

Comparison of Control Techniques for Three-Phase Distributed Generation Based on VOC and DPC

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1. Introduction

Recently, there has been a significant development of active rectifiers control techniques [1]. The most common control strategies of active rectifiers are based on current control of VSIs [2]. Among these, one of the most adopted is the so called VOC (Voltage Oriented Control), where the current control is performed in the voltage space-vector oriented reference frame [3]-[5]. Another approach is based on the idea of controlling directly the active and reactive powers by choosing the proper switching patterns on the basis of the instantaneous position of the grid voltage space-vector [6]. This technique has been called DPC (Direct Power Control). On the basis of a parallelism between the electrical grid and an electrical machine, both VOC and DPC have been further improved in their virtual flux based versions, called respectively VF-OC (Virtual Flux) and VF-DPC [7][8]. A comprehensive theoretical and experimental comparison of these techniques have been done in [9], where however the focus is the behaviour in case of a controlled load, in particular an adjustable speed drive. However, controlled rectifiers present the additional advantage of their bi-directional power flow. Therefore, control techniques devised for active rectifiers can be properly used also for grid connected VSI for distributed generation, from renewable sources. In [10] a first comparative analysis of classic VOC and DPC techniques in generating mode has been done. With this regard a new DPC control technique, called DPC-EMC (Electromagnetically Compatible), has been devised for 3-phase distributed generation systems from renewable sources (photovoltaic, eolic, Fuel-cells etc.) [11][12]. This technique, developed in two versions called respectively DPC EMC 1 and DPC EMC 2, permits the reduction of the common-mode emissions generated by the VSI towards the grid, by using either even or odd voltage vectors in each of the six sectors in which the grid voltage lies, without using any null vector. These approaches permit the common-mode emissions to be reduced in comparison with the classic DPC algorithm, at the expense of a slight increase of the harmonic content of the injected current waveform.

This paper presents a comparison of VOC and DPC techniques, but focuses the attention to their behaviours when used in generating mode, e.g. for grid connected distributed generation systems from renewable sources. Differently from [10], where only a comparison between the classic VOC and DPC have been done, in this work the comparative analysis has been extended also to the virtual flux versions of VOC and DPC, called VF-OC and VF-DPC, and to the DPC EMC 1 and DPC EMC 2. With this regard the virtual flux versions of these last two techniques have been set up and implemented. Finally, the ratio between the DC link voltage and the grid voltage amplitude has been taken into account with regard to its influence on the THD of the injected currents.

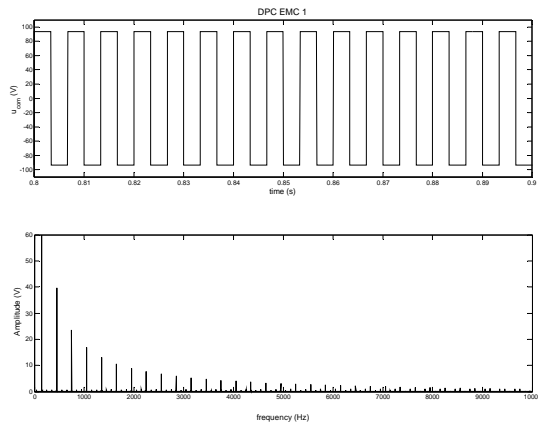
Results have been compared from the point of view of the harmonic content of the currents injected into the grid, the THD of the injected current vs. generated power and vs. DC link voltage. Finally, results have been compared also with the requirements of the European [13] and American [14] standards.

2. Results

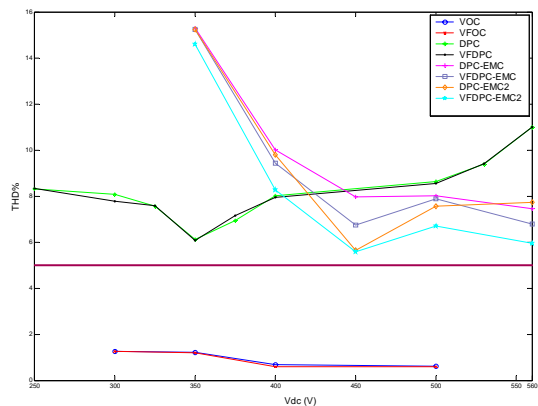
All the four described control techniques – VOC, DPC, DPC-EMC1 and DPC-EMC2 – with their virtual flux corresponding versions have been implemented in Matlab-Simulink® environment. In particular, for the circuitual scheme analysis the PLECS® has been adopted. The PLECS software has been used for the IGBT 3-phase inverter, the interconnecting inductance and the voltage and current sensors. All the control algorithms have been implemented in classic Simulink, in the discrete domain. A sampling frequency of the 15 kHz has been adopted for the DPC, DPC-EMC1 and DPC-EMC2 (and corresponding virtual flux versions), while for the VOC and VF-OC a sampling frequency of 10 kHz with a PWM frequency of 5 kHz has been adopted. All tests have been performed with active reference power equal to –2kW and reactive power equal to zero. As expected, VF-OC exhibits a slightly better harmonic content of the injected current, both considering an harmonic-by-harmonic analysis and considering the %THD equal respectively to 0.77% for the VOC and 0.72% for the VF-OC. As expected, VF-DPC exhibits a slightly better harmonic content of the injected current, both considering an harmonic-by-harmonic analysis and considering the %THD equal respectively to 11.47 % for the DPC and 10.68% for the VF-DPC. Also in this case, VF-DPC-EMC1 exhibits a slightly better harmonic content of the injected current, both considering an harmonic-by-harmonic analysis and considering the %THD equal respectively to 8.93 % for the DPC-EMC1 and 8.36% for the VF-DPC-EMC1. Also in this case, VF-DPC-EMC2 exhibits a slightly better harmonic content of the injected current, both considering an harmonic-by-harmonic analysis and considering the %THD equal respectively to 7.77 % for the DPC-EMC2 and 6.70% for the VF-DPC-EMC2. As a global comparative analysis, the %THD of the injected current versus the generated power has been drawn for all control techniques.

With regard to the DPC-EMC1, the common-mode voltage waveform is a square wave with fundamental frequency at 150 Hz and harmonics only at low frequency decreasing with inverse proportionality at increasing frequency. DPC-EMC 2 presents a common-mode voltage waveform which is a square wave at 150 Hz with some internal spikes; as a result its spectrum presents lower values of the low frequency harmonics and slightly higher values of the harmonics around higher frequencies than DPC-EMC 1. In general VOC and VF-OC present better performances, especially for low values of the generated power. Among the different DPC techniques, the worst is the DPC while the best is the DPC-EMC2. Each of them presents an improvement in its virtual flux version. In general, whatever technique is used, the lower the generated

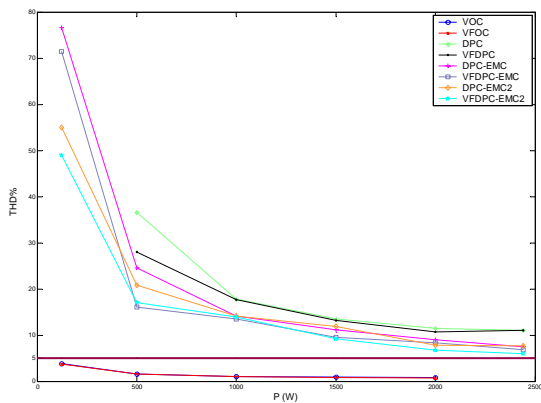
power the higher harmonic content. It should be noted that only VOC and VF-OC satisfies the requirements of the European [13] and American [14] Standards, equal in both cases to 5%. The knowledge of the power quality issues related to the DC link value is particularly important, especially when this value cannot be considered constant. Only VOC and VF-OC always respect the Standards limit. Other techniques are not complying with it for all values of voltage. With regard to DPC-EMC1 and DPC-EMC2 the trend is a significant increase of the THD for decreasing values of V_{dc} . Same considerations are true for VOC, which however present a slight increase of the THD at lower values of V_{dc} . Finally, DPC does not present significant variations of the THD for the different values of V_{dc} .



Common-mode voltage and its FFT with DPC-EMC 1



%THD of the injected current vs DC link voltage



%THD of the injected current vs. generated power

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References

- [1] M.P. Kazmierkowski, R. Krishnan and F. Blaabjerg, *Control in Power Electronics*, London, UK, 2002.
- [2] M. P. Kazmierkowski, "Current Control Techniques for Three-Phase Voltage-Source PWM Converters: A Survey", *IEEE Transactions on Industrial Electronics*, vol. 45, n. 5, October 1998, pp. 691-703.
- [3] M.P. Kazmierkowski, and H. Tunia, *Automatic Control of Converter-Fed Drives*, The Netherlands: Elsevier, 1994.
- [4] S. Hansen, M. Malinowski, F. Blaabjerg, M.P. Kazmierkowski, "Sensorless control strategies for PWM rectifier", *APEC 2000 (Applied Power Electronics Conference and Exposition)*, vol. 2, 6-10 Feb. 2000, pp. 832 – 838.
- [5] M. Liserre, A. Dell'Aquila, F. Blaabjerg, "An Overview of the Three-Phase Voltage Source Active Rectifiers Interfacing the Utility", *Powertech Conference 2003*, June 23-26, Bologna, Italy.
- [6] T. Noguchi, H. Tomini, S. Kondo, "Direct Power Control of PWM Converter Without Power-Source Voltage Sensor", *IEEE Transactions on Industry Applications*, Vol. 34, n. 3, May-June 1998, pp. 473-479.
- [7] M. Malinowski, *Sensorless Control Strategies for Three - Phase PWM Rectifiers*, PhD Thesis, University of Warsaw, Poland – 2001.
- [8] M. Malinowski, M.P. Kazmierkowski, S. Hansen, F. Blaabjerg, "Virtual-Flux-Based Direct Power Control of Three-Phase PWM Rectifiers", *IEEE Transactions on Industry Applications*, Vol. 37, n. 4, July-August 2001, pp. 1019-1027.
- [9] M. Malinowski, M.P. Kazmierkowski, M. Trzynadlowski, "A Comparative Study of Control Techniques for PWM Rectifiers in AC Adjustable Speed Drives", *IEEE Transactions on Power Electronics*, vol. 18, n. 6, November 2003, pp. 1390-1396.
- [10] G. Giglia, C. Serporta, M. Pucci, G. Vitale, "Experimental Comparison of Three-Phase Distributed Generation Systems Based on VOC and DPC Control Techniques", *EPE 2007 European Conference on Power Electronics and Applications*, 2-5 september 2007, Aalborg, Denmark.
- [11] M. Cirrincione, M. Pucci, G. Vitale, "Direct Power Control of Three-Phase VSIs for the Minimization of Common-Mode Emissions in Distributed Generation Systems", *ISIE 2007 IEEE International Symposium on Industrial Electronics ISIE07*, 4-7 June 2007 Vigo (Spain).
- [12] M. Cirrincione, M. Pucci, G. Vitale, "New Direct Power Control Strategies of Three-Phase VSIs for the Minimization of Common-Mode Emissions in Distributed Generation Systems", The 42th Annual Meeting of the IEEE Industry Applications Society (IAS 2007) New-Orleans USA Sept. 23 - 27, 2007.
- [13] Standard IEC/EN61727, *Photovoltaic (PV) Systems - Characteristics of the utility interface*, IEC Std, 1997
- [14] IEEE 1547-2003, *Standard for Interconnecting Distributed Resources with Electric Power Systems*, 2003.