

MODELING OF SINGLE PHASE INVERTER SYSTEM IN SIMULINK SOFTWARE

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ABSTRACT

SIMULINK software models graphs and charts as a modern method for creating mathematical models. A simulation structure of blocks in Simulink programming environment has been built.

Key words: filter, amplitude frequency response, duty cycle, Simulink.

INTRODUCTION

Voltage inverter control systems

The voltage at the output of the inverters has a strictly defined form, which depends on the control algorithm of the power devices in the circuit. Depending on the system of alternating voltages supplying the load in the output, single-phase and three-phase voltage inverters are most often used.

The shape of the current through the load, provided that a voltage with a strictly defined shape is applied to it, depends on the nature and parameters of the load circuit [3].

When using the method of symmetrical PWM control, signals are obtained for adjusting the power devices. The pulses in the half-cycle are symmetrical with respect to the beginning and the end. In the case of unregulated control of the output voltage, the PWM generator produces rectangular pulses for the output voltage with a control algorithm of 0.5, which are asymmetric in half-cycle.

The main elements of the power circuit of inverters are semiconductor devices controlled by a key method. These are most often bipolar transistors with isolated gate (IGBT), power field-effect transistors with induced channel (power MOSFET) or thyristors excluded from the gate (GTO thyristors).

Simulink single-phase inverter system project

Different schemes of single-phase voltage inverters are known, as well as different algorithms for controlling power devices and forming the output voltage curve in them. The most widely used are:

- single-phase inverters with rectangular shape of the output voltage - modified sine wave

Single-pulse PWM with fixed and adjustable width of control pulses is modelled.

- single-phase inverters with sinusoidal pulse - width modulation PWM control. They are modelled with one period and two period sinusoidal PWM function.

RESEARCH METHODS

The stages of modelling and measurement of a single-phase inverter with a modified sine wave were as follows:

1. The main output parameters of the inverter system are set;
2. The curves of currents and voltages in the two modes with different fill factors are measured;
3. The magnitudes of harmonics with serial numbers h_3 , h_5 , h_7 , as well as their initial phases are reported by a PowerGUI block;
4. The losses from active power in the line to the load are calculated by summing the active powers of the most influential harmonics.
5. The total power consumption from the consumption is analyzed and the efficiency of the inverter system is determined by comparing the two modes of operation;

- Output data for practical implementation of the inverter system:

$U_{dc}=300V$, $R_T=5\ \Omega$, $L=0.025H$, $f_1=50Hz$;

The first step of the project is to create the schematic diagram of the model in the Simulink software environment, shown in Fig. 1 [1, 2, 3]. The inverter system is modelled by several basic elements represented graphically in the scheme: source (U_{dc}), bridge single phase voltage inverter (U_{ac} , f_1) and active inductive load ($R_T L$). Measuring instruments, oscilloscopes, are also included [4, 5].

Power IGBT transistors T1, T2, T3 and T4 with parallel diodes to the EC junction are controlled by pulse generators, shown in Fig. 2. For T1 and T2, two fill factors are programmed 50% (35%), and for T3 and T4 50% (50%), for two simulation modes.

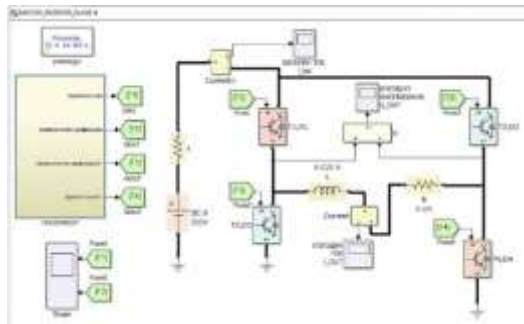


Fig. 1. Schematic diagram of a model inverter system

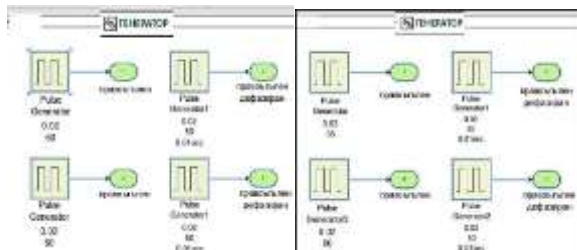


Fig. 2. Models created in the subsystem of Fig. 1 as rectangular pulse generators with fixed fill coefficients;

The complementary couples T1 and T2 are connected to the positive terminal, while T3 and T4 are connected to the negative terminal of a DC voltage source (rechargeable batteries or photovoltaic modules). The transistors have built-in diodes connected to the power supply in the opposite direction of their conductivity. The output parameters of the electrical circuit are measured using oscilloscope models for I_{OUT} , U_{OUT} . The voltage and current curves I are shown in the following figures and are in the form of a signal with two different control algorithms.

EXPERIMENT

Simulation results and evaluation of efficiency

• Starting the model with fill factor 50%/50%

Diagrams of the magnitudes of the harmonics from the output voltage with an unregulated control algorithm 50%/50% are shown in Fig. 3.

From the amplitude-frequency characteristic (AFC) the effective values and the initial phases for the voltage harmonics are taken into account:

First harmonic $U_{h1} = 267.8V$ and $THD_U = 48.49\%$

Initial phase of U_{h1} for first harmonic $\psi_{U1} = 0.4^\circ$.

$U_0 = 0.96V$, $I_0 = 10.93A$;

$U_{h3} = 89.6V$, $\psi_{U3} = 0.1^\circ$,

$U_{h5} = 53.8V$, $\psi_{U5} = -0.1^\circ$,

$U_{h7} = 38.4V$, $\psi_{U7} = -0.2^\circ$,

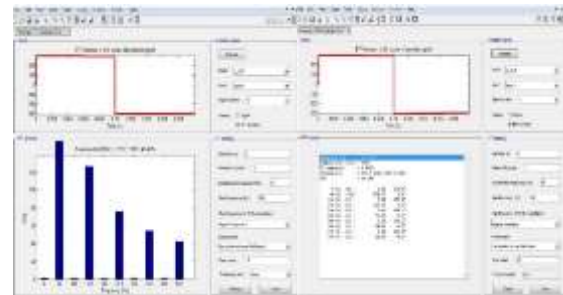


Fig. 3. Frequency spectrum and shape of the output voltage generated by the PowerGUI unit, at a duty cycle of 50% / 50%.

From the results for the frequency response in Fig. 4. the effective values and the initial phases for the output current harmonics are taken into account at the following programmed conductivity interval in the half-cycle:

First harmonic $I_{h1} = 29.9 A$ и $THD_I = 29.42\%$.

Initial phase of I_{h1} for first $\psi_{I1} = -40.9^\circ$.

$I_{h3} = 4.94A$, $\psi_{I3} = -36.6^\circ$;

$I_{h5} = 2.4A$, $\psi_{I5} = -26.8^\circ$;

$I_{h7} = 1.58A$, $\psi_{I7} = -20.4^\circ$.

The power losses along the lines to the load are calculated by summing the active powers of the most influential harmonics, with serial numbers h_3 , h_5 , h_7 .

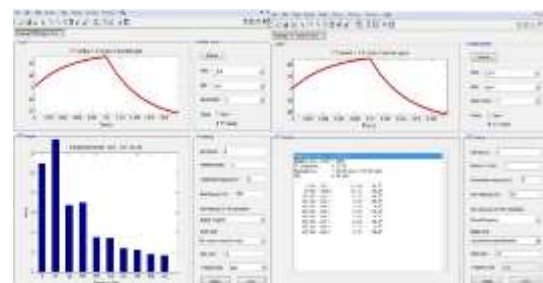


Fig. 4. Spectral synthesis and shape of the output current at 50% / 50%.

The integrated active power is calculated by the Fourier row by summing the given harmonics from the spectrum:

$$P_{out} = U_0 \times I_0 + \sum P_h \times \cos \varphi_h \quad (1)$$

The phase difference taking into account the displacement between the initial phases of voltage and current is determined for the first harmonic by:

$$\varphi_1 = \psi_{U1} - \psi_{I1} \quad (2)$$

The useful active power consumed by the load is calculated for the magnitudes of the first harmonics of current and voltage and shows the conversion efficiency through the voltage inverter:

$$P_1 = U_{h1} \times I_{h1} \cos \varphi_1 \quad (3)$$

After substitution with values for the reported data, it is obtained that:

$$\begin{aligned} P_0 &= 10.5 \text{ W}, \\ P_1 &= 8007 \times \cos(41.2^\circ) = 8007 \times 0.8 = 6406 \text{ W}; \\ P_3 &= 443 \times \cos(36.7^\circ) = 443 \times 0.84 = 372 \text{ W}; \\ P_5 &= 129 \times \cos(26.7^\circ) = 129 \times 0.9 = 116 \text{ W}; \\ P_7 &= 60.7 \times \cos(20.2^\circ) = 60.7 \times 0.95 = 57.6 \text{ W}. \end{aligned}$$

The calculated useful active power delivered to the load is:

$$P_{useful} = P_0 + P_1 = 6406 + 10.5 = 6416.5 \text{ W}.$$

The calculated loss of active power on the supply line is:

$$\begin{aligned} P_{loss} &= P_3 + P_5 + P_7 = 372 + 116 + 57.6 = 548.6 \text{ W}. \\ P_{loss} \% &= P_{loss} / P_{useful} \times 100 = 8.5\% \end{aligned}$$

• Starting the model with fill factor 35%/50%.

The magnitude of the harmonics from the frequency spectrum and the waveform of current and voltage are shown in Fig. 5 and 6. From Fig. 5 the effective values of the initial phases for the voltage harmonics are taken into account as a percentage:

First harmonic $U_{h1} = 238.9\text{V}$ and $THD_U = 29.7\%$

Initial phase of U_{h1} for first $\psi_{U1} = 27.1^\circ$,
 $U_0 = 0.47\text{V}$, $I_0 = 5.2\text{A}$;
 $U_{h3} = 14.2\text{V}$, $\psi_{U3} = 77.8^\circ$, $I_{h3} = 2.1\text{A}$, $\psi_{I3} = 8.9^\circ$;
 $U_{h5} = 38\text{V}$, $\psi_{U5} = -44.8^\circ$, $I_{h5} = 0.7\text{A}$, $\psi_{I5} = -60.3^\circ$;
 $U_{h7} = 38\text{V}$, $\psi_{U7} = 8.4^\circ$, $I_{h7} = 1\text{A}$, $\psi_{I7} = -35.4^\circ$.

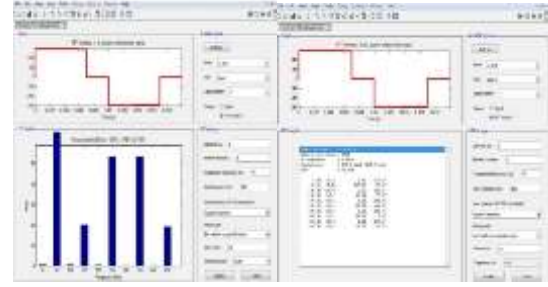


Fig. 5. Result diagrams and tabular data from the frequency synthesis of the output voltage with a control algorithm 35%/50%.

From Fig. 6 the rms values and the initial phases for the output current harmonics are taken into account at the thus programmed conductivity interval in the half-cycle:

First harmonic $I_{h1} = 27.8\text{A}$ and $THD_I = 14.74\%$.
Initial phase of I_{h1} for first $\psi_{I1} = -22.9^\circ$.



Fig. 6. Result diagrams and tabular data from the frequency synthesis of the output current with a control algorithm 35%/50%.

After substitution with values for the reported data, it is obtained that:

$$\begin{aligned} P_0 &= 2.44 \text{ W}; \\ P_1 &= 7095 \times \cos(50^\circ) = 7095 \times 0.71 = 5038 \text{ W}; \\ P_3 &= 29.8 \times \cos(69^\circ) = 29.8 \times 0.47 = 14 \text{ W}; \\ P_5 &= 27 \times \cos(15.5^\circ) = 27 \times 0.97 = 26.2 \text{ W}; \\ P_7 &= 38 \times \cos(43.8^\circ) = 38 \times 0.77 = 29.4 \text{ W}. \end{aligned}$$

The calculated useful active power delivered to the load is:

$$P_{useful} = P_0 + P_1 = 5038 + 2.44 = 5040.4 \text{ W}.$$

The calculated loss of active power on the supply line is:

$$P_{loss} = P_3 + P_5 + P_7 = 14 + 26.2 + 29.4 = 69.6 \text{ W}.$$

The percentage of losses in the inverter system with a symmetrical 35% / 50% control algorithm is:

$$P_{losses} \% = \frac{P_{loss}}{P_{useful}} \times 100 = 1.38\%$$

CONCLUSIONS

1. The comparative analysis shows a reduced harmonic composition when simulating the inverter system with a fill factor 35%/50% and $P_{\text{loss}} \% = 1.38\%$. At a fill factor of 50% / 50% the losses of active power are $P_{\text{loss}} \% = 8.5\%$.

2. The rectangular voltage pulses with control on algorithm 35%/50% have a reduced spectral composition, because the half-period is symmetrically located. Thus, it approaches the shape of the sinusoid, imitating a modified sine wave with better performance from the asymmetrically placed rectangular pulse.

3. The model gives an accurate forecast of the efficiency of the inverter system to make it a reality when choosing different electrical loads. Deteriorated harmonic composition in the output voltage spectrum affects the performance of sensitive consumers. It has been proven that the scheme of the model with a control algorithm 35%/50% is better.

The simulation analysis of a voltage inverter with a rectangular shape of the output signal proves its widespread use in the autonomous photovoltaic systems for low power, automotive power converters, UPS and etc.

Inverters can supply electrical loads such as lighting fixtures, pumps, television and radio receivers, computer stations, sites remote from the public power supply network and structures intended for uninterruptible power supply.

No filter was applied in the studied model, which takes into account the increased harmonic composition of the inverter system. When installing a cutting filter in the output circuit higher harmonics can be suppressed, which will improve the power factor, efficiency and quality of the energy applied to the load.

The economic efficiency of the application of single-phase inverters is low cost with the good technical characteristics.

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