Experimental Implementation of a DC/AC Converter

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Abstract — Nowadays, the demand of better power converters control systems plays an important role, for DC/AC or AC/DC conversion. With the introduction of microprocessors in control systems over the use of electronic components, systems have improved their efficiency.

This paper aims to study the experimental implementation of a voltage source inverter control system, comprising a PI controller responsible for controlling the voltage on the capacitor and a PI controller responsible for controlling the current. To this end, a DSP with software implemented was used, for the implementation of the control system proposed. The readings of voltages and currents values are taken from voltage and current sensors. For the inverter semiconductors gate signals, a PWM method that compares the sinusoidal voltages with a triangular wave was used.

The results confirm the proper functioning of the inverter, controlled by the proposed system. The system responds correctly to a variation of the reference values, verifying the decoupling between the d and q current components. Therefore, the active power is not influenced by the reactive power.

Keywords—DC/AC Converter, PI Controller, DSP, PWM

I. INTRODUCTION

Many of the control systems previously made use many electronic components, which, in case of failure of any component, caused great problems of reliability and robustness. With the introduction of microprocessors (such as DSP’s) in the control systems, the number of electronic components and the space they occupy were reduced and the system’s efficiency improved.

This paper aims to study the implementation in the laboratory of a voltage source inverter control system, controlled by a DSP, which contains proper software for implementing the voltage control with an internal current control loop.

To perform this implementation it is necessary that the proposed system contains current and voltage sensors, needed for the measures of the current and the voltage values in the DSP. After these values are available on the microprocessor, the routines for the implementation of the PI current and voltage controllers get into operation.

The influence of the PI controllers in the control system is also studied, as well as its implementation in a microprocessor.

Another important point to be checked is the system time response to disturbances imposed in order to provide system stability to the implementation of this system.

II. CONVERTER MODEL

A. Voltage Source Inverter

This inverter is responsible for the DC to AC conversion. Typically, the semiconductors used for this conversion are IGBT’s. The main advantages of this type of semiconductors are related to the high commutation frequency and the gate signal control system easy to implement. One can find the characteristics of IGBT’s in [1]. The inverter model in [1] consists of six semiconductors, with 3 arms, which each arm has 2 semiconductors associated: one superior and another one inferior. Each of this semiconductors, or IGBT’s, has a gate signal associated. The gate signal in the semiconductor inferior is a complement of the other superior.

Through the inverter model, the grid voltages, in function of the capacitor voltage, are as in

\[
e_a = \frac{2a_a - a_b - a_c}{3} U_{dc} \quad (1)
\]

\[
e_b = \frac{2a_b - a_a - a_c}{3} U_{dc} \quad (2)
\]

\[
e_c = \frac{2a_c - a_b - a_a}{3} U_{dc} \quad (3)
\]

To simplify the equations and the manipulation with them, some variable transformations are used. To transform the variable three-phase system into an invariable two-phase system, Clarke’s Transformation and Park’s Transformation are used [1] and [2]. The Clarke’s Transformations transforms the three-phase variables abc into a αβ reference system. With these variables from the two-phase reference one can transform to a reference synchronous with the main grid voltage, applying the Park’s Transformation. The axes in this reference are the direct component, d, and the quadrature component, q. The inverse transformations are also allowed to transform again to the three-phase system.

B. Sinusoidal Pulse Width Modulation (SPWM)

An inverter is usually used in conjunction with variable speed electric machines to produce sinusoidal, alternating and
three-phase voltages, from a continuous voltage source. Since the AC voltage is defined by two characteristics, such as magnitude and frequency, it is essential to set a strategy to control these quantities.

There are several modulation techniques of Pulse Width Modulation (PWM). A well known and used in many applications is the sinusoidal modulation technique, called Sinusoidal Pulse Width Modulation (SPWM). This technique consists in comparing the three-phase sinusoidal modulating waves, which are meant to drive an output, with a triangular carrier wave, with a certain frequency.

In order to create the desired sine waves, with a phase difference of 120° between each arm of the inverter, the method performs modulation with a low frequency sine wave and the magnitude defined by the modulation index, and a high frequency carrier triangular wave. The modulation index can be between 0 and 1 [3] and [4]. In this type of modulation, the output voltage is positive if the modulating wave is higher than the carrier wave and negative if the modulating wave is lower than the carrier wave.

Previously, this technique was applied by using an analog circuit, which was very complex and difficult to implement. Currently, with the great technological advances in the power systems control area, the generation of PWM signals have become digital. This brings many advantages, including the ability of the carrier wave frequency is much higher, which improves the waveform that one wish to obtain. The digital implementation of PWM allows greater flexibility in implementing a control system for a converter, due to the simplification of implementation.

III. CONVERTER CONTROL SYSTEM

A. Current Control Loop

The current control in a rotating frame is the most suitable for digital implementation. The main objective of this type of control is the fact that this type of controllers, consisting of PI controllers, process continuous signals. The controller proposed for the converter control system will be of this type. The outputs of the current controller will be the input of the voltage of SPWM modulator, which generates the six gate signals of the inverter semiconductors. Once again, this type of control along with the SPWM is the most common for digital implementation.

Compensators can be of various types, each specific for each situation. A compensator with only Proportional (P) gain does not guarantee zero static error. The Proportional compensator causes the controller to produce a response related to an error, i.e., as the error increases, the Proportional gain also increases so that correction can be possible. The proportional gain effect tends to reduce the error as time passes. However, the effect decreases when the error approaches zero, for which does not converge. The result is the appearance of a small static error. Moreover, for higher values the proportional gain can cause instability. On the other hand, a compensator with only Integral (I) action, results in a system with a slow time response [5]. Considering these aspects, the ideal is to choose a compensator which is efficient and simple to implement. Thus, the Proportional-Integral (PI) compensator is the correct solution, and therefore appropriate for systems with frequent load changes.

The current control loop is represented in Fig. 2.

1) Synthesis of the current control loop: In order to improve the controllers performance, typically decoupling systems are introduced. This decoupling system is represented in Fig. 1.

![Fig. 1. Current decoupling system.](image)

2) Current controller parameters: After some manipulations with the converter model equations, the PI current controllers are determined as in

$$K_i = \omega c R$$ (4)

$$K_p = \omega c L$$ (5)

By (4) and (5), the controller parameters depend on the grid parameters, like $R$ and $L$. The parameter $L$ must be dimensioned carefully because a low inductance value may lead to a significant increase in current. Moreover, a higher inductance value will decrease the current value but decreases the performance of the voltage source inverter.

B. Voltage Control

For the converter control to be complete, it is necessary to control the capacitator voltage, source of continuous voltage. The purpose of the voltage control is to change the current reference value in the supply internal control loop. The complete control system is represented in Fig. 2 [1].

The control system shown in Fig. 2 consists of two control loops of the inverter output currents and a control loop for the capacitor voltage on the reference current in the axis d. The component along the axis q can be used to control the reactive power exchanged between the inverter and the grid, while the component along the axis d controls the active power. Usually, the reference current in the axis q is null, which maximizes the power factor. This control will allow the alternating current
side to have the ability to follow the pattern of reference imposed by the control voltage in the capacitor.

![Fig. 2. Control system implementation scheme.](image)

**1) Synthesis of the voltage control loop:** Again, the choice of the compensator is important. To scale the voltage control parameters is necessary to apply a Proportional-Integral (PI) controller, because it provides zero static error and is suitable for this type of systems.

One of the main objectives of the converter control system is to control the active power and the reactive power. Thus, the voltage and current axes d components of the rotating two-phase reference control the active power delivered to the grid, while the components along axis q control the reactive power.

**2) Voltage control parameters:** The voltage control system is composed by a PI compensator. The controller must be dimensioned so that the closed loop system remains stable and with a good response to the elimination of possible disturbances. The proportional and the integral gains must be determined as in

\[
K_p = \frac{C_{U_{dc}}}{2T_{p}U_{d}} \\
K_i = \frac{C_{U_{dc}}}{8T_{p}U_{d}}
\]

As the internal current control, limiters are introduced to limit the converter short-circuit and to prevent the converter to generate currents above the converter nominal value.

**IV. IMPLEMENTATION**

The control system to be implemented in the lab, to control the inverter from the capacitor voltage and the output currents of the inverter, is composed by a Signal Acquisition Board (SAB) and a Digital Signal Processor (DSP).

The Signal Acquisition Board is responsible for acquiring the voltages and currents signals required for the control system. The signals are acquired through the use of voltage and current sensors, which convert these signals into voltages between certain values, thus allowing the input of analog signals in the DSP to be processed. To be able to perform the current control system proposed, it is only necessary to read the currents in two phases, and only two output voltages of the converter. On the other hand, for the control of the voltage across the capacitor is necessary that the Signal Acquisition Board has one more voltage sensor for reading of this voltage.

The Digital Signal Processor will then receive the two current values, the two phase voltages and the voltage of the capacitor read by the sensors and will generate the six control gate signals of the converter semiconductors. The processor will have software capable of performing the control of the voltage across the capacitor and the control of the output currents of the inverter. For reasons related to the power of the microprocessor, it is connected to a board called the DSP Board, whose function is to power the processor and make the connection of the DSP with the modules that trigger the inverter. In the Fig. 3 is shown the implementation scheme of the complete control system proposed, with the closed loop voltage and current control system.

![Fig. 3. Laboratory implementation scheme of the closed loop control system.](image)

**A. Equipment characteristics**

**1) Voltage Source Inverter:** To change the default, adjust the template as follows. The inverter chosen for the implementation of this control system is from the manufacturer SEMIKRON. The main inverter characteristics are described on Table I.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irms</td>
<td>50 A</td>
</tr>
<tr>
<td>Vac</td>
<td>380 V</td>
</tr>
<tr>
<td>Udc</td>
<td>800 V</td>
</tr>
<tr>
<td>Fsw máx</td>
<td>10 kHz</td>
</tr>
<tr>
<td>C</td>
<td>4700 μF</td>
</tr>
<tr>
<td>η</td>
<td>98%</td>
</tr>
</tbody>
</table>

![TABLE I. INVERTER CHARACTERISTICS.](image)
2) **Digital Signal Processor (DSP):** The microprocessor used to process these signals is a microprocessor from MICROCHIP, called *dsPIC30f4011* [6]. This processor has the ability to process these signals because it has 9 analog input channels and 6 PWM output channels. The characteristics are shown more detailed in [6].

**B. Software of the control system**

The software to control the inverter with this system proposed was made with the help of MPLAB.

**V. EXPERIMENTAL RESULTS**

The following tests were made, to evaluate the performance of this control system implemented on a microprocessor: a test with the closed loop current control and another one with the closed loop voltage control.

**A. Closed loop current control**

Some tests were made to evaluate the inverter performance with different values of the proportional and the integral gains. In the Fig. 4 are represented the three-phase currents for a variation of the reference value of the component d of the current from 0 to 10 A.

In the Fig. 5 are represented the time responses of the components d and q of the current, in p.u., for the same variation.

**B. Closed loop voltage control**

The test performed to control the voltage on the capacitor was to vary the reference voltage of the capacitor from 250 V to 350 V. This control loop will generate a d-axis reference current, which will generate a response in the PI controller in the internal current control loop. The system will have a time response, shown in Fig. 6. In Fig. 7 is represented the time response for the variation of the current on the d-axis in this test.

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**VI. CONCLUSIONS**

The purpose of this paper was to study the experimental implementation of a voltage source inverter control system, controlled by a DSP, which contains suitable software for the implementation of this complete control system. To this end, PI regulators were used. The system responded properly, due to the three-phase output currents with the desired frequency and amplitude, synchronized with the main grid.
In the internal current control loop test is concluded that the decoupling of the system current components \( d \) and \( q \) were working properly, because, as in the results, when a component of the current suffering a step, the other remained with the initial value.

In the voltage control loop test, the system worked properly and had a stable response. Nevertheless, there was not a rapid response as desired, due to the non utilization of the proportional gain, considering zero the integral gain of PI controller of the voltage control system. In addition, as it was not considered the integral gain, the static error was not zero for the voltage on the capacitor, but was less than 10\%, making this a good system response to an increase or decrease in the value of the reference voltage.

REFERENCES