SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348 – 8379 / https://doi.org/10.14445/23488379/IJEEE-V8I1P104

Volume 8 Issue 1, 21-26, January 2021

An intelligent control solution for Three-Phase Inverter Systems in Industrial Applications

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Received Date: 11 December 2020
Revised Date: 13 January 2021
Accepted Date: 23 January 2021

Abstract *- This paper presents the research results on an intelligent control solution for a three-phase inverter system applied to control three-phase asynchronous motors in the industry. The converter used in the system includes new chips, high-frequency power electronics, and complex switching technologies. A three-phase reverse flow system built with a control structure to control a mains-connected DC / AC converter capable of operating as required by the load-demand adjustment program. The surveyed results were evaluated by simulation models on Matlab-Simulink software. The model allows for a comparative evaluation of the modulated voltage quality between the improved and classical methods and shows that with improved three-phase inverting system switching law, better performance than the conventional three-phase reverse flow. Simultaneously, the calculated voltage and current characteristics at the output of the DC / AC converter are always sinusoidal to ensure the IEEE519 IEEE1547, IEC 6140-21 power quality standards, applicable in the control field of industrial.*

Keywords — *Inverse controller, Three-phase inverter, Asynchronous motor, Power controller, Power electronic, Power converter.*

I. INTRODUCTION

Digital automatic electric transmission with semiconductor transformations has great practical applications in many specialized scientific and technical fields such as aerospace engineering, automobile manufacturing, metallurgy, manufacturing machine tool creation, chemical industry, robotics engineering, weapon control engineering, and many other specialties. Current development trends of automatic electric actuators switch to coefficients with power electronic semiconductor converters, bipolar transistors such as BJT (Bipolar junction transistor), Thyristor (Silicon Controlled Rectifier), Gate turn-off thyristor - GTO, Mosfet, JFET, IGBT, etc ... is capable of withstanding high currents, high voltage and ensures fast impact for the drive system. The digital drive systems have outstanding advantages such as easy adjustment of voltage and frequency values of the power supplied to the motor [1, 3, 4, 5, 7, 9], compact size and mass, and stability of characteristics, fast action, easy parameter optimization thanks to microcontroller and microprocessor, [2, 4, 10, 11, 21, 22, 24].

Improving the switching control algorithm of semiconductor locks is one of the urgent requirements to improve the output voltage quality and ensure safety and improve the life of semiconductor and simple equipment. Hardware circuitry. With the switching rules of the current pulse-width modulated inverters, in the control system, the three-phase inverters often have an inductive current, to eliminate it normally in the microcontroller must accumulate incorporating the deat time firing tool 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 Easy-to-set control for each state of three-phase inverters, [5, 12, 15, 19].

In electric drive digital control, as in citations [15, 13] and [20, 23], to eliminate this duplicated current, energy-saving sequential switching rules or complex logic variable systems are introduced. To synthesize these variables, it is also necessary to have a deep understanding of knowledge of solving multiple logical equations and systems of logic equations. Not everyone does that well.

Therefore, with the strong development of modern programming languages integrated for microcontrollers, the study of intelligent control of three-phase reverse-ball transistor locks to eliminate currents Even in the programming algorithm is of great significance, it contributes to simplifying the design process for three-phase inverters in electric drive systems, without the need for a deat time shot. Or give complex logical variables in the hardware design of digital control systems, [6]-[9].

The paper's research content has given a method to supplement the intermediate states when the switch controls a three-phase inverter in the 180-degree switching law to eliminate currents, with this method no need to use. Use deat time or introduce new logic variables in conventional numerical control methods. The construction of a control structure for controlling the three-phase DC / AC inverter in power supply, with the controller studied for this reverse flow system, always capable of controlling the operation, according to the requirements of the program Adjusting the load demand of the distribution power system and ensure uninterrupted power supply to the grid system, these research results are applied in industrial, civil, defense and security control, [4, 16, 17, 18].

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

The three-phase inverters are commonly used converters, with pulse-width modulation that ensures a standard sinusoidal output voltage to supply the AC load. To ensure that the output voltage has a load-independent form, it is common to use bipolar pulse width modulation to control each phase of the three-phase scheme independently. That is, the operation of the electronic switches is independent of the network voltage.

A. Design of direct current capacitor and filter inductors of a three-phase inverter

In this research content limitation, the authors will analyze and improve the intelligent control of the three-phase inverters' switches according to the 180 - degree switching law to eliminate the wide-modulated co-conduction currents. Three-phase reverse - voltage ball control pulses in the control diagram of three-phase asynchronous motors in the mode of pulse width adjustment according to the frequency - voltage control method are shaped like Fig. 1:

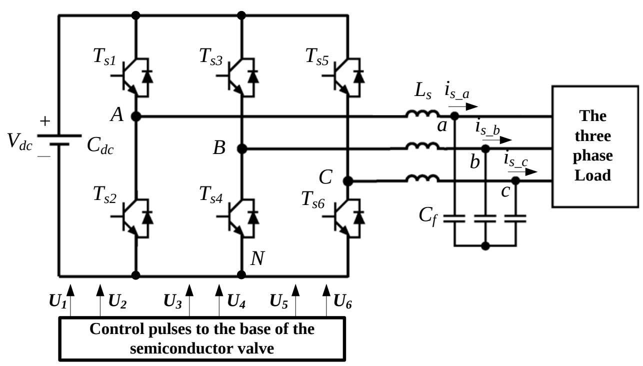


Fig. 1 The connection diagram of three-phase inverters

The main function of the DC link capacitor is to stabilize DC link voltage. If the DC link capacitance is too large, the DC link voltage's dynamic response will be slow, and the cost of the APF hardware system will be increased; if the DC capacitor is too small, it will be difficult to suppress the disturbance caused by external power flow. To design the appropriate size of the capacitor, we first define instantaneous power of the DC link. Then according to the documents [3, 4, 8], the authors have:

$$P_{dc} = V_{dc}.I_{dc} = (\bar{V}_{dc} + \tilde{V}_{dc}).(\bar{I}_{dc} + \tilde{I}_{dc}) \quad (1)$$

where, V_{dc} and I_{dc} represent DC voltage and current, respectively, which can be separated into their respective DC components ($\bar{V}_{dc}$ and $\bar{I}_{dc}$) and AC components ($\tilde{V}_{dc}$ and $\tilde{I}_{dc}$). To simplify the analysis, the authors make three assumptions: the conversion efficiency of the three-phase inverter is 100%, $\bar{V}_{dc}$ is considered zero, and $\bar{I}_{dc}$ is considered zero because $\tilde{I}_{dc}$ it is generally far larger than $\tilde{I}_{dc}$. As a result, authors obtain the following:

$$P_{dc} \cong \bar{V}_{dc}.\tilde{I}_{dc}(t) = \bar{V}_{dc}C_{dc}\frac{d\tilde{V}_{dc}}{dt} \quad (2)$$

where C_{dc} represents DC-link capacitance. Then, we obtain the voltage variation of the DC link capacitor:

$$\tilde{V}_{dc}(t) = \frac{1}{\bar{V}_{dc}C_{dc}}\int_0^t P_{dc}(t)dt \quad (3)$$

where $\int_0^t P_{dc}(t)dt$ represents the capacity of the three-phase inverter. Then, we obtain DC-link capacitance:

$$\Delta V_{dc} = \frac{S}{f_{sw}\bar{V}_{dc}C_{dc}} \Rightarrow C_{dc} = \frac{S}{f_{sw}\Delta V_{dc}\bar{V}_{dc}} \quad (4)$$

where f_{sw} represents the switching frequency. It should be noted that if an electrolytic capacitor were used for this active power filter design case, a higher capacitor specification will be required.

The function of the filter inductors is to filter out current ripples caused by the switching of the shunt three-phase inverter. Large inductances suppress the ripples of inductor currents but reduce the response speed of current controllers. On the other hand, although small inductances improve the current controller's response speed, they cause large current ripples. Therefore, the inductances can be adjusted according to the actual situation. To design the filter inductances, we first need the following inductor voltage equation:

$$v(t) = L_s\frac{di_s(t)}{dt} \quad (5)$$

where L_s is inductance value, and ish is inductor current. According to the relationship between voltage and current on an inductor, (5) can be expressed.

$$\Delta I_S = \frac{\frac{D}{2}T_{sw}.(V_{dc} - V_{grid})}{L_S} \quad (6)$$

where ΔI_s represents shunt inductor current ripple, D represents duty cycle, T_{sw} represents switching period, and V_{grid} represents grid voltage. The duty cycle can be expressed the following:

$$D(\omega t) = m_a sin(\omega t) \quad (7)$$

where m_a represents modulation factor and equals modulation signal divided by triangular wave amplitude. Then, we get output AC voltage:

$$V_s(\omega t) = V_{dc}m_a sin(\omega t) \quad (8)$$

Substituting (7) and (8) into (6) yields the following:

$$\Delta I_s(\omega t) = \frac{V_{dc}.T_{sw}}{2L_s} m_a \sin(\omega t)\left[1 - m_a \sin(\omega t)\right] \qquad (9)$$

Then, we differentiate (9) and let the result be zero to obtain the maximum value of inductor current ripple:

$$\frac{d\Delta I_s(\omega t)}{d\omega t} = \frac{V_{dc}.T_{sw}}{2L_s} m_a [\cos(\omega t)1 - \\ + 2m_a \sin(\omega t)s\cos(\omega t)] = 0 \qquad (10)$$

As a result,

$$\sin(\omega t) = \frac{1}{2m_a} \qquad (11)$$

Lastly, substituting (11) into (9) yields the following equation:

$$L_s = \frac{V_{dc}}{8f_{sw}\Delta I_s} \qquad (12)$$

According to the circuit specifications of the three-phase inverter and commonly assumed inductor current ripple, 10% of output current, it is calculated that the required inductance should be at least larger than 500 µH.

B. The pulse width modulation for a three-phase inverted control system

In this control strategy, shown in Fig. 3, measured load currents are compared with the references using hysteresis comparators. Each comparator determines the corresponding inverter leg (S_a, S_b, and S_c) such that the load currents are forced to remain within the hysteresis band [3, 4, 14]. The converter's switching states are determined by the gating signals S_a, S_b, and S_c as follows.

$$S_a = \begin{cases} 1, \text{if } T_{S1} \text{ on and } T_{S4} \text{ off} \\ 0, \text{if } T_{S1} \text{ off and } T_{S4} \text{ on} \end{cases} \qquad (1)$$

$$S_b = \begin{cases} 1, \text{ if } T_{S2} \text{ on and } Ts_5 \text{ off} \\ 0, \text{ if } T_{S2} \text{ off and } T_{S5} \text{ on} \end{cases} \qquad (2)$$

$$S_c = \begin{cases} 1, \text{ if } T_{S3} \text{ on and } T_{S6} \text{ off} \\ 0, \text{ if } T_{S3} \text{ off and } T_{S6} \text{ on} \end{cases} \qquad (3)$$

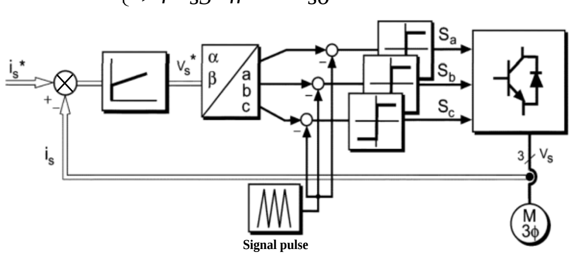


Fig. 3 The pulse width modulation current control with load three-phase is AC motor

The Pulse width modulation (PWM) current control scheme is shown in Fig. 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. The average value of voltage (and current) fed to the load is controlled by PWM is particularly suited for running three-phase loads such as AC motors, which are not as easily affected by this discrete switching inertia that causes them to react slowly. The PWM switching frequency must be high enough not to affect the AC motor load, which implies that the resultant waveform perceived by the load must be as smooth as possible [4, 5, 6].

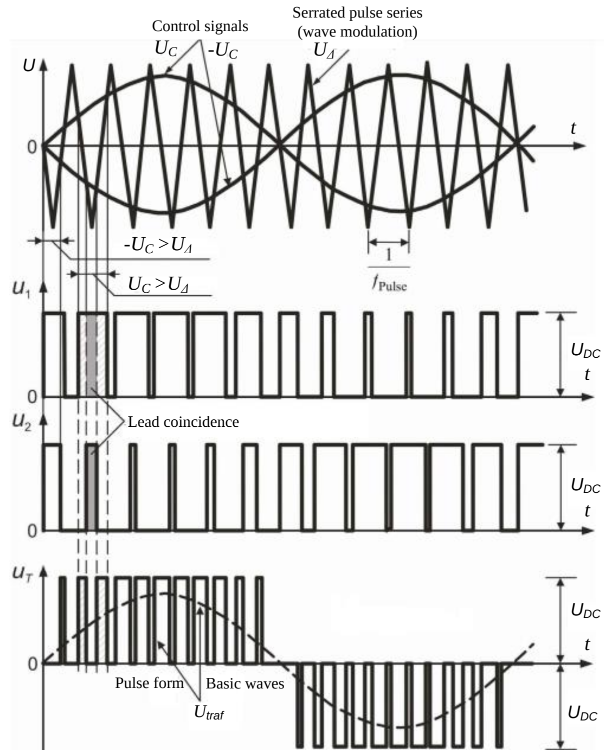


Fig. 4 The carrier waveform and modulation, the output voltage waveform for the controller

With the 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. IN the IGBT power in Fig. 1, we have the waveform simulated as shown in figure 4, as [2, 4].

III. THE RESEARCH SIMULATION

To check and evaluate the achieved results, we use the Matlab simulation model with a load of inductors and resistors corresponding to the stator phases of the star-shaped three-phase asynchronous motor as below. The simulation model consists of the following blocks in Fig. 5 included:

The Invertor IGBT block is a three-phase reverse ballast simulation block with IGBT switches; NewMetod180 is a simulation block to give the reversible control signals according to the switching law with intermediate states;

OldMetod1 is a simulation block to give the reverse ball control signals according to the 180 degrees switching law without an intermediate state; Ra, Rb, Rc and La, Lb, Lc are resistive-inductor units with values of 1Ω and 0.003H respectively; V- Faz is a voltmeter measuring phase A voltage; V_{dc} is the DC power supply to the inverter with value 50V, Voltage DC-link is 450V, filter frequency fc is 25Hz, Capacitor C_f of the filter 2500 µF. The control signal block is the display block that controls the switching pulses of the three-phase inverters. The modulated voltage frequency is 60Hz, the supplementary state retention time is 1/6000 s, which is much greater than the normal co-current survival time of 2 to 10 microseconds. The pulses controlling the switches of the reciprocating bridge in the 180-degree switching law are shaped as shown in Fig. 5 below.

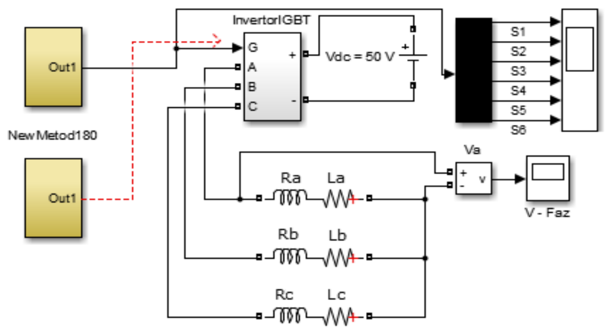


Fig. 5 The diagram to simulate three-phase inverter flow control according to control law is built on Matlab Simulink

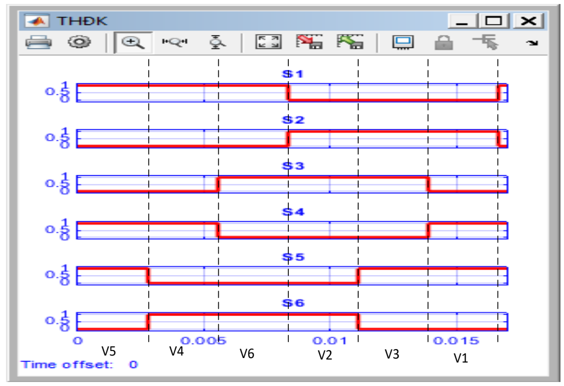
Thus, we have a switching sequence table of three-phase reverse ballast states and each semiconductor key's logic state with the improved 180 degrees switching law described in Table 1 below. The switching process of the three-phase reverse ballast is continuously repeated with this number and order of states.

Table 1. Status parameters of power semiconductor valves for inverters

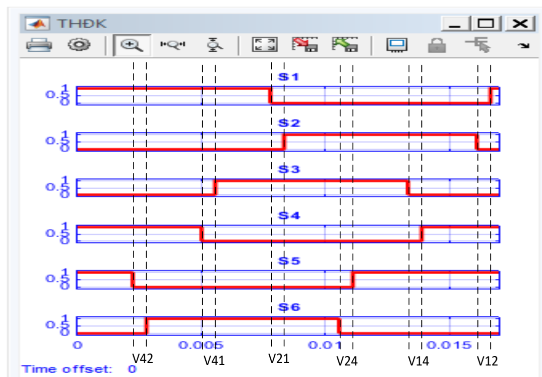
Status	S1	S2	S3	S4	S5	S6
V_5	1	0	0	1	1	0
V_{42}	1	0	0	1	0	0
V_4	1	0	0	1	0	1
V_{41}	1	0	0	0	0	1
V_6	1	0	1	0	0	1
V_{21}	0	0	1	0	0	1
V_2	0	1	1	0	0	1
V_{24}	0	1	1	0	0	0
V_3	0	1	1	0	1	0
V_{14}	0	1	0	0	1	0
V_1	0	1	0	1	1	0
V_{12}	0	0	0	1	1	0

From there, we have some simulation results, which are performed as follows:

Fig. 6 a) has obtained results such as controlling pulse states and switching states of the reciprocating bridge three-phase inverted. Fig. 6 b) shows that, when using intermediate states, no moment on the same column of a three-phase inverted bridge occurs a simultaneous switching of two keys with reciprocal values. Thus, the impulse modulation law with these intermediate states will eliminate the currents that coincide with the three-phase inverter's switching process.



(a)



(b)

Fig. 6 The pulse controls the switches of the reciprocating bridge three-phase inverted: a) control law switching, b) when using an intermediate state

Fig. 7 shows the A-phase voltage obtained in the 180 degrees switching law without an intermediate switching state. Based on the image, we see that the obtained phase voltage does not discern the difference.

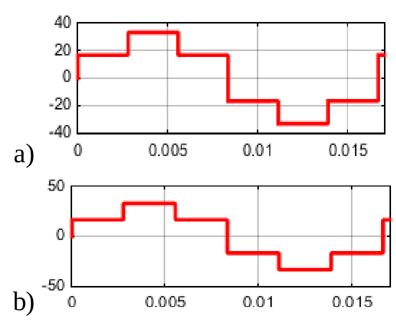
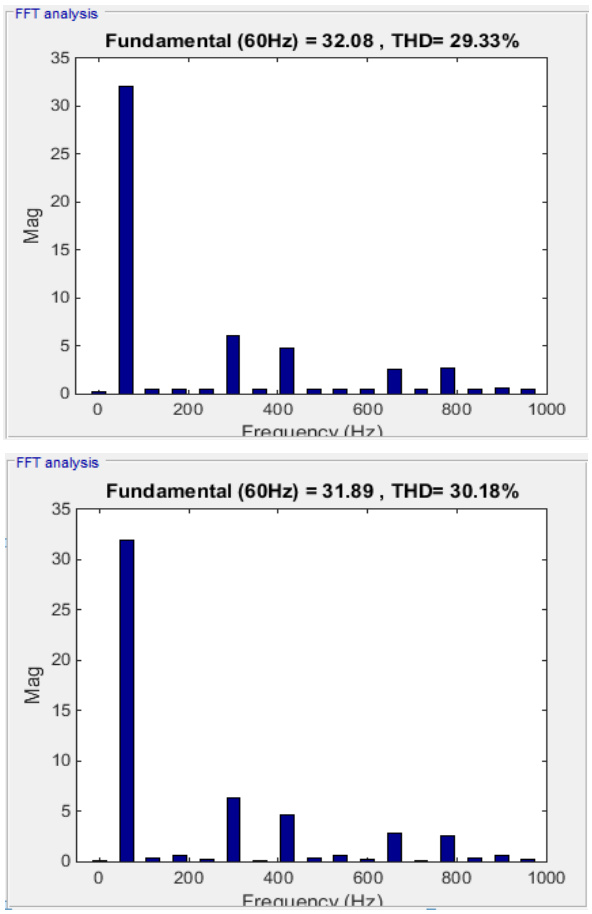


Fig. 7 Phase voltage A: a) in the absence of an intermediate state; b) when an intermediate switching state is used

To evaluate the quality of the stator three-phase induction motors' control voltage, we analyze the obtained voltage spectrum according to two switching laws, as shown in Fig. 8.



a)

b)

Fig. 8 Analysis of A-phase voltage FFT spectrum with switching algorithm of three-phase inverters: a) in the absence of an intermediate state; b) when an intermediate switching state is used

Based on the obtained A-phase voltage spectrum as shown in Fig. 9, we see that Fundamental harmonic indices and control signal distortion are approximately the same, so voltage quality according to the two switching algorithms is possible is considered equivalent, so we ignore the influence of the additional ballast states introduced into the improved switching law. From that, it can be confirmed that the inclusion of intermediate switching states and the 180 degrees switching law does not significantly affect the quality of the output voltage but eliminates the inductive currents produced in the three-phase inverter bridge.

VI. CONCLUSION

The paper analyzes the switching between states of a three-phase inverted bridge in the 180-degree switching law and shows the existence of co-conducting currents in the columns of the inverting bridge when this switching law occurs, thereby propose an improved switching law using additional intermediate inverse ballast states to eliminate the times that two semiconductor locks on the same switching column are simultaneously reversed. Then, the complementary states' retention time is large enough to eliminate currents and is very small compared to the pulse modulation cycle. Through testing, comparing simulation results on Matlab - Simulink can conclude that the intermediate switching states' influence on the quality of the modulated voltage is small and confirmed with the switching law. The circuit of the improved algorithm has eliminated the co-conducting currents on the columns of the three-phase inverters. This contributes to improved reliability, safety, and longevity for the inverter's semiconductor converters in three-phase asynchronous motor control systems.

ACKNOWLEDGMENT

This study was supported by Faculty of Electronic Engineering Technology, University of Economics - Technology for Industries, No. 353, Tran Hung Dao Road, Nam Dinh City of Viet Nam; http://www.uneti.edu.vn.

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