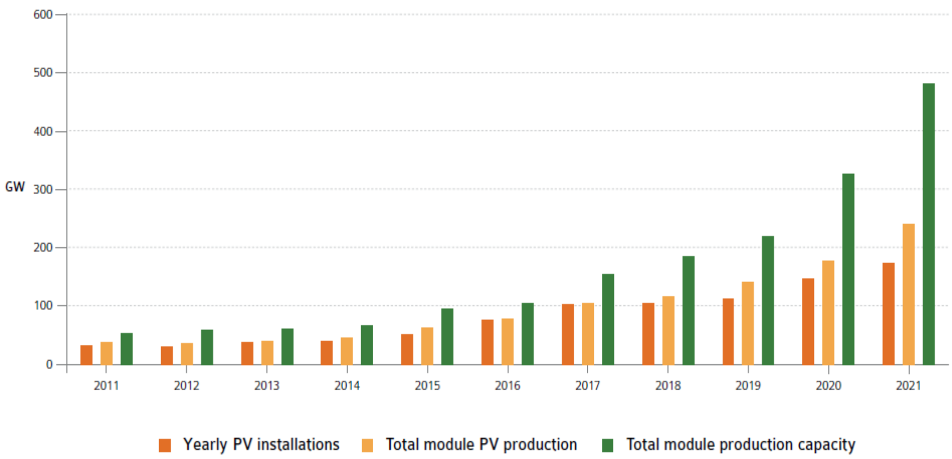


Fig 1.b Total PV installation, production and production capacity from 2011 to 2021. [1]

Grid-connected PV systems have a special problem with leakage current caused by a parasitic capacitor which happened in the PV panels with respect to ground in addition to their inherent intermittency[6]. Fig. 2(a) is shows the transformer based inverter. These transformer based inverters goes against the needs of compactness and affordability also high power density is requirement. Configuring transformer less single-phase topologies, as in Fig. 2(b) may be another option to mitigate this problem. The major goal is to implement various novel modulation techniques or auxiliary circuits to maintain the common-mode voltage (CMV) in tolerable amount. In terms of modulation techniques for a single phase full bridge inverter with the bipolar pulse width modulation (BPWM) technique is the common one. Due to the substantial switching losses associated with two-voltage level production, large sized heat-absorbing devices have a low power density [9]. Numerous review papers have examined various transformer less single-phase full bridge inverters from the standpoint of suppressing leakage current in innovative topologies.

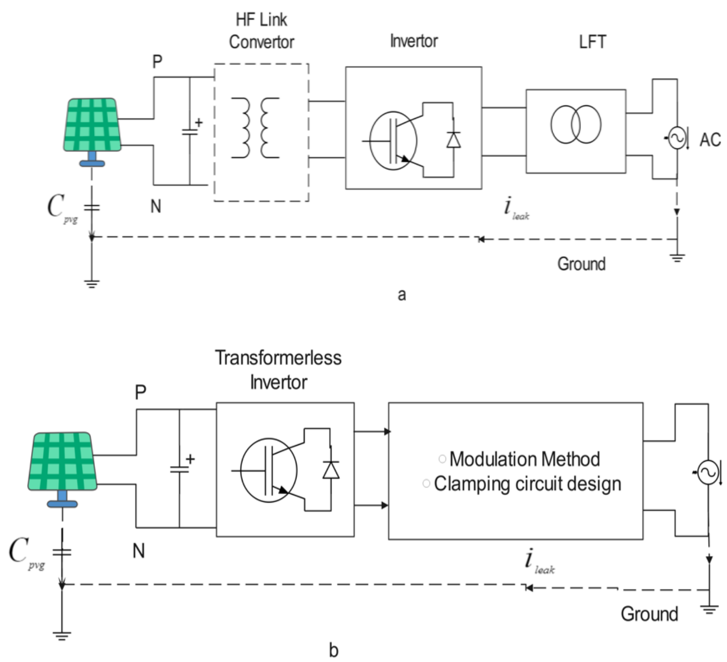


Fig. 2. Inverter arrangements, where C_{pvg} : parasitic capacitor created in the PV panels and ground, and i_{leak} : leakage current.
a. Transformer-based topologies
b. Transformer less inverters.

In addition to power density, grid-connected solar systems also need to address leakage current problems and the addition of reactive power. In this case, the least reactive power injected and taken from energy distribution networks lay between 44% and 25% accordingly, to the rated apparent power, according to IEEE Std. 1547-2018[10]. In order to improve the reactive power capabilities in transformer less inverters, numerous modulation strategies have been developed. Bidirectional flow with unipolar pulse width modulation [11, 12], as well as hybrid modulation approaches [13], have been examined for use in the aforementioned transformer less one phase inverters. Surprisingly few papers discuss the loss distribution under the sophisticated hybrid modulation approach and the performance of commutation oscillations induced by parasitic causes. The problem in (EMI) difficulties owing to parasitic oscillation grows in tandem with the fast advancement of wide-bandgap (WBG) devices, such as gallium-nitride (GaN) and silicon carbide (SiC) switching devices; this advancement is due to increased switching performance. Another critical consideration for solar inverters is the reliability-related system pricing, where the switching devices play a key role due to imbalance losses in it.

As a result, Sections 2 and 3 of this study discuss full-bridge PV inverters using reactive power injection and prior-art hybrid modulation techniques. A useful discussion for the transformer free PV inverters structure is provided in Section 3.a. The full-bridge inverter along with hybrid modulation is shown in Section 3.b, section 4 reflecting the discussions on to reduce the loss also distribute it. Finally, the conclusion in Section 5.

II.REVIEW ON FULL BRIDGE INVERTER

As a result of the split symmetrical AC inductors made up in their design, single-phase FB PV inverters performance is best in term of power density. The single phase FB PV inverters classified as:

1) Transformer-based: As illustrated in Fig. 2 (a), transformer-based FB inverters formations: one with a low-frequency transformer and another with a DC to DC converter uses as a high-frequency transformer. The S 1-4, both have a FB inverter with four switching components (such as IGBTs and MOSFETs). In addition, the aligned AC filter inductors L1 and L2 are the same in all the pictures that follow. In order to accomplish isolation, an inductor as a filter, and reactive power injection using transformer, a full-bridge inverter has used a unipolar pulse width modulation (UPWM) method [15]. Otherwise, the BPWM is used by the FB inverter to maintain a CMV always equal.

2) DC-decoupling: The single-phase inverters equipped with DC-decoupling transformers use an additional equipment at the DC bus to disconnect the solar panels and also in AC side during the freewheeling process. The well-known H5 inverter [14] also called a DC decoupling transformer-less inverter. An precise blocking switch can be installed at the positive/(optional)negative rail of the DC bus, as depicted in Fig. 3. However, compared to other switches, the two times switching losses happened in blocking switch S-5. In order to share the switching losses similarly to the S5 toggle in the negative rail, the H6 DC-decoupling transformer-less inverter adopted two blocking switches, as shown in Fig 5. Since the current requires pass through S1-4 switches during the conduction period, the symmetrical blocking switches S5 and S6 can share switching losses but raise conduction losses [16]. Modern H6 transformer-less DC-decoupling inverters incorporate another way to bypass the H5 architecture to address this problem [17].

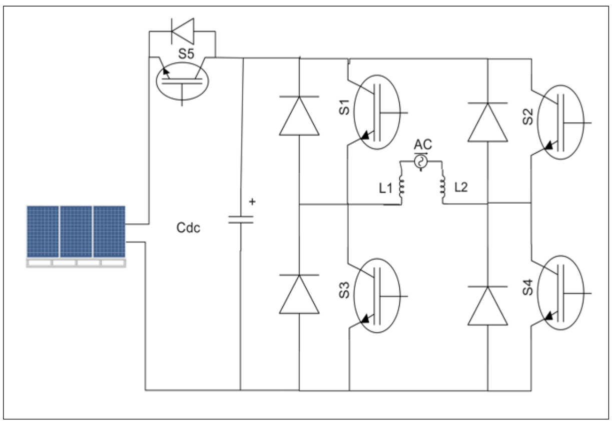


Fig. 3. DC-decoupling inverters

3) AC-decoupling: These AC-decoupling type transformer less inverters enhance the decoupling circuit at the AC side. In [18], The H6 AC-decoupling type inverter derivation method was provided, with the primary configuration being the embedding of an AC-decoupling circuit for bidirectional freewheeling paths in the mid-point of the FB inverter. For instance, symmetrical H6 transformer-less inverters with identical modulation and CMV performances but differing architectures are shown in Fig. 4 [19, 20]. Figures 4 show that the conduction losses are comparatively higher when the AC-decoupling arrangement is introduced into the FB inverter's branches. The highly effective and reliable inverter idea (HERIC) uses two active switches as AC-decoupling circuit to address this problem [21]. In comparison, the HERIC inverter has excellent qualities as of smaller switching devices and improved efficiency to the two anti-series linked active switches.

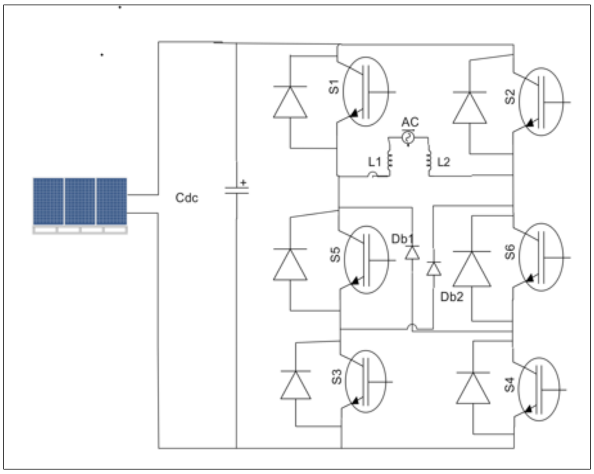


Fig. 4. H6 AC decoupling inverter,

4) Neutral Point Clamping (NPC): Switch junction capacitors are semiconductor devices that differ from physical switches (such as relays) and have an unanticipated effect on leakage current performance. For [3] and [22] examined junction capacitors intrinsic leakage current as it affects the H5 inverter. Due to asymmetrical nature of the H5 architecture is unable to maintain the CMV constant, in high-power inverters using high speeds switching components. As a result, it has been suggested to use NPC type inverters combined with a capacitor clamping circuit to maintain CMV. The DC/AC-decoupling inverters make it simple to construct NPC topologies, throughout the freewheeling phase which uses the CMV to maintain half of the DC-link voltage. The DC-decoupling Neutral point clamp transformer less topologies are shown in Fig 5. An H5-D

architecture that uses only a diode to perform NPC function was presented in [22], and on

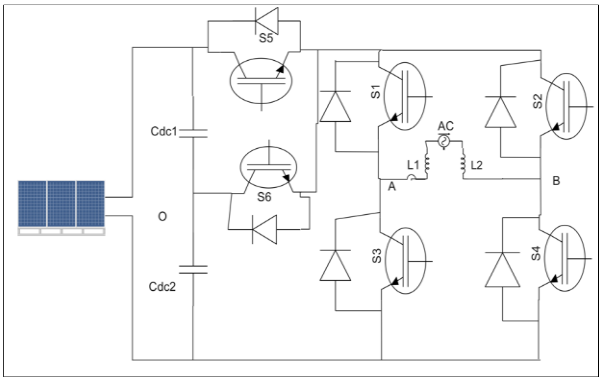


Fig. 5. DC-decoupling inverters H6 topology, where S5, S6 clip to both the positive/(optional) negative DC-links

the opposite side of the DC rail is S5. The performance of CMV clamping is lower than that of O-H5 topologies. Additionally, the H6-DC isolating inverter employed a diode-based bidirectional NPC circuit.

As AC decoupling NPC inverters, topology is exemplified in Fig. 6.

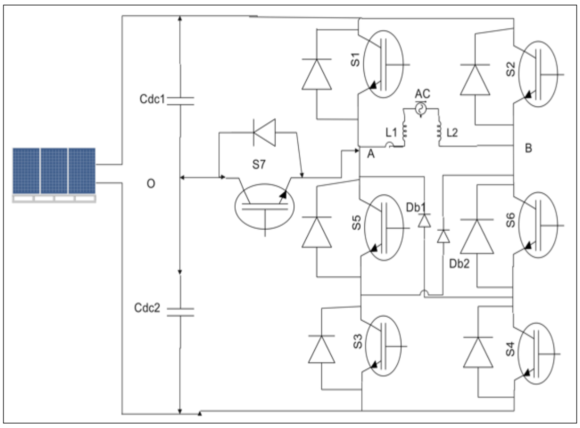


Fig.6. AC-decoupling NPC inverters a H6 AC decoupling NPC topologies.

In H6-AC-decoupling NPC inverters, the decoupling circuit is connected with the series capacitors neutral point by an active switch. The leakage current suppression strategies provide the foundation for the aformentioned classification of PV inverters. Efficiency and device count performance have also been taken into account in a number of comparisons and evaluations in review publications. The HERIC inverter is more efficient that the H5, as the H5 has the less device count, and with the help of NPC topologies provides the best CMV clamping characteristics. However, concerns like loss distribution and commutation oscillation, which are closely related to power density, are not given much attention. During the operating modes, inverters commute at a switching frequency due to the presence of parasitic inductor and capacitor in the circuit. Multi-frequency is caused by the varying parasitic characteristics in several current loops. EMI filters should be included under the considerable oscillation performance since many standards have strict EMI criteria (for instance, the Standard EN-61,800-3 specifies tolerable disturbance voltage in the frequency band 150 kHz-30 MHz) [23]. The heat sink built with the ability to cool down the component that is running the hottest [24]. As a consequence, loss balancing of switches can improve by heatsink design and average lifespan of the PV inverters. This article will analyse the performance of many common single-phase FB PV inverters with regard to parasitic oscillation and loss distribution with reactive power injection using a hybrid UPWM technique.

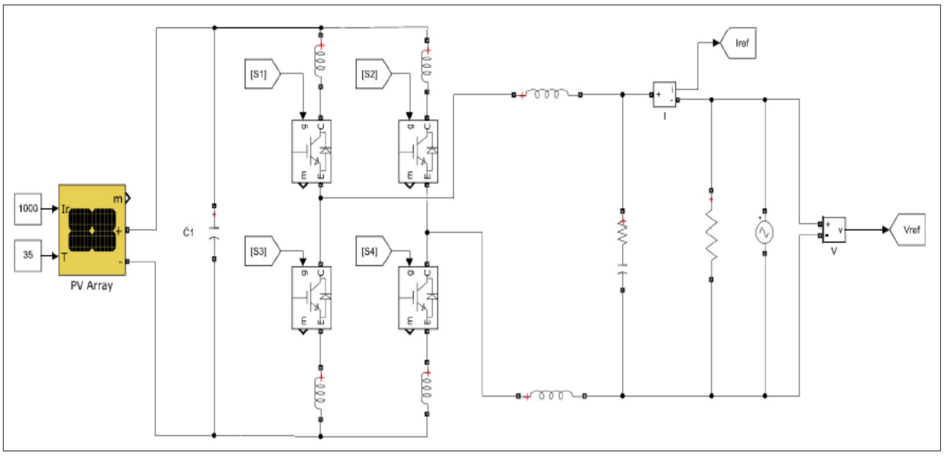
III. A PARASITIC OSCILLATION AND LOSS ANALYSIS

For a variety of single-phase FB grid-connected transformer less solar inverters, high efficiency and power quality requirements were met by summarising the hybrid UPWM schemes. The oscillation due to parasitic component and loss distribution performances for the aforementioned transformer-less single phase inverters are different while using this pulse generating approach. The different topology like full bridge inverter, H5-method, H6-DC decoupling method, and HERIC topology are chosen to analyse and compare in this work since they are almost based on the DC/AC decoupling topologies. The DC-link voltage Vdc is taken as constant as the parasitic oscillation and loss distribution are examined using the modulation approach. Additionally, the hybrid modulation approach [25] uses a basic current controller to create the duty cycle ratio.

III. B. DESIGN OF DIFFERENT TYPE OF TRANSFORMER LESS INVERTER TOPOLOGIES:

1) Single-Phase Transformer-less full bridge Inverter Topologies:

This section describes single-phase full-bridge (FB) transformer less inverter configurations with both unipolar and bipolar changing patterns. For obtaining constant CMV and low i_{cm} a standard Single phase FB inverter with a bipolar architecture has been adopted. However, as the loss grows, system effectiveness declines. As a result, unipolar has been developed to address the efficiency problem. This section includes detailed illustrations of bipolar and unipolar FB inverters with the proper wave patterns.



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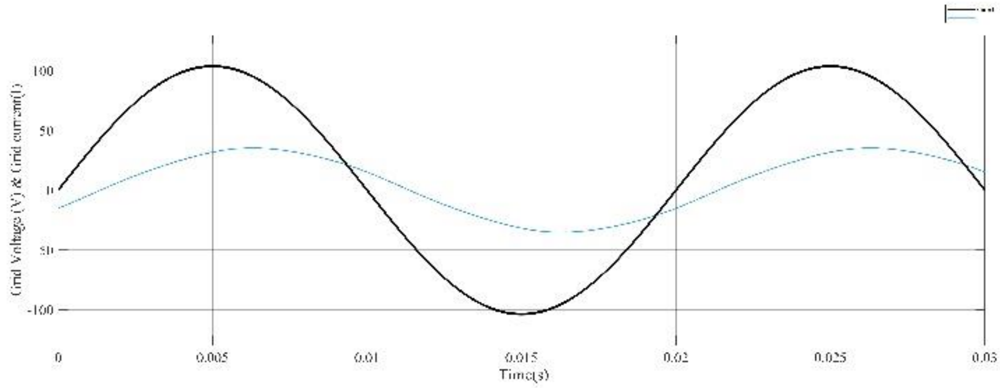

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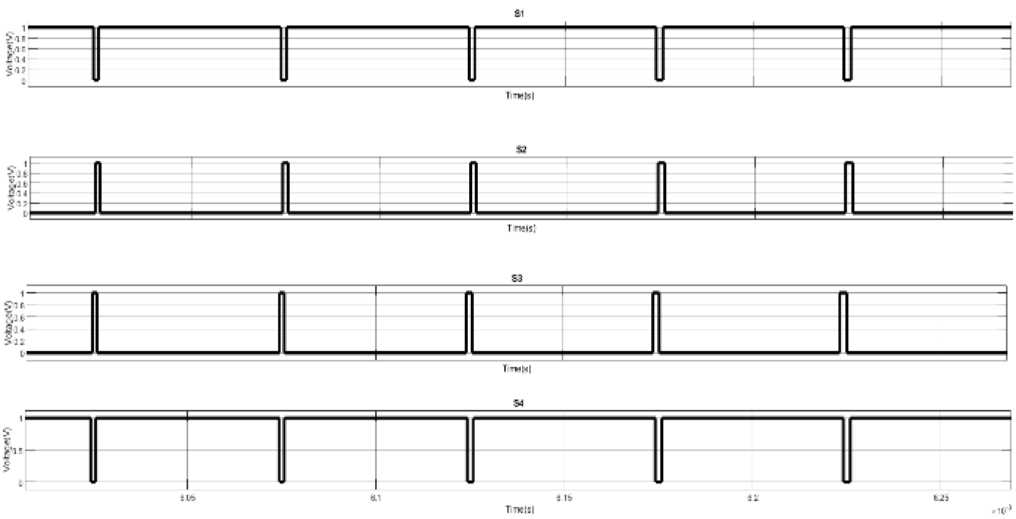


c.

Fig.7 Illustration of (a)Single phase Full Bridge inverter structure, (b) Output voltage and current waveform (c) Full Bridge inverter-modulation scheme

Figure 7.a depicts the single phase FB transformer-less inverter design with parasitic capacitors on each side of the solar panel. Figure 7.c depicts the hybrid modulation approach with reactive power insertion in this method. The switches S1 and S4 are switched on during the first half of the cycle, and their output current flows to the load via the antiparallel diodes S2 and S4. S2 is complimentary to S1, and S3 is complementary to S4 in this modulation scheme. S1 and S4 are ON for the

positive half cycle, hence the input voltage and output voltage are equal. For the first half cycle, the current flow during the freewheeling phase is through switching device S1 and antiparallel diode of S2 for the first half of the cycle and via S3 and the antiparallel diode of S4 for the negative half cycle.

B) H-5 inverter type:

Figure 8 depicts the analogous structure of the H5 topology having parasitic inductances, which uses an active switch S5 to the positive side of DC link to separate the DC and AC sides. Figure 8 shows the enhanced hybrid UPWM approach with reactive power injection. S1 is turned on during the positive half cycle, while S4,S5 are switch at a high frequency, producing a two-level voltage of $+V_{dc}$ and 0. S2 is ON, and S1 and S3,5 regulate at the switched frequency, resulting in a two-level voltage of $-V_{dc}$ and 0 for negative half-cycle. Accordingly, the loss distribution shows that S5 has large switching and conduction losses as a result of its prolonged operation. The H5 inverter's S5 component is the most vulnerable, according to the thermal investigation.

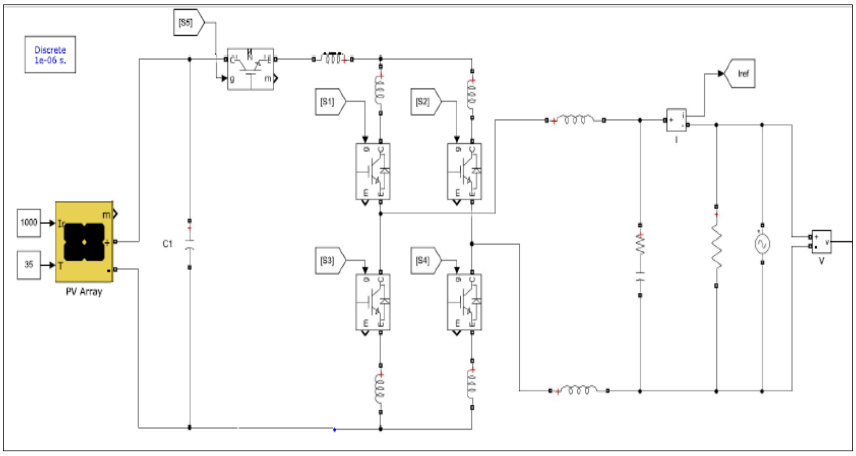
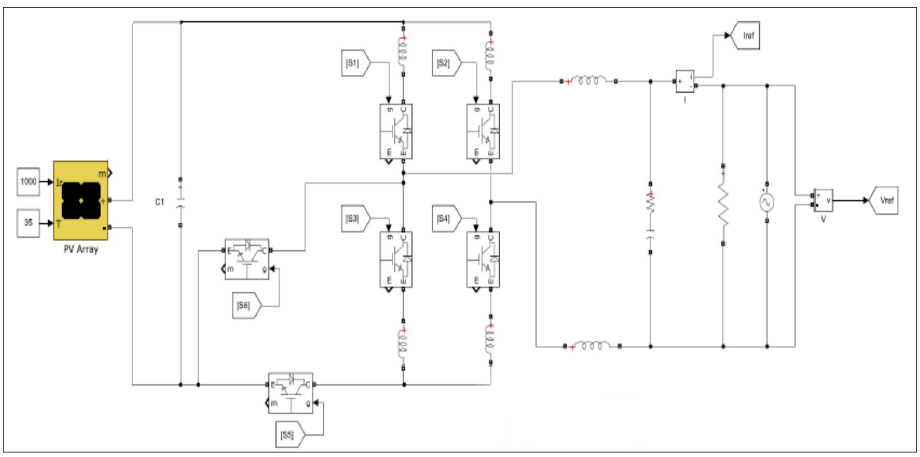


Fig. 8. H5 inverter-equivalent circuit with parasitic inductances,

The EMI filter used in the H5 inverter should be built to suppress oscillations in a wide range of frequencies, which entails a higher price and greater volume. This is how the loop inductances has be stated for both operating mode. Despite the removal of the transformer, the heat sink and EMI filter take up more space than in a symmetrical full-bridge inverter.

C) H6 Inverter:

The H6 inverter is used to reduce conduction loss, eliminate leakage current, and boost efficiency. Figure 9 depicts the circuit for H6 inverter. It is a variation in the H5 inverter circuit is to including an additional switch S6 between the negative terminals of the DC supply, as shown in the picture. The circuit employs the DC decoupling approach. During freewheeling the PV array disconnect for grid. During the active portion of the grid voltage, this circuit dis designed to offer an alternative current path. Although there are one more switches than in the H5 inverter, there is a comparative decrease in conduction loss and an increase in efficiency.



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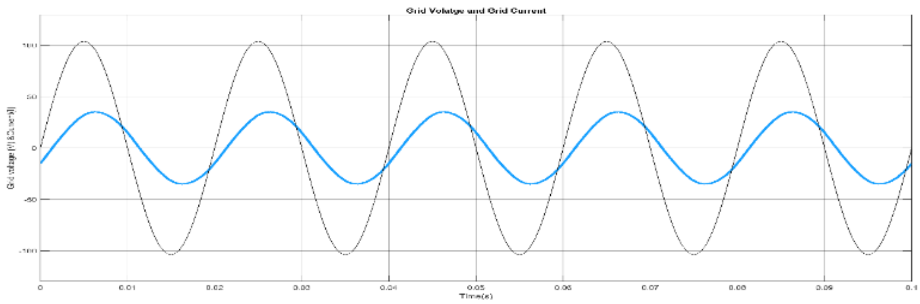

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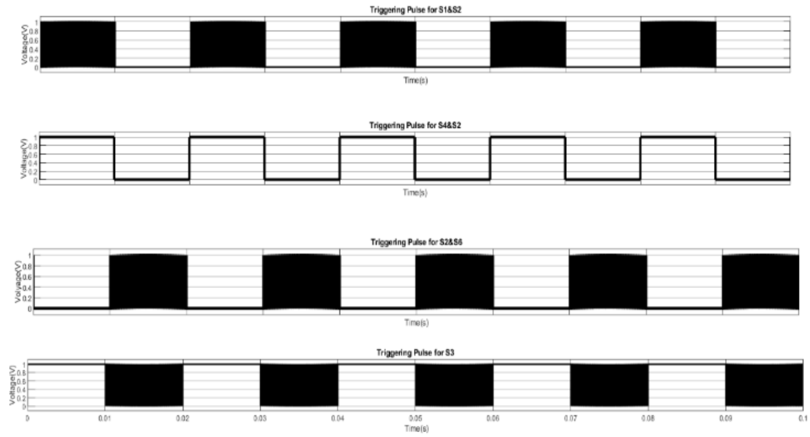


c.

Fig.9 Illustration of (a) H-6 inverter structure,
(b) Output voltage and current waveform
(c) Full Bridge inverter-modulation scheme

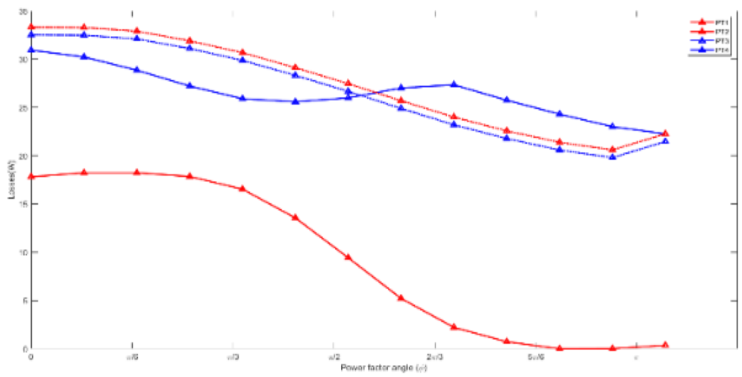
Leakage current is eliminated by maintaining a constant common mode voltage.

Switches S1 and S5 switch at the positive half cycle of the grid voltage, while switches S3 and S6 switch at the negative half cycle within the grid voltage. Switch S4 operates at grid frequency over the positive and for negative half cycles of voltage in a system, S2 performs on grid frequency. During negative half cycle switch S4 operates in parallel with S3 at the switching frequency of the grid voltage.

IV.RESULT

A. For Full bridge inverter

The comparison results are shown in Fig. 10, where total losses of devices (P1-4), losses due to unidirectional switches (PT1-4), and losses due to anti-parallel diodes (PD1-4) are represented in (a)-(c). The BPWM approach evenly distributes the power in the complete bridge inverter. S1,3 losses are considerably less than S2, 4 losses.



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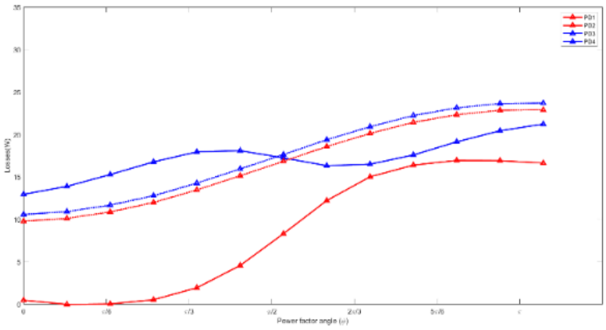

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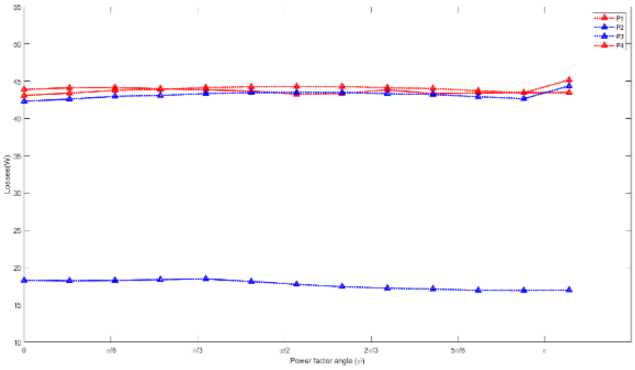


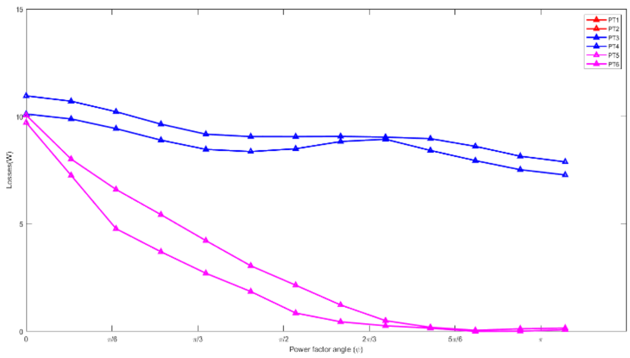
c.

Fig.10. Comparison on loss distribution of 1-phase inverter, where PT, PD and PS are conduction losses on IGBT, losses in the anti- parallel diodes and total switching losses under various cos□.
a. Losses due to unidirectional switches
b. Losses in anti-parallel diodes
c. Total losses

As represented in Fig. 10 (a) and (b), When the full-bridge inverter uses hybrid UPWM techniques, power losses due to the diodes and unidirectional switches vary with the cos angle. That is, reactive power injection will affect the inner losses dispersion in the switching device, which may be taken into consideration when developing the power control strategy. Furthermore, when the full-bridge inverter uses the BPWM approach, the power losses of the unidirectional switching devices and anti-parallel diodes are the same.

B. For H6 bridge inverter

Fig. 11 gives the results, where total losses of devices (P1–6), losses because of unidirectional switches (PT1–6), and losses of antiparallel diodes (PD1–6) are depicted in Fig. 11(a)-(c). As shown in Figs. 11(c), the total losses of semiconductor devices S1–6 in the H6 inverter are equally distributed under the BPWM method. The losses of S5-1, 6-3 are far less than that of S2,4.



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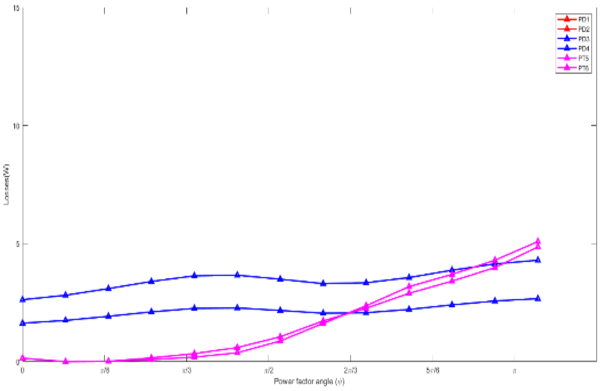

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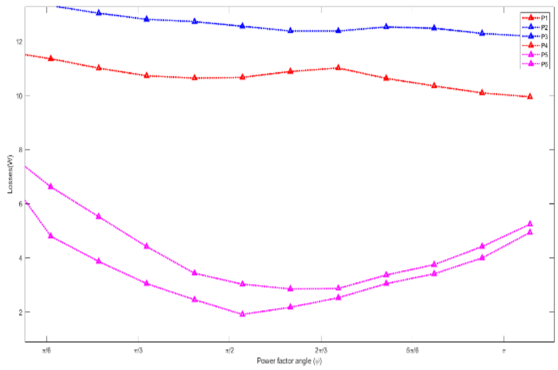

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Fig.11. A comparison of the H6 inverter's loss distribution, where PT, PD, and PS are conduction losses on IGBT, losses in the anti- parallel diodes and total switching losses under various cos□.
a. Losses in unidirectional switches
b. Losses in anti-parallel diodes
c. Total losses

As represented in Fig. 11 (a) and (b), the power losses of the body diodes and the unidirectional switches change with the power factor angle for the H6 inverter. The below table show the aggregate switching losses in different switching devices at different power factor for single phase full bridge inverter and H6 inverter.

TABLE I. AGGREGATE SWITCHING LOSSES AT DIFFERENT PF

Topology		**Losses at different Power factor Angle (in watt)**					
		$\pi/6$	$\frac{\pi}{3}$	$\frac{\pi}{2}$	$\frac{2\pi}{3}$	$\frac{5\pi}{6}$	π
Full Bridge Inverter	Losses across IGBT	27.6	26.5	23.3	20.1	18.1	17.7
	Losses across anti-parallel diodes	9	10.5	13	16.3	18	19.2
	Total losses	37.1	36.8	36.7	36.7	36.8	36.7
Novel H6 inverter	Losses across IGBT	7.7	6.7	6.3	5.3	4.7	4.6
	Losses across anti-parallel diodes	1.4	1.6	1.9	2.6	2.5	3.6
	Total losses	9.2	8.1	7.3	7.4	7.6	7.7

V.CONCLUSION.

The leakage current suppression of single phase full bridge PV inverters has classified and studied in this paper. The synchronization oscillation and losses distribution abilities of the chosen single phase FB PV inverters using the hybrid UPWM with reactive power injections were analyzed. It is beneficial to EMI filters with identical loop inductances because of its high oscillation performance in different commutation modes.

Then, a complete evaluation of full bridge inverters in terms of loss distribution across different switches was given. The analysis of loss distribution for both the full bridge inverter and the H6 with a combined modulation technique based on reactive power injection was also aided by simulations.

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