



# Development of Power Converter Digital Control System Using Psim, Matlab/Simulink And Digital Signal Processor Stm32f407

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## Abstract

At present, the development of digital control systems based on a microcontroller is carried out using a variety of modeling systems such as, for example, Matlab and PSIM. Modern programming technologies allow to combine Matlab and PSIM to perform simulations to take advantage of both modeling systems. The present market offers evaluation boards with a powerful microcontroller, which supports different peripheral units and data exchange protocols and allows connecting to a personal computer [1, 2]. This article deals with the development of the modeling method in which the control system based on the STM32F407 microcontroller will control the mathematical model of the developed converter.

**Keywords:** power electronics, digital control system, converter, PI-regulator, microcontroller.

## 1. Introduction

Nowadays, there is a lot of perfect modelling tools to simulate power electronics in different regimes and conditions. It helps engineers to improve efficiency, reliability, quality and reduce development time of an electronic device.

This article proposes the simulation technique of the digital control of the converter by using a current loop by means of PSIM, Matlab/Simulink and the digital signal processor (DSP) – STM32F407. The STM32F407/STM32F417 microcontroller line is designed for industrial and automobile applications where a high level of performance, embedded memories and rich peripheral set are required.

## 2. Simulink Model

Figure 1 shows the Simulink model, which provides the link between PSIM and the DSP evaluation board. The DC-current is controlled by means of the STM32F4DISCOVERY evaluation board. The STM32F4DISCOVERY kit is based on the STM32F407VG microcontroller with the ARM Cortex-M4 32-bit core and FPU. The STM32F407VG is a low-cost high-performance microcontroller with frequency up to 168 MHz, up to 1 Mbyte of Flash memory, up to 15 communication interfaces and a wide peripheral support. The STM32F4DISCOVERY supports the USB 2.0 OTG FS protocol. We will set up a virtual COM-port in Matlab to transfer data by this protocol. So, the numerated blocks in Figure 1 provide the following: Block 1 starts simulation of the electrical scheme in PSIM; Block 2 converts data from PSIM model into two-byte message; Block 3 transmits and receives data from the evaluation board; Block 4 converts data in two-byte format from the evaluation board into the model data. Block 3 is the developed S-function, which creates a virtual COM-port, sets the baud rate at 115200 bps, writes data into

the virtual COM-port and receives the computation results from the microcontroller.

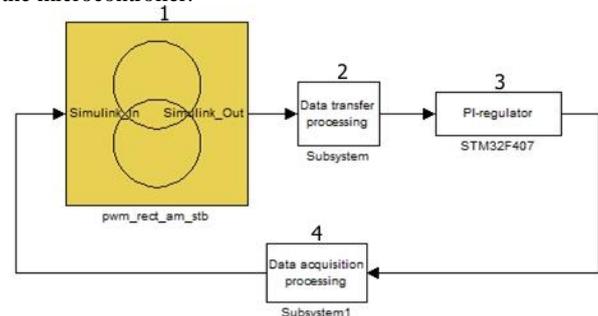


Figure 1. Simulink model for simulation the electrical control of the converter

## 3. Psim Model

The PSIM model of the developed converter can be seen in Figure 2. The converter uses sinusoidal pulse-width modulation. The base frequency of the sinusoidal reference wave is set at 50 Hz and the triangular carrier wave's frequency is set at 2500 Hz.

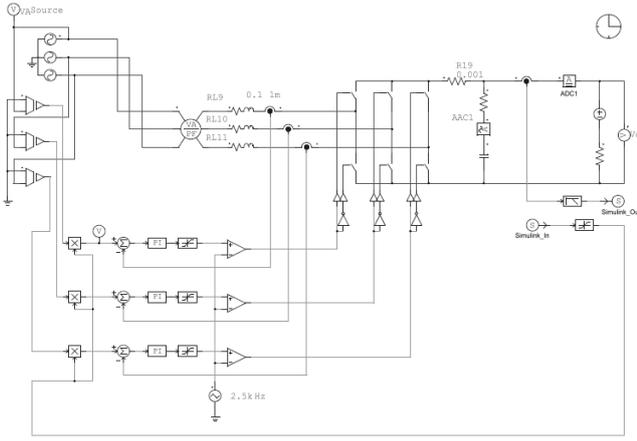


Figure 2. PSIM model of the converter

The SimCoupler Module provides the interface between PSIM and Simulink using SLink nodes [3]. Out Link Nodes send values from the PSIM model to the Simulink model, and In Link Nodes receive values from the Simulink model for the PSIM model.

We are going to measure the DC-current and send it to Simulink by connecting a current sensor across the DC-bus and placing an Out Link Node at the current sensor output. The Out Link Node will be renamed as “Simulink\_Out”.

In order to determine references for the converter a comparison between ideal and actual values of the DC-current is implemented and this error signal is regulated by means of a PI-regulator [4].

#### 4. Pi-Regulator Equations

In this work we use the series PI-regulator with the structure shown in Figure 3. The series PI-regulator has configuration in which the proportional gain appears in series with the integral gain. A feature of this structure is that there is less inter-action between the two gains, simplifying the tuning process slightly. The series configuration is useless in applications where the proportional gain can be equal to zero.

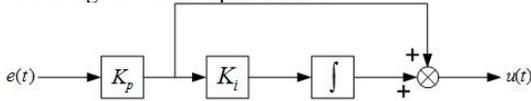


Figure 3. Structure of the series PI-regulator in continues time

The transfer function of the series PI-regulator is:

$$F(s) = K_p \left( 1 + \frac{K_i}{s} \right) = \frac{K_p s + K_p K_i}{s} \quad (1)$$

We can rewrite series configuration in the form:

$$F(s) = \frac{b_1 s + b_0}{s}, \quad (2)$$

where:

$$b_0 = K_p K_i, \quad (3)$$

$$b_1 = K_p. \quad (4)$$

We can perform replacement of each instance of ‘s’ in the original transfer function with the following term involving ‘z’ and the sampling period T for converting a continuous time transfer function into equivalent discrete time form:

$$s = \frac{z-1}{Tz+1} \quad (5)$$

After the substitution to equation (2), we have:

$$\begin{aligned} F(z) &= \frac{b_1 \frac{z-1}{Tz+1} + b_0}{\frac{z-1}{Tz+1}} \\ &= \frac{[b_1 2(z-1) + b_0 T(z+1)] T(z+1)}{T(z+1)} \\ &= \frac{b_1 2(z-1) + b_0 T(z+1)}{2(z-1)} = \\ &= \frac{2[b_1(z-1) + b_0 \frac{T}{2}(z+1)]}{2(z-1)} = \frac{b_1(z-1) + b_0 \frac{T}{2}(z+1)}{z-1} = \\ &= \frac{b_1 z - b_1 + b_0 \frac{T}{2} z + b_0 \frac{T}{2}}{z-1} = \frac{(b_1 + b_0 \frac{T}{2}) z - b_1 + b_0 \frac{T}{2}}{z-1} \quad (6) \end{aligned}$$

Now we can write the transformed equation (6) in the form:

$$F(z) = \frac{c_1 z + c_0}{z-1}, \quad (7)$$

where the numerator coefficients are:

$$c_1 = b_1 + \frac{T}{2} b_0, \quad (8)$$

$$c_0 = -b_1 + \frac{T}{2} b_0. \quad (9)$$

The transformed equation (5) must be modified by proportional coefficient in order that the gains of the original and transformed systems are matched:

$$A = \frac{b_0}{c_1 + c_0} = \frac{b_0}{b_1 + \frac{T}{2} b_0 - b_1 + \frac{T}{2} b_0} = \frac{b_0}{T b_0} = \frac{1}{T}. \quad (10)$$

Therefore, a discrete time transfer function is:

$$F(z) = A \frac{c_1 z + c_0}{z-1}. \quad (11)$$

The corresponding difference equation is:

$$F(z) = \frac{u(z)}{e(z)} = A \frac{c_1 z + c_0}{z-1}, \quad (12)$$

$$u(z)(z-1) = A(c_1 z + c_0)e(z), \quad (13)$$

$$zu(z) = u(z) + A c_1 z e(z) + A c_0 e(z). \quad (14)$$

Application of the shifting theorem of the z-transform gives:

$$u(k+1) = u(k) + A c_1 e(k+1) + A c_0 e(k), \quad (15)$$

or at current sampling time:

$$u(k) = u(k-1) + A c_1 e(k) + A c_0 e(k-1). \quad (16)$$

The series structure of the PI-regulator in discrete time is shown in Figure 4.

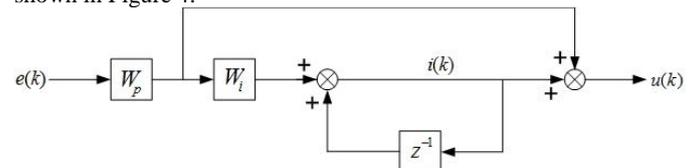


Figure 4. Structure of the series PI-regulator in discrete time

The difference equation can be found as follows:

$$u(k) = W_p e(k) + i(k), \quad (17)$$

$$i(k) = W_p W_i e(k) + i(k-1), \quad (18)$$

$$i(k-1) = u(k-1) - W_p e(k-1), \quad (19)$$

$$u(k) = W_p e(k) + W_p W_i e(k) + u(k-1) - W_p e(k-1), \quad (20)$$

$$u(k) = u(k-1) + W_p (1 + W_i) e(k) - W_p e(k-1). \quad (21)$$

Comparing equations (16) and (21), we see that:

$$W_p = -Ac_0, \quad (22)$$

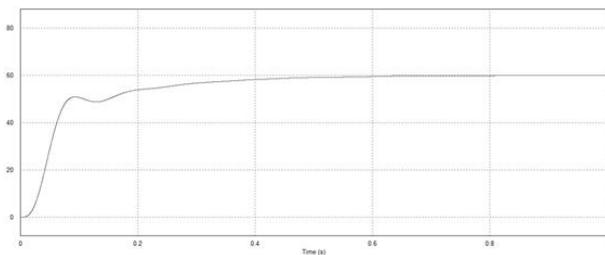
$$W_i = -\left(1 + \frac{c_1}{c_0}\right). \quad (23)$$

Substituting in (22)-(23) expressions (3)-(4) and (8)-(10) we can write the discrete time series PI gains using corresponding continuous time PI gains:

$$W_p = \frac{1}{T} K_p \left(1 - \frac{T}{2} K_i\right), \quad (24)$$

$$W_i = \frac{TK_i}{1 - \frac{T}{2} K_i}. \quad (25)$$

## 5. Simulation Results



**Figure 5.** Stabilized current of 60 A, measured by ammeter ADC1 in Figure 2

The presented model has been tested with different values of the PI gains. In Figure 5 is shown that the system has been stabilized at the reference current of 60 A in 1 second by the PI-regulator.

## 6. Conclusion

In this paper we considered the simulation technique which gives an opportunity to control the mathematical model by means of the DSP evaluation board. The presented model has a block structure, which facilitates tuning of different aspects of the model even by different engineers at the same time. The mathematical background is also described, which gives perfect simulation results.

## 7. Acknowledgments

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## References

- [1] Talanov M.V., Karasev A.V., Talanov V.M. Implementation of extended Kalman filtering algorithm with improved flux estimator on TMS320F28335 processor for induction sensorless

drive // Proceedings of the 6th European Embedded Design in Education and Research Conference (EDERC), Milano, Italy: IEEE-INST ELECTRICAL ELECTRONICS ENGINEERS INC. – 11-12, September, 2014. – Pp. 119-123.

- [2] Talanov M V, Karasev A V, Talanov V M. Application of the kalman filter in control systems of power electronics. J. Fundam. Appl. Sci., 2017, 9(7S), 917-924.
- [3] SimCoupler Module Tutorial. – URL: <https://powersimtech.com/drive/uploads/2016/12/Tutorial-Simcoupler-Module.pdf> [cit. 2018-06-04].
- [4] Digital PI Controller Equations. – URL: [https://e2e.ti.com/cfs-file/\\_\\_key/](https://e2e.ti.com/cfs-file/__key/)
- [5] communityserver-discussions-components-files/902/PI-controller-equations.pdf [cit. 2018-06-04].