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Simulation of Various Topologies considering Single phase transformerless inverters

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Abstract : The power electronics field has grown and evolved over the last 60 years, today static converters can effectively transform electric energy to meet the needs of many applications. As a result, the technology is now crucial for integrating renewable power into the electric grid. So, power electronics will play an important role in modernizing existing electric networks in the coming years. Single phase transformer less inverter topologies with reduced leakage current were introduced for grid-tied photovoltaic (PV) applications in the last couple of years. These topologies are mainly classified based on methods to reduce leakage current: galvanic isolation with CMV clamping and without AC clamping. The galvanic isolation can be achieved by incorporation of extra switches either on the AC side or DC side of a full bridge (H4) inverter topology for AC or DC decoupling respectively. The implementation simulation of 10 different transformer less inverter topologies such as H5, HERIC, H6 and improved H6 topologies. All of these topologies are designed for single stage conversion. With SPWM-enabled technology and other advanced components, these designs offer the benefits of high efficiency and increased power density.

***IndexTerms* – Single Phase Transformer less Inverters, Transformer Topologies.**

I. Introduction

The inverter is the center of your solar energy system, responsible for converting the DC electricity produced by your panels into AC current that powers your home appliances. Standard inverters use a transformer that synchronizes the voltage with those of the grid and your appliances, while transformerless inverters use a series of electronic components and processing power to convert DC power to high-frequency AC and back. [1] Transformerless inverters are used predominantly in Europe because buildings already have transformers located near them, so the individual transformer within the home-scale inverter becomes redundant. Inverters can be either transformerless or standard. Inverters are devices that turn DC currents into AC currents. Conventional inverters have an internal transformer which synchronizes the DC voltage with the AC output. [1]

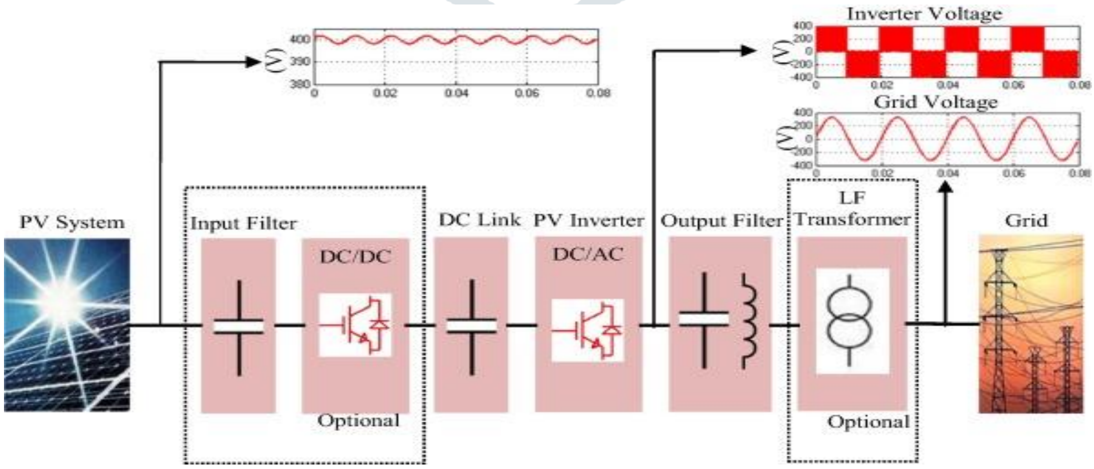

Fig 1. Transformerless Invertors

Transformerless (TL) inverters are built without a transformer and use a computerized process and electronic components to convert Direct Current (DC) to high-frequency Alternating Current (AC), back to Direct Current, and finally to standard Alternating Current. Transformerless inverters are popular in European and Australian markets. In 2010, SMA Solar Technology

AG earned the first UL certification for their transformerless inverters, which increased product availability for residential consumers in the United States. [2]

Transformerless inverters are light and compact, which means you won't need as much space. They're also inexpensive, so you can get more power to your home at a better price. They use electronic switching, so they produce less heat and humidity than standard inverters. TL inverters maintain the ability to utilize two power point trackers that allow for installations to be treated as separate systems. In other words, with TL inverters, panels can be installed in different orientations on the same rooftop and still generate DC output at peak hours. [2]

Traditional inverters only work through one power point, which means that panels producing at lower frequencies will affect the output of the system as a whole. Transformerless inverters do not have electrical isolation between DC and AC circuits. This may result in some grounding and lightning protection issues and make the inverters more expensive than it would be for the transformer type of inverter to comply with NEC specifications. Transformerless inverters are mostly meant for grid-tie solar PV systems, so if you mount them onto an off-grid power system, they're less likely to work. [3]

The efficiency of an inverter is determined by the amount of time it takes to produce AC power after taking in DC power. Converters are typically more efficient when operating at full capacity, or in doing so during peak times. Efficiency calculations include peak and off-peak percentages as well as the number of hours a converter operates at rated capacity. Studies show that even a small percentage increase in inverter efficiency can be quite significant if it's factored throughout the life span of the inverter. [3]

II. Literature Survey

H. -J. Lee and Y. -D. Yoon, 2019 [4] A new transformer unit topology is proposed in this paper. The proposed transformer unit consists of a three-lead converter, which can be installed on the distribution transformer easily added to the conventional power supply circuit. With this transformer topology.

H. Helali, et.a; 2016 [5] Smart transformer (ST), a technology among the 10 most emergent technologies according to MIT, has acquired growing importance in the electricity grid. This paper presents at first the concept of ST and its advantages in the electricity network. Then, existing topologies are reviewed and compared for the most performing which is three-stage topology. Moreover, selected topology is simulated with its different architectures. Simulation results show differences between architectures' performances regarding power quality.

S. Shi, et. al. 2019 [6] A study by Shi et. al. in 2019 showed that DC transformer is needed for voltage level conversion and power transmission. This paper showed a modular multilevel converter (MMC) F2F topology that consists of two different voltage DC systems. When the two systems have an identical voltage, the topology can increase transmission power and reduce AC transformer insulation requirements. An example from MATLAB/Simulink demonstrated the feasibility of this paper's approach.

A. Dannier and R. Rizzo, 2012 [7] have investigated the applicability of power electronic transformers with a medium frequency transformer (MFT) and the behavior of the conduction ratio in terms of the instant switching ratio. For this purpose two LPF filters are used for voltage transformation and two PFOSs for synchronous reactance and power factor correction. The study demonstrates that it is possible to use PET transformers, albeit from a theoretical point of view, because it's impossible to discard a significant percentage of loads on MF systems. Simplicity, effectiveness, high-resolution control are important aspects which can strongly improve performance of PETs.

E. S. Deepak, e.t.al 2011 [8] This new multilevel topology for generating sinusoidal AC waveform based on a novel transformation technique promises a high quality circuit design with minimal complexity. Utilizing multiple self-balancing transformers, the new multilevel topology can achieve 27 output levels by utilizing only 8 switches and 3 full bridge rectifiers.

The basic working principle is based on the selective addition and subtraction of magnetic flux in the transformer's coil cores. Although the mathematical modeling of multi-winding multi-tapped transformers is not particularly easy, the construction complexities are reduced when compared to conventional circuits like diode clamped, capacitor clamped, and cascaded multilevel inverters. Authors have utilized modesimulation techniques to simulate our system using synthesized transformer models derived from single source DC supply input in a hierarchical manner to further simplify the transformer specifications.

The proposed methodology offers higher quality performance than traditional designs because it avoids major flaws such as capacitor voltage unbalancing, common mode voltage stresses at load end and need for large filters to eliminate harmonic frequencies at output while ensuring stability against odd order harmonics.

III. Proposed Approach

The power electronics field has matured over the last 60 years. Today, static converters can efficiently convert energy to meet different needs such as powering homes and offices. They're essential for integrating renewable energy into the electric grid. That's why power electronics will be essential in the preservation of the existing electric network. Recent years have seen the introduction of single-phase transformers with reduced leakage current for grid-tied PV applications.

Leakage current can be reduced by two different ways. You might be able to employ one of the following: galvanic isolation with common-mode voltage clamping or without any clamping. In both cases, it's possible to complete the leakages with an additional switch on either the AC side or the DC side of a full bridge inverter (H4) topology for AC or DC decoupling respectively.

IV. Implementation and Simulation

Table 1 Parameters of 1Soltech 1STH-215-P solar module

Parameter	Value
Maximum power (Pmax)	213.15 W
Voltage at Pmax (Vmax)	29 V
Current at Pmax (Imax)	7.35 A
Short circuit current (Isc)	7.84 A
Open circuit voltage (Voc)	36.3 V

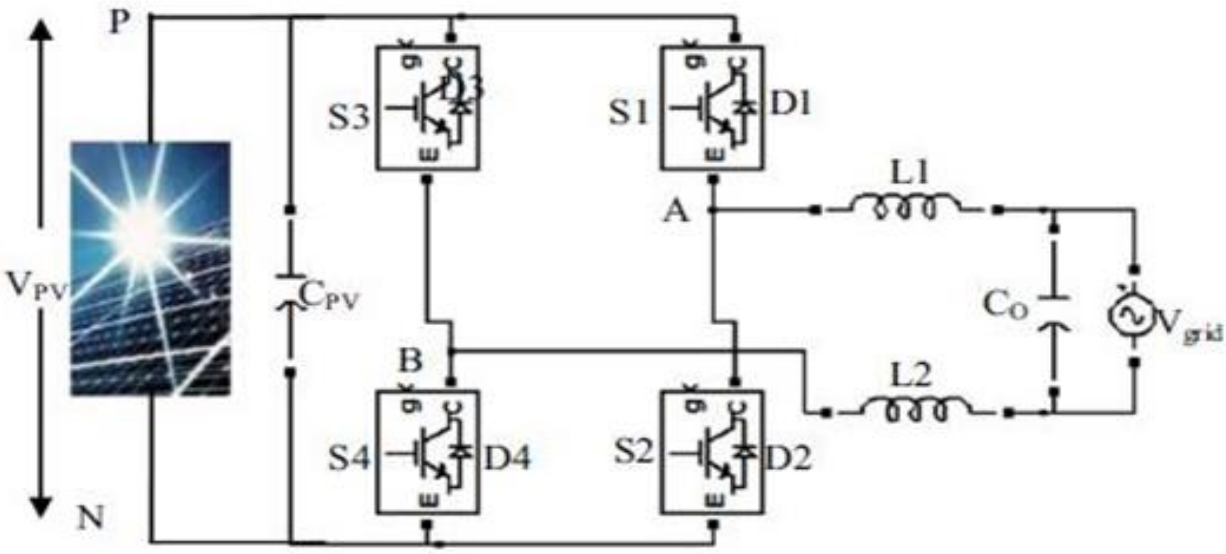

Figure 2 H4 topology

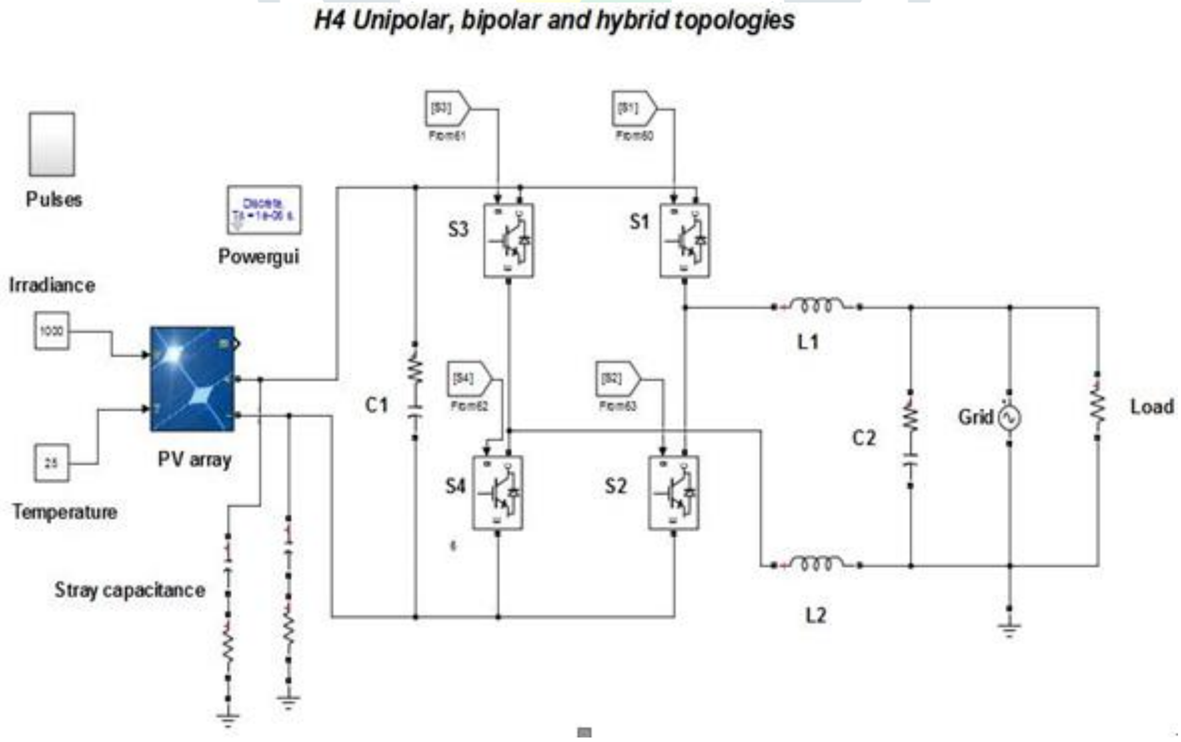

Fig 3 Simulink diagram of H4 unipolar, bipolar and hybrid topologies

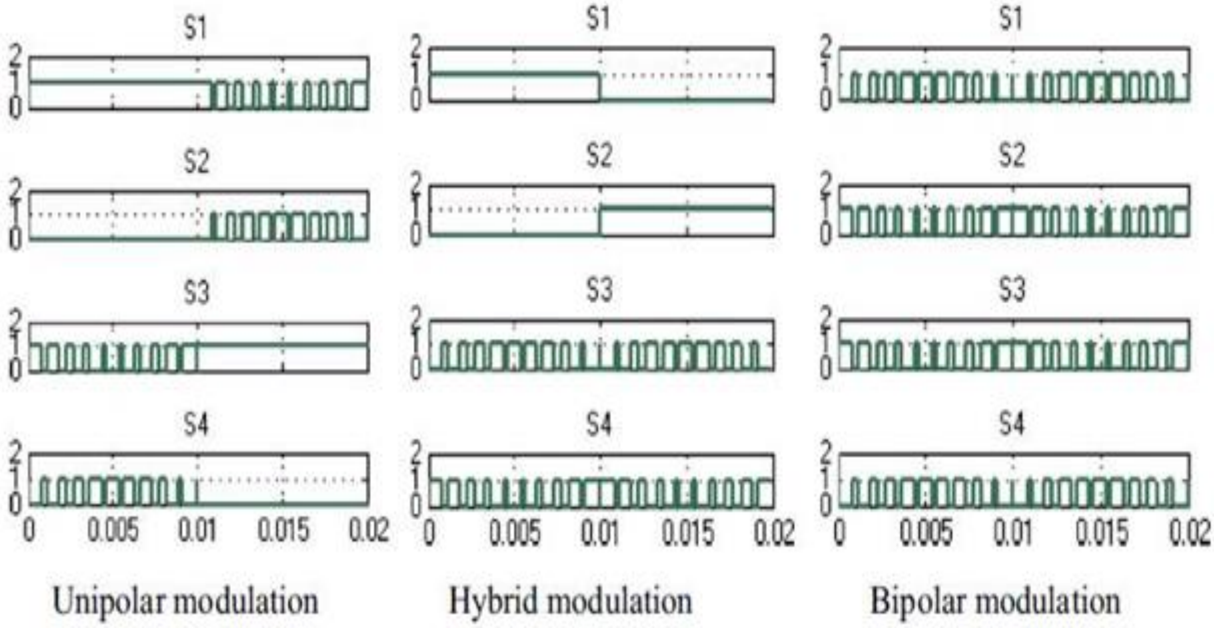

Figure 4 Differential mode and common mode characteristics of H4 topology using unipolar, bipolar and hybrid modulation strategies

Bipolar SPWM Technique							
Positive Half Cycle				Negative Half Cycle			
Switching States in a switching cycle	V_{AO}	V_{BO}	$V_{CM} = \frac{V_{AO}+V_{BO}}{2}$	Switching States in a switching cycle	V_{AO}	V_{BO}	$V_{CM} = \frac{V_{AO}+V_{BO}}{2}$
S_1, S_2 ON	V_{PV}	0	$V_{PV}/2$	S_1, S_2 ON	V_{PV}	0	$V_{PV}/2$
S_3, S_4 ON	0	V_{PV}	$V_{PV}/2$	S_3, S_4 ON	0	V_{PV}	$V_{PV}/2$
Unipolar SPWM Technique							
Positive Half Cycle				Negative Half Cycle			
Switching States in a switching cycle	V_{AO}	V_{BO}	$V_{CM} = \frac{V_{AO}+V_{BO}}{2}$	Switching States in a switching cycle	V_{AO}	V_{BO}	$V_{CM} = \frac{V_{AO}+V_{BO}}{2}$
S_1, S_2 ON	V_{PV}	0	$V_{PV}/2$	S_3, S_4 ON	0	V_{PV}	$V_{PV}/2$
S_2, S_4 ON	0	0	0	S_1, S_3 ON	V_{PV}	V_{PV}	V_{PV}
S_1, S_2 ON	V_{PV}	0	$V_{PV}/2$	S_3, S_4 ON	0	V_{PV}	$V_{PV}/2$
S_1, S_3 ON	V_{PV}	V_{PV}	V_{PV}	S_2, S_4 ON	0	0	0
Hybrid SPWM Technique							
Positive Half Cycle				Negative Half Cycle			
Switching States in a switching cycle	V_{AO}	V_{BO}	$V_{CM} = \frac{V_{AO}+V_{BO}}{2}$	Switching States in a switching cycle	V_{AO}	V_{BO}	$V_{CM} = \frac{V_{AO}+V_{BO}}{2}$
S_1, S_2 ON	V_{PV}	0	$V_{PV}/2$	S_3, S_4 ON	0	V_{PV}	$V_{PV}/2$
S_2, S_4 ON	0	0	0	S_1, S_3 ON	V_{PV}	V_{PV}	V_{PV}

Figure 5 Common mode voltages of three basic PWMs

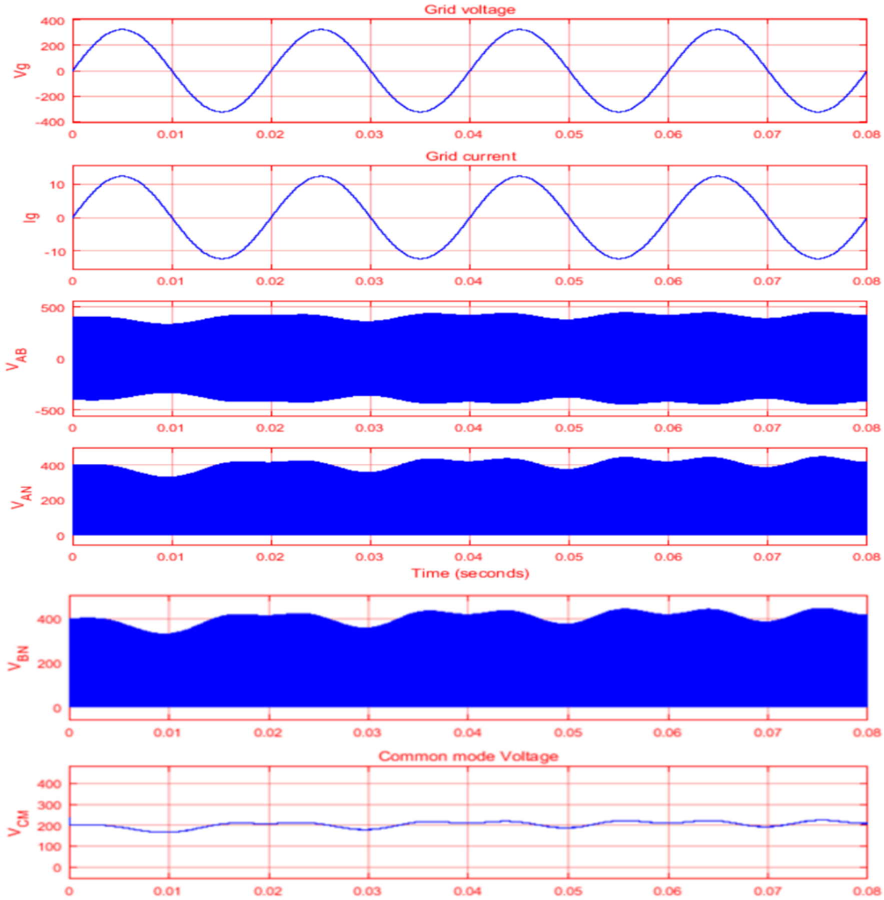

Figure 6 Bipolar: DM and CM characteristics

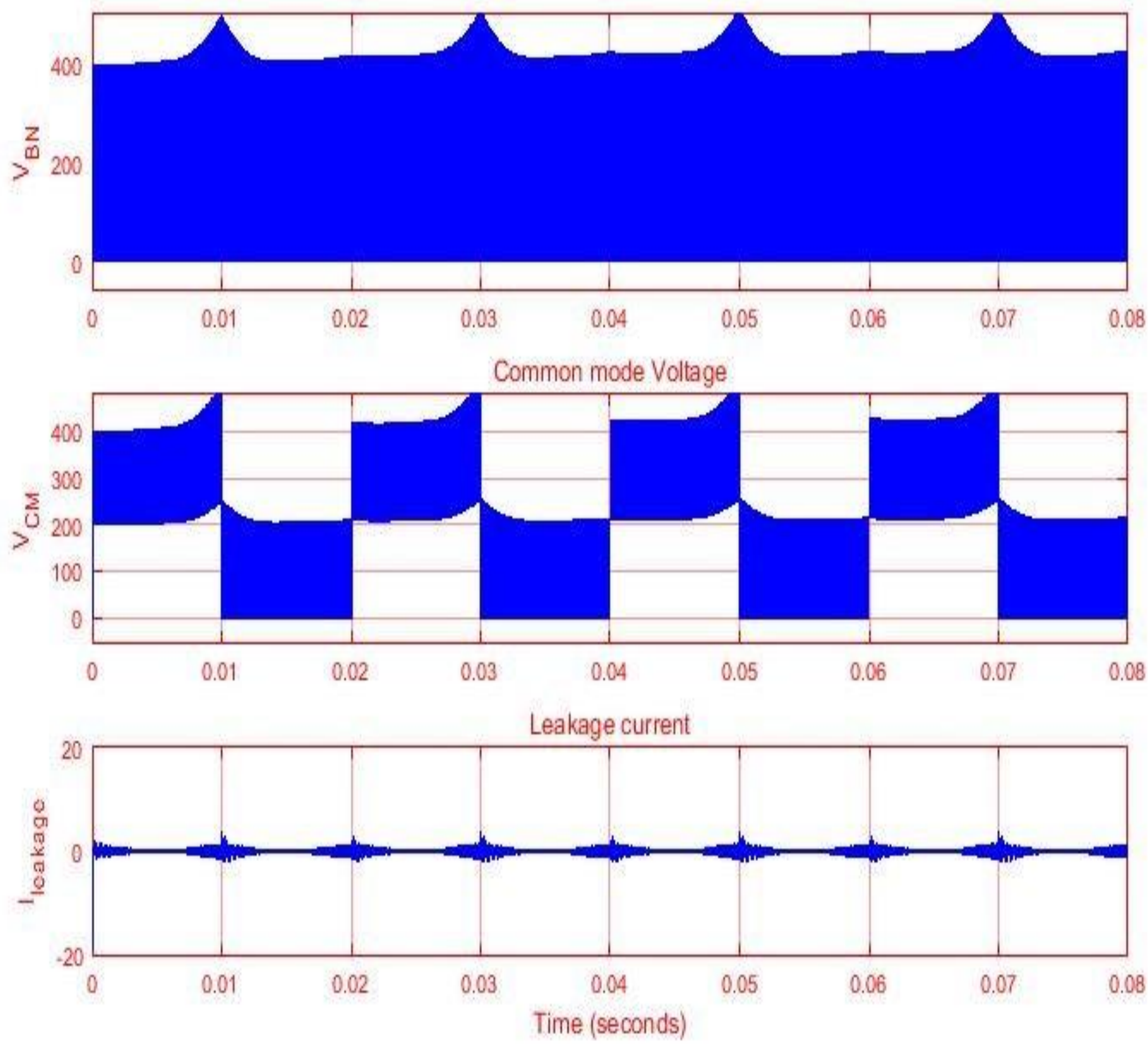

Figure 7 Hybrid: DM and CM characteristics

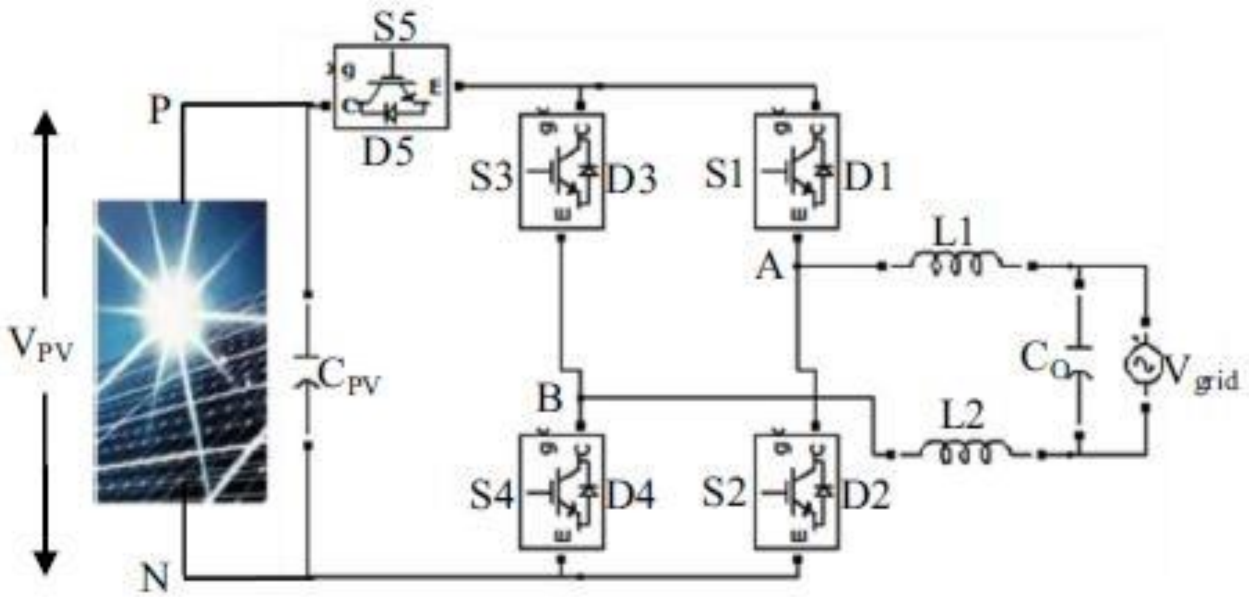

Figure 8 H5 topology(SMA)

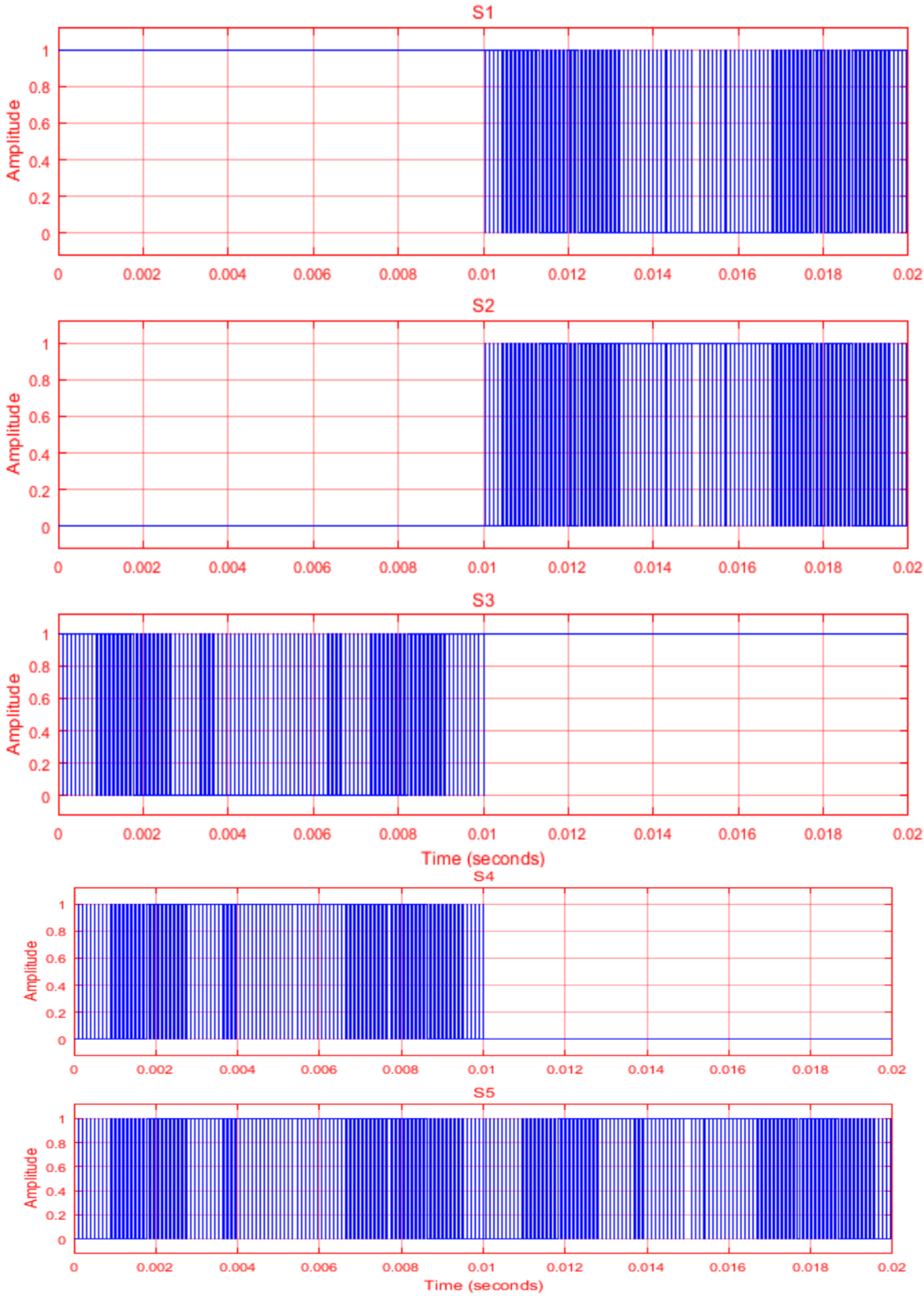

Figure 9 PWM for H5 topology

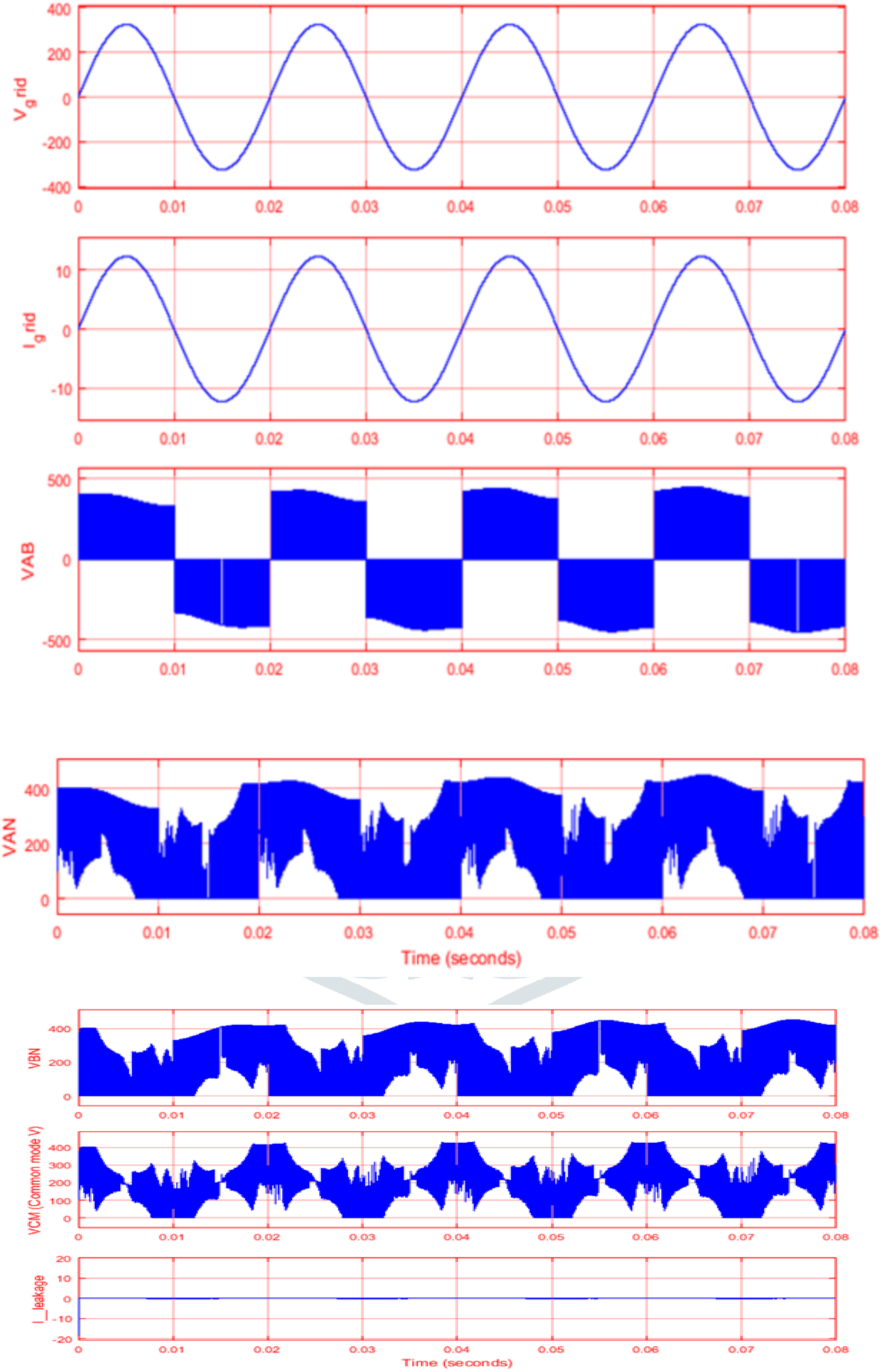

Figure 10 H5 topology: DM and CM characteristics

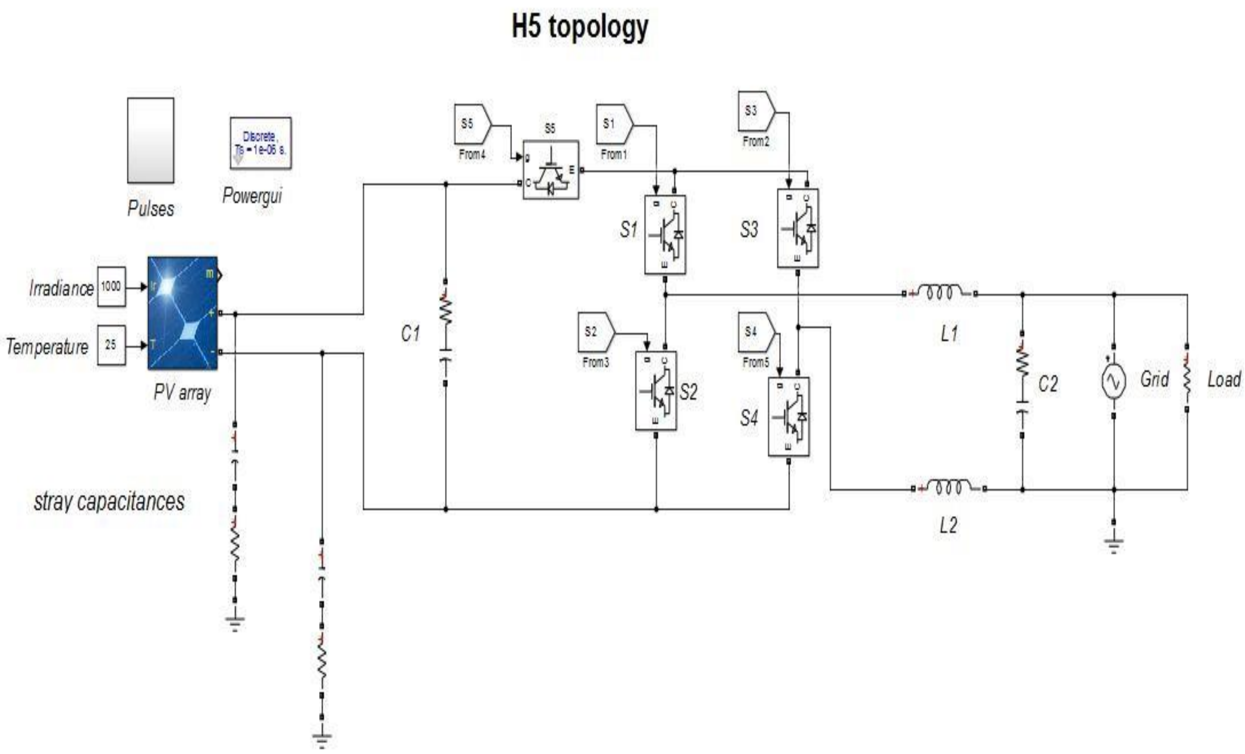

Figure 11 Simulink diagram of H5 topology

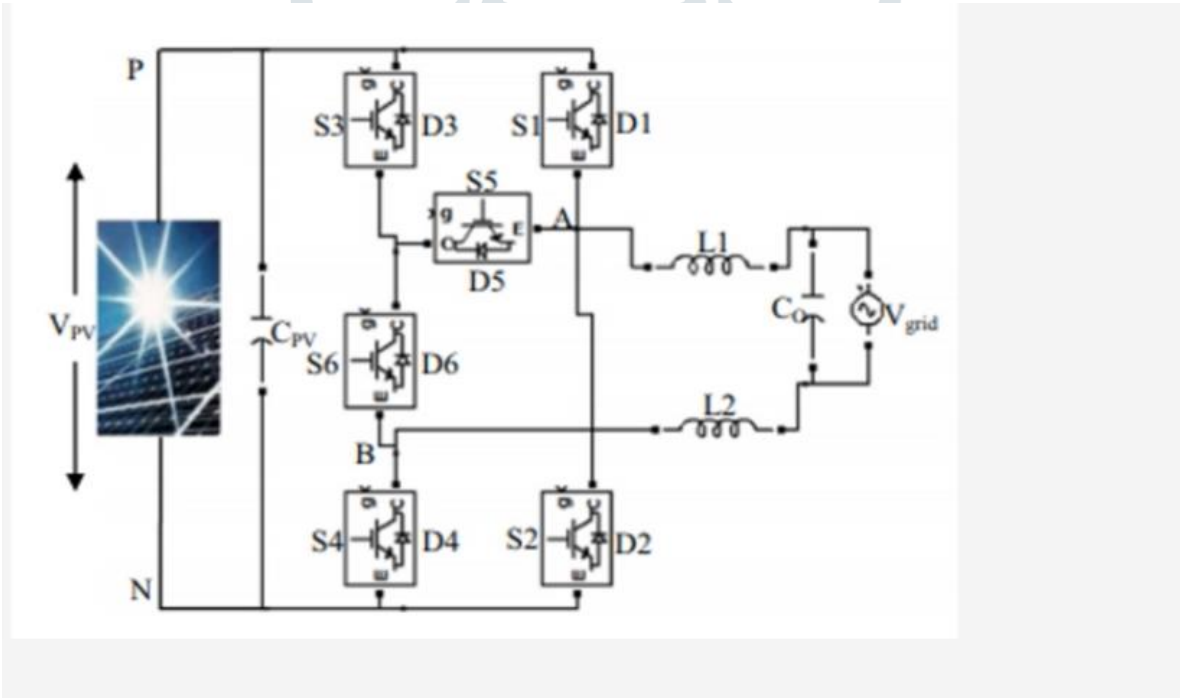

Figure 12 Improved H6 Topology

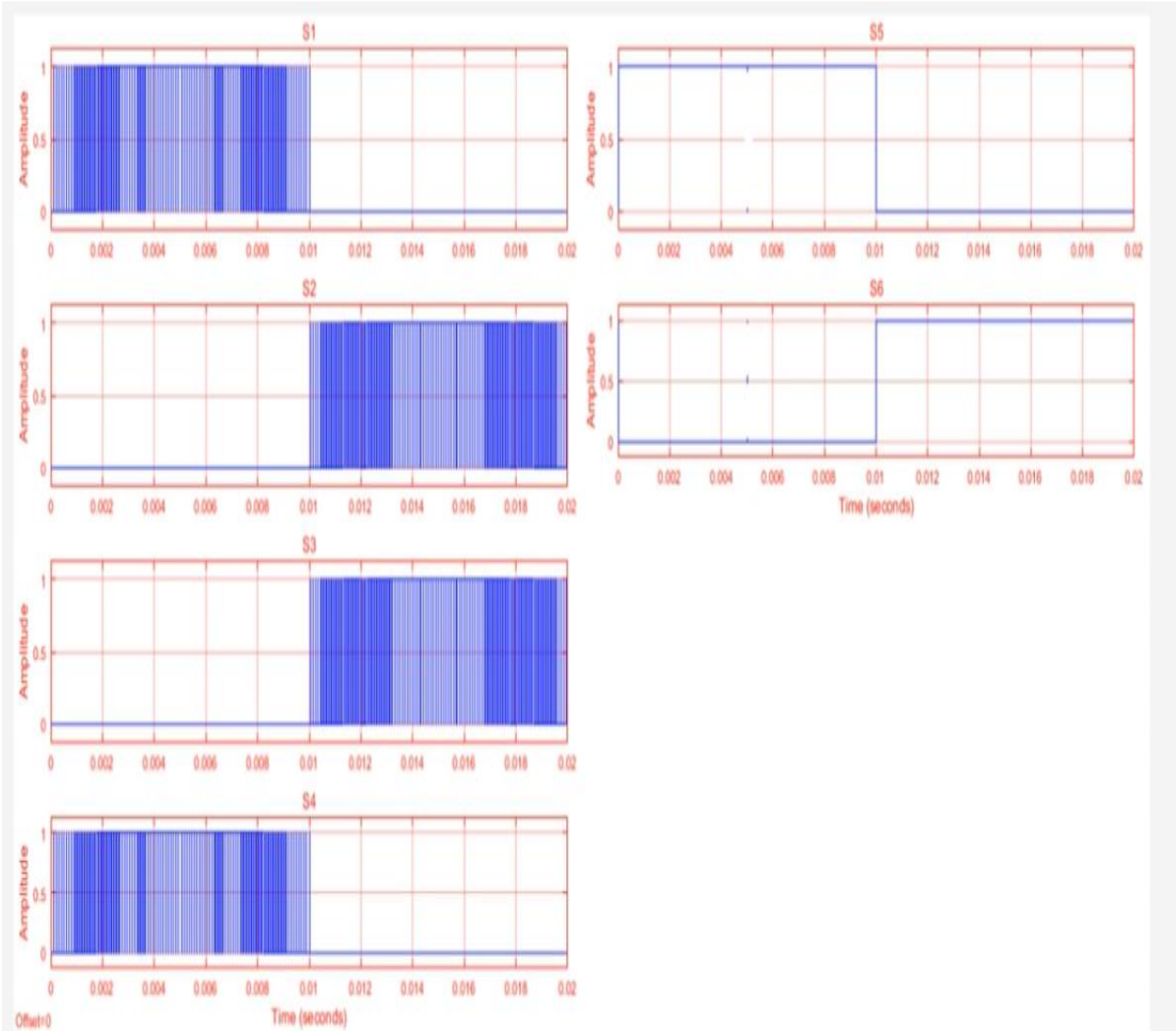

Figure 13 SPWM for H6 Improved

V. CONCLUSION

There are many inverter topologies that have been introduced in the past few years. Single-phase transformer-less inverters with reduced leakage current, such as shore power or battery backup, have seen a lot of use in grid-tied PV applications. These topologies are mainly classified on the basis of the reduction method: galvanic isolation by incorporating extra switches to isolate AC from DC and CMV clamping without CMV clamping which can be done by incorporating additional switch for AC decoupling circuitry or for DC decoupling circuitry. This paper presents the implementation of 10 different transformer-less inverter topologies, such as H5, HERIC, and H6. All of these topologies were designed only for single-stage conversion apart from SPWM strategies which were simulated by two transformers.

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