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Original Article

Research, Development and Application of Single-Phase Inverters in Industrial Machineries

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Abstract *- This paper presents the study, calculation and fabrication of a single-phase grid-connected inverter at high frequency to control a grid-connected single-phase direct current/alternating current inverter according to the requirements of ac load a phase. This converter overcomes the shortcomings of existing traditional inverters in the system of inverter circuits such as: single-phase alternating current grid-connected solar power systems, single-phase wind power systems, etc. This single-phase inverter system structure consists of a current controller in the inner loop and a power control loop in the outer loop. According to this structure, the inner loop controller uses a resonant controller with parameters defined in the frequency domain and clearly demonstrates the high quality of the controller. The construction of the control structure to control the grid-connected single-phase direct current/alternating current inverter is capable of operating according to the requirements of the load demand adjustment program. The research results show that the characteristic curves: current, voltage, and power at the output of the direct current/alternating current inverter always have high control quality, and the output characteristics always follow the input characteristic line. At the same time, the calculated voltage and current characteristics at the output of the single-phase direct current/alternating current inverter are always in the standard sine form, ensuring compliance with IEEE519 power quality standards in industry and civil.*

Keywords *- Single-phase direct current/alternating current power converter, Inverter controller, Power controller, Power electronic, Power converter.*

1. Introduction

Currently, fossil energy sources are gradually being exhausted (such as coal, oil, etc.), and there is a need for new and available renewable energy sources such as solar power and wind power. Therefore, power converters are widely used in civil and industrial applications. The electrical energy produced has been stored in the battery. Then an inverter from direct current to alternating current is required (stabilizing the power source and power quality is necessary). Because electricity has an indispensable role in life and daily life, as well as in industry and the military [1-3]. Electrical energy increases productivity and efficiency and enables high safety, reliability and life comfort levels. Failure in the power transformation process is unacceptable in important areas related to electrical safety, security, continuous industrial processes, data protection in information technology, and the machines industry [3, 4, 5]. Nowadays, direct current/alternating current inverters are rapidly evolving with the knowledge of power conversion circuits applied in industrial applications compared to other power conversion circuits. Over the past century, many topologies of direct current/alternating current inverters have been created [6-8]. Although backup generators were previously capable of drawing power in the event of a power supply interruption, long delays in generator start-up and switchover are now unacceptable. Such delays adversely affect critical loads such as computers, internet providers, telecommunications providers, etc., as power outages cause data loss, process failure, and recovery costs recovery becomes unacceptable. Although the power industry has made many efforts to ensure uninterrupted power transmission and uninterrupted line voltage, problems such as distortion, sagging, bulging, spikes in electrical signals, etc., [8]-[11]. Therefore, research, calculation and design of single-phase direct current/alternating current inverter flow controllers in the field of industrial and civil machine control are very necessary for researchers at present [12, 13, 14, 15].

Figure 1 shows the power circuit diagram for a single-phase bridge voltage source inverter. Four switches (on two pins) are used to generate the alternating current waveform at the output from the direct current source. Any semiconductor switch like IGBT, MOSFET or BJT can be used. Diodes parallel to the switch are called feedback diodes (for protection). This schematic provides power back to the direct current source in case of inductive load when the main switch is off. The special type of inverter used to connect the load system of a renewable energy system (grid-tied solar converter) to the alternating current network is called a grid-tied (synchronous) inverter [16,18,19,31].

The research, calculation, design and development of single-phase direct current/alternating current converters are usually studied in two main directions as follows: The first direction studies the control of grid-connected current to regulate the direct current voltage to maintain a fixed value when there is no energy balance factor like the direct current source side, [20,21,23,24,32]. The second direction studies alternating current side current control in a system with stable voltage on the direct current side [12, 14, 19, 29]. In particular, the current control through direct current/alternating current voltage fluctuations according to preset values this issue has been. It has been studied in recent times as demand management programs are applied more in industrial and civil applications.

This paper studies the development and application of single-phase inverters in industrial machines to perform and calculate the construction of a control structure to control single-phase direct current/alternating current inverters connected to the grid. The controller studied for this system is always capable of automatically controlling the operation, according to the load requirements, to ensure continuous power supply for the power system direct current/alternating current, for application in control industrial and civil today.

2. Building a Computational Model and Design of a Single-Phase direct Current/Alternating Current Inverter Controller

In this part, the author goes to the model, calculate, set up and designs a single-phase direct current/alternating current inverter controller for current industrial and civil electrical equipment [26]. The single-phase inverter is considered a common converter used to convert direct current power into single-phase alternating current power supply for the load (used in electrical energy converter equipment systems), solar or wind power, etc., to connect to the single-phase grid) is also known as a direct current/alternating current converter that supplies power to alternating current loads. Operating a system based on electronic switches does not depend on the mains voltage [18, 21, 26, 27].

The load of this inverter system can be any alternating current load; moreover, many types of alternating current loads need a power supply with parameters such as voltage, current, frequency, etc., wide scope. Standalone back-flow systems are used in conjunction with rectifiers, forming frequency converters to convert constant-parameter power from the grid into variable-parameter power, responding to any problem according to the needs of the load. Therefore, a single-phase direct current/alternating current converter is used to link between the direct current side and alternating current side, as shown in Figure 2, thereby helping to transmit power between the parties by controlling the switches [23, 29, 30].

The direct current/alternating current converters use four switches SW_1, SW_2, SW_3, and SW_4, as shown in Figure 3, and with the current modes depicted in Figure 4.

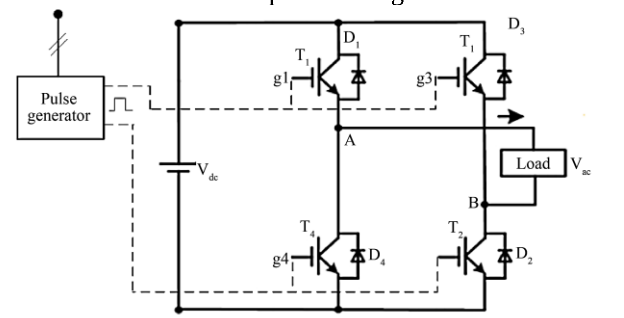

Fig. 1 The structure diagram of a full-bridge single-phase inverter based on IGBT

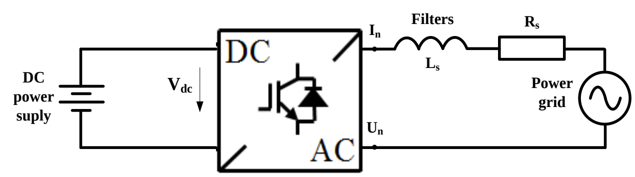

Fig. 2 The system uses a single-phase direct current/alternating current converter

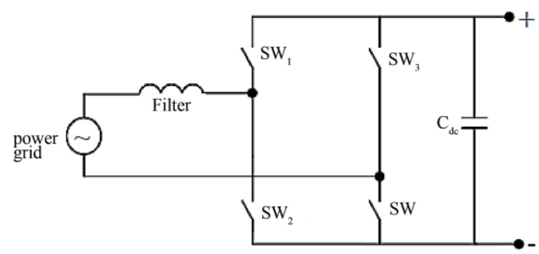

Fig. 3 Circuit dynamic diagram of alternating current/direct current converter

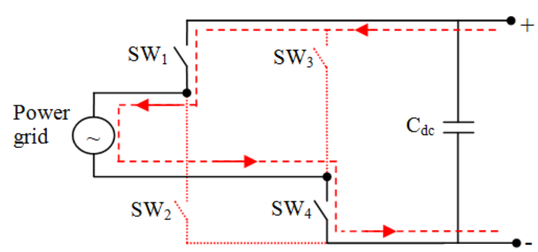

Fig. 4 Conductive state of alternating current/direct current converter when SW_1, SW_4 on; SW_2, SW_3 off

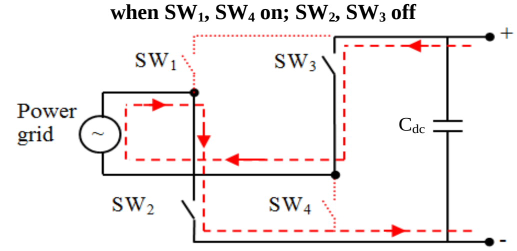

Fig. 5 Conductive state of alternating current/direct current converter when SW_1, SW_4 off; SW_2, SW_3 on

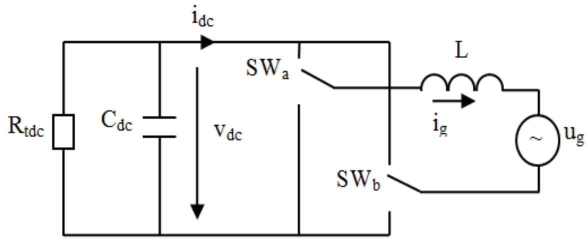

Fig. 6 The simple model of switch switches for direct current/alternating current converter systems

A simple semiconductor valve diagram of a single-phase direct current/alternating current converter switch is shown in Figure 6, where the direct current - side voltage and current values are equivalent to one resistor R_{tdc} and four switches are equivalent to two semiconductor valves SW_a, SW_b.

The author has a system of equations in a mathematical form describing a single-phase direct current/alternating current converter represented by expression (1), which is written as follows [2, 5]:

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

In which: component 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 direct current side, ingredient v_{dc} is the instantaneous voltage on the direct current side, i_g is the current flowing through the filter (converter output). Component R and L values are the resistance and inductance of the filter.

3. The Controller Design for Single-Phase Direct Current/Alternating Current Inverter

In the diagram in Figure 7 above, the author proceeds to calculate and model the PWM pulse converter to control the direct current/alternating current single-phase reverse flow system as follows [15].

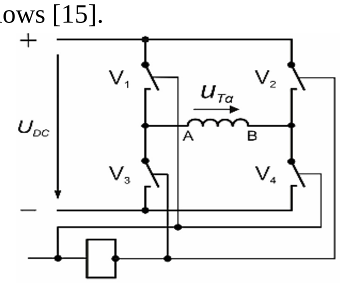

Fig. 7 The schematic diagram of the control signal of the inverter valve according to the two-pole pulse signal modulation method

In the diagram of Figure 7, the author sees that: Because the control requires two valves belonging to the reverse bridge diagonal to be opened the same, but to ensure the negation between the two pairs of valves V_1/V_4 and V_2/V_3, I only need a single modulated signal using the bipolar method.

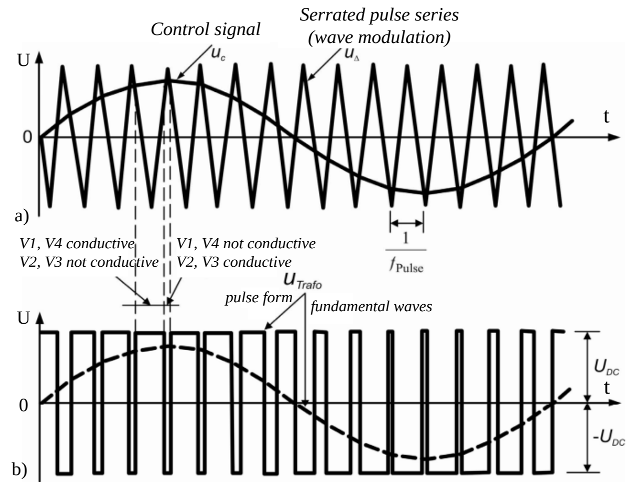

Fig. 8 a) Carrier waveform and modulation; b) output voltage waveform for controller

The pulse PWM modulators are particularly well suited for running inertial loads such as motors, which are not easily affected by this discrete switching since their inertia makes them respond slowly [11, 29, 23, 24, 30]. The PWM switching frequency should be high enough not to affect the load, which means that the resulting waveform perceived by the load should be as smooth as possible. With this method, the carrier's fixed constant switching frequency is obtained. The performance of this control scheme depends on the design of the controller parameters and the frequency of the reference current. Although the controller guarantees zero steady-state error for a continuous reference, it can present such an error for a sinusoidal reference. This error increases with the frequency of the reference current and may become unacceptable for certain applications [15, 24]. With a design and control structure on a single-phase direct current/alternating current inverter, the author has a PWM-modulated reverse voltage source converter waveform with a structure diagram of a single-phase direct current/alternating current inverter using a valve. The IGBT author has simulated waveform as shown in Figure 6, like [7, 9, 10].

The author assumes 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, component m(t) can be considered constant in each cycle T_s. From there on the graph in Figure 6 author has:

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

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

$$\bar{U}_n(t) = \frac{1}{T_s}\int_t^{1+T_s} U_n\,(\tau)d\tau$$

$$= \frac{1}{T_s}[E_d(t)T_s - E(1 - d(t)T_s)] = E(2d(t) - 1) \quad (3)$$

Given component and d(t) small fluctuations around any given working point, expression (3) show the relationship between small fluctuations as follows:

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

From the general inverse flow diagram in Figure 1, the author 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 the laplace operator, have:

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

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:

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

Replace expression (4) with expression (7); the author has a function that conveys the small variation of the fill factor component 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 component $U_{r.m}$ is the amplitude of the dominant sinusoidal waveform, and component $U_{c.m}$ is the amplitude of the serrated wave.

4. Results and Discussion

4.1. The Simulation Results

The research on calculation, algorithm, modeling and control of single phase direct current/alternating current inverter system with control system structure proposed in Part II. Illustrate the control system operation with alternating current load in industry and civil. To demonstrate the computational research process proposed in the article, the author has built a simulation in the Matlab/ Simulink 2021 environment, presented in Figure 9, showing a single-phase grid-connected direct current/alternating current inverter model [6].

On the diagram figure 9 here is the diagram the control structure diagram of a single-phase direct current/alternating current inverter connected to the grid built on matlab simulink 2021 software. The blog diagram of the PWM converter is constructed and shown in Figure 10. Here, the error between the reference and the measured load current is processed by a proportional integral controller to generate the reference load voltages.

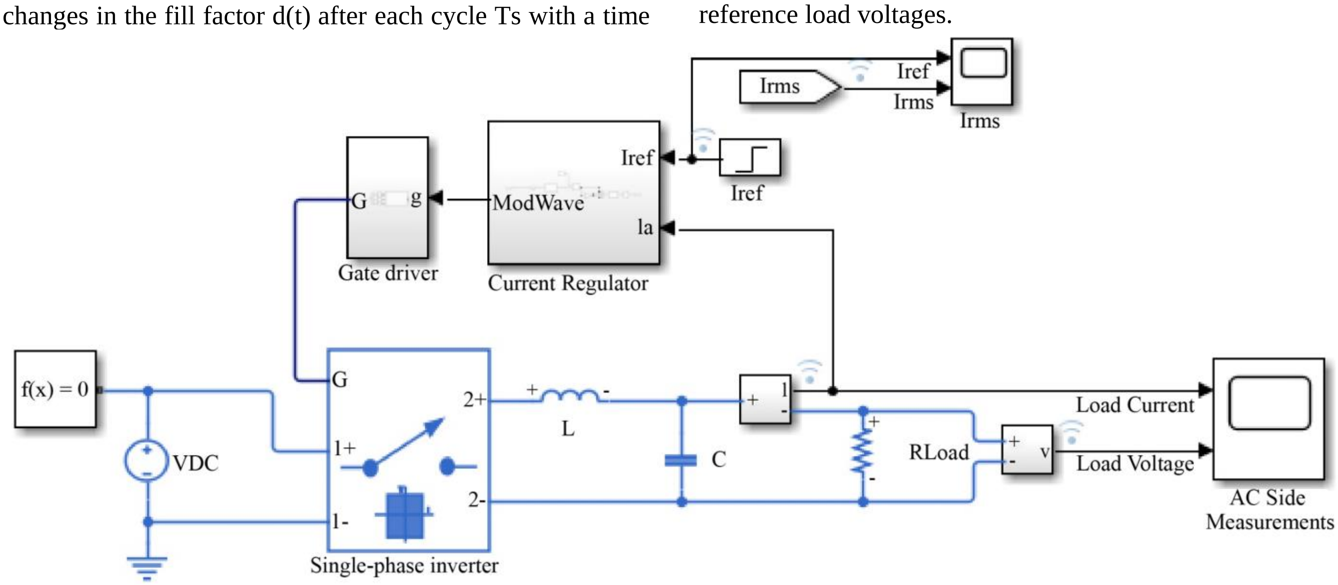

Fig. 9 The control structure diagram of a single-phase direct current/alternating current inverter

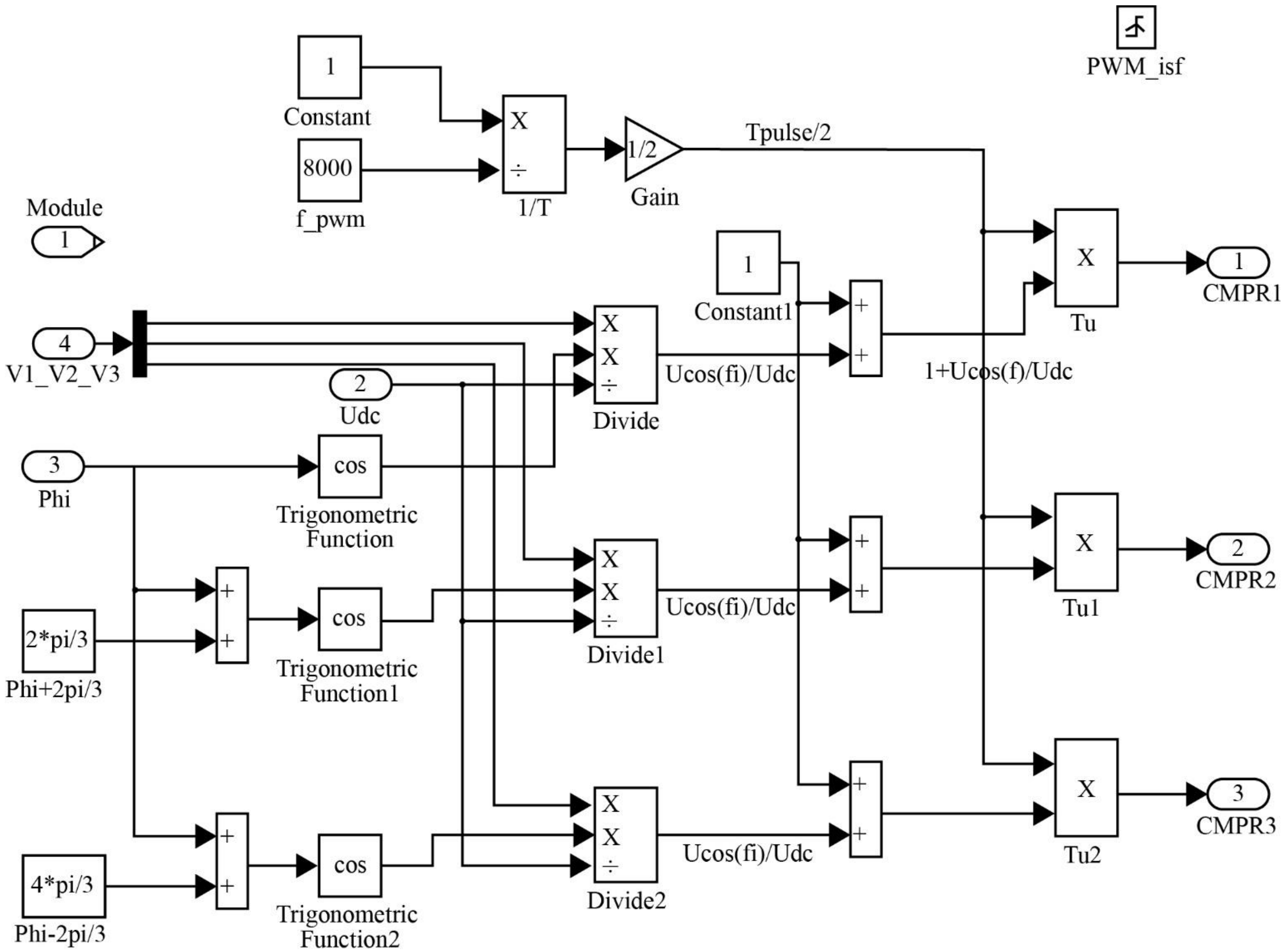

Fig. 10 Structure of a sinusoidal pulse width modulator

From there, have the following simulation results:

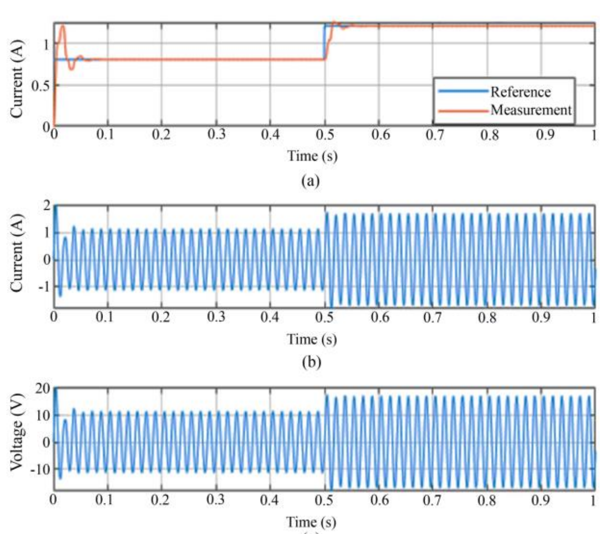

Fig. 11 The response value of input and output current and voltage of single phase inverter

A signal pulse modulator is considered necessary to generate a control signal for the controller of the single-phase inverter. The reference load voltages are compared with a triangular carrier signal, and the output of each comparator is used to drive a signal pin [11].

From the simulation results in Figure 11, the actual output current value is measured when simulating and the input signal of the 1-phase inverter control process as shown in Figure 11a; The current output signal always follows the input set value in Figure 11b the measured current value at a time of the inverter when changing the load at 0.5s time. In Figure 11c, the inverter's output voltage clearly shows the quality of applying the control theory developed in the second part. Through Figure 11, the author can see the value of the set current and the output current value when changing the load at 0.5s time in the total response time of 1s; the grid-connected single-phase inverter always gives a good working response, the quantity The output always follows the input in the equilibrium process.

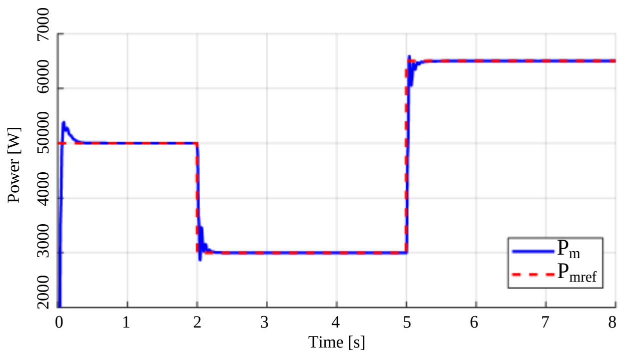

Fig. 12 The Results of the simulation of passing power characteristic of direct current/alternating current single-phase inverted

Simulation results in Figure 12 shows that the output signal always ensures that the used power at the output of direct current/alternating current single-phase inverter always follows the exact set power value (the P_m value always follows the value P_{mref}). At times of change of the set value (at 2s and 5s, the power characteristic of the converter oscillates before changing the value of P_{mref}) in the total response time of 1 cycle so that from the response of the controller, the author can see that the system is always adaptable to the change of the set power.

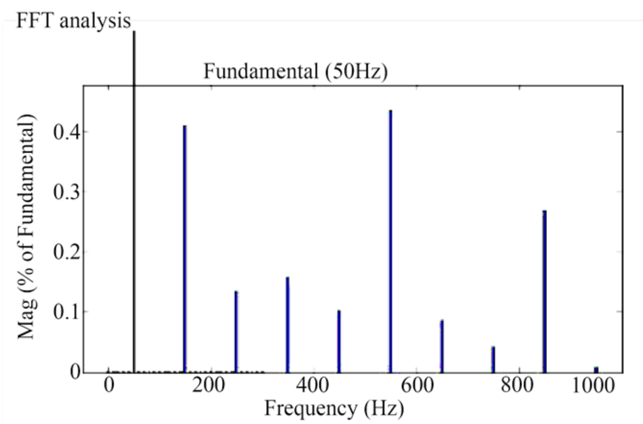

Fig. 13 The FFT analysis results of direct current/alternating current single-phase inverters

Figure 13 shows the output current, and the analysis of the FFT signal spectrum shows that the values before using the low pass filter of the single-phase grid-connected inverter give $m_a = 0.9$, respectively.

From the above simulation results, the author can see that in the response time from 0 to 0.5 seconds, the response of the control system of the single-phase inverter has shown clearly for the voltage and current values. The power of the inverter shows the correct control structure. True to the selected parameter of the rectifier. From the simulation results showing the values of voltage, the current, output power of the inverter and phase angle, the author sees that the output response always reaches a balanced and stable value even when the load changes while the inverter system still works fine. The results of the analysis of the FFT signal spectrum of the grid-connected direct current/alternating current single-phase inverter clearly show that the inverter's working process is always stable with AC loads in the industry.

Simulation results in Figure 11 shows the current amplitude when working with stable load and load changing mode in the period from 0 to 0.5s, with power characteristics with reduced power setting (reduced from 5000 W to 3000 W). At the same time, the current amplitude increases with an increase in power consumption (increased from 5000 W to 6500 W). This simulation result shows that the current controller has effectively controlled the appropriate current amplitude, always closely following the set capacity of the inverter. This new scientific problem can be applied in practice to industrial production machines (CNC machining systems, cranes and cranes, etc.) and civil (in power systems). Renewable energy: grid-connected solar battery system, wind power system, etc.).

4.2. The Experiment Results

The Experimental study with a single-phase system model, using an alternating current motor with reverse rotation as shown below: on the control system, including Parameters of single-phase alternating current motor, P = 1.5kW, U = 220V, I = 2.6A, speed 1500 rpm, 2p = 2, m = 1 frequency 50Hz same as in simulation, the motor is hard coupled to load: direct current motor: P=2kW, U=220V, I=3.5A, speed 1500rpm, frequency 50Hz. The devices located on the inverter board: current transformer 50A/5A, power module IGBT 25A/1200V, the digital control module dsPIC30F4011, LCD display module - ICEA, oscilloscope, power transformer, etc. The number of single-phase direct current/alternating current inverters in Table 1 is as follows:

Table 1. The parameters to select devices for inverters

Description	Value
Voltage DC input for inverter	12-24-60-400VDC
Grid voltage	220V- 50Hz
Switching frequency	10kHz
Filter damping resistor	2,5Ω
Capacitor C of the filter	4800 µF
Filter reactor L	2,5mH

The author has the following result:

At the time, the single-phase direct current/alternating current inverter system supplies power to the active load; The object here is a single-phase alternating current motor, with the motor being loaded as a direct current motor coaxially connected to the alternating current motor. Then the no-load-to-load transition then works stably, with a total system response time of 100ms.

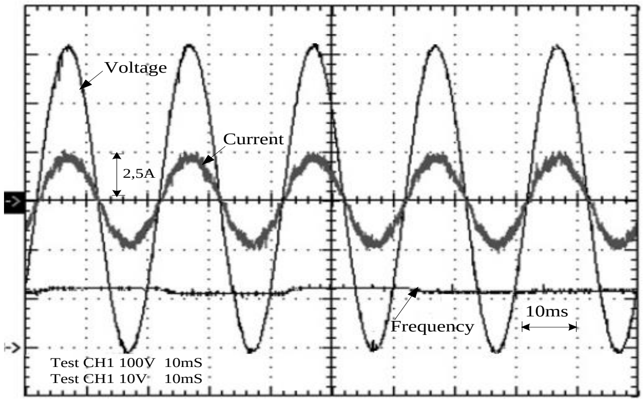

Fig. 14 The value of voltage, current and frequency of the inverter system when there is an alternating current load

Measurement results are shown in Figure 14 at the time of stable working load; single-phase inverter systems always meet the power supply for a high-quality working load. The measured response is the value of voltage, current and frequency at single-phase direct current/alternating current inverter output when the pass filter is implemented with high efficiency.

5. Conclusion

The improvement of power quality from other energy sources, such as (solar batteries, wind power, generator power, etc.) is a direct current power source that is produced and wants to be used in For industrial and civil use; it is necessary to adopt an optimized direct current/alternating current single-phase inverter connected to the grid. The direct current/alternating current inverter controls current, voltage, and power in order to improve the power quality of the power system to be applied to industrial and civil machines that the author has studied. The simulation results have shown the correctness and effectiveness of the proposed solution. The system can be used for industrial and civil production and to balance energy supply and demand in renewable energy converter systems operating independently or with small and medium capacity grids. The optimal current-driven inverter to improve the quality of single-phase alternating current power in controlling industrial machines has been built and verified with the experimental results of the single-phase direct current/alternating current inverter shown in Figure 14. From the results presented in this paper it is consistent with the power quality standards IEEE 519, IEEE1547, and IEC 6140-21 that countries around the world and in Vietnam are using.

Acknowledgments

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