Impact of ZVS on AC Filters Performance in Grid-connected Inverters

Emanuel Serban, PhD, PEng and Jalal Amini, PhD

Abstract

In grid-connected three-phase inverter systems, passive filters are employed to suppress high-frequency switching harmonics and ensure compliance with grid codes. The filter selection has a direct impact on an inverter's performance in terms of harmonic attenuation, system stability, physical size and cost.

In this paper, a higher inverter switching frequency is promoted, to achieve good harmonic attenuation, improved stability, reduced wight, volume for a compact design (densification) and reduced overall cost.

While high switching frequency operation brings benefits, the challenges of increased EMI, losses, and thermal complexity need to be addressed. A comparison between hard switching and zero voltage switching (ZVS) is analysed through the impact of the filter design. Designing an inverter for higher switching frequency operation requires multiple design considerations. The implementation of ZVS enables a significant reduction in switching losses and electromagnetic interference (EMI). Hillcrest's ZVS technology enables higher switching frequencies for inverters at higher rated power (e.g., 200/250 kW), allowing for AC filter design optimization with significant weight and cost reduction.

I. INTRODUCTION

Grid-connected inverters are widely deployed in renewable energy systems, electric vehicle charging infrastructure, and industrial power converters to enable efficient AC power delivery from DC sources. However, the high-frequency switching operations intrinsic to these inverters generate voltage and current harmonics that can degrade power quality, cause electromagnetic interference, and potentially lead to thermal and operational stress in grid-connected equipment.

To mitigate these adverse effects and ensure compliance with grid codes and harmonic distortion standards, such as IEEE 519 [1] or IEC 61000, effective AC filtering is essential. The filter, typically positioned between the inverter output and the point of common coupling (PCC), serves to attenuate high-frequency components while preserving the fundamental power signal. Commonly adopted topologies include LC, and LCL filter variants, where the LCL configurations may offer improved harmonic attenuation [2].

The design of AC filters involves a careful balance between harmonic suppression, system stability, efficiency, and cost. Key considerations include switching frequency, grid impedance variations, damping strategies, and control loop interactions. This makes AC filtering not only a critical aspect of power quality management but also a determinant of overall system performance and grid compliance in modern inverter-based energy systems.

In this study, the inverter performance at higher switching frequencies is analyzed, highlighting its direct impact on performance and reducing the size of the filter inductor, which contributes to weight and cost saving.

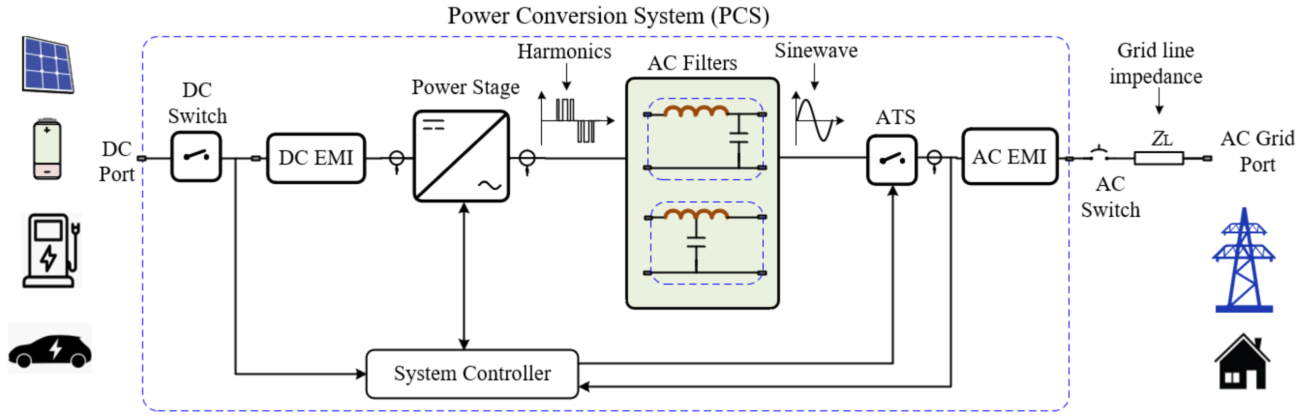


Fig. 1. AC filters in Power Conversion Systems.

II. FILTER DESIGN AND COMPARISONS FOR THREE-PHASE INVERTER APPLICATIONS

For grid-connected systems, the injection of harmonic currents is subject to strict limitations as recommended by the IEEE 519-2022 standard. A common application, for systems where the rated voltage at the Point of Common Coupling (PCC) ranges from 120 V to 69 kV, the standard defines acceptable harmonic distortion limits (Table I) to ensure power quality and protect both utility and customer equipment. As shown in Table I, these limits apply to individual harmonic components as well as total demand distortion (TDD) and are intended to minimize adverse effects such as equipment overheating, mis operation, and increased losses in the power system. The total demand distortion (TDD) and total harmonic distortion (THD) of the current are given by

$$\begin{cases} TDD_{\mathrm{i}} = \dfrac{\sqrt{\sum_{h=2}^{n} I_h^2}}{I_{\mathrm{L}}} \\ THD_{\mathrm{i}} = \dfrac{\sqrt{\sum_{h=2}^{n} I_h^2}}{I_1} \end{cases} \tag{1}$$

where I_{h} is the magnitude of individual harmonic components (measured in RMS), h is harmonic order (e.g., 2…50), I_{L} is the maximum demand load current and I_1 is the fundamental component of the maximum demand load current. The maximum short-circuit current I_{sc} and maximum demand load I_{L} is considered at the point of common coupling (PCC). The short-circuit ratios $I_{sc}/\ I_L$ is used to differentiate loads size. For example, lower ratios or higher impedance systems must have lower current distortion limits to keep voltage distortion at reasonable limits.

Table I. Maximum current distortion allowed in percentage of rated current according to IEEE519-2022 for systems rated 120V – 69 kV.

Short-circuit ratio I_{sc}/ I_L	Maximum harmonic current distortion [%] of I_L Individual harmonic order					Total Demand Distortion (TDD) [%]
	$2 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	
< 20 (weak grid)	4.0	2.0	1.5	0.6	0.3	5
20 - 50	7.0	3.5	2.5	1.0	0.5	8
50 - 100	10.0	4.5	4.0	1.5	0.7	12
100 - 1000	12.0	5.5	5.0	2.0	1.0	15
> 1000 (stiff grid)	15.0	7.0	6.0	2.5	1.4	20

The dominant harmonics generated by the inverter output generally occur around the switching frequency $f_{sw}$and its sidebands, rather than at the fundamental frequency. These harmonics arise due to high-frequency PWM switching and are clustered near integer multiples (m, n) of the switching frequency, often referred to as switching sideband harmonics f_h. The most dominant harmonics generated by the inverter output typically occur at the switching side-band frequency $f_{sw} \pm 2f_L$, where f_{sw} and f_L are switching frequency and grid line frequency, respectively. In general, the PWM-controlled inverter generates harmonics as sidebands frequency components given by

$$f_h = mf_{sw} + nf_L \tag{2}$$

Various approaches have been proposed in the literature to attenuate these harmonics. Among them, LC and LCL passive filters are used in power conversion, which are briefly discussed in the following sections.

A. LC Filter

An LC filter consists of a single inductor in series with the inverter output and a shunt capacitor at the point of common coupling (PCC) with design parameters example:

- Inductance L: Design selection to attenuate switching harmonics but small enough to maintain acceptable voltage drop and dynamic response.
- Capacitance C: Provides a low-impedance path to high-frequency harmonics while maintaining grid-side voltage stability.
- Resonant frequency f_{r}:

$$\begin{cases} f_{\mathrm{r}} = \frac{1}{2\pi\sqrt{LC}} \\ 10f_{\mathrm{L}} < f_{\mathrm{r}} < \frac{\sqrt{3}}{12} f_{sw} \end{cases} \tag{3}$$

The merits and demerits of the LC-type filter are shown in Table II.

Table II. LC type filter advantages and disadvantages.

Pros	Cons
Simple design (-40 dB/decade)	Lower high-frequency filtering attenuation
Low cost components	Higher inductance may be required for effective filtering
Stable without damping	Requires inverter operation at higher switching frequency to meet harmonic limits

B. LCL Filter

An LCL filter introduces a third element - an additional inductor between the grid and shunt capacitor. It enhances attenuation of switching harmonics with design parameters example:

- L_i : Inverter-side inductance
- L_g: Grid-side inductance
- C: Filter capacitor
- R_d: Damping resistor (optional, compensation through inverter controls)
- Resonant frequency:

$$\begin{cases} f_r = \frac{1}{2\pi}\sqrt{\frac{L_i+L_g}{L_iL_gC}} \\ 10f_L < f_r < \frac{1}{3} f_{sw} \end{cases} \tag{4}$$

The design of an LCL filter requires an optimization process, with several methodologies proposed to guide its design process [2-5]. To minimize the phase difference between voltage and current—accounting for the reactive power absorbed by the filter capacitor - the selection of filter capacitance and inductance per phase must satisfy the following constraints:

$$C < 5\% \frac{P_n}{6\pi f_L V_g^2} \tag{5}$$

where P_n is the inverter nominal power, f_L is the line frequency and V_g is the grid phase voltage.

$$\begin{cases} L_t \le 10\% \frac{3V_g^2}{2\pi f_L P_n} \\ L_i \ge \frac{\sqrt{3}}{12} m \frac{V_{dc}}{30\% I_n f_{sw}} \\ L_t = L_i + L_g \end{cases} \tag{6}$$

where L_t is the total inductance, I_n is the inverter nominal current, m is the modulation index, and f_{sw} is the inverter operating switching frequency. For weak grids smaller L_g may be preferred (e.g., 0.2 … 0.3).

Table III. LCL type filter advantages and disadvantages.

Pros	Cons
High harmonic attenuation (-60 dB/decade)	Higher complex control due to resonance
Smaller inductors than LC	Require active damping to ensure stability
Better size-to-performance tradeoff	Sensitive to grid impedance variation

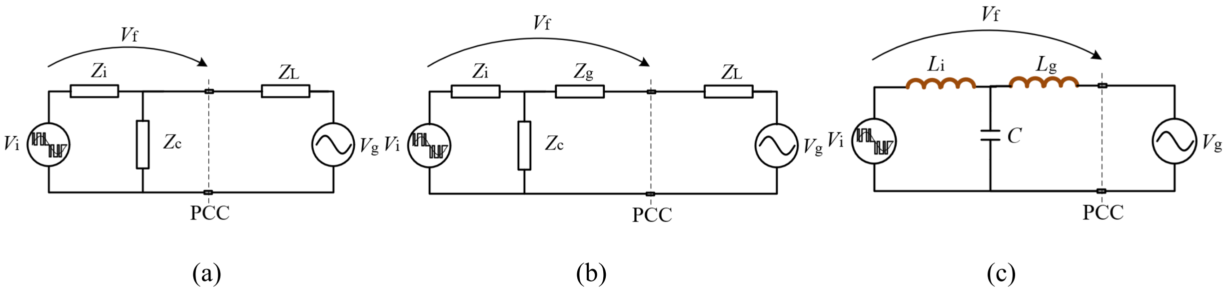


Fig. 2 Grid-connected single phase inverter equivalent circuit of AC filters. A) LC-type filter, b) LCL-type general equivalent circuit with grid impedance and b) simplified inverter circuit

As shown in Fig. 2, grid-connected inverters are designed with AC filters (e.g., LC, LCL) which use inductors and capacitors. The inductive reactance of the filter components at the fundamental frequency causes a voltage drop proportional to the output current I_L (RMS) for each phase:

$$V_{Ldrop} = I_L X_L = I_L \, 2\pi f_L L \tag{7}$$

From equation (5), the voltage drop is proportional to the line frequency and more importantly to filter inductance *L*. The higher the inductance and volume, the larger voltage drop occurs with two negative outcomes:

a) Higher power dissipation in the copper resistance and core material reducing the system efficiency

b) DC bus utilization reduction, for example higher battery voltage is required for inverter operation

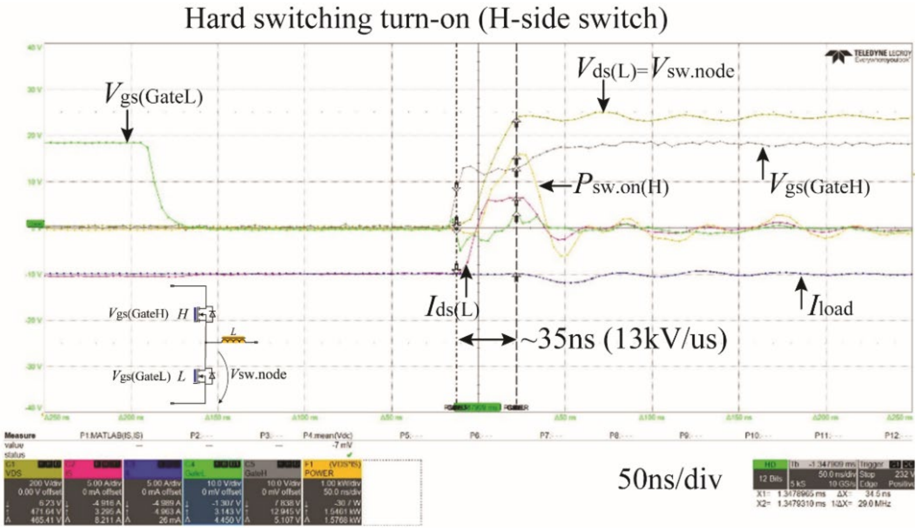
The reactor impedance (%Z), neglecting the resistance is typically expressed as a percentage of the base system impedance with respect to the line-to-neutral (phase) voltage $V_{LN}$and is is given by

$$\%Z_L = \frac{V_{Ldrop}}{V_{LN}} 100\% = \frac{I_L \, 2\pi f_L L}{V_{LN}} 100\%. \tag{8}$$

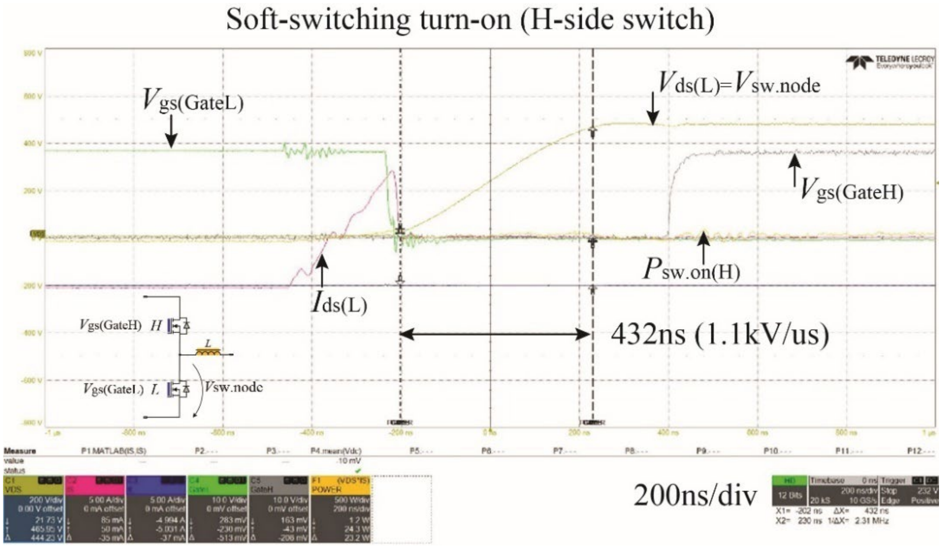
For example, a 3% impedance reactor per phase will cause a voltage drop of 3% and a maximum limit of 5% voltage drop is recommended. The AC inductor filter design is a trade off between minimizing the voltage drop, while providing the necessary harmonic filtering for meeting the power quality (IEEE 519-2022).

As will be discussed, the Hillcrest ZVS inverter addresses these challenges by requiring a lower inductance value, which enables the use of a wider DC battery voltage range.

A comparison between hard switching and ZVS inverter operating for a half-bridge is shown in Fig. 3. The high-side switch H turn-on event is shown in Fig. 3 (a) with turn-on power dissipation $P_{sw.on(H)}$ and drain-source dv/dt slew-rate of 13 kV/µs. In a direct comparison, the ZVS turn-on event is shown in Fig. 3 (b) with the elimination of $P_{sw.on(H)}$ and approximately ten times lower slew-rate 1.1 kV/μs, which obviously lead to lower EMI generation and lower shielded requirements.



(a) Example of hard-switching inverter operation.



(b) Example of ZVS inverter operation.

Fig. 3 Inverter operation under (a) hard switching and (b) ZVS with emphasis at the turn-on event for the high-side switch (H). Test conditions: V_{dc}= 470 V, V_{load} = 5 A.

Y-axis: Switching-node voltage $V_{sw.node}$ 200 V/div, Low-side switch drain-source current $V_{ds(L)}$ 5A/div, Low-side gate-source $V_{gs(GateL)}$ 10 V/div, High-side gate-source $V_{gs(GateH)}$ 10 V/div, High-side turn-on switching losses $P_{sw.on(H)}$ 500 W/div. X-axis: 200 ns/div.

Table IV shows an inverter's switching frequency selection with impacts on system cost. Operating the inverter at higher switching frequency offers significant advantages in waveform quality, filter size, and power density, making it suitable for compact and high-performance applications such as EV drives, aerospace power systems, and advanced grid-tied inverters. However, it introduces challenges in thermal management, EMI, and control complexity, which must be carefully addressed through wide band gap devices, optimized cooling, and fast control platforms. As can be seen in Table IV, the Hillcrest ZVS inverter technology offers advantages to overcome the challenges of operating at higher switching frequency (e.g., 40 kHz). Due to the switching losses elimination, the inverter efficiency is increased, while the thermal management and EMI components are reduced. Therefore, the Hillcrest ZVS inverter power density is increased due to reduced size of components.

Table IV. Inverter's switching frequency selection: comparison between Conventional inverters and Hilcrest ZVS inverter (200 kW power range) considering 2-level inverters.

Parameter	Conventional Inverter 10kHz switching frequency	Conventional Inverter 40kHz switching frequency	Hillcrest ZVS Inverter 40kHz switching frequency
Filter size	Standard	Smaller	Smaller/cost savings
Switching losses	Standard	Higher	Elimination
Efficiency	Standard	Lower	Increased
Thermal management	Standard	More demanding	Reduced/cost savings
EMI filtering requirements	Standard	More critical	Reduced/cost savings
Inverter power density	Lower (bulky)	Higher	Compact / smaller
Dielectric breakdown (>800Vdc)	Standard	More critical	Reduced
Overall cost	Higher cost	Reduced at the system level	Further reduced /cost savings

As inverter switching frequencies increase (e.g., from 10 kHz to 40 kHz or higher), the electric field stress imposed on insulation materials and components also intensifies. This escalation significantly impacts system reliability, partial discharge susceptibility, and overall insulation design. As shown in Table IV, by pushing a conventional inverter (2-level) to operate at 40 kHz, challenging design issues arises: higher switching losses, lower efficiency, EMI and dv/dt concerns with respect to dielectric breakdown of insulators. Hillcrest's ZVS technology mitigates these effects by reducing the voltage slew rate (dv/dt) during switching transitions, therefore lowering the resulting transient electric fields. As a result, cumulative electric stress on insulation is diminished, enhancing long-term system durability. Additionally, this reduction in stress helps to mitigate partial discharge risks, enabling compliance with safety standards for creepage and clearance distances without requiring derating and increase in spacings.

Filter magnetics significantly influence the total weight of an inverter. As illustrated in Fig. 4, they represent one of the largest contributors to the overall weight in medium-power (e.g. 50 – 500 kW) inverters. Consequently, ongoing innovation aimed at reducing the size and weight of magnetic components remains a critical area of development as it will be discussed in the next sections.

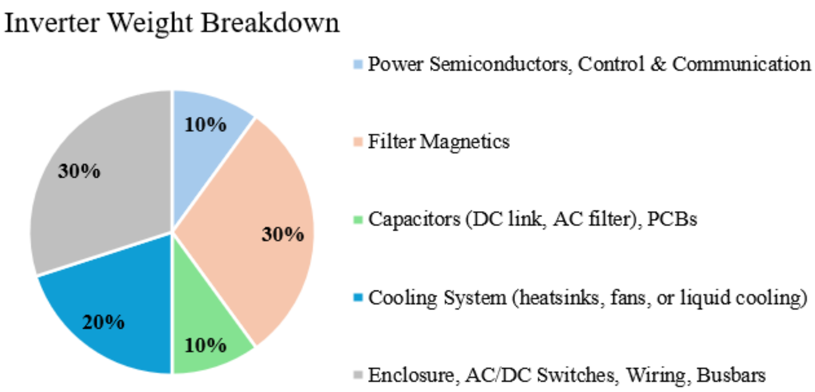


Fig. 4 Typical component weight breakdown in medium power inverters.

III. AC FILTER DESIGN EXAMPLE

In an inverter system, the AC output contains both the desired fundamental frequency (50/60 Hz) and undesired harmonic content, mainly due to the high frequency switching operations. The AC filter is designed to smooth the inverter's PWM output and to limit conducted and radiated EMI. Table V provides a brief summary of key inverter parameters relevant to AC filter design.

Table V. Inverter parameters considered in the filter design.

Parameter	Value
DC bus nominal voltage (V_{dc})	800 V_{dc}
Grid line frequency (f_L)	50/60 Hz
AC grid voltage (line-to-line, V_{LL})	400 / 480 V_{rms}
Phase nominal current (I_L)	300 A_{rms}

The AC power filters require high saturation flux density (to handle high current without core saturation), low core loss at the inverter's switching frequency, high thermal stability, lower cost and availability.

Table VI shows the common core materials used in AC power filters in inverter design. The physical size and geometry of the inductor or filter assembly is important for performance, thermal handling, and integration into the inverter enclosure. The proposed design under study utilizes a high-flux powdered core in a C-shape configuration, featuring a distributed air gap to accommodate high DC bias conditions and large AC excitation amplitudes. A distributed air gap, where the gap is spread uniformly throughout the core rather than concentrated in a single location, helps reduce magnetic fringing effects and enhances performance under AC operating conditions. This design approach ensures better magnetic field control and improved efficiency of the core and preventing core saturation.

VI. Common core materials used in power converters.

Core material	B_{sat} (T)	DC bias	Core losses	Frequency Range (kHz)	Relative permeability μ_r	Cost	General Observations
Ferrite	0.25-0.5	Poor	Low	10-5000	750-20,000	Cost-effective	Lower loss at high frequency with limited magnetic flux saturation. Use case: EMI, transformers, inductors, ferrite beads.
Alloy Powder Cores	0.5-1.6	Best	Moderate	10-1000	4-550	Expensive	Moderate saturation, used for higher power current, higher losses than ferrite. Low relative permeability. Use case: power inductors.
Amorphous Metals	0.5-1.56	Better	Lower	10-250	10,000-150,000	More Expensive	High saturation, very low loss, expensive. Suitable for compact, high-efficiency designs. Vey high relative permeability. Use case: power inductors, transformers.
Nanocrystalline	1-1.25	Good	Lowest	100	500-100,000	Most Expensive	Superior performance in loss and saturation; very compact but high cost. High saturation. High permeability. Use case: EMI/CMC, current transformers.
Laminated Steel	0.8-2.0	Good	Highest	0.04-20	2000-35,000	Economic	High saturation, lossy at higher frequencies. Use case: line frequency (50/60 Hz) transformers

The AC filter design is conducted for a conventional hard switching inverter (10kHz) and ZVS inverter (40kHz). In order to maintain the same ripple current, the conventional approach uses a 250 µH inductor and the ZVS uses a 65 µH inductor as shown in Table VII.

Table VII. AC filter parameters for conventional and ZVS inverter.

Parameter	Value
A: Conventional inverter	
Switching frequency	10 kHz
LC filter inductance-capacitance L_i , C	250 µH, 90 µF
B: ZVS inverter	
Switching frequency	40 kHz
Case 1: LC filter inductance-capacitance L_i , C	65 µH, 40 µF
Case 2: LCL filter inductance-capacitance-inductance L_i, C, L_g	30 µH, 40 µF, 6.8 µH

A. *Conventional inverter AC Filter*

Medium and higher power conventional 1000V and 1500V inverters are designed for limited switching frequency operation (e.g. 10 kHz) in order to keep the power losses low. As an example, a two-level three phase inverter waveforms are shown in Fig. 5. With the inverter operation at 750V, the inductor ripple measures at the peak current region Δi_{Li} =21A and at zero-crossing region Δi_{Li} =43A. When the inverter operates at DC bus voltage of 950V, the ripple increases at the peak current region with Δi_{Li} = 30A where at zero-crossing measures the same value, i.e. Δi_{Li} =43A.

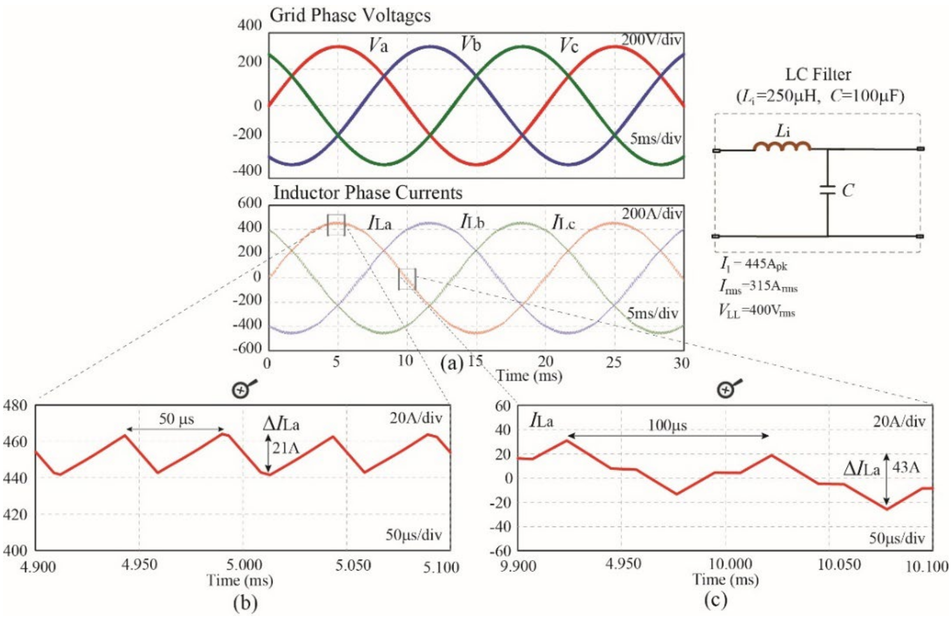


Fig. 5 LC-type (10 kHz) grid-connected inverter key waveforms example (V_{dc} = 750V). a) Three-phase grid voltages and inductor currents (with $L_a = L_b = L_c = L_i$ = 250µH, and C =90µH), b) Inductor ripple current zoom-in details at the peak current and b) Inductor ripple current zoom-in details at the zero cross.

B. ZVS inverter AC Filter

For the ZVS inverter, two filter types are analysed, with the inductor roles to limit the rate of change of current di/dt, and the capacitor provides a low-impedance path for high-frequency components, thereby significantly reducing voltage and current ripple at the point of common coupling.

For comparison, the analysis is performed using the same magnetic core material and identical number of turns for both the LC and LCL AC filters. The inductance for the LC filter is expressed as

$$L = L_i = A_L N^2. \tag{9}$$

The total inductance for an LCL filter consists of inverter-side inductance L_i and grid-side inductance L_g for each phase and is given by

$$\begin{cases} L_i = A_L N_i^2 \\ L_g = A_L N_g^2 \\ N = N_i + N_g. \end{cases} \tag{10}$$

Fig. 6 shows the key waveforms of the grid-connected inverter, highlighting the ripple current in a LC-type filter design. The ripple current behavior exhibits distinct characteristics depending on the instantaneous current level: at peak current region, Fig. 6 (a), and near current zero-crossing region, Fig. 6 (b), where the inverter output voltage undergoes rapid switching transitions, leading to pronounced ripple components.

For example, at 750V inverter operation, the inductor ripple measures at the peak current region Δi_{Li} =21A and at zero-crossing region Δi_{Li} =38A. When the inverter operates at DC bus voltage of 950V, the ripple increases at the peak current region with Δi_{Li} = 30A where at zero-crossing measures the same value, i.e. Δi_{Li} =38A.

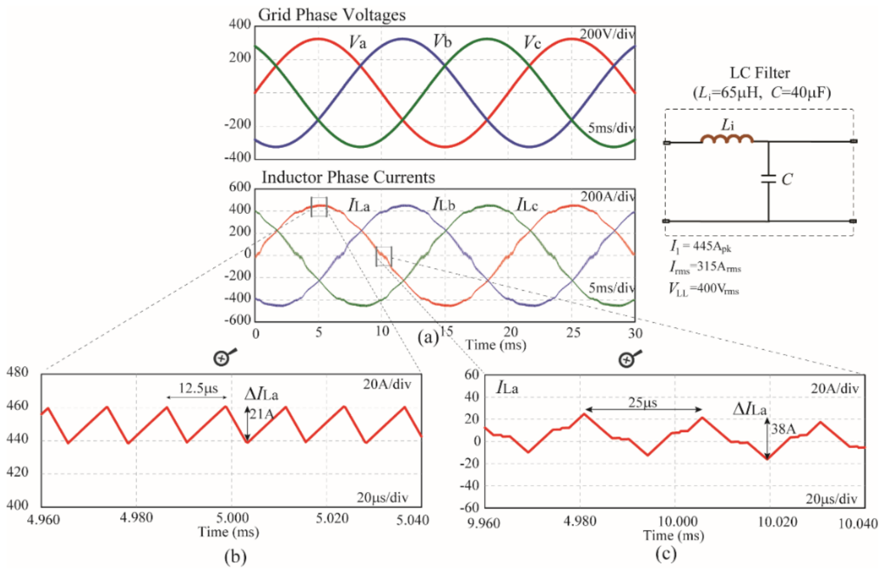


Fig. 6 LC-type (40 kHz) grid-connected inverter key waveforms example (V_{dc} = 750V). a) Three-phase grid voltages and inductor currents (with $L_a = L_b = L_c = L_i$ = 65μH, and C =40μH), b) Inductor ripple current zoom-in details at the peak current and b) Inductor ripple current zoom-in details at the zero cross.

The LCL-type filter is designed with lower inverter-side inductance ($L_i = 35\mu H$) where the ripple current is obviously higher than in the case of LC-filter as illustrated in Fig. 7 (a) and (b). With the inverter operation at 750V, the inductor ripple measures at the peak current region Δi_{Li} =40A and at zero-crossing region Δi_{Li} =70A. When the inverter operates at DC bus voltage of 950V, the ripple increases at the peak current region with Δi_{Li} = 57A where at zero-crossing measures the same value, i.e. Δi_{Li} =70A.

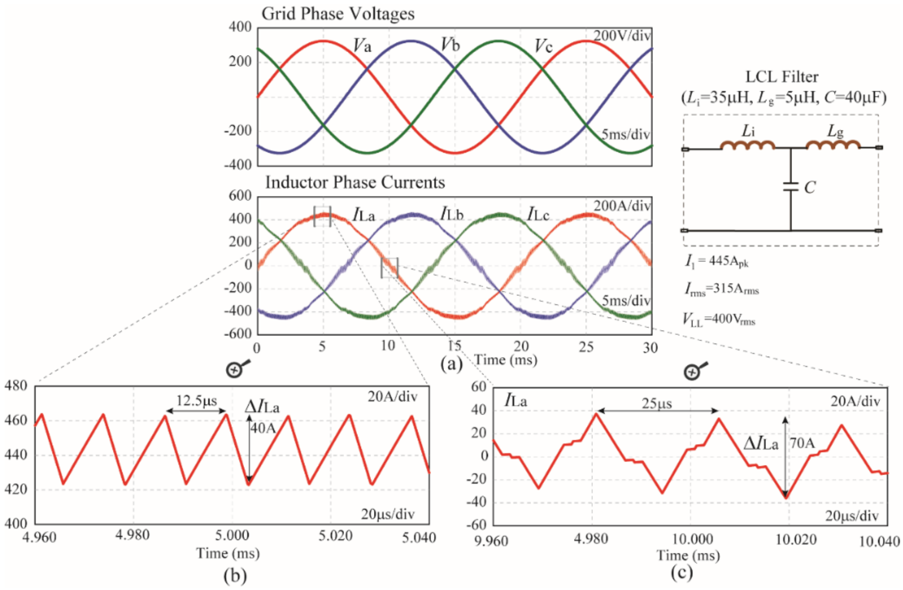
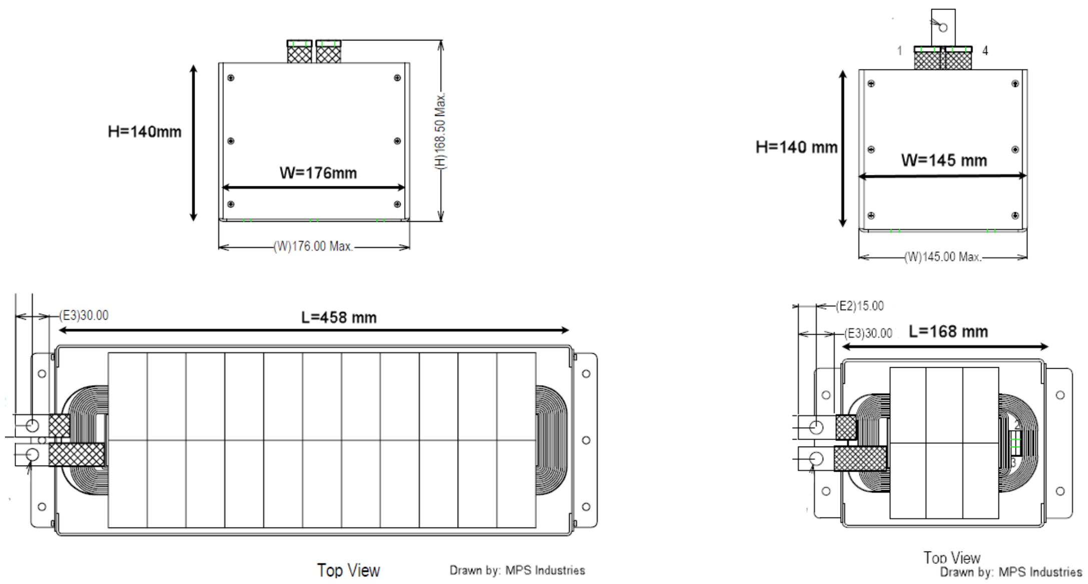


Fig. 7 LCL-type (40 kHz) grid-connected inverter key waveforms example (V_{dc} = 750V). a) Three-phase grid voltages and inductor currents (with $L_a = L_b = L_c = L_i$ =35µH and C =40µH), b) Inductor ripple current zoom-in details at the peak current and b) Inductor ripple current zoom-in details at the zero cross.

Figures 6 and 7 present a comparative analysis of LC and LCL filters, which is essential for evaluating current distortion, filter sizing, and control performance in grid-connected inverter systems.

Fig. 8 shows the inductor design for a 200/250 kW rated power inverter. In Fig. 8 (a) is shown the inductor dimensions (W-width, L-length, H-height) designed for an inverter operating at 10 kHz switching frequency. In a direct comparison, Fig. 8 (b) shows a reduction in size by a factor of three, due to increased switching frequency of 40 kHz. The increase in switching frequency of high-power inverters is now possible using the Hillcrest ZVS technology.



(a) Dimensions: WxLxH = (176x458x140) mm (b) Dimensions: WxLxH = (145x140x140) mm

Fig. 8 AC power filter design example rated at 300A: a) Power inductor for Conventional inverter operating at 10 kHz b) Hillcrest ZVS inverter operating at 40kHz.

Fig. 9 shows the Fast Fourier Transform (FFT) analysis on the inverter grid current (I) performance operating at 315Arms/400Vrms with grid impedance of $1m\Omega$ and $5\mu H$. The inverter operates at the line frequency of 50 Hz and with switching frequency of 40 kHz. Fig. 9 (a) and (b) show the FFT current measurements using an LC-type filter ($L_i = 65\mu H$) and its equivalent circuit. Fig. 9 (c) and (d) show the FFT current measurements using an LCL-type filter ($L_i = 35\mu H, L_g = 5\mu H$) and its equivalent circuit. Based on the measurement, the total harmonic distortion (THD) for LCL-type is 1.8% compared with LC-type filter at 2.1%.

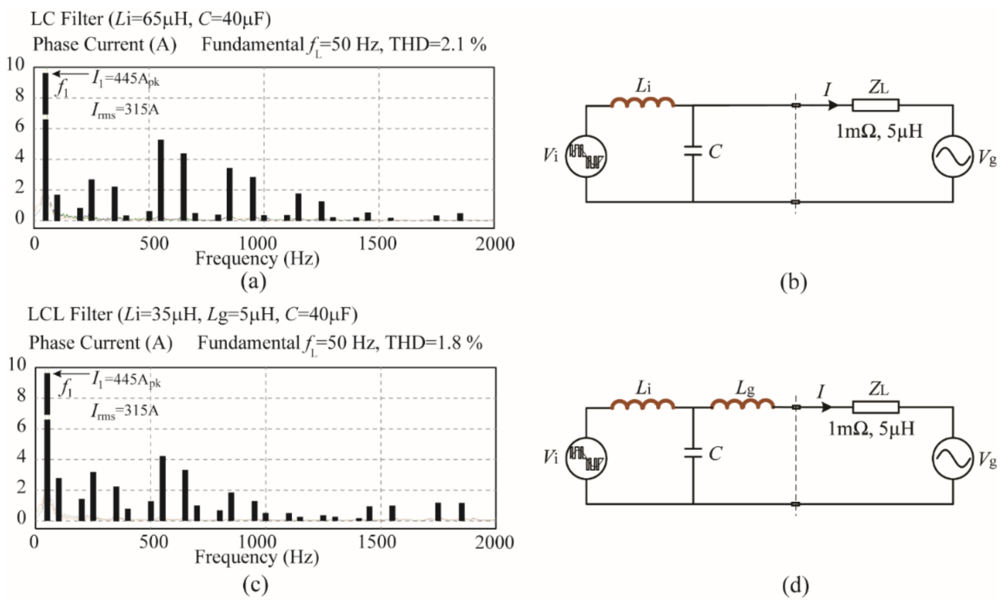


Fig. 9 Inverter phase currents FFT analysis: a) LC-type FFT measurements b) Simplified LC-type filter equivalent circuit. c) LCL-type filter FFT measurements d) Simplified LCL-type equivalent circuit.

In summary, the analysis of ZVS effect on the inverter AC filter performance is detailed in Table VIII. The design example shows a side-by-side comparison between conventional inductor versus Hillcrest inductor. Clearly, the operation at high switching frequency brings the following key advantages:

1) *Performance:*

Reduced losses → High-efficiency

a) *Lower voltage drop → Wider DC bus utilization*

2) *Reduced size:*

a) *Compact design → Product densification*

b) *Significant lower cost → 4x cost savings*

VIII. Design example of power inductor for one phase: conventional versus Hillcrest comparison.

Parameter	Conventional Inductor	**Hillcrest Inductor**	UoM	Direct comparison Hillcrest design advantages
Nominal current	300	300	Arms	--
Inverter Switching frequency	10	**40**	kHz	**4x higher switching frequency**
Resistance	2.1	**1.2**	mΩ	**40% lower resistance**
Inductance value	250	**65**	µH	**~4x lower inductance**
Copper Power loss	189	**108**	W	**40% lower copper losses**
Core loss	40	**15**	W	**2.5x lower core losses**
Total losses	229	**123**	W	**45% lower total losses**
AC Filter voltage drop at 60Hz	28.3	**7.4**	V	**3.8x voltage gain**
Reactor impedance %Z	12.3%	**3.2%**	%	**3.5x lower impedance**
Inductor volume	11285	**3410**	cm3	**3.3x lower volume**
Weight	100%	**25%**	kg	**4x less weight**
Inductor price	100%	**25%**	%	**4x cost savings**

IV. CONCLUSION

This paper investigated the impact of increased switching frequency on power converter performance, with a particular focus on AC filter design for electrification-oriented power conversion systems. Applications such as electric vehicle charging infrastructure, grid electrification in remote areas, and transportation electrification are considered. Two AC filter topologies—such as LC and LCL have been analyzed in terms of their influence on harmonic attenuation and performance. The results demonstrate that the choice of filter topology plays a critical role in balancing size, performance, and economic viability. Furthermore, by leveraging advancements in Zero Voltage Switching (ZVS) technology within AC-DC inverters, the study shows that it is possible to achieve significant improvements in power density, system efficiency, and overall cost savings. Finally, these findings support the promotion of high-frequency, soft-switched inverters as a viable path toward compact and high-performance electrified power systems.

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