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Implementation of Cascade Multilevel Inverter in Distribution Systems as Power Line Conditioner

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Abstract— This paper deals with the implementation of cascade multilevel inverter-based STATCOM, which employs H-bridge inverter. The STATCOM system is modeled using the d-q transform, which calculates the instantaneous reactive power. In this paper, a power line conditioner using a cascade multilevel inverter is presented for voltage regulation, harmonic filtering and reactive power compensation (var). 11 level STATCOM is selected as demonstration. The cascade multilevel converter consists of five single-phase full bridges in which each bridge has its own DC source. This new inverter can: 1) It can eliminate transformers of multilevel inverters used in conventional static var compensators; 2) make possible to direct connect to power distribution system in parallel and series without any transformer; 3) generate almost sinusoidal voltage. This paper focuses on feasibility and control schemes of the cascade inverter foe voltage regulation and harmonic filtering in distribution systems. The results are analyzed and discussed.

Index Terms— Active power filter, STATCOM, cascade multilevel inverter, power line conditioner,

1 Introduction

IN large power network, the active control of reactive power is indispensable to stabilize the power systems and to maintain the supply voltage. A static synchronous compensator (STATCOM) using the voltage source inverters (VSIs) have been widely accepted as the next generation of the reactive power controllers of power system. Recently, power quality and custom power have been hot topics because of widespread use of nonlinear electronic equipment and the power quality requirements of sensitive loads. To provide high power quality at the point of common coupling (PCC) of distribution system, line conditioning, including voltage regulation, reactive power compensator, harmonic compensator is an indispensably necessary remedy.

Traditionally, a multipulse inverter consisting of several voltage source inverters connected together through zig-zag arrangement transformers is used for var compensation. These transformers are: 1) most expensive equipment in the system; 2) produce about 50% of the total losses of the system; 3) causes difficulties in control due to dc magnetizing and surge over voltage problems resulting from saturation of the transformers.

A cascade multilevel inverter have been proposed for static var compensation and generation applications, The new cascaded inverter eliminates the bulk of transformers required by static var compensators (SVC's) that employ the multipulse inverter and that can respond much faster. This inverter generates almost sinusoidal staircase voltage with only one time switching per line cycle.

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2 System Configuration of Power Line Conditioner

The proposed power line conditioner is using the cascaded multilevel inverter is presented for voltage regulation, reactive power (var) compensation and harmonic filtering of a power distribution system in this paper. A STATCOM is connected to the power network at PCC, where the voltage-quality problem is concern. All required voltages and currents are measured and fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches of the power converter accordingly. The single line diagram of the STATCOM system is illustrated in Figure 2-1. In general, VSC is represented by an ideal voltage source associated with internal loss connected to the AC power via coupling reactors

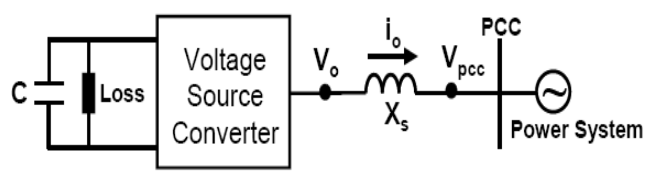

Figure 2-1 Single line diagram of VSC based STATCOM

A power line conditioner can be connected in series with the source before the PCC as shown in Figure 2-2 or connected in parallel with the system at the PCC.

The series power line conditioner can be control to provide pure, constant sine-wave voltage to the loads that are sensitive to voltage fluctuations, sags, swings and harmonics

The parallel power line conditioner is to compensate the reactive power and harmonics.

This paper focuses on this power line conditioner and reveals a control method for dc voltage balancing of cascade inverters

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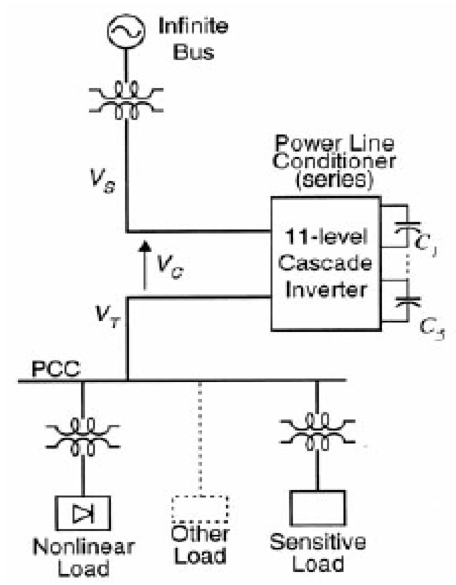

Figure 2-2 Single line diagram of series connected power line conditioner for distribution system

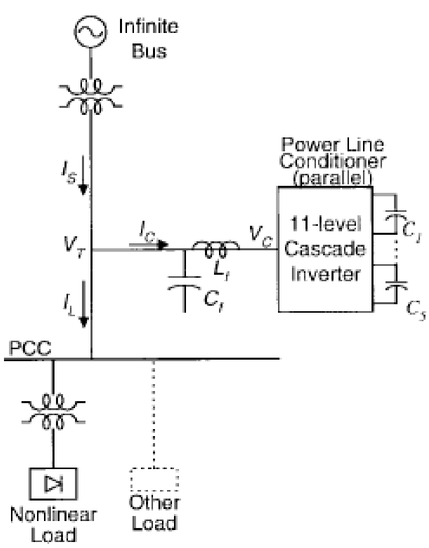

Figure 2-3 Single line diagram of parallel connected power line conditioner for distribution system

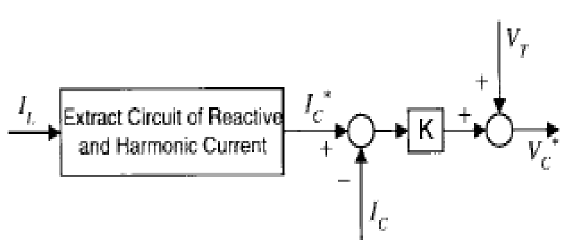

Figure 2-4 Control block diagram of power line conditioner

2.1 Control of Power Line Conditioner

Fig. 2-3 shows the experimental system configuration of the 11-level cascade-inverter-based power line conditioner. The cascade inverter is connected to the power system through a small filter, L_f and C_f. Fig. 2-4 shows the control block diagram for the power line conditioner. To compensate for reactive and harmonic current, the load current I_L is sensed, and its reactive and harmonic components are extracted. The current reference I_C*of the power line conditioner can be the load reactive current component, harmonic component, or both, depending upon the compensation objectives. The cascade inverter has to provide a voltage V_C* so that the power line conditioner current I_C tracks the current reference I_C. V_T is the line terminal voltage, and K is a gain. In a distribution system, the purpose of a power line conditioner is to provide a constant and stable terminal voltage to loads. In this case, a constant sine wave is assigned to the voltage reference V_C*.

2.2 Cascade Multilevel Inverter

A cascaded multilevel inverter is made up from a series of H-bridge (single-phase full bridge) inverters, each with their own isolated dc bus. This multilevel inverter can generate almost sinusoidal waveform voltage from several separate dc sources (SDCSs), Figure 2-4 shows a single phase structure of an M-level H-bridges multilevel cascaded inverter. Each level can generate three different voltage outputs $+V_{dc}$, 0, $-V_{dc}$ by connecting the dc sources to the ac output side by different combinations of the four switches.

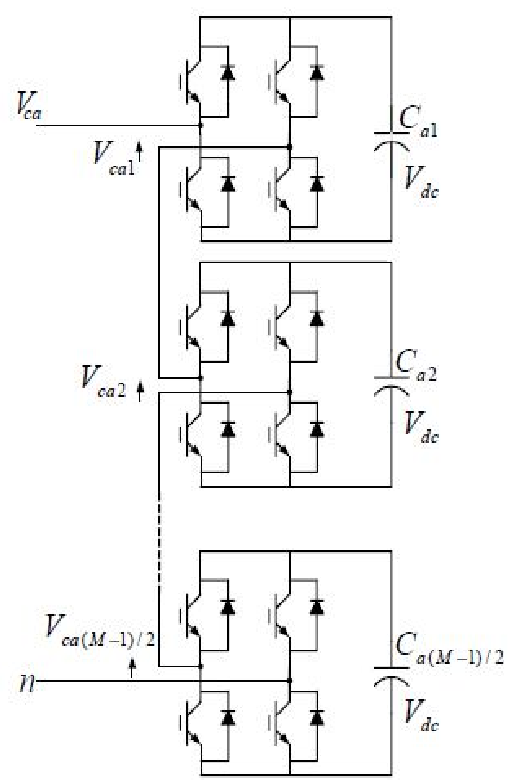

Figure 2-5 Single Phase Structure of a m-level H-bridges multilevel cascaded inverter

The output voltage of an M-level inverter is the sum of all of the individual inverter outputs. It is clear from Figure 2-5 that to have an M-level cascaded multilevel inverter we need (M-1)/2 H-bridge units in each phase. An example phase voltage waveform for a 11-level cascaded multilevel inverter with three dc sources and five full bridges is shown in Figure2-6. The output phase voltage is given by van = va1+va2+va3+va4+va5.

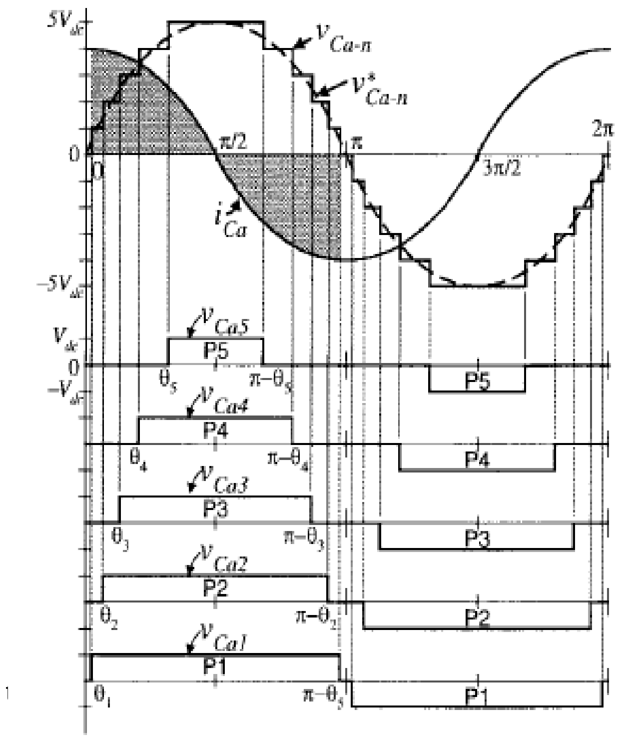

Figure 2-6 Waveforms of the 11-level cascade inverter

3 CONTROL OF CASCADE INVERTER

Fig. 2-6 shows waveforms of the 11-level cascade inverter for var compensation. The output phase voltage $V_{Ca\text{-}n}$ is the sum of five H-bridge inverter units' outputs. The phase voltage magnitude is controlled by each inverter's duty cycle. For var compensation, the phase current *Ica* is always leading or lagging the phase voltage $V_{Ca\text{-}n}$ by 90. The average charge to each dc capacitor is equal to zero over every half-line cycle for all pulses *P1–P5*. In other words, the voltage of each dc capacitor is always balanced [11], [12]. However, this is not true when the cascade inverter is applied to harmonic filtering. Fig. 6 shows the waveforms, where, for instance, a fifth harmonic current needs to be absorbed by the inverter. In this case, as shown in the figure, an H-bridge inverter unit will be overcharged if it repeats pulse *P5* and over discharged if it repeats pulse *P4*. In order to overcome this problem, swapping pulses every half cycle, as shown in Fig.3-1 , is proposed. As a result, all dc capacitors will be equally charged and balanced

3.1 Voltage Balancing Control

As shown in Fig. 3.1, rotating pulses *P1–P5* every half cycle among the five inverter units makes all dc capacitors equally charged and balanced over five half cycles. Therefore, in order to regulate all dc capacitors' average voltages, only one dc capacitor's voltage needs to be monitored and fed back. This feature makes control very simple and reliable. Fig. 3-2 shows the control block diagram of the power line conditioner system. To control all dc capacitors' voltages, a feedback loop is used. Note that only one dc capacitor's voltage is detected.

In Fig. 3-2, a vector phase-locked loop (PLL) is used to get the phase angle of the line terminal voltage. A proportional and integral (PI) controller is employed to regulate the dc capacitors' voltage. See [11] and [12] for details. In the duty-cycle lookup table, the duty cycle data, θ_1– $\theta_5$is stored over one fundamental cycle. Table I shows the phase angles calculated offline to minimize harmonics for each modulation index (*MI*). A duty-cycle swapping circuit rotates pulses every half cycle, as shown in Fig. 3-1

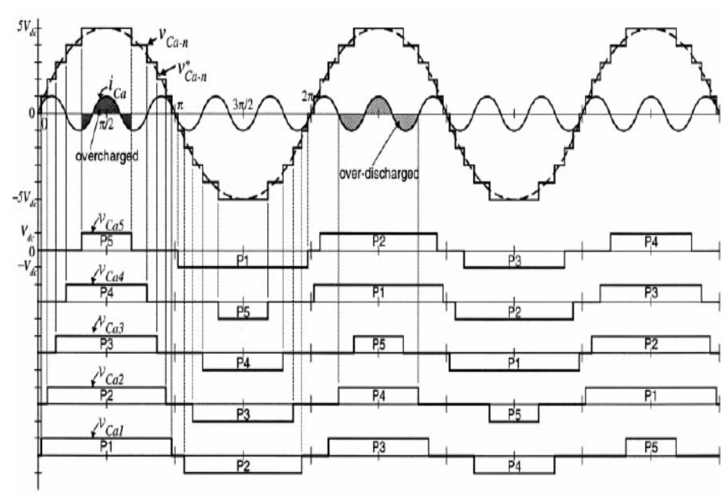

Figure 3-1 Waveforms of the 11-level cascade inverter for Harmonic filtering.

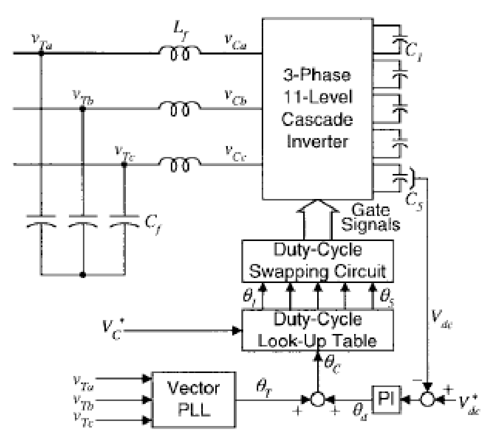

Figure 3-2 Control Diagram of 11-level cascade Inverter

3.2 Required DC Capacitance

From the cascade inverter structure, it is obvious that more capacitance is needed compared with a traditional two-level inverter. For the 11-level cascade inverter to compensate reactive power only, it has been shown that 1.36 times of conventional var compensator's capacitance is required**.** For var and harmonic compensation, all dc capacitors should have an equal capacitance because of pulse rotation among the H-bridge units instead of fixed pulse patterns. In addition, the required capacitance should be determined in the worst case. From Figs. 2-6 and 3-1, one can see that harmonics have little contribution to the capacitors' charge because of their higher frequency, but the reactive current may dominate voltage ripples of the dc capacitors at the fundamental frequency. Therefore, the required dc capacitance of each capacitor can be expressed as

$$C_{\mathrm{dc}} = \frac{\Delta Q}{\Delta V_{\mathrm{dc}}} = \frac{\int_{\theta_1}^{T/4} \sqrt{2} I_{Cq} \cos \omega t \, dt}{\Delta V_{\mathrm{dc}}}.$$

4 EXPERIMENTAL VERIFICATION

The experimental power line conditioner system uses an 11-level (21 line-to-line level) three-phase cascade inverter. The line voltage is 240 V, power line conditioner rating 10 kVA. The power line conditioner adopts the conventional current injection method as used in active power filters to compensate load harmonics and reactive power.

5 SIMULATION RESULTS

A three phase system with 240V, 50hz circuit has been computed

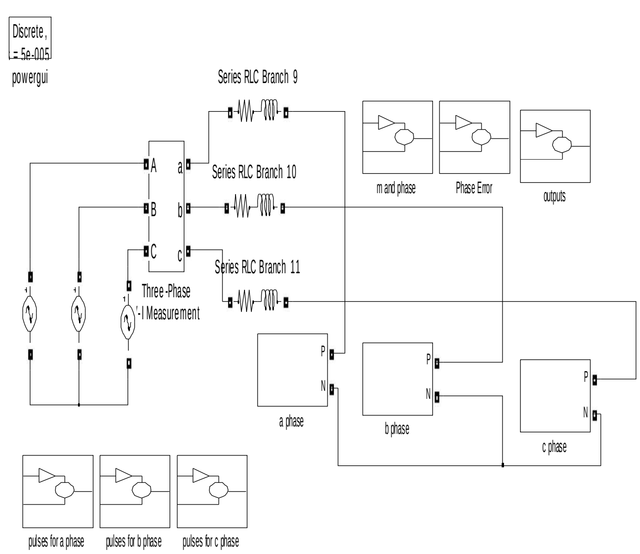

Figure 4-1 Simulink diagram of Cascaded Multipulse Inverter

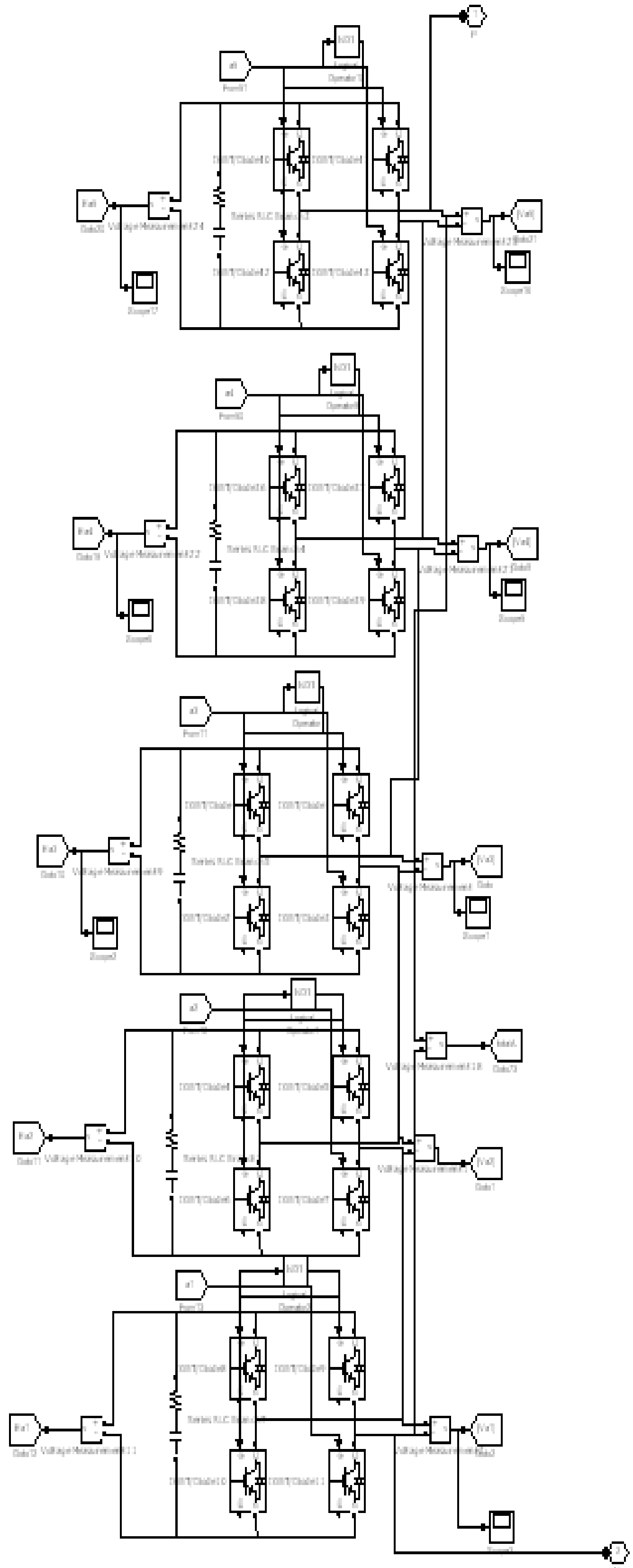

Figure 4-2 Simulink diagram of Single Phase Structure of a 11-level H-bridges multilevel cascaded inverter.

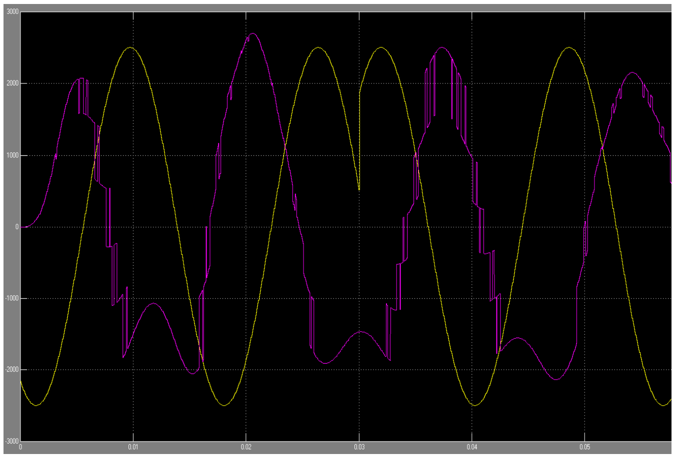

Figure 4-3 Simulation Results of 11-Level CMLI STSTCOM.

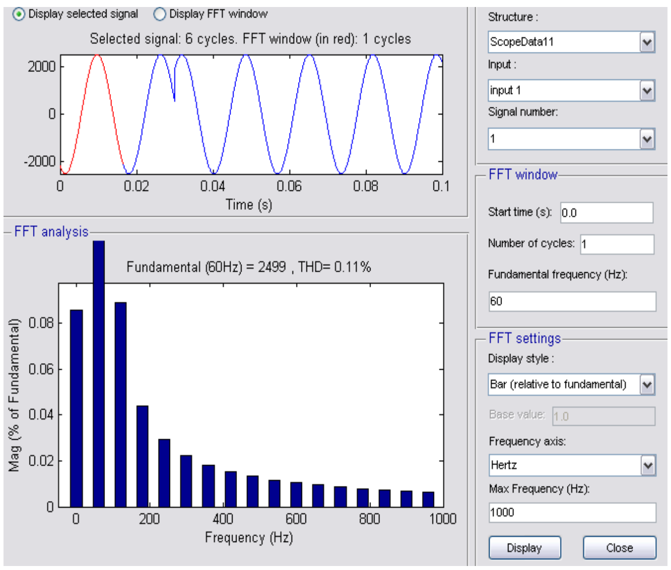

Figure 4-4 FFT Analysis of 11-Level CMLI SATACOM.

6 Conclusion

The voltage control scheme presented in this paper for cascade multilevel inverter based STATCOM is a simple and effective method for load voltage regulation. Results presented here validate the basic principle of STATCOM for voltage regulation applications. Although, in this paper, only single-phase 11- level Cascaded Multilevel Inverter based STATCOM has been employed the same procedure canbe easily extended for a three-phase system.

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References

[1] J. Rodriguez, J.-S. Lai, and F. Z. Peng, *"Multilevel inverters: A survey of topologies, controls, and applications,"* IEEE Trans. Ind. Electron., vol. 49, no. 4, pp. 724–738, Aug. 2002.

[2] L. G. Franquelo, J. Rodriguez, J. I. Leon, S. Kouro, R. Portillo, and M. A. M. Prats, *"The age of multilevel converters arrives,"* IEEE Ind. Electron. Mag., vol. 2, no. 2, pp. 28–39, Jun. 2008.

[3] M. F. Escalante and J. J. Arellano, *"Harmonics and reactive power compensation using a cascaded H-bridge multilevel inverter,"* in Proc. IEEE Int. Symp. Ind. Electron., Jul. 2006, vol. 3, pp. 1966–1971.

[4] C. Rech and J. R. Pinheiro, *"Hybrid multilevel converters: Unified analysis and design considerations*," IEEE Trans. Ind. Electron., vol. 54, no. 2, pp. 1092–1104, Apr. 2007.

[5] M. Marchesoni, "*High-performance current control techniques for applications to multilevel high-power voltage source inverters*," IEEE Trans. Power Electron., vol. 7, pp. 189–204, Jan. 1992

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