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Simulation Based Analysis of Transformerless Photovoltaic Inverter Topologies for Reactive Power handling Capability

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Abstract— This study investigates the reactive power generation capability of the existing transformerless Photovoltaic Inverter Topologies (PVIT) with their conventional switching strategies. The topologies such as H5, families of H6 (H6, H6-I, H6-II, H6-III and H6-IV), HERIC, and clamped topologies (optimized H5, passive clamped H6 and HBZVR) have been selected for analysis. Matlab/Simulink simulation platform is employed for the analysis of PVIT. It has been observed that transformer-less PVIT with their conventional switching strategies are not suitable for reactive power injection. These topologies are generating highly distorted current at zero crossings during the reactive power flow. The improved switching strategies are needed to make these topologies suitable for the reactive power applications without any modification in the structure of the inverter.

Keywords—Photovoltaic, Inverter topologies, Grid, Reactive power, THD

I. INTRODUCTION

Power generation from clean carbon-less renewable resources is playing a crucial role to fulfill the world's energy demand. Power generation from photovoltaic (PV) plant is dominating throughout the world, especially rural areas.

Generally, PV power is either used to feed the isolated load with storage or injected to the grid. Presently, the majority of the PV plants are connected to the grid. PV modules generate DC power from the sunlight. To feed the DC power of PV modules to AC grid, a power conversion device (power electronic converter) is needed [1]. The power converter can be a single stage or two stages converter, depending on the input DC voltage and AC grid voltage as depicted in Fig. 1. Furthermore, converters can have a transformer or transformer-less. The transformer can be of three types, isolation, 50 Hz frequency transformer on the AC side or high frequency transformer employed in DC side. The functions of the transformer are to provide step-up/step-down voltage level and galvanic isolation. the transformer provides isolation between the dc side and ac grid side [2]. As a result, it prevents the flow of leakage current. However, the transformer increases the size, cost and reduces the efficiency of the overall system. On the other hand transformerless topologies exhibit high efficiency, low cost, compact size [3]. The main problem of a transformerless inverter is that it has no galvanic isolation between PV modules and the ac grid. As a result, it may inject high-frequency leakage current. The leakage current causes distortion of grid current injected by inverter, Power losses and personal safety issues [4-6].

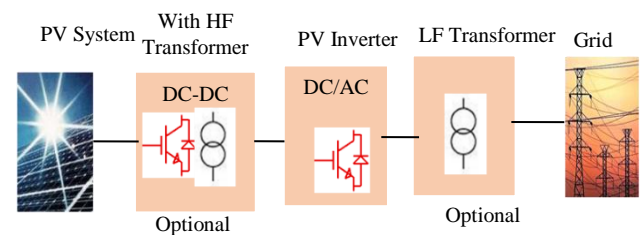


Fig. 1 PV system connected to the grid

To reduce the leakage current problem, various transformerless PV inverter topologies and their switching strategies are introducing in literature. These topologies are H5, families of H6 (H6, H6-I, H6-II, H6-III and H6-IV), HERIC, and clamped topologies (optimized H5, passive clamped H6 and HBZVR) and many more [7]-[14]. [2] presented the detailed operation and classification of transformerless topologies at unity power factor. The main goal of these topologies was the reduction of leakage current. However, to increase the PV penetration at low voltage grid, these topologies should also be capable of injecting reactive power. Reactive power generation capability of H5 and HERIC topologies were presented in [15]. Reactive power generation capability of PV inverters is mandatory according to VDE-AR-N 4105 [16]

This study investigates simulation-based analysis of the reactive power generation capability of the existing transformerless photovoltaic inverter topologies (PVIT) with their conventional switching strategies. The structure of the topologies and their switching waveforms are presented in the next section II.

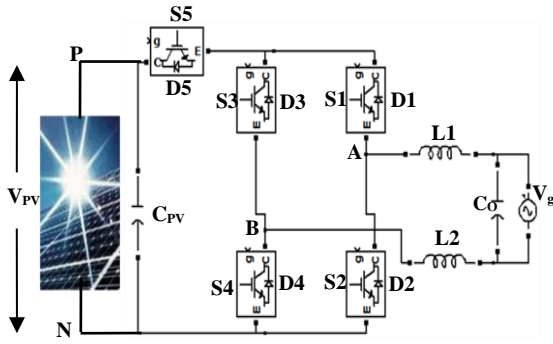
The paper organization is as follows. Section II presents PV inverter topologies and their switching strategies. Simulation results are presented in section III. Section IV finally concludes the paper.

II. PV INVERTER TOPOLOGIES AND SWITCHING STRATEGIES

This section deals with the structure of existing inverter topologies and their switching waveforms. Fig. 2 (a) – Fig. 9 (a) and Fig. 2 (b) – Fig. 9 (b) show H5, H6, H6-I, H6-II, H6-IV, HERIC, clamped H6 and HBZVR PV inverter topologies and their switching strategies respectively.

With convention switching strategy, the switches of the topologies have provided a path for freewheeling current commutates at line frequency (for example switches S1 and

S3 in case of H5 topology). The remaining switches S2, S4 and S5 commute at high frequency (switching frequency) to generate three-level unipolar voltage..

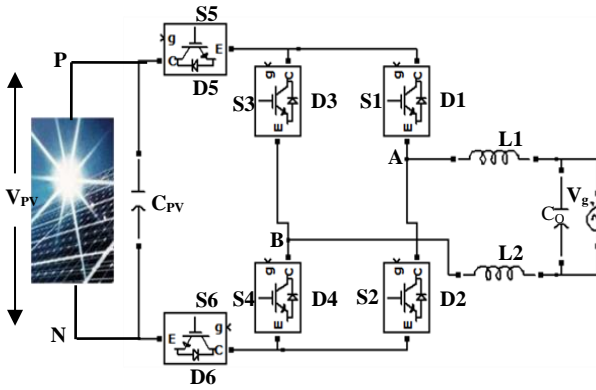


(a)

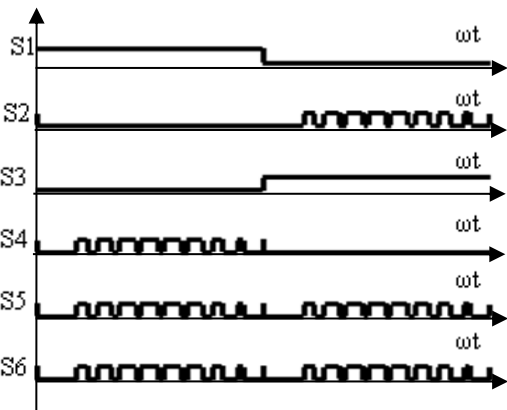


(b)

Fig. 2: (a) H5 PV inverter topology (b) switching strategy of H5 PV inverter topology

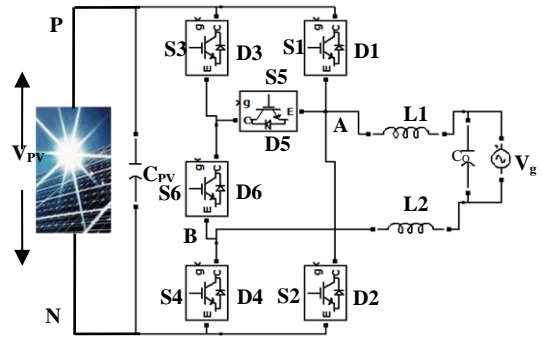


(a)



(b)

Fig. 3: (a) H6 PV inverter topology (b) switching strategy of H6 PV inverter topology

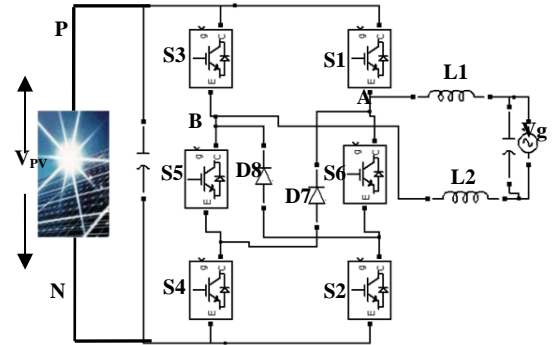


(a)

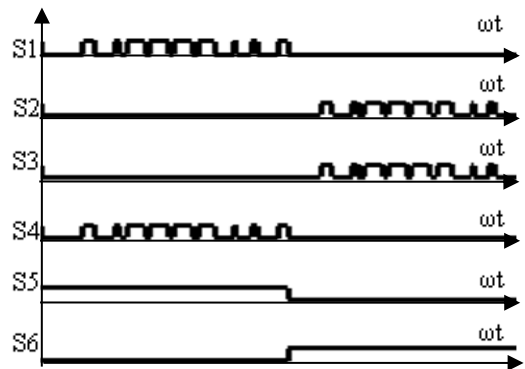


(b)

Fig. 4: (a) H6-I PV inverter topology (b) switching strategy of H6-I PV inverter topology



(a)



(b)

Fig. 5: (a) H6-II PV inverter topology (b) switching strategy of H6-II PV inverter topology

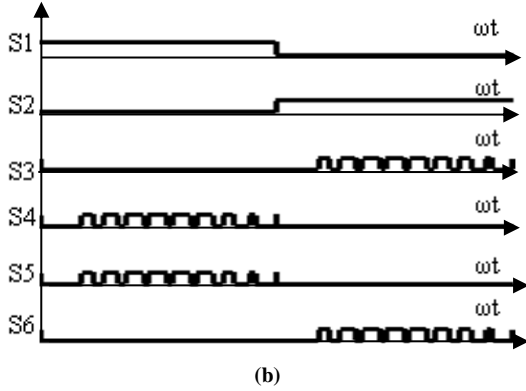
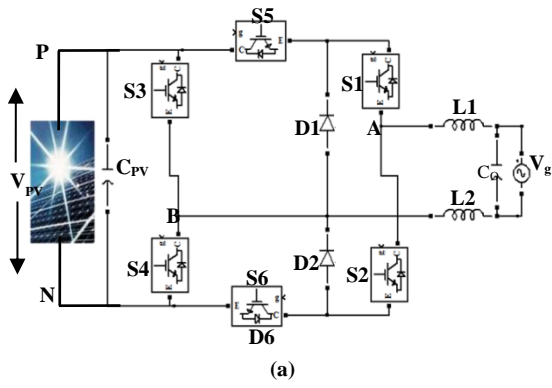


Fig. 6: (a) H6-IV PV inverter topology (b) switching strategy of H6-IV PV inverter topology

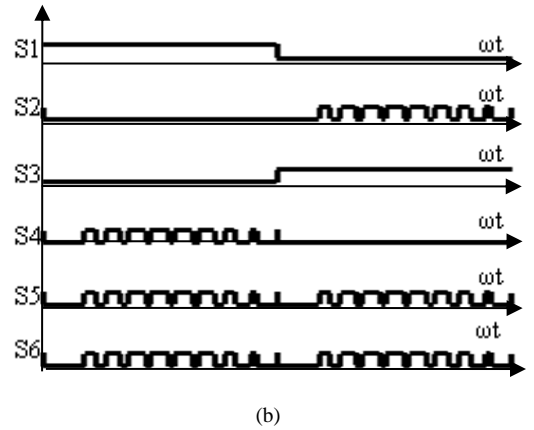
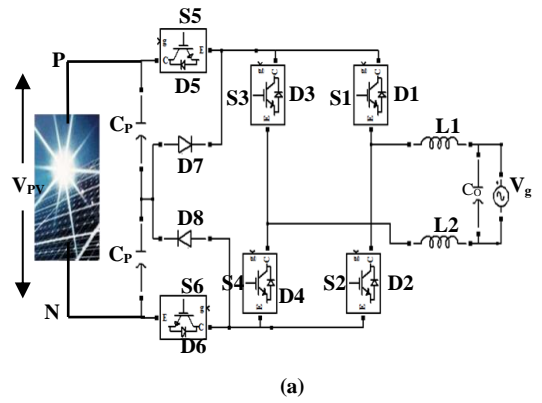


Fig. 8: (a) Clamped H6 PV inverter topology (b) switching strategy of clamped H6 PV inverter topology

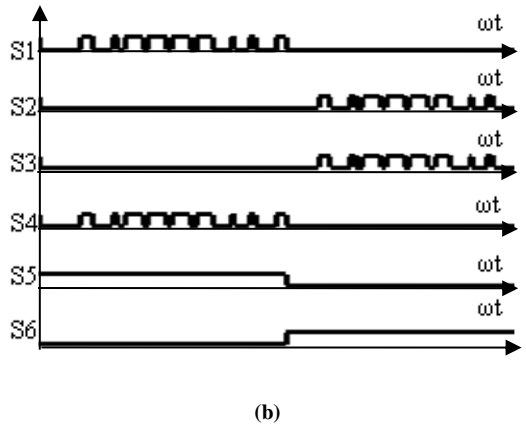
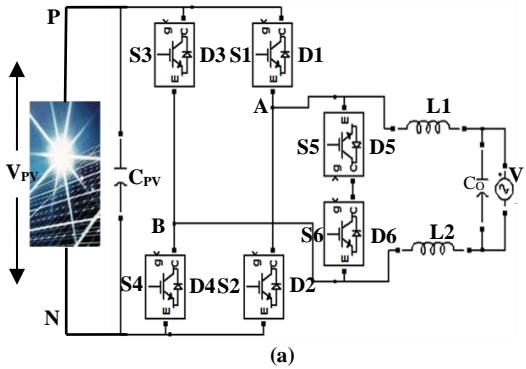


Fig. 7: (a) HERIC PV inverter topology (b) switching strategy of HERIC PV inverter topology

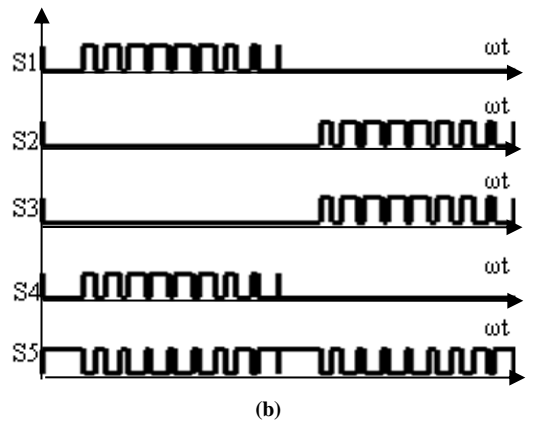
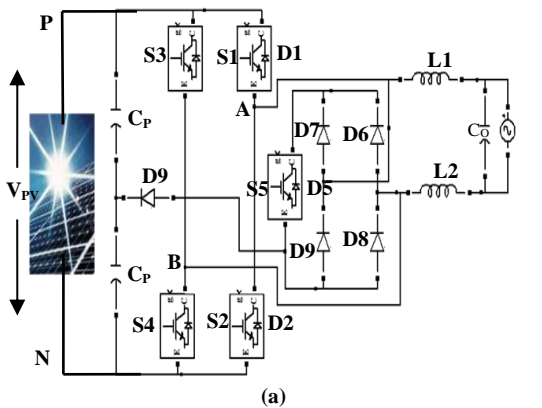


Fig. 9: (a) HBZVR PV inverter topology (b) switching strategy of HBZVR PV inverter topology

III. SIMULATION RESULTS

The simulation model of the PVIT under study such as H5, families of H6 (H6, H6-I, H6-II and H6-IV), HERIC, and clamped topologies (optimized H5, passive clamped H6 and HBZVR) are developed by using Matlab/Simulink platform. Figure 10 shows the developed Simulink model for the analysis, which comprises of solar PV arrays, inverter, filter, inverter controller and grid. The controller is based on the d-q current components. The injected active and reactive power depends on the I_d and I_q current components respectively. The PV arrays are a series combination of twelve Sanyo HIP-225 HDE1 PV modules.

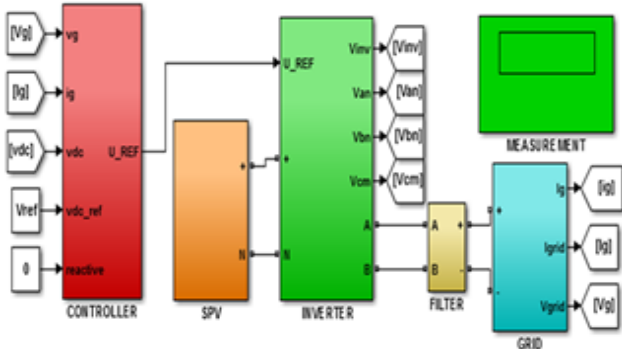
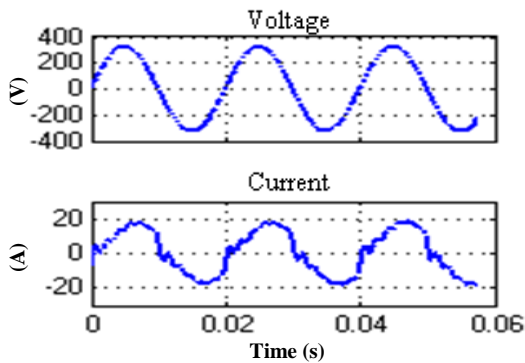
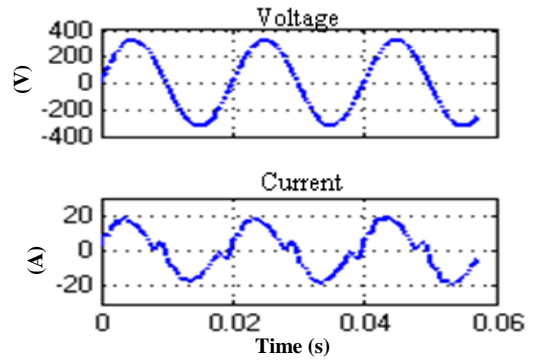


Fig. 10: Simulink model of grid connected PV inverter

The detailed analysis of the topologies at unity power factor (pf) was presented in Ref. [2]. In this study, topologies are simulated at 0.9 leading and lagging power factor to demonstrate the reactive power handling capability of the topologies under study. The simulated results of topologies are presented in the form of grid voltage and current waveforms. The grid voltage and grid injected current of the topologies H5, H6, H6-I, H6-II, H6-IV, HERIC, clamped H6 and HBZVR are illustrated in Fig. 11- Fig. 18. Figs. 11 (a), 12 (a), 13 (a), 14 (a), 15 (a), 16 (a), 17 (a), 18 (a) and Figs. 11 (b), 12 (b), 13 (b), 14 (b), 15 (b), 16 (b), 17 (b), 18 (b) show the injected current waveforms of these topologies at 0.9 leading and lagging pf respectively. It can be seen that the injected grid current is distorted during reactive power injection at zero crossings. These topologies with conventional switching strategies inject grid current with a high value of THD more than 5% which violates the IEEE 1547 standards.

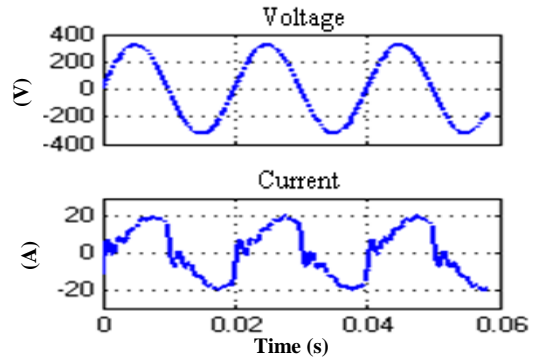


(a)

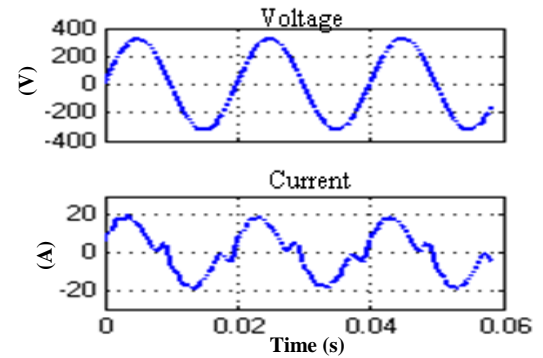


(b)

Fig. 11: H5 PV inverter topology injected current with conventional switching strategy at (a) 0.9 leading and (a) 0.9 lagging pf.

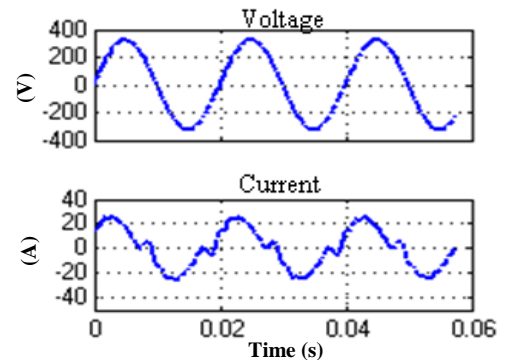


(a)

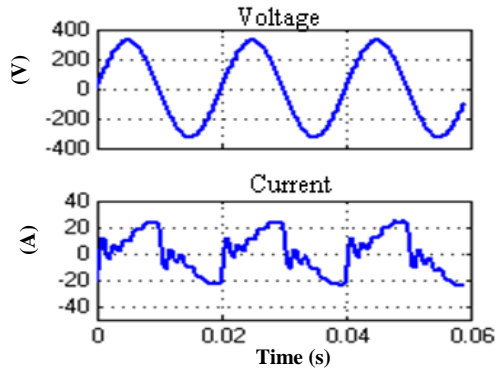


(b)

Fig. 12: H6 PV inverter topology injected current with conventional switching strategy at (a) 0.9 leading and (a) 0.9 lagging pf.

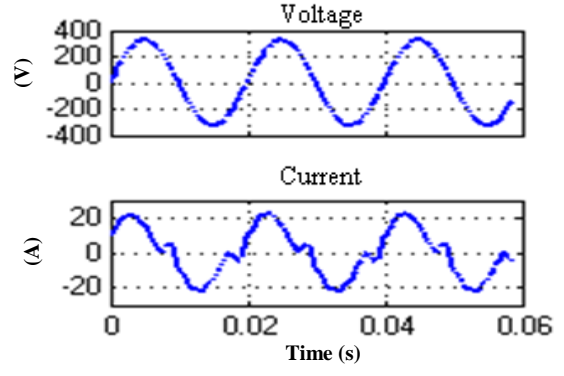


(a)



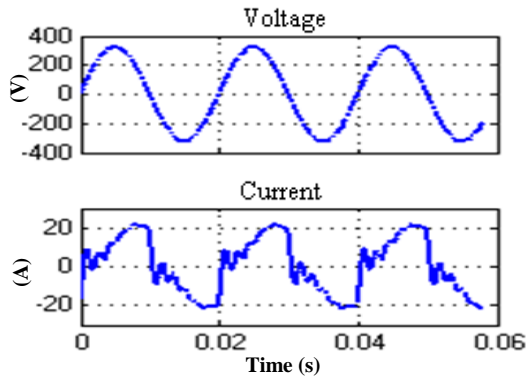
(b)

Fig. 13: H6-I PV inverter topology injected current with conventional switching strategy at (a) 0.9 leading and (a) 0.9 lagging pf.

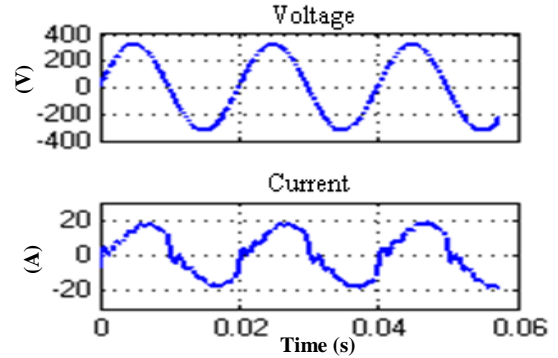


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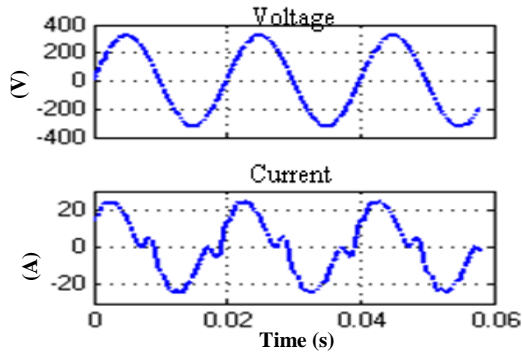
Fig. 15: H6-IV PV inverter topology injected current with conventional switching strategy at (a) 0.9 leading and (a) 0.9 lagging pf.



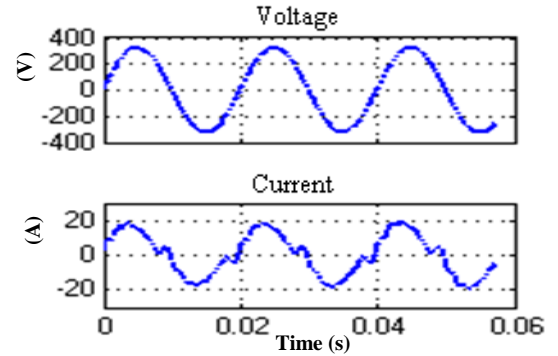
(a)



(a)



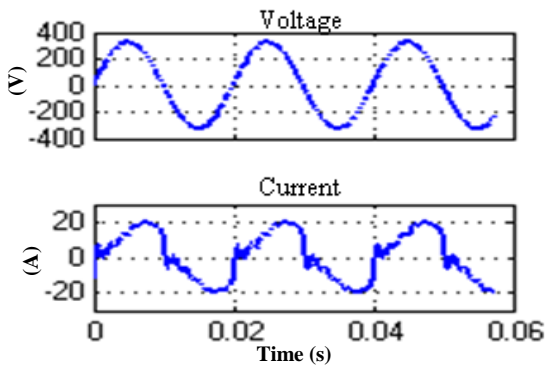
(b)



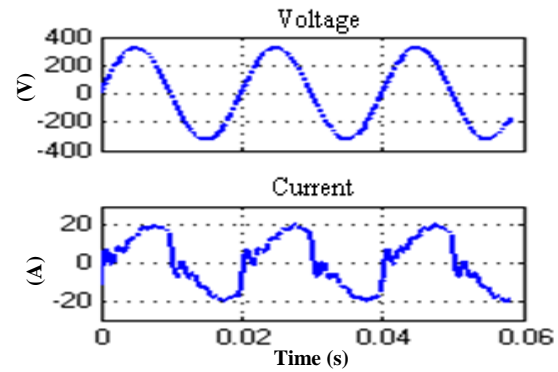
(b)

Fig. 14: H6-II PV inverter topology injected current with conventional modulation strategy at (a) 0.9 leading and (a) 0.9 lagging pf.

Fig. 16: HERIC PV inverter topology injected current with conventional switching strategy at (a) 0.9 leading and (a) 0.9 lagging pf.



(a)



(a)

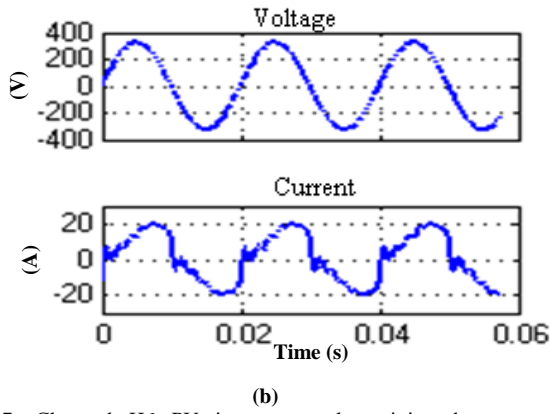


Fig. 17: Clamped H6 PV inverter topology injected current with conventional switching strategy at (a) 0.9 leading and (a) 0.9 lagging pf.

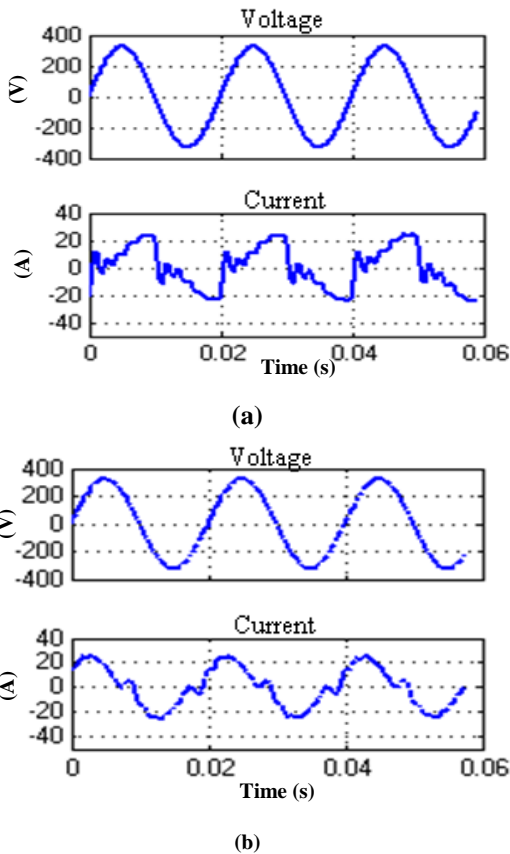


Fig. 18: HBZVR PV inverter topology injected current with conventional switching strategy at (a) 0.9 leading and (a) 0.9 lagging pf.

IV. CONCLUSIONS

The Simulation based analysis of the various transformerless Photovoltaic Inverter Topologies (PVIT) with their conventional switching strategies been performed for the suitability of reactive power injection. To increase the PV power contribution in the grid, the PV inverters should be capable of injecting/absorbing reactive power. It has been observed that these topologies are injecting highly distorted current in the grid with their convention switching strategies. Improved switching strategies need to operate these topologies in reactive power applications. In the future study, these topologies will be analyzed with improved switching strategies and it will also be validated through a hardware test setup. The Improved switching strategies will make these

topologies suitable for the reactive power applications without alerting the structure of the inverter.

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