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Research, Calculation and Design of Single-Phase Inverter Flow Regulator for Application in Industrial

Pham Thi Thu Ha

Faculty of Electronic Engineering Technology, University of Economics - Technology for Industries, Viet Nam

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Abstract - *This paper presents the results of the research, calculation and manufacture of a single-phase inverter with an intermediate stage at high frequency, to control a grid-connected single-phase DC/AC converter as required by the load demand regulation program. This converter overcomes the shortcomings of traditional inverters. The use of a high frequency transformer provides better separation between stages, and the output frequency can be customized through the control of input pulses. This control structure consists of a current control loop on the inner ring and a power control loop on the outer ring. According to this structure, the internal loop controller uses a resonant controller with parameters defined in the frequency domain and controller. This paper constructs a control structure for controlling a grid-coupled single-phase DC / AC converter capable of operating as required by a load demand regulation program. The research results show that the instantaneous power characteristic curve at the output of the DC/AC converter always follows exactly the set power characteristic curve. At the same time, the voltage characteristics and current calculation at the output of DC/AC converters are always standard sinusoidal form to ensure the IEEE519 power quality standard, applied in the field of industrial control.*

Keywords — *Inverse controller, Single - phase DC/AC power converter, DC-AC converter, Power controller, Power electronic, Power converter.*

I. INTRODUCTION

In the modern world, electricity has an indispensable role with its ability to combine power and intelligence. Most of the systems which are located in critical points in daily life need electricity to operate. The electrical energy increases productivity, efficiency, and allows a high degree of safety, reliability, and comfort of life. Contingency in the electric power line cannot be accepted critical areas involving safety, security, continuous industrial processes, data protection in information technolo-gies, [1]-[5]. Although in the past backup generators were satisfactory to get power in case of interruption in the utility, long delay of generator starting and switching in today is not acceptable. Such delays badly affect critical loads such as computers, internet providers, telecom service providers, etc, as the power interruption causes data loss, process failure, and the cost for recovery becomes unacceptable. Even though the electric utility industry has made great effort for uninterrupted power line and undistorted line voltage, inevitably still there exist problems such as distortions, sag, swell, and spikes, [4]-[7]. Therefore, the research, calculation and design of single-phase DC/AC inverter flow controller in the field of industrial machine control is very necessary today for researchers, [16, 18, 20, 21, 26].

The research, calculation and design of a single-phase DC/AC converter controller is often studied in two main directions. The first direction studies the grid-connected current control to regulate the DC voltage maintained at a fixed value when there is no energy equilibrium element such as the power bank on the DC side [2], [3], [4], [11]. The second direction studies the power current control on the AC side in systems that have a constant voltage hold on the DC side [12, 14], [19]. In particular, controlling the power flow through DC / AC voltage fluctuations according to preset values has been researched recently when on-demand management programs are more widely applied.

This paper constructs a control structure for controlling a mains - coupled single - phase DC / AC inverter, with the controller studied for this inverse system, always capable of control operation, according to requirements of the program regulate load demand and ensure continuous power supply to the system for application in industrial control.

II. THE BUILDING MODEL OF THE SINGLE – PHASE INVERTER CONTROL SYSTEM

The single - phase inverters are commonly used converters used to convert DC power into single-phase AC power supply for the load, also known as DC/AC converters that supply AC loads. That is, the operation of the electronic switches is independent of the grid voltage.

A. *Mathematical model of single-phase DC/AC inverter*

The load of the reciprocating system can be any AC load, moreover, many types of AC loads need a power supply with parameters such as voltage, current, frequency, can be changed in a wide range. Independent reverse flow systems are used in conjunction with rectifiers, which form inverters, to convert the power supply with constant parameters from the grid to a variable parameter power supply, covering all the needs of the additional loads. Therefore a single-phase AC/DC converters are used to link the DC side and the AC side as shown in Fig. 1, thereby helping to transmit power between the sides by controlling the switches, [3, 4, 6, 7, 8, 10].

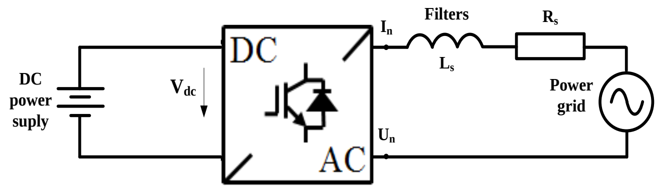

Fig. 1 The system uses a single-phase DC / AC converter

The AC/DC converters use four switches SW_1, SW_2, SW_3 and SW_4 as shown in Fig. 2 with the current modes depicted in Fig. 3.

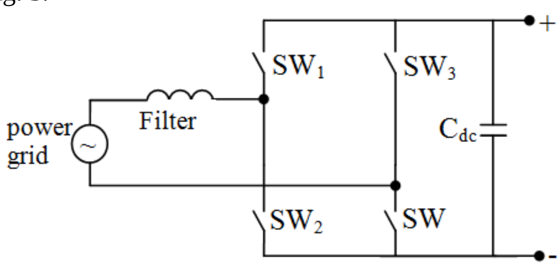

Fig. 2 The circuit dynamic diagram of AC/DC converter

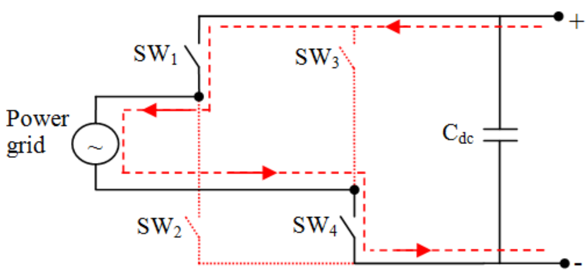

Fig. 3 The conductive state of AC / DC converter when SW_1, SW_4 on; SW_2, SW_3 off

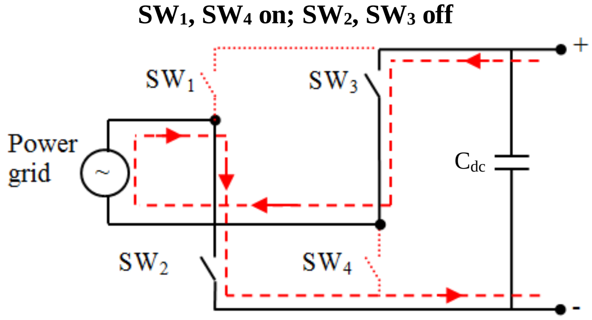

Fig. 4 The conductive state of AC / DC converter when SW_1, SW_4 off; SW_2, SW_3 on

Schematic diagram of the switch's simple lock a single-phase DC/AC converter is depicted in Fig. 5, where the DC side current and voltage are equivalent to one resistor R_{tdc} and four equivalent switches into two valves SW_a, SW_b.

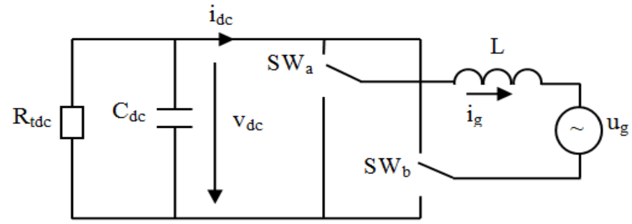

Fig. 5 The simple model of switch switches for DC/AC converter systems

Then we have a system of mathematical equations describing a single - phase DC / AC converter represented by (1) [3], [4]:

$$\begin{cases} v_{ab} = s_{ab} v_{dc} \\ i_{dc} = s_{ab} i_g \\ L \dfrac{di_g}{dt} + Ri_L = v_{ab} - u_g \\ C_{dc} \dfrac{dv_{dc}}{dt} = i_{dc} - \dfrac{v_{dc}}{R_{tdc}} \end{cases} \tag{1}$$

In which: v_{ab} is the voltage applied to the keys SW_a and SW_b, i_{dc} is the current flowing into the converter on the DC side, v_{dc} is the instantaneous voltage on the DC side, i_g is the current flowing through the filter (converter output). R, L values are resistance and inductance of the filter.

B. *The controller design calculation for single-phase DC / AC inverter*

From the diagram in Fig. 1 above, we proceed to calculate and model the PWM pulse converter to control the DC / AC single-phase reverse flow system as follows, [10].

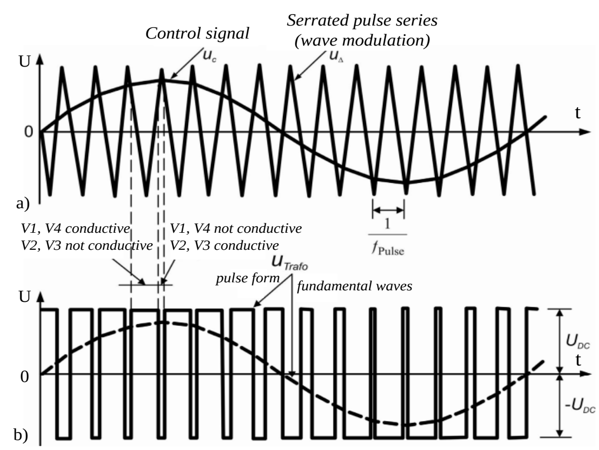

Fig. 6 a) Carrier waveform and modulation; b) the output voltage waveform for controller

The PWM is particularly suited for running inertial loads such as motors, which are not as easily affected by this discrete switching, because their inertia causes them to react slowly, [10, 22, 23, 24, 25]. The PWM switching frequency has to be high enough not to affect the load, which is to say that the resultant waveform perceived by the load must be as smooth as possible. With this method, constant switching frequency, fixed by the carrier is obtained. The performance of this control scheme de pends on the design of the controller parameters, and on the frequency of the reference current. Although the controller assures zero steady - state error for continuous reference, it can present such an error for sinusoidal references. This error in creases with the frequency of the reference current and may become unacceptable for certain applications, [1, 3, 4, 15]. With the design and control structure on the single - phase inverters, we have the waveform of the PWM - modulated reverse voltage source converter with the single - phase inverters structure diagram using the valve. IGBT, we have the waveform simulated as shown in Fig. 6, as [3, 4, 11, 19].

We assume that the desired control pulse signal is the constant m(t) value in each serrated pulse cycle, since fs is many times higher than the output frequency f_0, m(t) can be considered as constant in each cycle T_s. From there on the graph in Fig. 6 we have:

$$d = \frac{t_x}{T_s} = \frac{m(t)}{U_{c.m}} \quad (2)$$

During dT_s, the output voltage is +E, for the rest of the cycle $(1-d)T_s$ the output voltage has -E. So the average value of the reverse output voltage in each cycle T_s, then can be determined as:

$$\begin{aligned}\bar{U}_n(t) &= \frac{1}{T_s}\int_t^{1+T_s} U_n(\tau)d\tau \\ &= \frac{1}{T_s}[E_d(t)T_s - E(1-d(t)T_s)] = E(2d(t)-1)\end{aligned} \quad (3)$$

Given $\bar{U}_n(t)$ and d(t) small fluctuations around any given working point, expression (3) shows the relationship between small fluctuations as follows:

$$\frac{\partial \bar{U}_n}{\partial d} = 2E \quad (4)$$

From the general inverse flow diagram in Fig. 1, we can write the equation describing the circuit as follows:

$$L_s \frac{di_n}{dt} + R_s i_n = u_n - E_s \quad (5)$$

Converting equation (5) to laplace operator, we have:

$$L_s sI_n(s) + R_s I_n(s) = U_n(s) - E_s(s) \quad (6)$$

From here, it is possible to write a transfer function between the inverted voltage input $U_s(s)$, with the output current $I_n(s)$ as follows:

$$G_{I_nU_n}(s) = \frac{1}{R_s}\frac{1}{1+s\frac{L_s}{R_s}} \quad (7)$$

Replace the expression (4) with the expression (7), we have a function that conveys the small variation of the fill factor d(t) and the load current as follows:

$$G(s) = \frac{\tilde{I}_n}{\tilde{d}}(s) = \frac{2E}{R_s}\frac{1}{1+s\frac{L_s}{R_s}} \quad (8)$$

In which, the symbols $\tilde{I}_n$, $\tilde{d}$, show that these are small fluctuations of the respective quantity. thus the modulator will ensure that the mean load current will follow small changes in the fill factor d(t) after each cycle Ts with a time constant of L_s / R_s.

In all cases, the output voltage will consist of a series of pulses of varying width with a repetition period equal to a jagged wave cycle. Such voltage form will contain the first harmonic component with the frequency of the dominant wave, the amplitude depends on the modulation factor m, where:

$$m = \frac{U_{r.m}}{U_{c.m}} \quad (9)$$

In which, $U_{r.m}$ is the amplitude of the dominant sinusoidal waveform, and $U_{c.m}$ is the amplitude of the serrated wave.

III. THE RESEARCH SIMULATION AND EXPERIMENT CONTROL SYSTEM OF SINGLE-PHASE DC/AC INVERTER

A. The Simulation

The after studying the calculation, algorithm and modeling and control of the single - phase DC/AC inverted system with the control system structure was proposed in Part II. To illustrate the operation of the control system with alternating loads in industry. In order to demonstrate the proposed computational research in the article, the author has made a model construction as Fig. 7 shows the single-phase grid - connected DC/AC inverter model using Matlab/Simulink, [9].

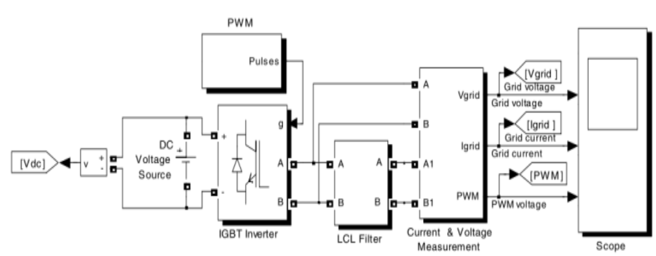

Fig. 7 The matlab simulink model of single - phase DC/AC inverter grid - connected

Diagram of the PWM converter is constructed and shown in Fig. 8. Here, the error between the reference and the measured load current is processed by a proportional integral controller to generate the reference load voltages. A modulator is needed to generate the drive signals for the inverter switches. The reference load voltages are compared with a triangular carrier signal, and the output of each comparator is used to drive an inverter leg, [11].

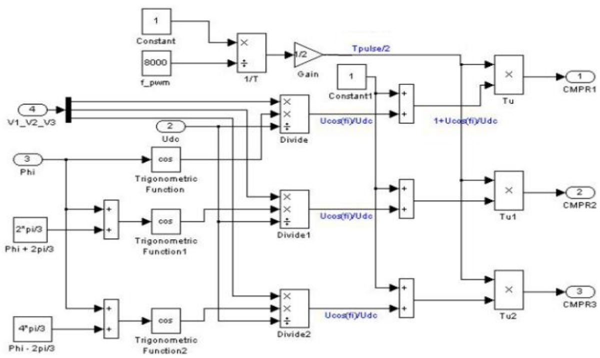

Fig. 8 The structure diagram sinusoidal pulse width modulation

Some simulation results are shown as follows:

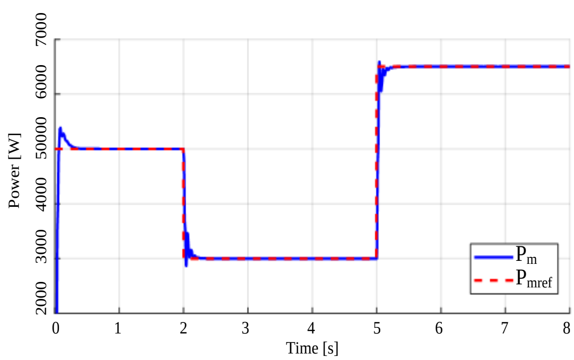

Fig. 9 The Results of simulation of passing power characteristic of DC/AC single-phase inverted

The simulation results in Fig. 9 show that the momentary output at the DC/AC single-phase inverter output always accurately adheres to the set power value (P_m line always sticks to P_{mref}). At times of change in set value (at the time of 2s and 5s, the instantaneous power characteristic has fluctuation before trapping P_{mref}) in the total time of 1 cycle. so that the controller can adapt to changes in installed capacity.

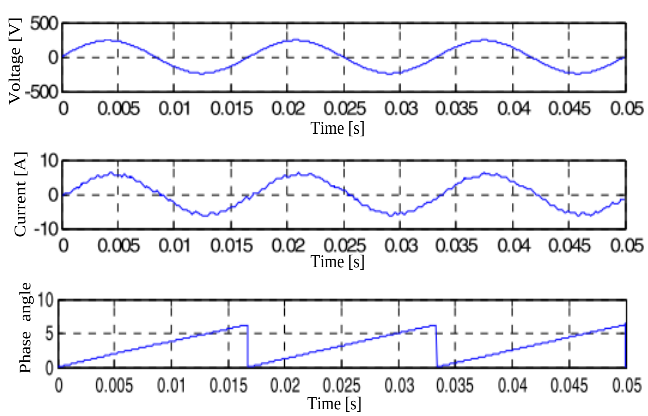

Fig. 10 The voltage, current and grid phase angle values of DC/AC single-phase inverters have load

The simulation results in Fig. 10 show that the voltage characteristic is in pure sinusoidal form with the frequency of 50Hz and the amplitude of 250V, suitable for the modulation factor to convert 400V DC voltage to connect-grid the 220V single-phase. The Results of simulation of current characteristics at DC/AC single-phase inverter output corresponding to the time of stable working load.

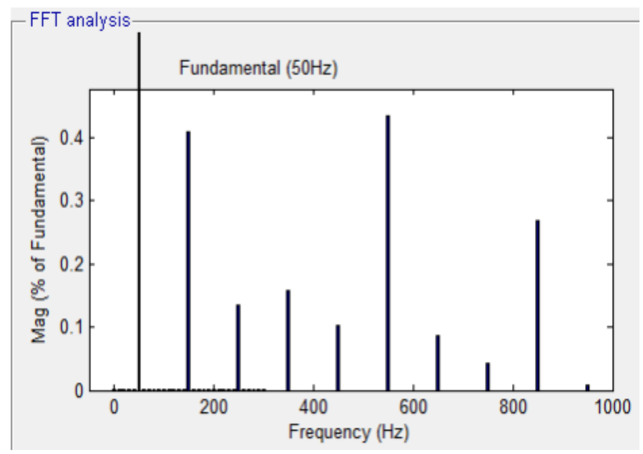

Fig. 11 The FFT analysis results of DC/AC single-phase inverters

Fig. 11 show the output current and FFT analysis before using Low Pass Filter of the Unipolar inverter for m_a = 0.9 respectively.

Observing the simulation results above we see that in the response time from 0 to 0,05 second, the system response to the voltage and current values of the inverter shows the correct control structure. Correct with the selected parameters of the rectifier. From the simulation results showing the values of voltage, current, power and phase angle we see that the output response always achieves equilibrium and stable values even when the load changes, then the system is still working fine. The FFT analysis results of single-phase DC/AC inverters clearly show that the inverter working processes are always stable with AC load in industry. The simulation results in Fig. 9 show current amplitude when working with stable load at the time of 0 to 0.5s. with the power characteristic with reduced set power (reduced from 5000 W to 3000 W). At the same time, the current amplitude has increased with an increase in the applied power (increased from 5000 W to 6500 W). This simulation results show that the current controller has been effective in controlling the current amplitude to match the set capacity.This is a new scientific issue, completely applicable to the practical industrial and civil production.

B. The experiment

Experimental study with three - phase reverse flow system as shown in Fig. 12 and Fig. 10, including: Parameters of single-phase AC motor, P = 1,5kW, U = 220V, I = 2,6A, speed 1500 rpm, 2p = 2, m = 1 frequency 50Hz are the same as those in simulation, motor is hard coupled to the load: DC motor: P = 2kW, U = 220V, I = 3,5A, speed 1500 rpm, frequency 50Hz. Devices located on inverted table: current transformer 50A / 5A, power module IGBT 25A / 1200V, digital control module dsPIC30F4011, display module LCD - ICEA, oscilloscope, power source transformer, etc. The test system with single - phase DC/AC inverters parameter table 1 is as follows:

Table 1. Parameters to select devices for inverters

Description	Value
Voltage DC input for inverter	60-400VDC
Grid voltage	220V- 50Hz
Switching frequency	10kHz
Filter damping resistor	2,5Ω
Capacitor C of the filter	4800 μF
Filter reactor L	2,5mH

At the time the system operates under load is a single-phase AC motor, with the load-generating motor being a DC motor coaxially connected to the ac motor. Then the process of switching from no load to load then works stably, with over the total response time of the system is 100ms. Measured results are shown in Fig. 12 at the time of stable working load. The measured response is the value of voltage, current and frequency at the back of the single - phase DC/AC inverter, when the filter is passed.

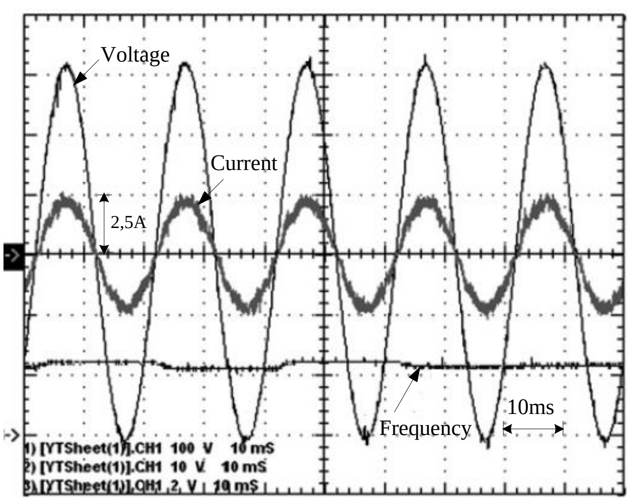

Fig. 12 Voltage, current and frequency values of the system with with load alternating

Comparing the results with studies in [12], and in previous studies [14], the results achieved by the paper are better than the simulation with time to reach a small equilibrium value both value of value current, value voltage, value frequency and experimentation with optimal current control system to improve the quality of single-phase DC/AC inverter systems in control in industrial machines, with process control Load controls work well in real time.

VI. CONCLUSION

The improving quality of electrical energy from other energy sources such as (solar energy, wind energy, generator energy, etc.) that is DC power produced, want to bring In industrial use, it is necessary to pass an optimized single - phase DC/AC inverter to control current to improve the quality of single-phase inverter systems in industrial machine control that the author have studied. The simulation result have shown the correctness and feasibility of the proposed solution. The system can be used for industrial and civil production and to balance energy supply and demand in renewable energy systems that work either independently or with a microgrid. The optimal current - controlled inverter for improved quality of single- phase DC/AC inverter systems in industrial machine control have been developed and verified with experimental results single-phase DC/AC inverters in Fig. 12, the results given in this paper are consistent with the IEEE 519, IEEE1547, IEC 6140-21 power quality standard that countries are using in the world.

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