SIMULATION ANALYSIS OF DC/AC INVERTER UNDER NONLINEAR LOAD

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Abstract

This article represents an application of Matlab-Simulink in investigation of behavior of single phase voltage source PWM DC/AC inverter (VSI PWM). The aim of the article is to develop a robust, fully digital control algorithm with using of deadbeat control theory in controlling of proposed VSI. Proposed control algorithm consists of two controllers, current and voltage. Control algorithm is tested on developed inverter model. Simulation results have been given to verify the proposed control scheme.

1 Introduction

In recent years there has been a big boom in area of mobile devices such as mobile phones, computer and tablets. People are using them whether at work or while traveling, etc. However, these devices must be charged in order to maintain their functionality. If a passenger wants to use them on board of the wagon, there must be an isolated network with mains voltage 230V/50Hz. One of the ways to create such a network is to use a single-phase VSI.

An input rectifier with capacitive filter represents a pure nonlinear load. This input rectifier is part of almost all mobile chargers. Nonlinear load causing a huge amount of harmonic distortion in the output voltage of the inverter. Therefore, the proposed control algorithm must be able to maintain this Total Harmonic Distortion (THD) as small as possible (below 5% by UIC standard).

2 System modeling

As we mentioned before, we developed a Simulink model of the VSI. A half-bridge topology with LC output filter had been chosen as inverter topology Fig. 1. The advantages of this topology are: small amount of switches, reduced switching losses, increased reliability, simple control, lower price [1].

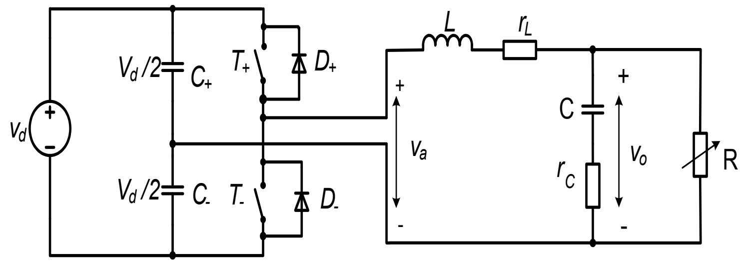


Figure 1. Half-bridge topology with LC output filter.

The Simulink model (Fig. 2) has been developed by using of SimPowerSystems library and common control blocks. As switches we had used a model of IGBT and model of diode with initial parameters. For inductor, capacitor and resistor we used an RLC branch.

Sine modulated PWM (SPWM) can be used to create the sinusoidal output voltage. SPWM can be divided to two categories:

- unipolar SPWM,

- bipolar SPWM.

The unipolar SPWM cannot be used for controlling of the half-bridge topology because we cannot create zero vectors of the output voltage. Instead, we are forced to use a bipolar SPWM (Fig. 3).

The amplitude modulation ratio m_a is defined as:

$$m_a = \frac{V_{control}}{V_{tri}} \quad (1)$$

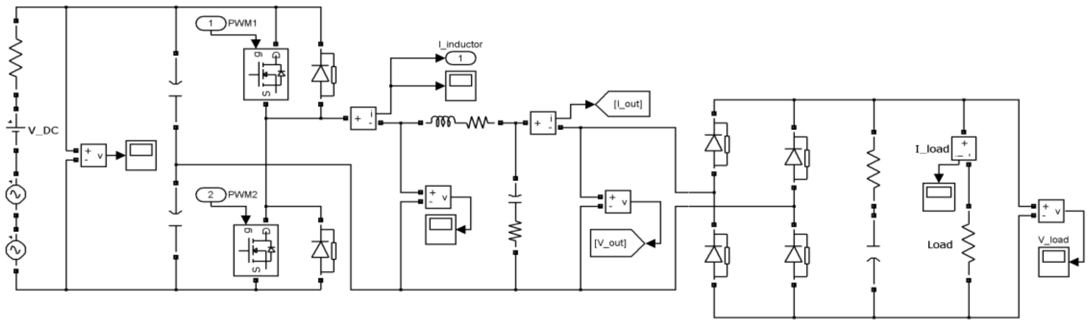


Figure 2. Simulink model of the proposed VSI with rectifier load.

where $V_{control}$ is the peak amplitude of the modulation signal and V_{tri} is the peak amplitude of the carrier triangular signal. The frequency modulation ratio m_f is defined as:

$$m_f = \frac{fs}{f_f} \quad (2)$$

where f_s is switching or carrier frequency of the triangular signal and f_f is desired fundamental frequency of the inverter output voltage.

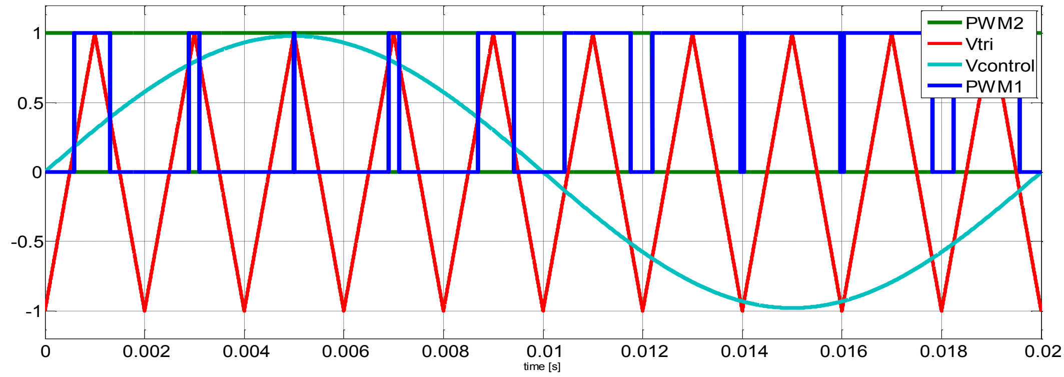


Figure 3. SPWM with bipolar switching.

The amplitude of the fundamental frequency component of the output voltage varies linearly with m_a ($0 > m_a < 1$). The harmonics in the output voltage waveform appear as sidebands centered around the switching frequency and its multiples. In real world application, we must ensure that both switches will never be switched on simultaneously. If both switches will be switched on simultaneously, they will create the short circuit. To prevent this situation we include a dead time to SPWM pulses (Fig 4 and Fig 5), [1, 2].

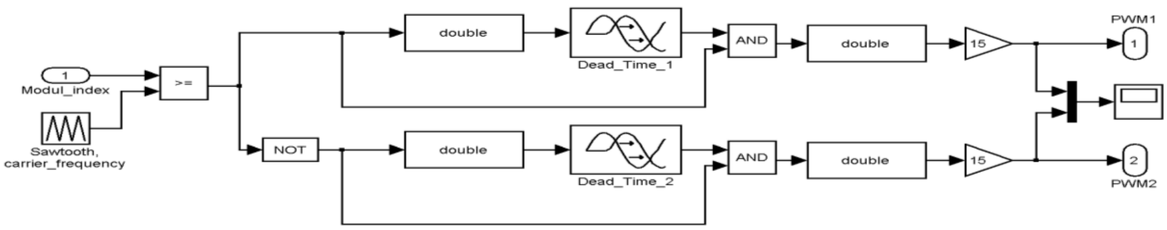


Figure 4. Simulink model of the bipolar SPWM with dead time.

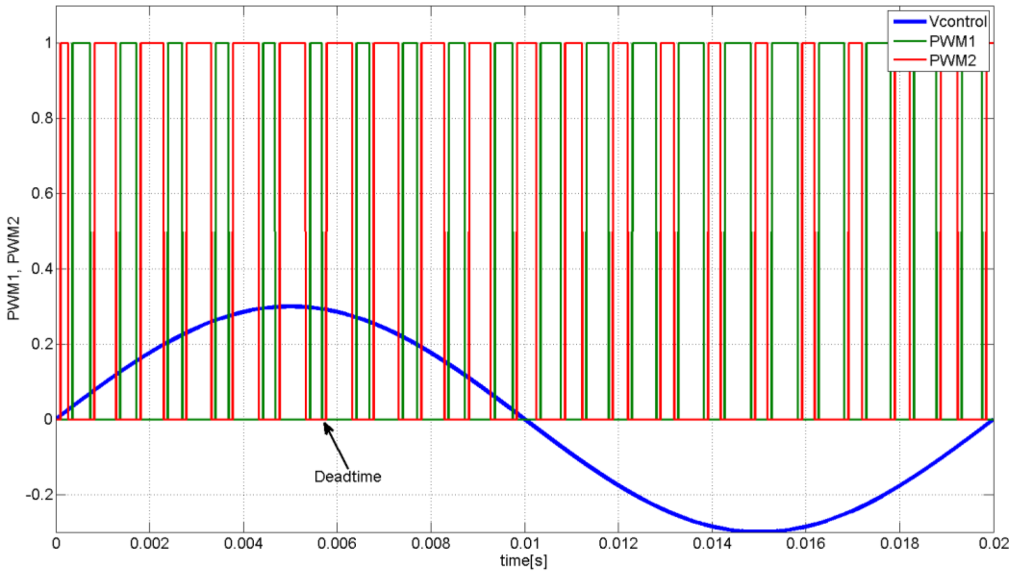


Figure 5. SPWM with dead time.

3 Control scheme

Proposed control scheme consist of two cascades loops – voltage loop and current loop. It has effect of decoupling the resonant poles produced by the output LC filter. On the other hand, inner current and outer voltage loop can be designed separately. Discrete PI controller is used in outer voltage loop and deadbeat controller is used in inner current loop (Fig. 6). Design of these controllers and control algorithm is described in [3, 4, 5, 6].

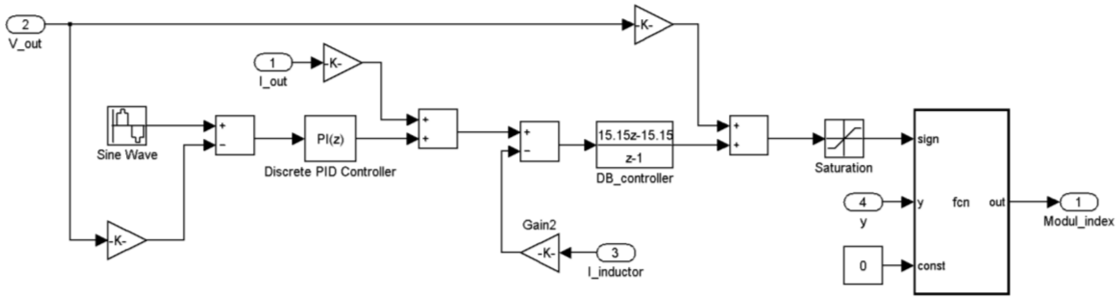


Figure 6. Proposed control algorithm DB_&_PI.

We must remark, that use of such high controller gains is only approved if there is a nonlinear load. If the load is linear (reactive) a traditional approach with a PI controller (outer voltage loop) and a P controller (inner current loop) gives good results (Fig. 7).

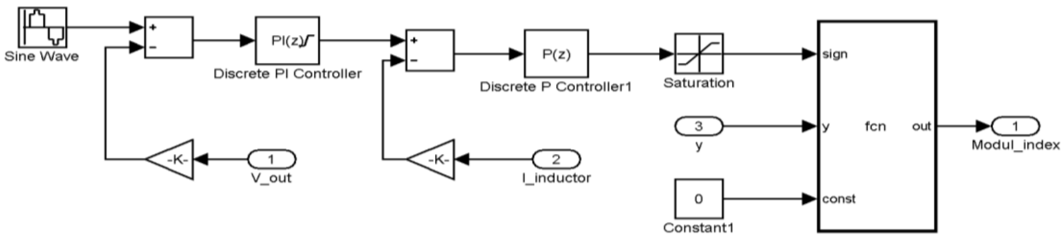


Figure 7. Proposed control algorithm PI_&_P.

To decide, which type of load is connected to the inverter, we developed the control strategy. This strategy is illustrated by the flowchart shown in the (Fig. 8). From this control strategy is obvious that if the output current is determined to have only a reactive component than traditional approach is selected (PI_&_P, Fig. 7). If there is nonlinear load (harmonic component) the new control algorithm is selected (DB_&_PI, Fig. 6).

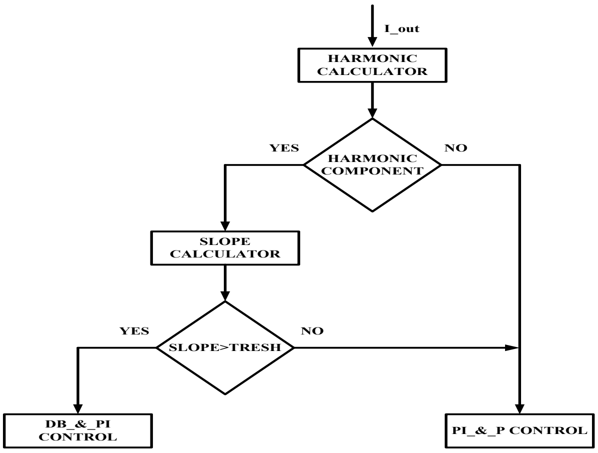


Figure 8. Flowchart of proposed control strategy.

Harmonic component calculation is done based on the active current separation method (Fig 9a.), described in [7, 8, 9, 10]. A simple slope calculator (Fig 9.b) determines a variable proportional with dI_out/dt by calculating the difference between two consecutive samples I_out(k) - I_out(k-1) of the output current.

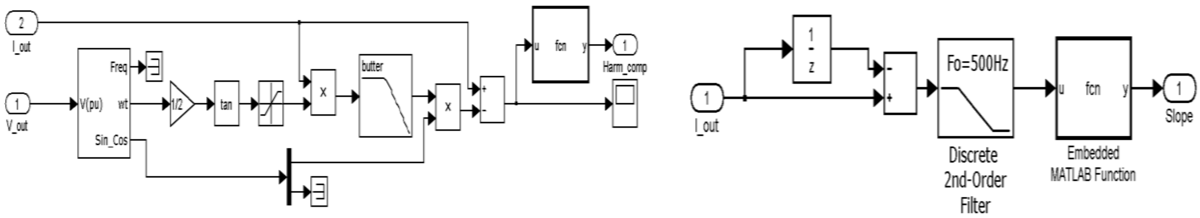


Figure 9. a) Harmonic calculator, b) Slope calculator.

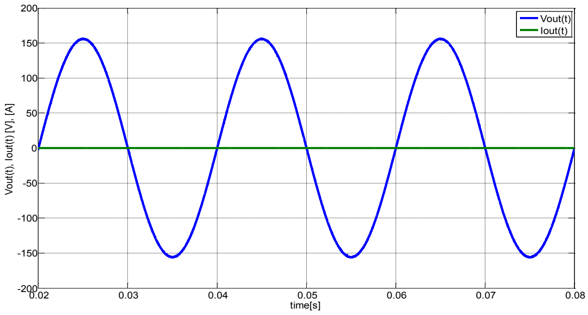
If the load is determined to have nonlinear component and slope variable is greater than preset threshold than the controllers based on the deadbeat theory are selected. The nonlinear load may draw current spikes for limited time only and high frequency oscillations due to the high gain of controllers may occur during the time the current is zero or it has small variation.

4 Simulation results

The simulation was done on developed Simulink model of the inverter. Parameters of the inverter (Table 1.) comes from real world application (SK2 24/230, EVPU a. s.).

Table 1. Parameters of the PWM inverter.

Parameters of inverter	Values [Units]
L	1mH
C	6,7μF
P_O	1kW
U_O	110V
$f_{fundamenal}$	50Hz
f_{switch}	15kHz
f_{sample}	15kHz



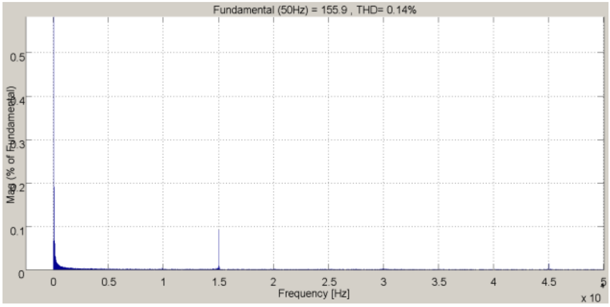
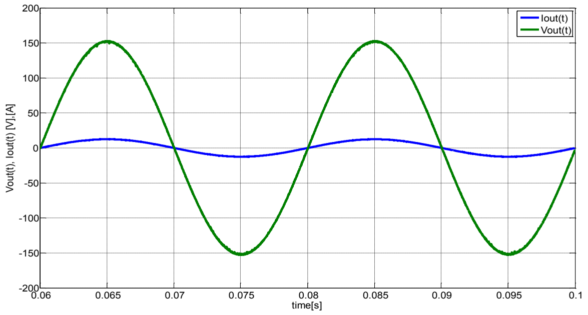


Figure 10. a) Output voltage waveform, b) FFT of the output voltage. No load.

On the Fig. 10a, we can see the inverter output voltage waveform and fast fourier transformation of this output voltage (Fig. 10b) under no load. The fundamental harmonic has value of 156V and THD has value of 0.14%. The influence of the bipolar SPWM is obvious from the Fig. 10b.



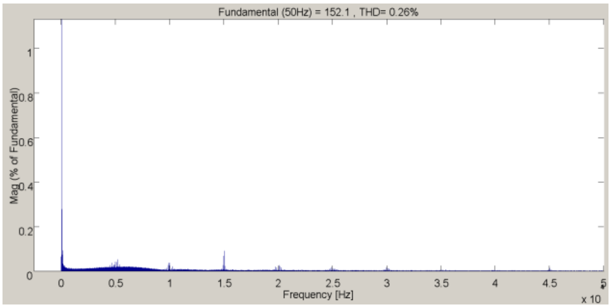


Figure 11. a) Output voltage and output current, b) FFF of the output voltage. Full load.

Fig. 11a, shows us the output voltage and output current waveform of the inverter under full linear load. The THD value has raised up to 0.26% (Fig. 11b).

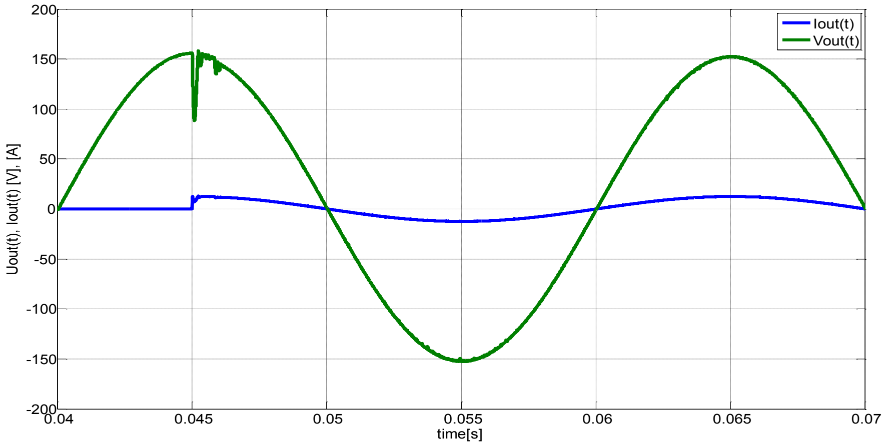


Figure 10. Step change of load from 0 to 100%.

The influence of the step change of the load is very important too. Fig. 12 represents this step change of the load (from 0 to 100%). A huge voltage drop (approx. 70V) will appear in the time of sudden load change (0.045s). This voltage drop is diminished in 0.5ms.

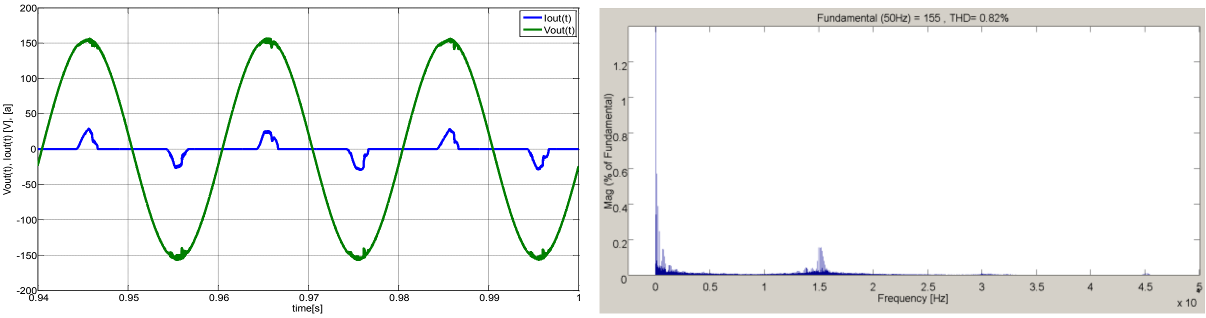


Figure 13. a) Output voltage and output current, b) FFT of the output voltage. Full nonlinear load.

It is obvious (Fig. 13a), that the proposed control scheme almost fully compensate the influence of the output current spikes. The THD reach the value of the 0.82% (Fig. 13b).

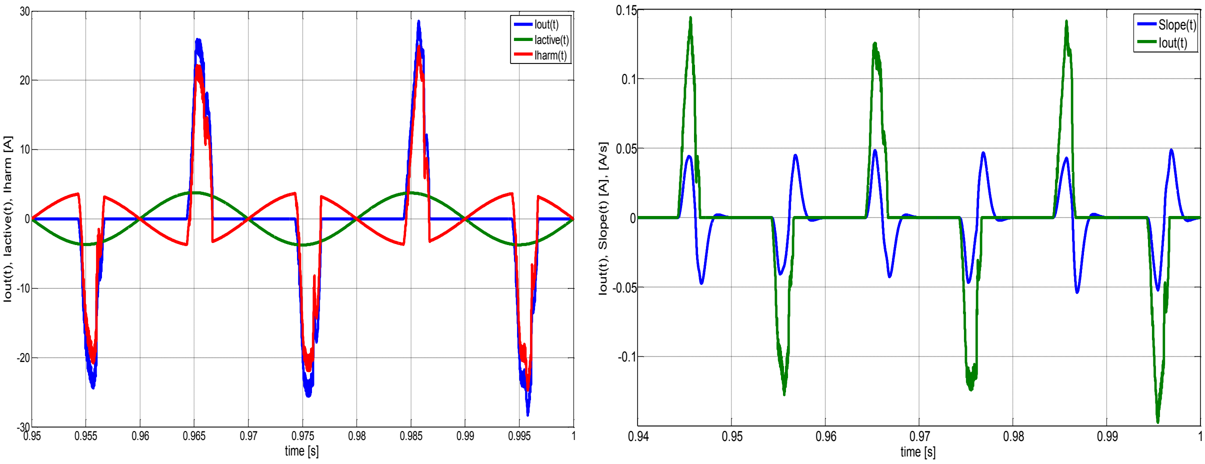


Figure 11. a) Harmonic calculator, b) Slope calculator (dI_out/dt). Full nonlinear load.

The proper function of the harmonic calculator can be observed from the Fig. 14a. The output current (blue), the active current (green) and the harmonic current (red) are showed. The output of the slope calculator is showed on the Fig. 14b.

5 Conclusion

In this paper we develop a digital model of the VSI inverter in Simulink environment. The new deadbeat control algorithm has been implemented. This proposed model has been tested under different types of load. The simulation results shows that proposed control algorithm exhibits very fast dynamic response towards step load changes. Besides a sinusoidal voltage waveform with low distortion can be maintained even under highly nonlinear loads. Parameters of the simulation model comes from real world application, VSI inverter SK2 24/230 from EVPU a.s., Nova Dubnica, Slovakia.

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