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Optimal modulation and filter design to increase efficiency at partial loads

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Abstract

The switching frequency of medium-voltage high power converters is limited to about 1 kHz due to semiconductor junction temperature constraint. The frequency band between the fundamental and carrier frequency is limited to a little more than one decade and the LCL filter design is usually a challenge to meet grid codes for grid connected applications [1, 3]. Traditional designs focus on the optimization of the filter parameters and different damping circuits once a modulation strategy is given. However, this approach does not exploit all the available degrees of freedom (DoF) yielding suboptimal results [2, 4, 5]. This paper demonstrates that an efficiency enhancement can be achieved if the modulation technique selection and the filter design are jointly carried out. Specifically, an efficiency enhancement on a Multi-Megawatt Medium-Voltage neutral point clamped (NPC) converter for a wind turbine is achieved.

Objectives

The main goal of this presentation is to provide a new method for designing the filter stage and the modulation of a low-switching frequency 3L-NPC power converter. Efficiency of the conversion stage is a key issue in windpower and so, a reduction in the losses of the power converter and the filter stage is always desirable. Reducing the losses in the conversion stage has traditionally been against the fulfilment of the harmonic emission limits.

With the method presented here, this statement is no longer valid, as a combined design of the filter stage and the modulation strategy can lead to a great reduction in the overall losses, while guaranteeing the fulfilment of the harmonic limits. For this purpose, a modulation with certain DoF is required to have additional flexibility in the filter design. The typical sinusoidal PWM does not provide any DoF as nothing can be done to alter its harmonic emission. Modulations such as Selective Harmonic Elimination (SHE).do provide this DoF as the designer is able to alter its harmonic content to certain degree.

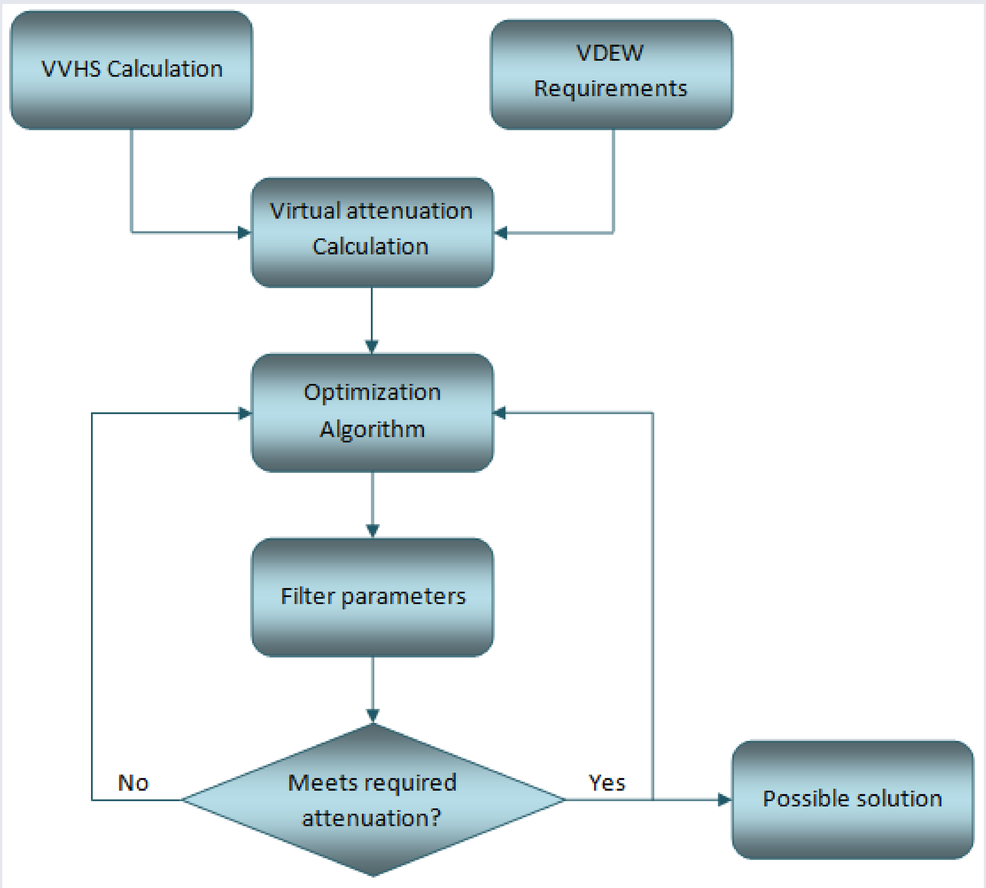
Methods

The harmonic emission limits impose the grid current attenuation required at each harmonic frequency. This attenuation needs to be fulfiled by the combination of the harmonic emission (modulation) and the harmonic absortion (filter).

In the modulation side, SHE allows to select certain number of harmonics which will be nulled in the voltage waveform of the converter. With this DoF, a perfect match between the harmonics in the voltage waveform and the frequency response of the filter stage can be found. The more harmonics to be nulled, the higher the converter switching frequency will be; so the procedure needs to define the minimum indispensable harmonics to be nulled so as to keep the switching frequency at minimum.

In the grid side, the SHE capability to null some harmonics can be used to greatly reduce the passive damping (increase the damping resistor value), so that a reduction in the filter losses is obtained.

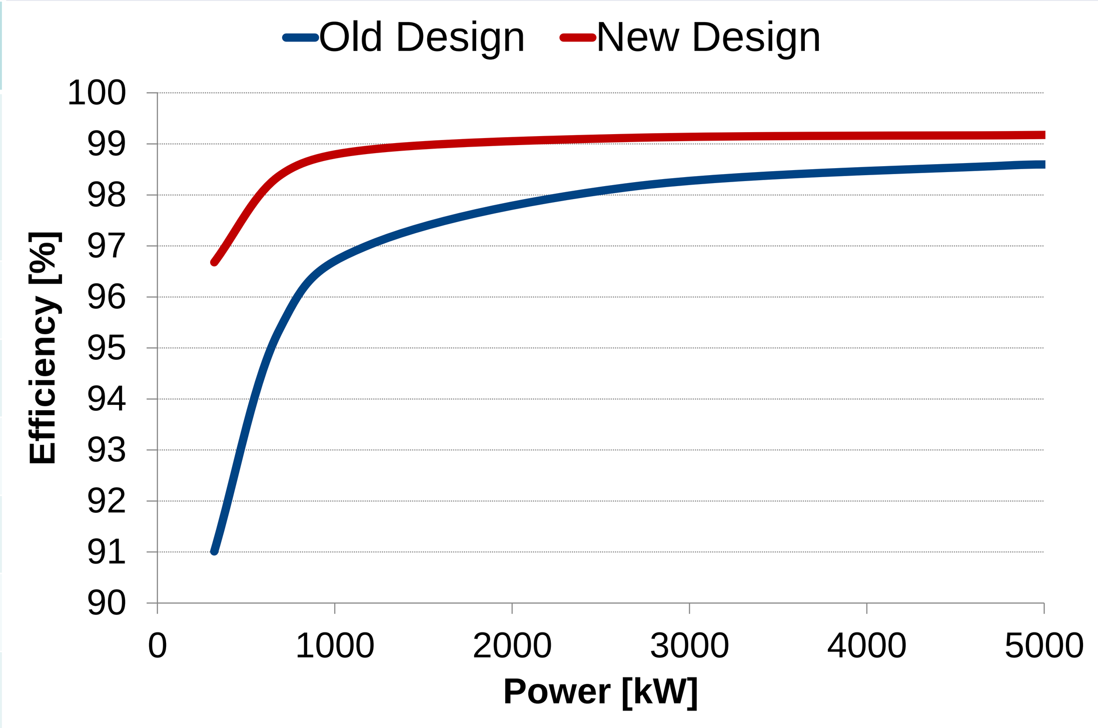
The harmonic spectrum created by the modulation is analysed using the virtual voltage harmonic spectrum (VVHS) concept [1]. The filter design is constrained by the VVHS created by the modulation and the grid code limits (let's assume its VDEW). The filter must provide enough attenuation to reduce the VVHS to acceptable values in concordance to the grid code limits. Thus, the virtual attenuation required can be defined as the attenuation required from the filter to meet said grid code for a given VVHS. That is, it defines the ig/vc transfer function that the filter should present. Once the desired ig/vc transfer function is obtained, a constrained sweep of the different parameters of the filter is performed selecting those combinations that comply with the required transfer function.



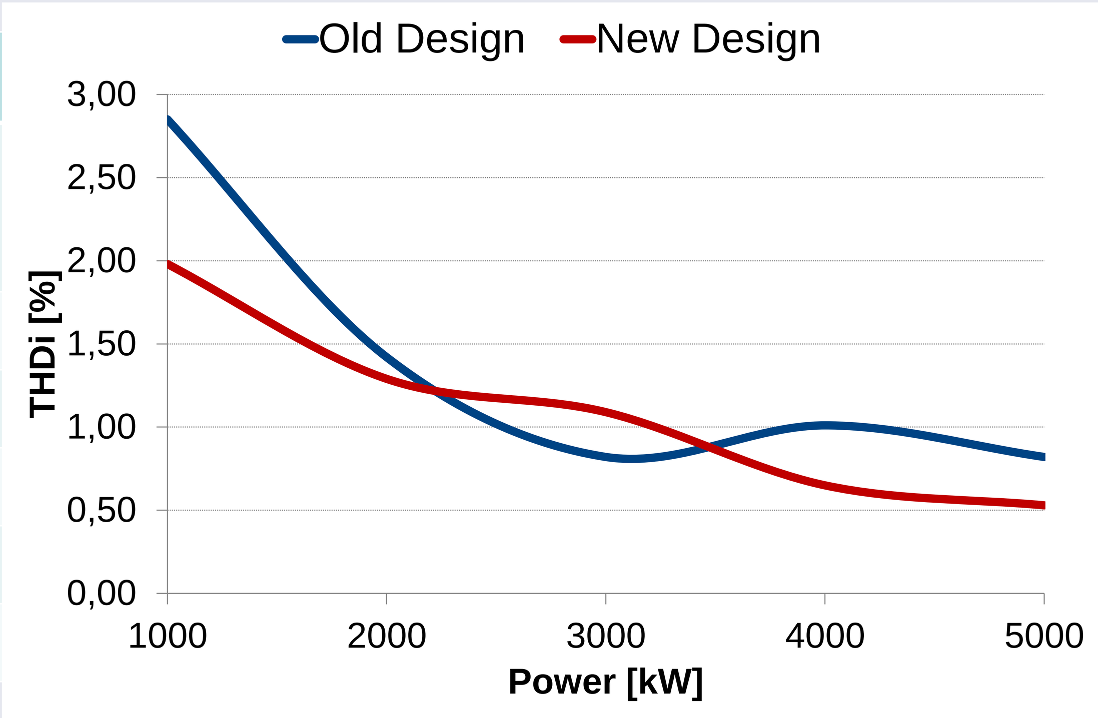
Results

The following results were obtained in a 5 MW 3L-NPC converter especially designed for offshore windturbines. The old design consisted in a typical sinusoidal PWM modulation with a sinusoidal filter while the new design implements a SHE modulation and a filter designed following the method presented. Following this procedure, a reduction in the converter switching frequency is obtained while keeping low THDi values.

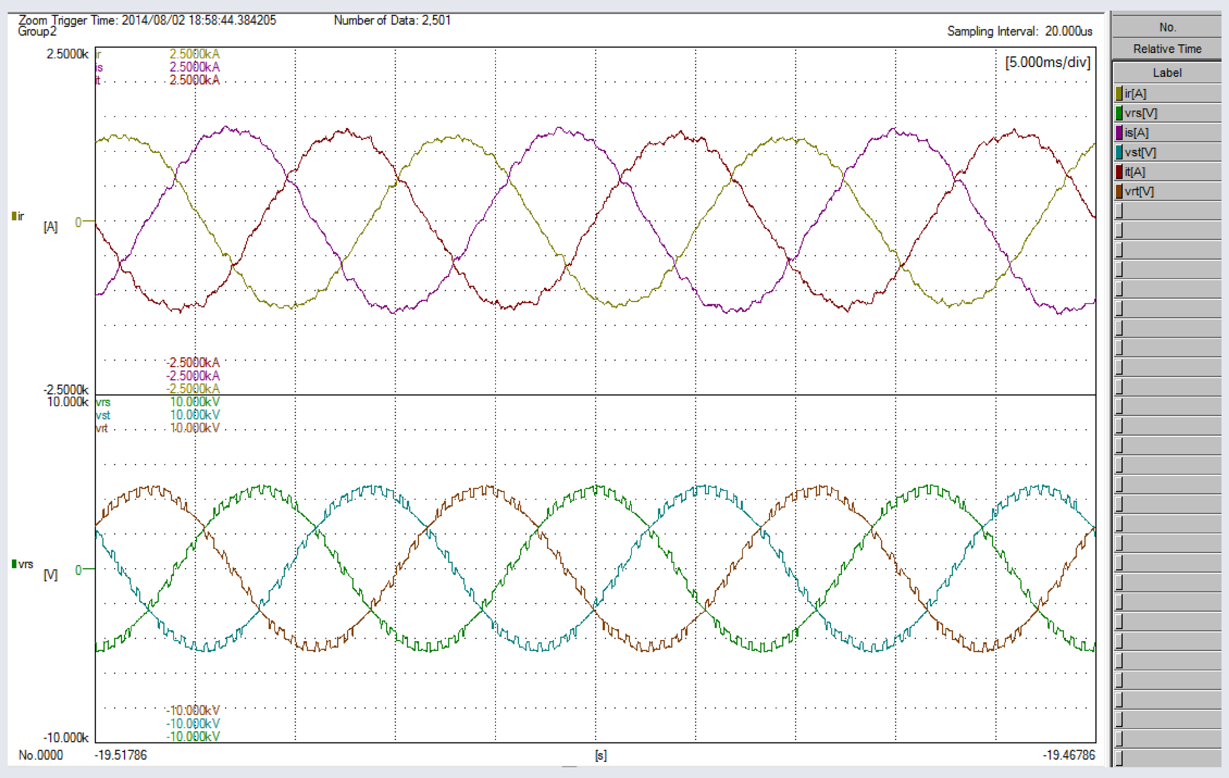
Efficiency [%]		
Power [kW]	Old Design	New Design
320	91.01	96.68
685	95.34	98.37
1200	97.03	98.89
2692	98.17	99.12
4800	98.58	99.17
5100	98.60	99.18



THDi [%]		
Power [kW]	Old Design Fsw=1150 Hz	New Design Fsw=800 Hz
1000	2.85	1.98
2000	1.42	1.29
3000	0.82	1.09
4000	1.01	0.65
5000	0.82	0.53



Experimental grid side currents (upper) and voltages (lower)



Conclusions

An efficiency enhancement of 0.6-2 % on a multi-Megawatt medium-voltage NPC for a wind power application has been achieved especially at low and medium loads.

The low switching frequency requirement for HV-IGBTs requires high damping at the resonance frequency of the LCL filter for a sinusoidal PWM modulation as the modulation can hit the resonance. This modulation has shown to be suboptimal in terms of efficiency on both the filter and the converter requiring high switching frequencies (increasing losses in the converter) and damping values (increasing losses in the filter). .

The SHE modulation provides additional DoF to the design which can be used to eliminate the harmonics around the resonance frequency. This avoids the necessity of attenuating it by means of passive damping (reducing filter losses). Additionally, a similar harmonic emission to the grid can be obtained with fewer commutations, thus reducing converter losses..

Comparing the simulation and experimental results of the SHE modulation with the previously used sinusoidal PWM modulation, the losses on the damping resistor and the switching losses have been reduced (as expected). Additionally, the harmonic emission also fulfils the requirements of the VDEW grid code and the THD remains similar.

Last but not least, designing the filter for a given modulation, without taking into account different pairs of modulation and filter can lead to suboptimal solutions.

References

[1] A. A. Rockhill, M. Liserre, R. Teodorescu, and P. Rodriguez, "Grid-filter design for a multimegawatt medium-voltage voltage-source inverter", IEEE Trans. on Industrial Electronics, vol. 58, pp. 1205-1217, 2011.
[2] C. Zhang, T. Dragicevic, J.C. Vasquez, J.M. Guerrero, "Resonance damping techniques for grid-connected voltage source converters with LCL filters — A review", in Proc. IEEE International Energy Conference (ENERGYCON), Dubrovnik, Croatia, 2014, pp. 169 - 176.
[3] J. San-Sebastian, I. Etxeberria-Otadui, A. Rujas, J.A. Barrena, P. Rodriguez, "Optimized LCL filter design methodology applied to MV grid-connected multimegawatt VSC", in Proc. IEEE Energy Conversion Congress and Exposition (ECCE), Raleigh, NC, USA, 2012, pp. 2506-2512.
[4] S. V. Araujo, A. Engler, B. Sahan, and F. Antunes, "LCL filter design for grid-connected NPC inverters in offshore wind turbines", in Proc. International Conf. Power Electronics ICPE, Daegu, South Korea, 2007, pp. 1133-1138.
[5] T. C. Y. Wang, Z. Ye, G. Sinha, and X. Yuan, "Output filter design for a grid-interconnected three-phase inverter," in Proc. IEEE Annual Power Electronics Specialist Conf. (PESC), Acapulco, Mexico, 2003, pp. 779-784.