IMPROVING CONTROLLERS QUALITY OF ELECTRIC DRIVE SYSTEMS FOR INDUSTRIAL MACHINES ON THE BASIS OF POWER CONVERTER - INVERTER

NÂNG CAO CHẤT LƯỢNG BỘ ĐIỀU KHIỂN CHO HỆ THỐNG TRUYỀN ĐỘNG MÁY CÔNG NGHIỆP TRÊN CƠ SỞ BỘ BIẾN TẦN CÔNG SUẤT

Vu Huu Thich[1,*], Pham Nhat Khiem[2], Pham Thi Thu Ha[2], Tran Duc Chuyen[2]

ABSTRACT

The paper presents research on the calculation method of designing optimal current control problem sets to improve the quality of inverter systems used in industrial machine control with loads of, three phase AC asynchronous motors. System kinetics to evaluate control methods. The main goal of adopting the optimal control method of the energy flow to the converter and the three phase inverter is to regulate the output current. The AC side has the desired sine wave shape, the voltage across the ac phases is stable with low oscillation. The simulation results when applying the proposed research method for the three phase inverters were simulated on Matlab Simulink software. And experiment with phase flow inverters has proven the advantages of the converter, the proposed algorithm has improved the output voltage and current quality of three phase inverters with industrial load.

Keywords: *Power controller, current control, three phase AC motor control, power electronics, inverters.*

TÓM TẮT

Bài báo trình bày nghiên cứu về phương pháp tính toán thiết kế bộ điều khiển dòng điện tối ưu nhằm nâng cao chất lượng hệ thống biến tần sử dụng trong điều khiển máy công nghiệp có động cơ truyền động tải loại không đồng bộ xoay chiều ba pha. Mục tiêu chính của việc áp dụng phương pháp điều khiển tối ưu dòng năng lượng tới bộ biến đổi và bộ nghịch lưu ba pha để điều chỉnh dòng điện đầu ra, từ đó đem lại kết quả điện áp và dòng điện xoay chiều có dạng sóng sin mong muốn, ổn định với dao động thấp. Kết quả mô phỏng khi áp dụng phương pháp nghiên cứu đề xuất cho bộ nghịch lưu 3 pha được mô phỏng trên phần mềm Matlab Simulink. Kết quả thực nghiệm với bộ nghịch lưu dòng pha đã chứng minh được ưu điểm của bộ biến đổi, thuật toán đề xuất, đã cải thiện điện áp đầu ra và chất lượng dòng điện của bộ nghịch lưu ba pha với phụ tải công nghiệp.

Từ khóa: *Bộ điều khiển nguồn công suất, điều khiển dòng điện, điều khiển động cơ xoay chiều ba pha, điện tử công suất, biến tần.*

[1]Hanoi University of Industry
[2]University of Economics - Technology for Industries
[*]Email: thichvh@haui.edu.vn
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1. INTRODUCTION

In recent years around the world, science and technology are making great leaps. The electric drive field has grown strongly and is present in many fields of industrial and military control. The developed capacity electronic control systems associated with electric drive systems and microprocessor techniques, programmable control techniques, technological process automation, etc. Therefore, it is necessary to Improving controllers quality of electric drive systems for industrial machines on the basis of power converter - Inverter [1, 2, 4, 5, 6].

Using power electronic converters with power semiconductor elements such as transistors, Bipolar junction transistors (BJT), Thyristor (Silicon Controlled Rectifier), Gate turn off thyristor is GTO, Mosfet, JFET, IGBT, etc. is possible ability to withstand high currents and voltages and ensures fast action of the drive system. In the control measurement circuits using microchip components, microprocessors and informatics technology to have compact structure, high technical features to maximize the working ability of the electric motor to satisfy the technological requirements with high precision, wide control area.

The improving quality digital drive control systems are increasingly used and have outstanding advantages such as easy adjustment of voltage and frequency value of power supply to motor [2, 4], size and compact weight, stability of characteristics, fast actuation, and easy parameter optimization thanks to microcontrollers and microprocessors. Improving the switching control algorithm of semiconductor locks is one of the urgent requirements to improve the output voltage quality and ensure safety as well as improve the life of semiconductor and simple equipment hardware circuitry [8, 11, 12, 15].

Some previous studies have focused only on the problem of controlling reverse system, optimally using semiconductor valves, some control methods of frequency change, modeling and change, the opening and closing of semiconductor valves in a ballast system [7, 9]. These documents do not pay attention to the quality problem of the system control and when the load is consumed.

The main research content of the paper is to study the optimal current control to improve the quality of the three phase inverter system controlling in industrial machines: such as CNC machine tool system, robot machine system in industrial, conveyor system of mixing plants in cement factories, etc is now very necessary.

2. THE BUILD A CONTROLLER MODEL

2.1. Structure diagram of three phase inverted bridge

The power circuit of three phase inverter with output LC filter considered in this paper is shown in Figure 1. The converter and filter models are presented here, and the load is three phase load.

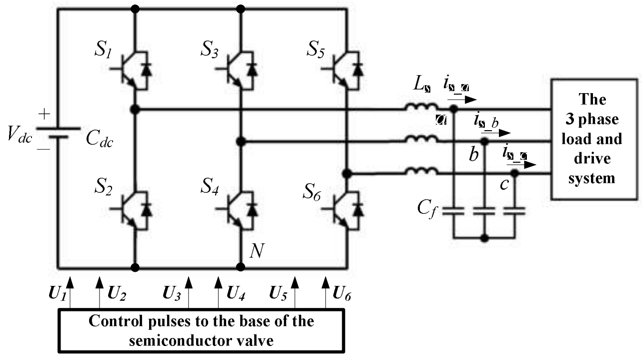

Figure 1. The three-phase inverter with output LC filter

The controller uses a model of the system to three phase inverter, on each sampling interval, the behavior of the output voltage for each possible switching state. Then, a cost function is used as a criterion for selecting the switching state that will be applied during the next sampling interval. There is no need of internal current control loops and no modulators; the gate drive signals are generated directly by the control [3, 6, 8, 10].

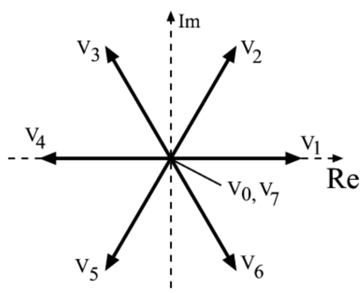

Figure 2. The voltage vectors generated by the inverter

2.2. The Optimized quality improvement for a three phase reverse flow system

With the switching rules of the current pulse-width modulated inverters, the same current is often present in the column of the inverters, to eliminate it normally in the microcontroller must integrate a firing tool. Deat time complicates the programming algorithm, so the problem of eliminating duplicate current only by improving the switching law contributes to simplify the microcontroller structure as well as easily set up control. each state of the inverse bridge. The switching states of the converter are determined by the gating signals S_a, S_b, and S_c as follows [2, 4, 5, 11]:

$$S_a = \begin{cases} 1, \text{ if } S_1 \text{ on and } S_4 \text{ off} \\ 0, \text{ if } S_1 \text{ off and } S_4 \text{ on} \end{cases} \quad (1)$$

$$S_a = \begin{cases} 1, \text{ if } S_2 \text{ on and } S_5 \text{ off} \\ 0, \text{ if } S_2 \text{ off and } S_5 \text{ on} \end{cases} \quad (2)$$

$$S_a = \begin{cases} 1, \text{ if } S_3 \text{ on and } S_6 \text{ off} \\ 0, \text{ if } S_3 \text{ off and } S_6 \text{ on} \end{cases} \quad (3)$$

and can be expressed in vectorial form by:

$$S = \frac{2}{3}(S_a + aS_b + a^2 S_c) \quad (4)$$

Where, $a = e^{j2\pi/3}$. The output voltage space vectors generated by the inverter are defined by:

$$v = \frac{2}{3}(\upsilon_{aN} + a\upsilon_{bN} + a^2\upsilon_{cN}) \quad (5)$$

Where, υ_{aN}, υ_{bN}, υ_{cN} are the phase to neutral (N) voltages of the inverter (Figure 1). Then, the load voltage vector v can be related to the switching state vector by:

$$v = V_{dc}.S \quad (6)$$

Where, V_{dc} is the DC link voltage.

Considering all the possible combinations of the gating signals S_a, S_b, and S_c, eight switching states, and consequently, eight voltage vectors are obtained. Note that $v_0 = v_7$ resulting in only seven different voltage vectors, as shown in Figure 2. Here, using modulation techniques like PWM, the inverter can be modeled as a linear system.

With a more accurate model of the converter model could be used for higher switching frequencies. It may include deadtime, insulated gate bipolar transistor (IGBT) saturation voltage, and diode forward voltage drop, for example. In this work, emphasis has been put in simplicity, so a simple model of the inverter will be used for control system.

In a balanced three phase load, the current can be defined as a space vector by:

$$i = \frac{2}{3}(i_a + ai_b + a^2 i_c) \quad (7)$$

and the load EMF as

$$e = \frac{2}{3}(e_a + ae_b + a^2 e_c) \quad (8)$$

In this way, the load current dynamics can be described by the vector equation.

$$v = Ri + L\frac{di}{dt} + e \quad (9)$$

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where R is the load resistance, L the load inductance, v the voltage generated by the inverter, and e the load back EMF. For simulation and experimental results, the load back EMF is assumed to be a sinusoidal with constant amplitude and constant frequency. Then authors building a discrete time form of the load current (9) for a sampling time T_s can be used to predict the future value of load current with the voltage and measured current at the k_{th} sampling instant. Approximating the derivative di/dt by:

$$\frac{di}{dt} \approx \frac{i(k) - i(k-1)}{T_S} \quad (10)$$

And then replacing it in (9), the following expression is obtained for the future load current:

$$i(k) = \frac{1}{RT_S + L}[Li(k-1) + T_S v(k) - T_S(k)] \quad (11)$$

where the term *RTs* could be neglected if the sampling period is small enough and the load is mainly inductive. The shifting the discrete time one step forward in (11), the future load current can be determined by:

$$i(k+1) = \frac{1}{RT_S + L}[Li(k) + T_S v(k+1) - T_S e(k+1)] \quad (12)$$

The load back - EMF can be estimated using (11) and measure ments of the load voltage and current, resulting in the following expression:

$$\hat{e}(k) = v(k) + \frac{L}{T_S} i(k-1) - \frac{RT_S + L}{T_S} i(k) \quad (13)$$

where, $\hat{e}(k)$ is the estimated value of e(k).

Then during the time the semiconductor valves are in service, the EMF component value can be calculated using the extrapolation of the estimated current and past values of the set setback EMF, or the state that the following EMF did not change significantly over a sampling period and in that case, assume $e(k+1) = \hat{e}(k)$.

Then in the proposed predictive algorithm, (12) is evaluated for each of the possible seven voltage vectors, giving seven different current predictions. The voltage vector whose current prediction is closest to the expected current reference is applied to the load at the next sampling instant.

2.3. The linear Current Control With PWM

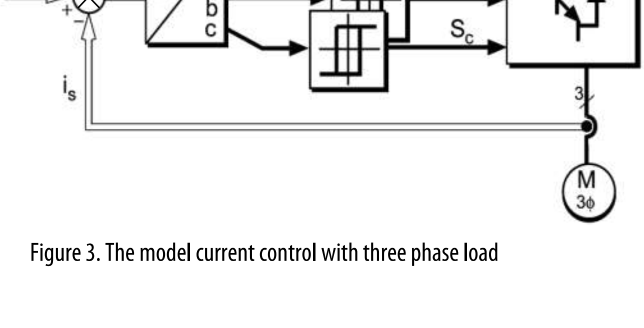

Figure 3. The model current control with three phase load

In this control strategy, shown in Figure 3, measured load currents are compared with the references using hysteresis comparators. Each comparator determines the switching state of the corresponding inverter leg (S_a, S_b, and S_c) such that the load currents are forced to remain within the hysteresis band.

The PWM current control scheme is shown in Figure 4. 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.

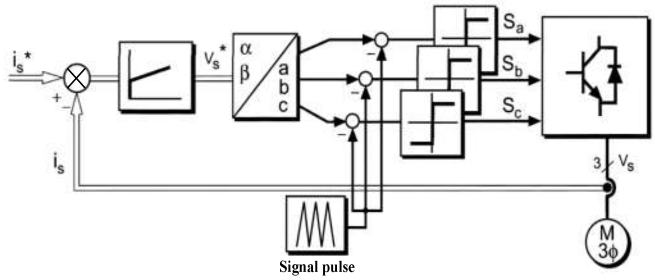

Figure 4. The pulse width modulation current control

Pulse width modulation (PWM), or pulse duration modulation, is a method of reducing the average power delivered by an electrical signal, by effectively chopping it up into discrete parts. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. Along with maximum power point tracking, it is one of the primary methods of reducing the output of solar panels to that which can be utilized by a battery. 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 [2, 5]. 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 PI 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, 2].

With the design and control structure on the three-phase inverters, we have the waveform of the PWM modulated reverse voltage source converter with the three phase inverters structure diagram using the valve IGBT, we have the waveform simulated as shown in Figure 5, as [2, 4].

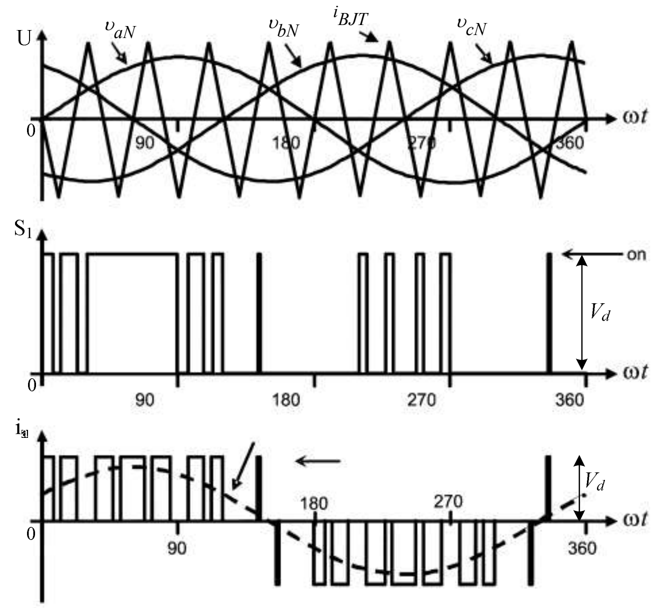

Figure 5. The carrier waveform and modulation, the output voltage waveform for controllers

3. THE SIMULATION AND EXPERIMENTATION

3.1. The Simulation

The after studying the calculation, algorithm and modeling and control of the three phase inverted system with the control system structure was proposed in Part II. To illustrate the operation of the control system with three phase asynchronous motor alternating loads, we conduct simulation and evaluation results to verify the correctness of the system is research problems in the environment Matlab Simulink [13, 14] with the following parameters: three phase AC motor, P = 2,2kW, U = 380V, I = 8,6A, speed 1500rpm, p = 2, frequency 50Hz.

The simulation model of the PWM modulated three phase voltage inverter system for the load is a three phase asynchronous motor built on Matlab Simulink as shown in Figure 6.

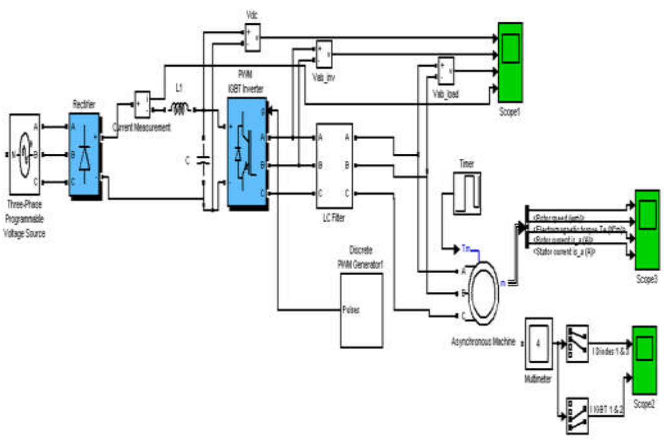

Figure 6. Schematic simulation system built on Matlab Simulink

The simulate a three - phase reverse flow system with voltage values of phases A, B, C and current values corresponding to phases A, B, C as shown in Figure 7, results of simulation of separate price The value of phase A voltage and current of phase A are shown in Figure 8.

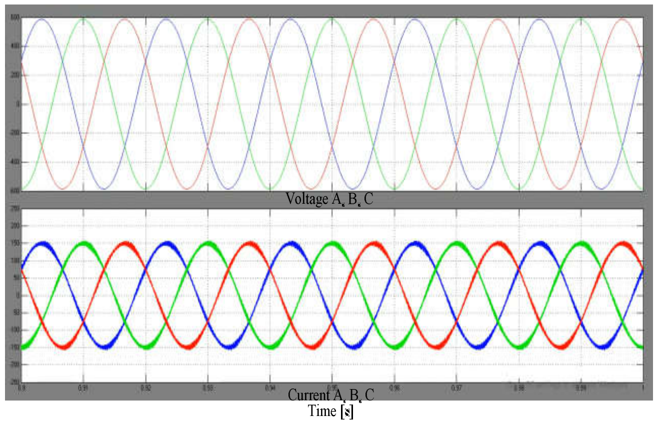

Figure 7. The voltage and current values of phase A, B, C of three-phase inverters simulated on Matlab Simulinks

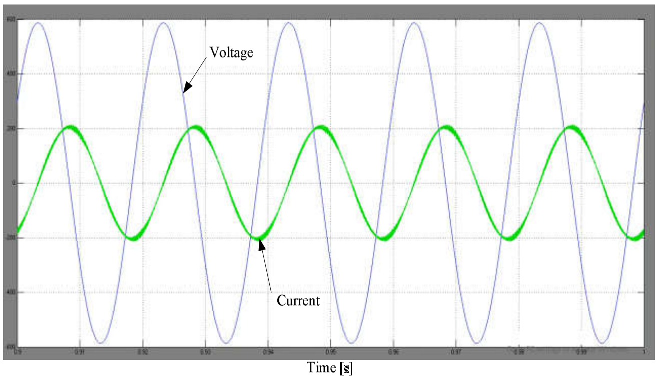

Figure 8. Voltage and current in one phase

Observing the simulation results above we see that in the response time from 0 to 1 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 curvature characteristics of the speed, current, and flux we see that the output response is always asymptotic to the initial set value even when the speed of a three phase motor is changed, the system always works well. This is a new scientific issue, completely applicable to the practical industrial and civil production.

3.2. The experiment

Experimental study with three phase reverse flow system as shown in figure 9 and figure 10, including: Parameters of AC asynchronous motor three phase are the same as those in simulation, motor is hard coupled to the load: DC motor: P = 4kW, U = 220V, I = 8,6A, speed 1750rpm, 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 inverters parameter table is as follows:

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Table 1. Parameters to select devices for inverters

Description	Value
Voltage DC input for inverter	60 - 200VDC
Voltage DC - link	750V
Pulse frequency	10kHz
Filter cutoff frequency fc	25Hz
Capacitor C of the filter	4800µF
Filter reactor L	2,5mH

The detailed layout of the control equipment of the three phase inverted test table is shown in Figure 9 and Figure 10 is an actual experimental table connected to a three phase motor load and a DC motor load (to generate load).

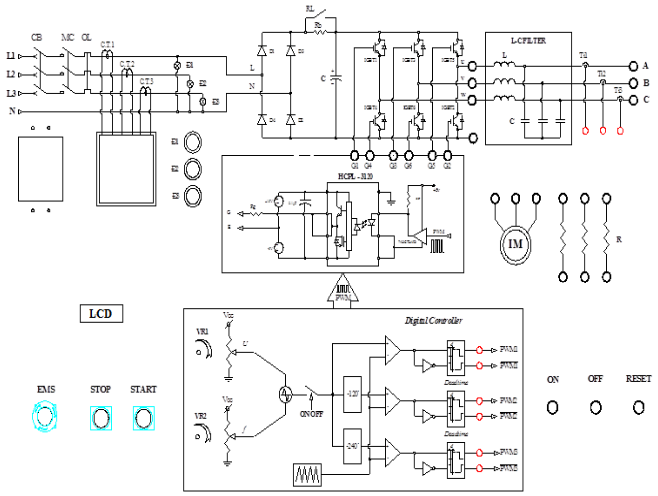

Figure 9. The structure diagram of reverse flow table with three phase storage AC motor control with load

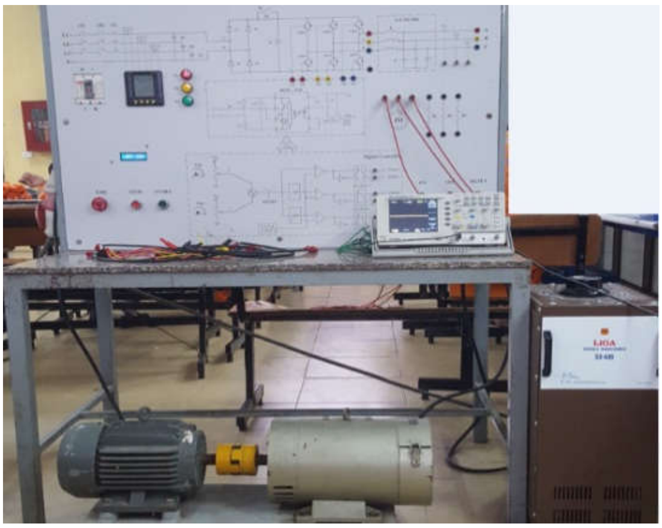

Figure 10. Image of experimental structure of three phase inverter flow in the laboratory

The objective of the experimental process is to evaluate the quality, demonstrate the performance of a three phase inverter using the filter to improve the output voltage of the inverter, to feed the rotating machine dimension with the load as calculated and proposed above. From there, checking, surveying and evaluating the quality and comparing with the simulation results of the system, thereby proving that the system not only works well on the Matlab Simulink simulation, but also works well in the system real time system.

The measured response is the value of voltage and current at the back of the three phase inverter, when the filter is passed. At the time the system is operating when the load changes from no load to the load, the load change time is 25ms out of the total system response time of 50ms.

The measured response is the value of the voltage and current at the back of the three phase inverter, when passed through the filter as shown in Figure 11. At the time of system operation when the load changes from no load to load, the load change time is 25ms in total system response time is 50ms.

Through the research results, we can see that the system has been calculated and built to contribute to improving the quality of electric energy sources of three phase inverter systems in industrial machine control. The system meets the standards of power quality, this is a new scientific issue, completely applicable to the practical production of industrial machines, in civil, defense and security.

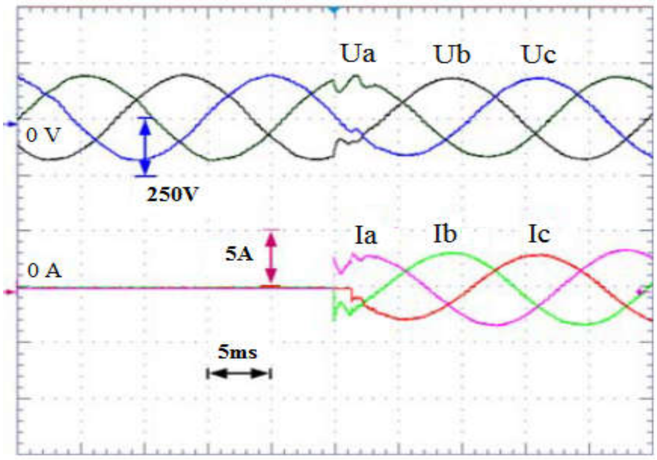

Figure 11. Voltage and current values of the system with variable load: from no load to have load

Comparing the results with studies in [7], and in previous studies [9], the results achieved by the paper are better than the simulation with time to reach a small equilibrium value both value of current, voltage, capacity and experimentation with optimal current control system to improve the quality of inverter systems in control in industrial machines, with process control Load controls work well in real time.

4. CONCLUSIONS

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 three phase inverter to control current to improve the quality of inverter systems in industrial machine control that the authors have studied. The simulation results 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. Optimal current controlled inverters for improved quality of three phase inverter systems in industrial machine control have been developed and verified with experimental results on in-room three phase inverters experiments in Figure 11, the results given in this paper are consistent with the IEEE 519 power quality standard that countries are using.

REFERENCES

[1]. Vo Minh Chinh, Pham Quoc Hai, Tran Trong Minh, 2007. *Power electronics.* Science and Technics Publishing House.

[2]. Tran Duc Chuyen, Tran Xuan Kien, 2017. *Power electronics and application.* Science and Technics Publishing House.

[3]. Nguyen Doan Phuoc, 2009. *Enhance control theory.* Science and Technics Publishing House.

[4]. John Chiasson, 2005. *Modeling and high performance control of electric machines.* Wiley-IEEE Press. Published by Inc., Hoboken, New Jersey, Printed in the United States of America.

[5]. Nguyen Phung Quang, Jörg - Andreas Dittrich, 2008. *Vector Control of Three - Phase AC Machines.* Springer Science & Business Media.

[6]. Harish. S. Krishnamoorthy, Pawan Garg, Puspa J. Kunwor, Prasad. N. Enjeti, 2014. *3-Phase AC-DC converter topologies with higher frequency transformer isolation for utility grid interface.* Published in: IEEE Applied Power Electronics Conference and Exposition, pp. 1240-1247.

[7]. Zafar Iqbal, Nadeem Javaid, Saleem Iqbal, Sheraz Aslam, Zahoor Ali Khan, Wadood Abdul, Ahmad Almogren, Atif Alamri, 2018. *A Domestic Microgrid with Optimized Home Energy Management System.* Energy, 11, 1002, ISSN: 0360-5442.

[8]. Jacques Peronnet, 2018. *Electrical Installation Guide: Calculations for Electricians and Designers.* According to IEC international standards, France.

[9]. Qingrui Tu, Zheng Xu, Lie Xu, 2011. *Reduced Switching-Frequency Modulation and Circulating Current Suppression for Modular Multilevel Converters.* IEEE Trans. on Power Delivery, Vol. 26, No 3.

[10]. Teresa Orlowska - Kowalska, Frede Blaabjerg, Jose Rodriguez, 2014. *Advanced and Intelligent Control in Power Electronics and Drives.* Springer Publisher, ISSN 1860-9503, ISBN 978-3-319-03401-0.

[11]. Rodriguez, J., P. Cortes, 2012. *Predictive Control of Power Converters and Electrical Drives.* John Wiley.

[12]. J.C. Das, 2018. *Power Systems Handbook Short-Circuits in AC and DC Systems.* Publishing International Standard Book New York, by Taylor & Francis Group, LLC.

[13]. S. Sumathi, L. Ashok Kumar, P. Surekha, 2016. *Solar PV and Wind Energy Conversion Systems.* Springer International Publishing AG Switzerland.

[14]. Andrea Bacciotti, 2019. *Stability and Control of Linear Systems.* Publishing Ltd; Springer Nature Switzerland AG.

[15]. László Keviczky, Ruth Bars, Jenő Hetthéssy, Csilla Bányász, 2019. *Control Engineering: MATLAB Exercises*. Springer Nature Singapore Pte Ltd, USA ISSN 1439-2232.

THÔNG TIN TÁC GIẢ

Vũ Hữu Thích[1], Phạm Nhất Khiêm[2], Phạm Thị Thu Hà[2] , Trần Đức Chuyển[2]

[1]Trường Đại học Công nghiệp Hà Nội

[2]Trường Đại học Kinh tế - Kỹ thuật Công nghiệp