Proceedings of the 7th International Caribbean Conference on Devices, Circuits and Systems, Mexico, Apr. 28-30, 2008

A Simplified Rectifier Voltage Vector Selection for Direct Power Control

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***Abstract*—This work presents a simple scheme for vector selection in Direct Power Control (DPC) in a three-phase rectifier without the use of switch selection tables, by using a rectifier voltage computed with a closed expression. The method is simulated using a C language description of the system and its results are later verified on an experimental test rig. The use of an optimum rectifier voltage and the use of Space Vector Modulation (SVM) provides an operation with lower ripple in the current and in the calculated active and reactive power.**

I. INTRODUCTION

Nowadays, the use of active filters has been increasingly important due to the restrictions on harmonic contamination imposed by the utility companies, and to the widespread use of uncontrolled solid state converters. These uncontrolled converters have reduced power factors, and for four wire systems feeding single-phase loads they inject a measurable third harmonic component to the neutral wire.

Several attempts have been made to correct this, from changing the structure of the solid state converters to draw nearly unity power factor [1], to the use of compensating systems, or active power filters. There are a plethora of active power filter that have been proposed over the last few decades. However, the use of a non contaminating AC/DC stage is preferred. For the switched rectifier there are several control techniques for controlling or for compensation harmonics in a power system, each with their advantages and disadvantages. In this work, a direct power control of the switched rectifier based on the Optimal Selection of the Space Vector Voltage [2] is presented. An advantage of this approach over traditional strategies is that does not require the use of pre-computed switching tables and does not require integrators or virtual flux estimation. Results obtained by simulations show an improvement over the OVS presented in [3], in terms of harmonic and ripple reduction. An additional improvement was added with respect [2], because the optimum rectifier voltage is obtained by strait forward calculations without use of the optimization algorithms which are computer time consuming.

A. Direct Power Control (DTC)

The principle of DTC was first introduced in [4] where an optimum switching table was defined for demands of active or reactive power as a function of the power source voltage angle. In [5] proposes the use of a PWM controlled switched rectifier using the virtual flux signal for power estimation. A similar block scheme is proposed in [2] for the use of a PWM controlled switched rectifier, but without using the virtual flux, and closer to the original scheme; i.e. using a set of space vectors. The block scheme of the proposed controller is depicted in Fig. 1. The rectifier voltage can be obtained by analyzing the instantaneous complex power $s(t)$, defined as.

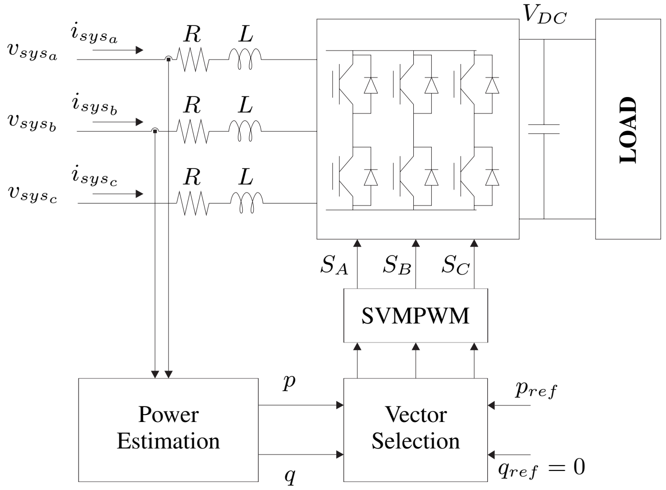

Fig. 1. Block Scheme of the proposed control strategy.

$$\mathbf{s}(t) = \mathbf{v}_{sys} \cdot \mathbf{i}^*_{sys} = (i_{sys\,\alpha} \cdot v_{sys\,\alpha} + i_{sys\,\beta} \cdot v_{sys\,\beta}) + j(i_{sys\,\alpha} \cdot v_{sys\,\beta} - i_{sys\,\beta} \cdot v_{sys\,\alpha}) \quad (1)$$

The change in the system current can be obtained from the following expression.

$$\frac{d\mathbf{i}_{sys}}{dt} = \frac{1}{L}\left(\mathbf{v}_{sys} - R\mathbf{i}_{sys} - \mathbf{v}_{rec}\right) \quad (2)$$

by changing the rectifier voltage, a corresponding change in the system current is obtained and the active and reactive power drawn from the mains can be controlled.

For a zero voltage vector the change in active and reactive power is [2].

$$\Delta p_0(k) = \{v_{sys\,\alpha}(k)\left[v_{sys\,\alpha}(k) - i_{sys\,\alpha}(k)\,R\right] + v_{sys\,\beta}(k)\left[v_{sys\,\beta}(k) - i_{sys\,\beta}(k)\,R\right]\}\,\frac{T_s}{L} \quad (3)$$

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$$\Delta q_0(k) = \{v_{sys\,\alpha}(k)\,[v_{sys\,\beta}(k) - i_{sys\,\beta}(k)\,R] - v_{sys\,\beta}(k)\,[v_{sys\,\alpha}(k) - i_{sys\,\alpha}(k)\,R]\,\}\,\frac{T_s}{L} \tag{4}$$

And for a generic rectifier voltage $\mathbf{v}_{rec} = v_{rec\alpha} + jv_{rec\beta}$ the change in active and reactive power is.

$$\Delta p_j(k) = \Delta p_0(k) - [v_{sys\,\alpha}(k)v_{rec\,\alpha} + v_{sys\,\beta}(k)v_{rec\,\beta}]\,\frac{T_s}{L} \tag{5}$$

$$\Delta q_j(k) = \Delta q_0(k) - [v_{sys\,\alpha}(k)v_{rec\,\beta} - v_{sys\,\beta}(k)v_{rec\,\alpha}]\,\frac{T_s}{L} \tag{6}$$

The strategy in [2] was to test from a set of space vectors the one that minimize a cost function, and the amount of ripple was related to the number of test vectors in the set. In this work an optimum voltage is obtained by forcing the change in active and reactive power such that their respective error signals are reduced to zero. A drawback of this approach is that the inductor parameters are required, but the processing requirements and current ripple are greatly reduced.

By using the following error signals,

$$\begin{aligned}\epsilon_p &= P_{ref} - P = \Delta p_0 - \frac{T_s}{L}\,[v_{sys\,\alpha}v_{rec\,\alpha} + v_{sys\,\beta}v_{rec\,\beta}]\\ \epsilon_q &= Q_{ref} - Q = \Delta q_0 - \frac{T_s}{L}\,[v_{sys\,\alpha}v_{rec\,\beta} - v_{sys\,\beta}v_{rec\,\alpha}]\end{aligned} \tag{7}$$

From (7), (5), and (6) the required rectifier voltage can be obtained as

$$v_{rec\,\alpha} = \frac{\frac{L}{T_s}\,[(\Delta p_0 - \epsilon_p)v_{sys\,\alpha} - (\Delta q_0 - \epsilon_q)v_{sys\,\beta}]}{v_{sys\,\alpha}^2 + v_{sys\,\beta}^2} \tag{8}$$

$$v_{rec\,\beta} = \frac{\frac{L}{T_s}\,[(\Delta p_0 - \epsilon_p)v_{sys\,\beta} + (\Delta q_0 - \epsilon_q)v_{sys\,\alpha}]}{v_{sys\,\alpha}^2 + v_{sys\,\beta}^2} \tag{9}$$

For unity power operation the resistive terms in (3) and (4) can be neglected, and the last equations can be computed using the following expressions.

$$v_{rec\,\alpha} = \frac{\left[(v_{sys\,\alpha}^2 + v_{sys\,\beta}^2 - \frac{L}{T_s}\epsilon_p)v_{sys\,\alpha} + \frac{L}{T_s}\epsilon_q v_{sys\,\beta}\right]}{v_{sys\,\alpha}^2 + v_{sys\,\beta}^2} \tag{10}$$

$$v_{rec\,\beta} = \frac{\left[(v_{sys\,\alpha}^2 + v_{sys\,\beta}^2 - \frac{L}{T_s}\epsilon_p)v_{sys\,\beta} - \frac{L}{T_s}\epsilon_q v_{sys\,\alpha}\right]}{v_{sys\,\alpha}^2 + v_{sys\,\beta}^2} \tag{11}$$

It can be seen that this strategy requires a correct value for the inductance connecting the rectifier to the mains. However, if this value is known, the computation for the rectifier voltage is straight forward.

II. SIMULATIONS

The simulations are executed on a ADSP-21369 board, and programmed using the manufacturer's compiler for that DSP, VisualDSP++ 5.0 [6] on an IBM compatible PC. The DSP executable file was downloaded into the DSP board through a USB interface and when the simulation was completed the information gathered from the DSP was plotted using GNUPlot. The parameters for the power system are shown in Table I. For the simulation initially the active and reactive power references were set to 250 W and 0 VAR and in t=0.1 s the references were stepped to 400 W and 100 VAR respectively. For comparison purposes, the strategy employed in [2] is simulated for the case where a set of 25 vector is used, the results for this case are shown in Figs. 2 and 3. The control scheme proposed in this work was simulated for the same reference in active and reactive power; the results for this simulation are shown in Figs. 4 and 5. These results show that the proposed technique provides cleaner signals.

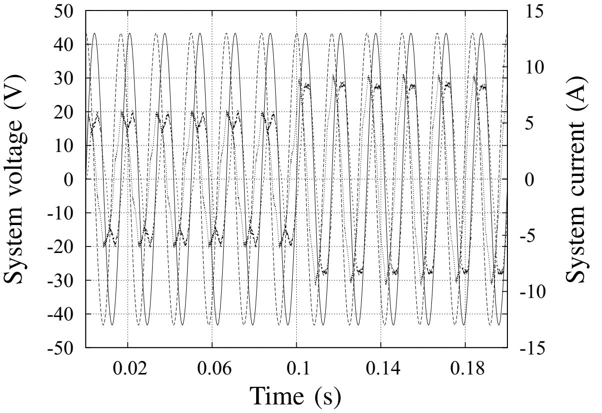

Fig. 2. Steady state simulated α and β component of the system current and voltage using 25 vectors

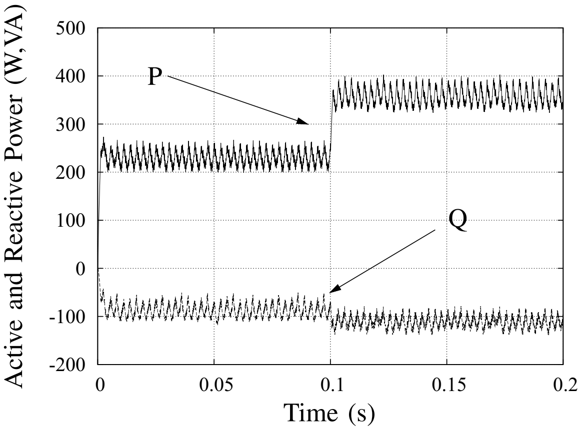

Fig. 3. Active and reactive power taken from the mains using 25 vectors.

III. EXPERIMENTAL RESULTS

The experimental results were obtained using **"PLATFORM III"**[7]. A three-phase IGBT based inverter form the power stage, where the gating signals are provided through an isolating driver. The experimental setup is shown in Fig. 8 and Fig. 9 shows an isolation transformer and the input inductors present at the rectifier's input. Fig. 10 shows the experimental results obtained for phase current and the corresponding line voltage when the OVS method with 25 vectors is used.

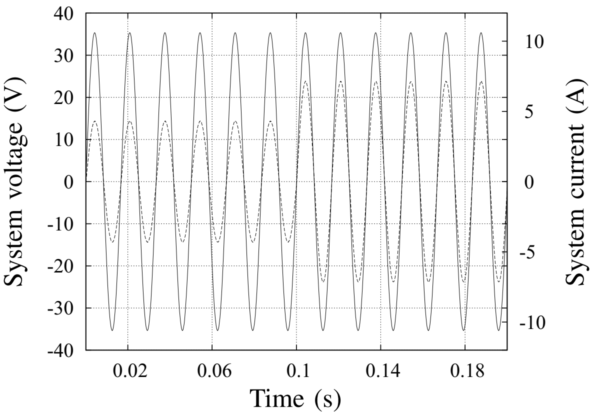

Fig. 4. Steady state simulated α and β component of the system current and voltage when using the proposed control scheme with tuned parameters

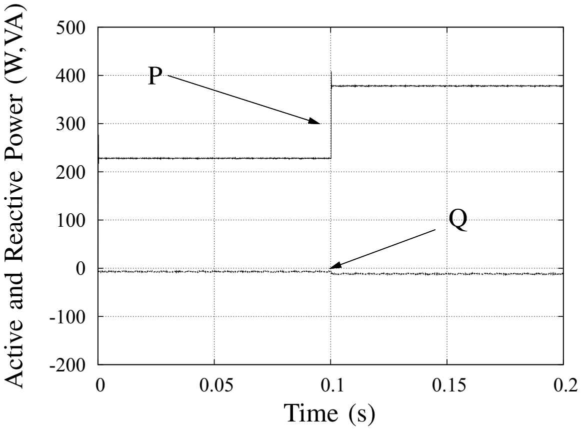

Fig. 5. Active and reactive power taken from the mains when using the proposed control scheme with tuned parameters

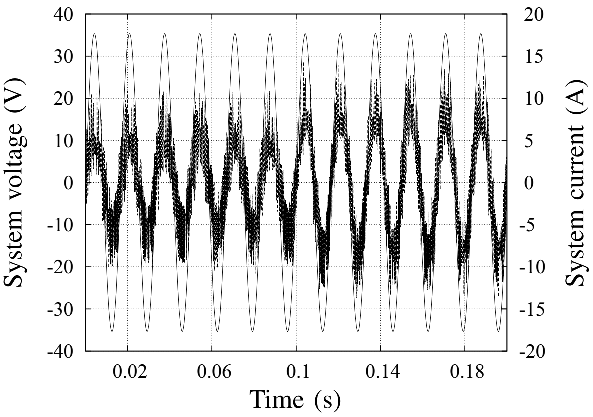

Fig. 6. Steady state simulated α and β component of the system current and voltage when using the proposed control scheme with detuned parameters

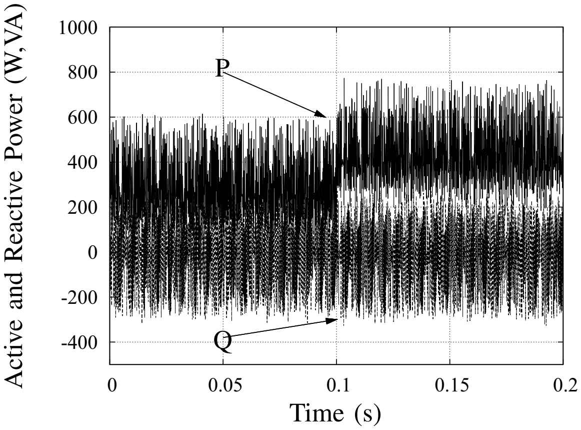

Fig. 7. Active and reactive power taken from the mains when using the proposed control scheme with detuned parameters

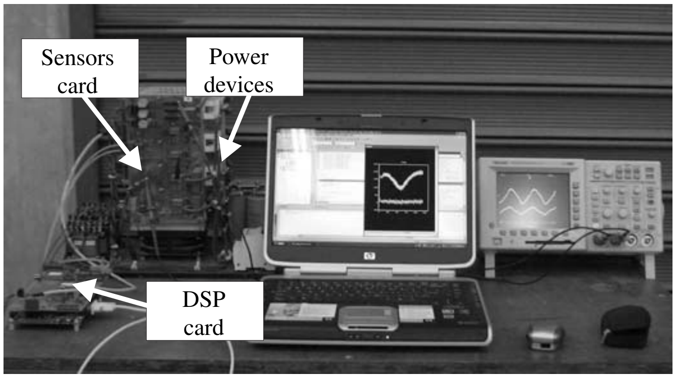

Fig. 8. Experimental test set-up.

Computed active and reactive power during the system startup are shown in Fig. 11. In this case the active power reference was 400 W and the reactive power reference was 0 VAR. When the proposed method is used an improvement in the input currents is obtained. As a result the computed active and reactive power have a lower ripple level. Fig. 12 shows the resulting phase current for the proposed method. The increase in the current magnitude at t=0.1s corresponds to a step in the active power reference as can be seen in Fig. 13. The value of L used in this case was L=1.5 mH. The effect, on the phase current and line voltage, of detuning the value of L is shown in Fig. 14 when L is changed from L=1.5 mH to 4.0 mH.

IV. CONCLUSION

The simulated results show that the proposed strategy based on the direct computation of the rectifier voltage, required to follow the active and reactive power references, is a simple and better choice than the OVS or the traditional table based DPC algorithm. The proposed control scheme was later verified on an experimental test-rig, where the simulation results were similar to those obtained during the experimental tests. Additionally, the effect of detuning of the inductor parameter was tested, and although the performance is lower for a change of more than 100% in the value of L, it still gives a response

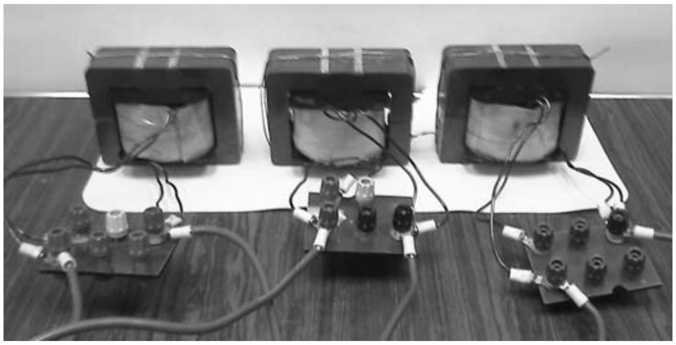

Fig. 9. Input reactors to the switched rectifier.

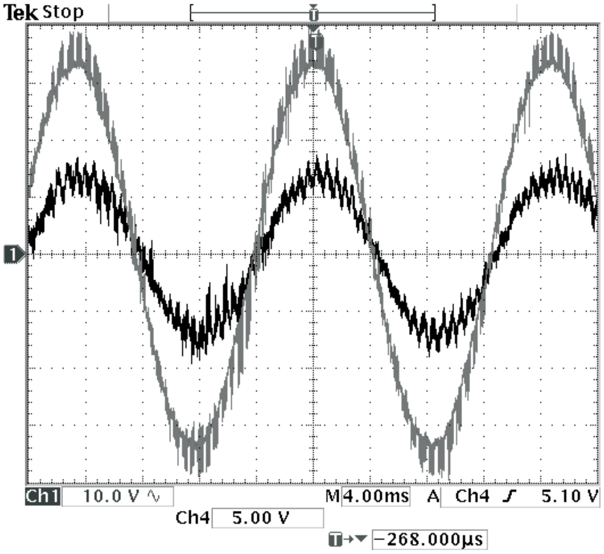

Fig. 10. Steady state experimental phase current and voltage of the system for OVS with 25 vectors

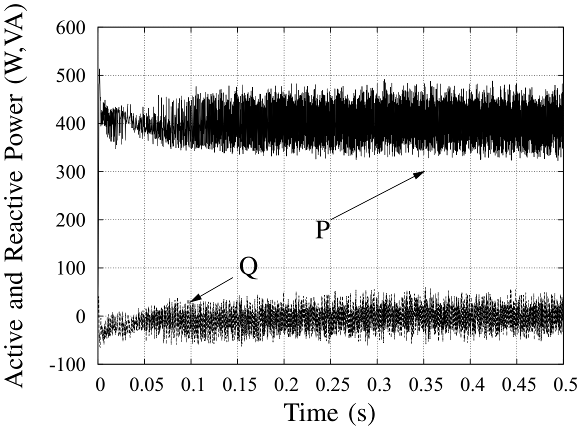

Fig. 11. Computed active and reactive power when using the OVS scheme with 25 vectors

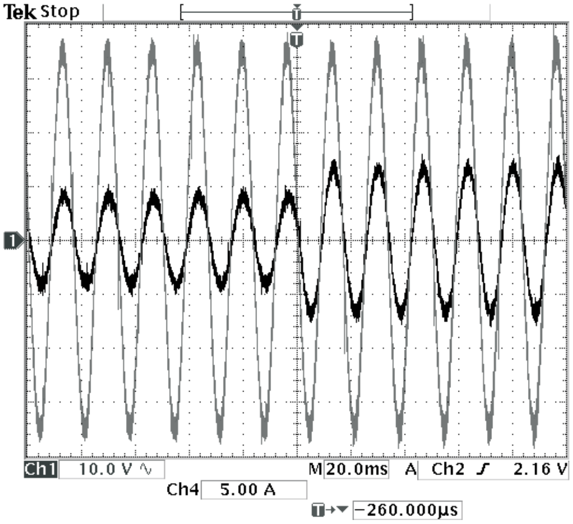

Fig. 12. Steady state experimental phase current and voltage of the system for the proposed control scheme with tuned parameters

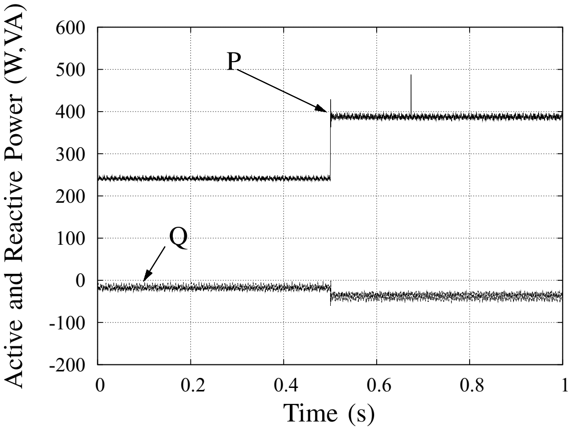

Fig. 13. Computed active and reactive power for the proposed control scheme with tuned parameters

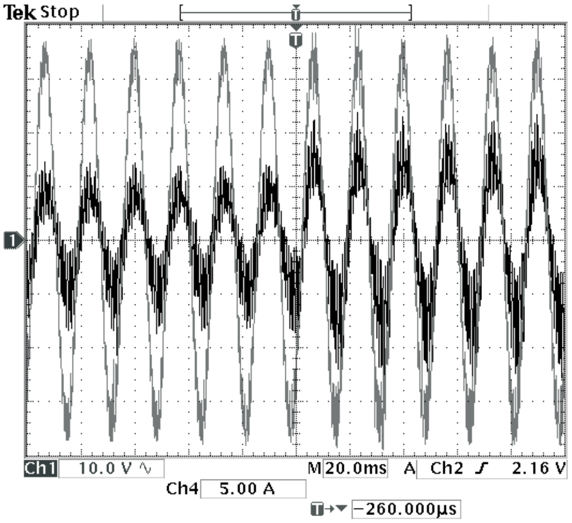

Fig. 14. Steady state experimental phase current and voltage of the system for the proposed control scheme with detuned parameters

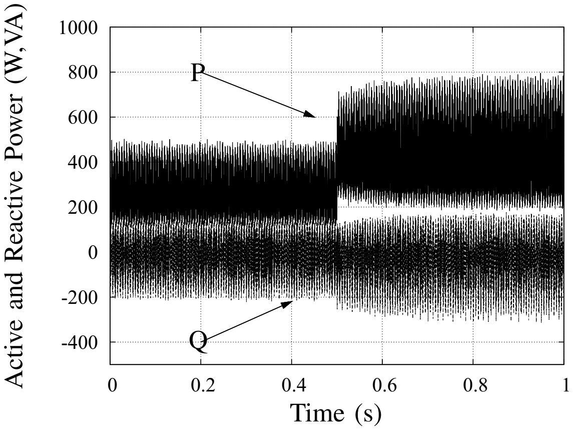

Fig. 15. Computed active and reactive power for the proposed control scheme with detuned parameter

TABLE I
POWER CIRCUIT SIMULATION AND EXPERIMENTAL PARAMETERS

Per phase system voltage	25 V_{RMS}
System frequency	60 Hz
L	1.5 mH
R	0 Ω
Load Current	2 A
DC link capacitor	1000 μF
Switching frequency	10 kHz

similar to the one obtained with the OVS. The decrease in computational cost makes this method a candidate for implementation on low grade processors o micro-controllers.

ACKNOWLEDGMENT

The authors would like to thank the Dean of research and development at the Simón Bolívar University for the financial support to this work.

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