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DECENTRALIZED CONTROL MULTILEVEL THREE PHASE INVERTER USING LEVEL SHIFT CARRIER METHOD

Nguyen Phu Cong[1*], Phan Quoc Dung[2]

[1]*Ho Chi Minh City University of Food Industry*

[2]*Ho Chi Minh City University of Technology, VNU-HCM*

*Email: *congnp@hufi.edu.vn*

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ABSTRACT

In recent years, the decentralized control structure in multilevel power converters has been increasingly interested in research, application, implementation in practice because of its outstanding characteristics and techniques compared to traditional methods. One of the key features of decentralized control is the system's ability to extend and dynamically reconfigure the system. This study presents the application of a decentralized control structure of multilevel inverters using the level shift carrier pulse width modulation method (LSC-PWM) as the control algorithm. For the traditional control method, the carrier signal is provided by a central controller. The decentralized control method provides basic local connections so that carriers can alternate themselves for the configuration of a multi-cell serial system. Efficient performance of decentralized control in power converters demonstrates power and voltage response suitable for a wide range of applications, as well as the ability to dynamically reconfigure the system (add or discard a cell). Control method, algorithm and structure were evaluated through simulation results on Matlab/Simulink.

Keywords: Decentralized control, carrier phase shift, multilevel power converter, full bridge cascade.

1. INTRODUCTION

In terms of control structure, the classical method used to implement the control system of a multilevel power converter which generally consists of a centralized controller to compute a set of appropriate PWM signals, can be capacitor voltage balance, voltage balance between cells, current balance between phases, etc. [1-3]. For multilevel inverter as shown in Figure 1, the central control unit must perform a very large and complex calculation volume, be able to connect, control many devices at the same time, and be able to handle at high speed. For these above reasons, the central controller is quite expensive.

During the operation, if the system needs a change (removing or adding an active cell to increase overall efficiency or to provide a solution in case of failure), centralized control must reconfigure all cells. Thus, this reconfiguration requires a lot of communication between the main control system and the various panels. Also, in the case of cell failure, error detection is firstly performed locally by the cell driver and then the error signal is sent to the main controller to request reconfiguration. This sequence may take a relatively long time.

In order to solve the above problems and reduce the processing volume of the central controller, increase operational flexibility and restructure as needed, a decentralized control algorithm is a reasonable choice for all inverters.

Research on structure and decentralized control method of power converter have had positive results with scientific publications in three main research directions as follows:

According to the first research direction, the decentralized control is characterized by a hierarchical architecture that has two control levels such as primary-secondary controller [4, 5], master-slave controller [6-11] or local-central controller [12-15]. The system level controllers, namely, secondary, master, or central, are responsible for general information management, for performing tasks as voltage balance, current balance, and power exchange. Meanwhile, the controllers of the lower level, namely, primary, slave or local, are in charge of creating PWM control signals. The system easily reaches global optimization. However, the reliability is reduced due to the high dependence on the central control unit and the high cost of the system. In addition, the system requires very high communication bandwidth as the configuration and refactoring process need~~s~~ to be done quickly [6-9].

In the second direction, each power converter module operates independently on its own current and voltage information, not communicating with neighboring modules. The module's carrier phase shift angle will be calculated through a rather complex algorithm. This structure is easy to connect due to decentralized control, but requires complex computation for power converter configurations with large number of modules [16, 17].

As for the third research direction, the cells of the power converter will exchange information with neighboring cells. The information exchanged can be cell position, carrier phase angle, carrier amplitude, etc. The system will be stable after several loops of the algorithm. This structure also increases reliability due to decentralized control, no complicated control algorithm, however the time to configure the system depends on the processing speed of the cell controller, the controller sampling time and the number of cells in the system [18-26]. This structure increases the system flexibility in term of allowing to expand the range of voltage and power requirements by adding or removing the number of cells in parallel and/or serial connections [19-21, 26].

This paper presents the design of multilevel three phase inverters according to a decentralized control structure, using the LSC-PWM as a control algorithm with an improvement in the carrier level update method of each cell controller. In this method, each cell can self-tune its own carrier to produce a transducer carrier, they are independent of the number of cells activated in the system. The information exchanged between cells can be the number of cells active in the system, the location of the current cell, etc. From this information, the cells will calculate the carrier strength and their arrangement. This allows for the dynamic reconstruction of the inverter's cell number when performing the decentralized carrier PWM in the case of a change in the number of cells. The performance and efficiency of the decentralized inverters were verified through a system simulated on Matlab/Simulink.

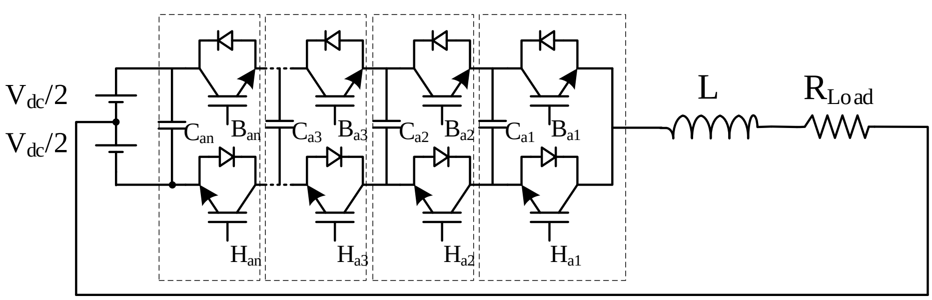

Figure 1. Multilevel power converter

2. PROPOSED DECENTRALIZED CONTROL METHOD FOR MULTILEVEL THREE PHASE INVERTER

Figure 2 shows the topology of the IGBT (Insulated Gated Bipolar Transistor) connection of a multilevel three phase inverters. In order to perform multilevel modulation at the voltage output, the carriers will be arranged in segments 0 to 1. Figure 3 shows the arrangement of four carriers for one phase as an example. For the proposed structure of each cell consists of a full bridge, each cell controller to compute, generate a carrier with amplitude and position depending on the number of cells contained in the structure single phase, the position of the cell being calculated. The cell will exchange information about the position and the total number of cells active in the system, which are received from the front cell.

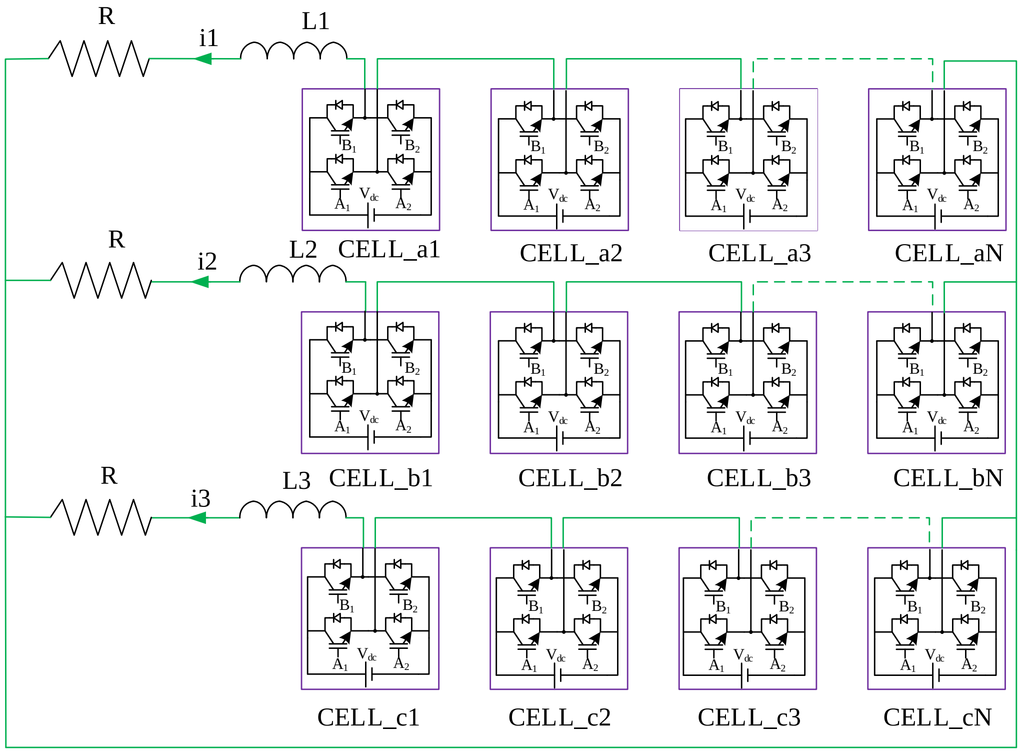

Figure 2. Topology of the IGBT connection of a multilevel three phase inverter

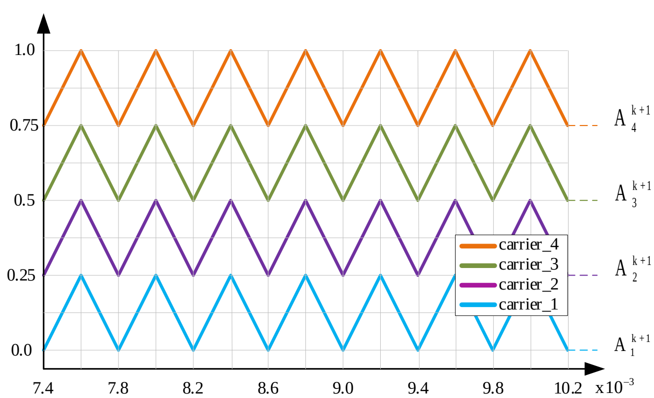

Figure 3. Rules for updating the distributed carrier level with the improved LSC-PWM method (for single phase)

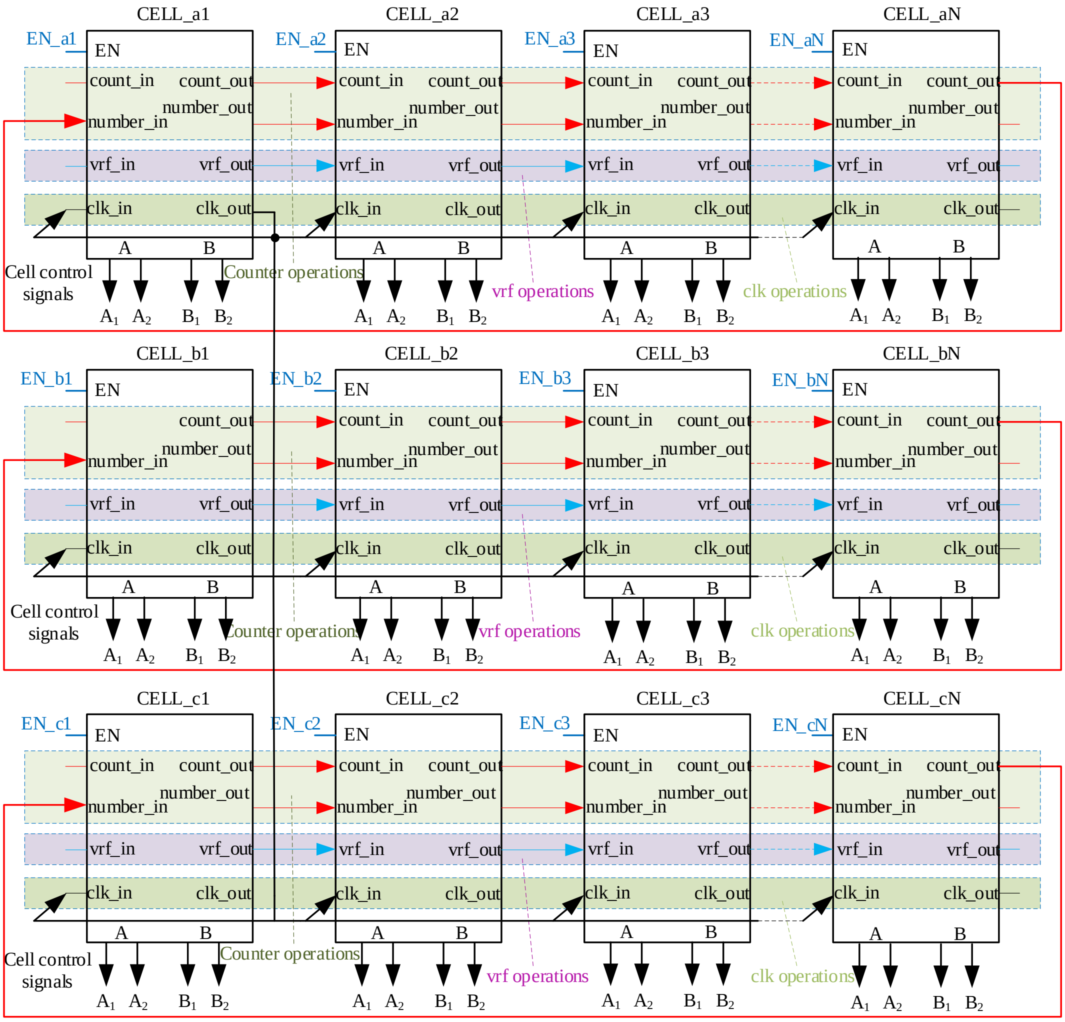

Figure 4. Connection between each cell controller with the proposed decentralized method for multilevel three phase inverter

For the proposed structure, each cell will compute, and generate two high frequency carriers. The proposed method is performed using equations (1)-(4). In which, formulas (3) and (4) are improved compared to traditional method [26]. The rule of doing cell position numbering is very simple: at cell n, at repetition k, the cell number n-1 (count_in) is read and incremented by one position, assigned as count_out. The same sequence is applied to all cells. Since the serial digital information path is just an open loop, the cell in the first position has the value 0 (no information). The last cell information count is the total number of active cells in the chain and it can be passed to all cells (see equation (1) and Figure 4). The peak-to-peak amplitude of a carrier is calculated using equation (2). And the level of two carriers in the same cell is calculated according to the (3) and (4) tasks using the cell controller's internal variables and there is no need to update the level information A_{n-1} (external) of the $(n-1)^{th}$ front-end cell as proposed in the traditional method [26], increases data processing reliability.

The functions and meanings of the inputs, outputs and local variables of a cell are explained in Table 1. Algorithm flowchart of the improved LSC-PWM method is illustrated in Figure 5. Elimination of any cell is controlled by a enable signal (EN).

$$count\_out_{n}^{k+1} = count\_in_{n-1}^{k} + 1 \tag{1}$$

$$\Delta A_{base}^{k+1} = \frac{1}{2*N_{total}^{k}} \tag{2}$$

$$A_{n\_A}^{k+1} = \Delta A_{base}^{k} + \Delta A_{base}^{k} * count\_in_{n}^{k+1} + 0.5 \tag{3}$$

$$A_{n\_B}^{k+1} = 0.5 - \Delta A_{base}^{k} * count\_in_{n}^{k+1} \tag{4}$$

Table 1. Input/output functions of one cell

Input	
EN	Enable
count_in	Get information of cell index from the previous cell
number_in	Get information of total number of cells in the system
vrf_in	Get information of modulation index from the previous cell
clk_in	Receive synchronous clock pulse
Output	
count_out	Send information of cell index to the next cell
number_out	Send information of total number of cells in the system
vrf_out	Send information of modulation index to the next cell
clk_out	Send information of synchronous clock pulse to the next cell
A1, A2, B1, B2	IGBT control signal A1, A2, B1, B2
Internal variable	
ΔA_{base}	A carrier's peak-to-peak amplitude
A_{n_A}, A_{n_B}	The n^{th} carrier level
N_{total}	Total number of active cells

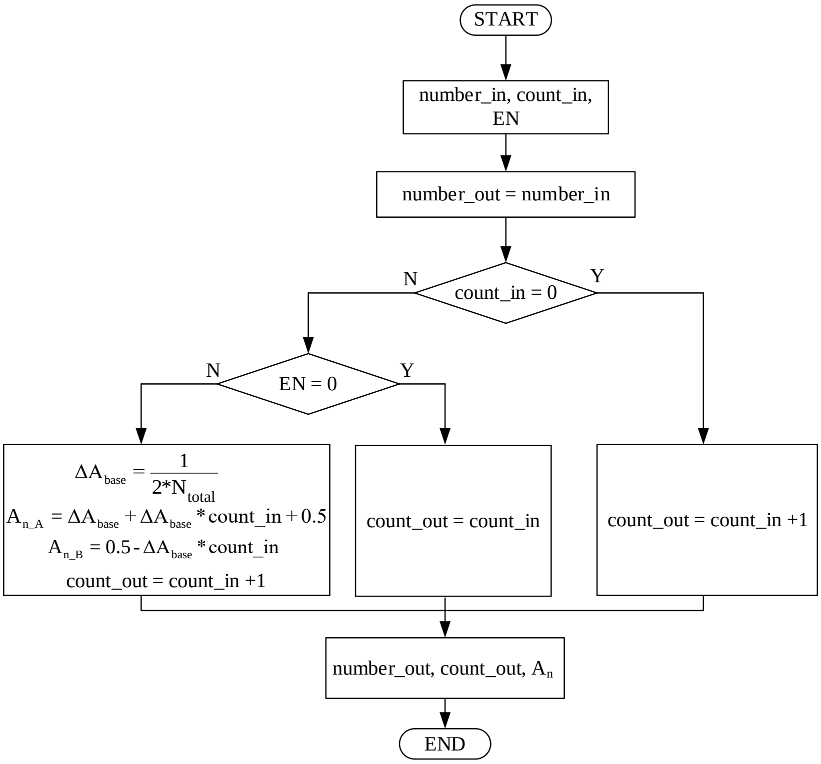

Figure 5. Modified LSC-PWM decentralized control algorithm flowchart of the cell

3. SIMULATION RESULTS AND DISCUSSION

3.1. Configuration and simulation parameters

Building a simulation model on Matlab/Simulink with the proposed configuration as shown in Figures 2 and 3, each phase of the power converter consists of 4 serial cells, simulation parameters are given in Table 2.

The simulation process focuses on key tasks:

- Checking the system responsiveness when changing the modulation voltage amplitude, the modulation frequency of inverter.

- Consider and evaluate the possibility of dynamic reconfiguration of the system when adding or removing some cells in the inverter.

- Analyzing and evaluating the waveform of output voltage and load current.

Table 2. Simulation parameters

Parameter	Symbol	Unit	Value
Inductor	L	H	0.0001
Resistor	R	Ω	100
DC input voltage	Vdc	V	150
Switching frequency	fsw	Hz	10000
Sampling time	Ts	s	2e-6

3.2. Simulation results

Figure 6 shows the waveform of output voltage and load current of three phase load when changing the modulation voltage. At 0.00 and 0.04 seconds, the modulation voltage is 550 V, the 9 levels output voltage is the contribution of all cells, which is the sum of the component voltages of the cells. Result of 3 phase output voltage reaches 9 levels (full level). From 0.04 to 0.08 seconds, the modulation voltage is 400 V, the output voltage has 7 levels which is the contribution of 3 cells in the same phase. From 0.08 to 0.1 seconds, the modulation voltage is 200 V, the output voltage has 5 levels which are the contribution of 2 cells in the same phase. The simulation results show that the output voltage of the distributed three-phase inverter responds well to the required voltage amplitude.

Figure 7 shows waveform of output voltage and load current of three phase load when changing the modulation frequency. At 0.00 and 0.04 seconds, the modulation frequency is 60 Hz. From 0.04 to 0.08 seconds, the modulation frequency is 50 Hz. From 0.08 to 0.1 seconds, the modulation frequency is 40 Hz. The results show that the output voltage meets the required frequency.

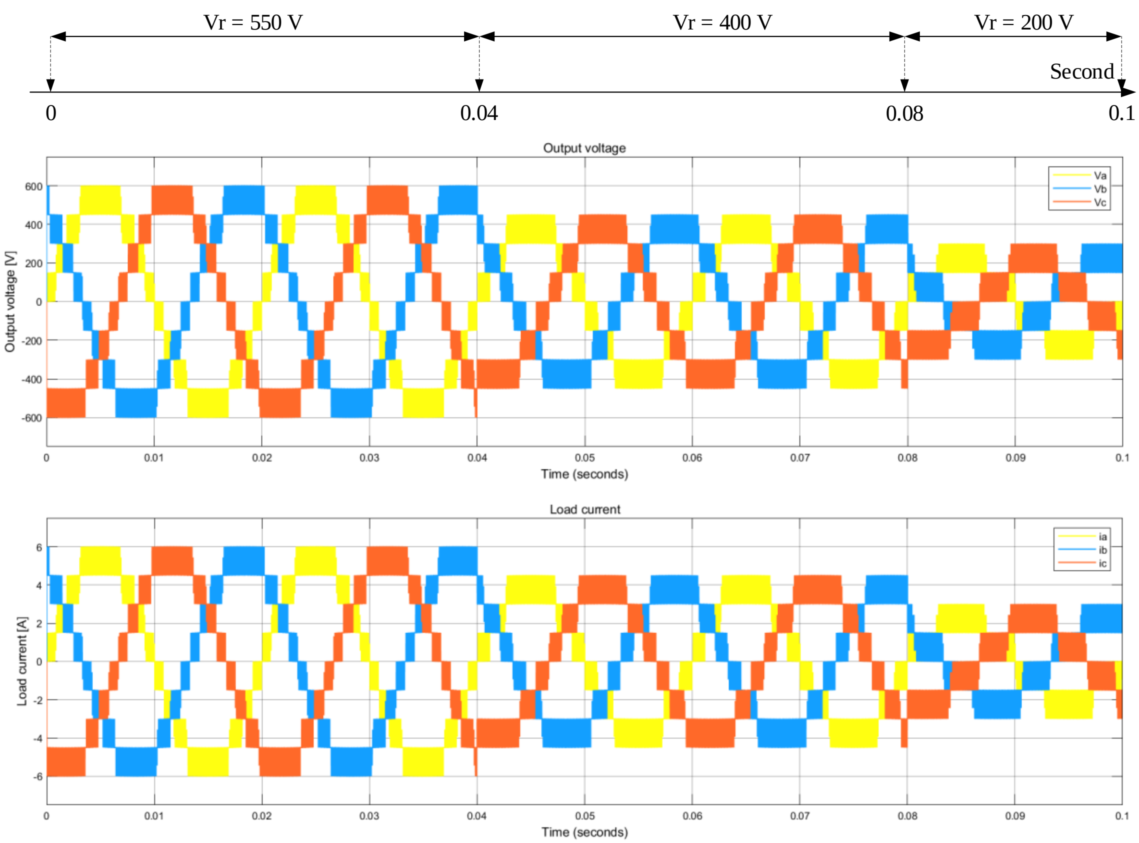

Figure 6. Waveform of output voltage and load current of three phase load when changing the modulation voltage

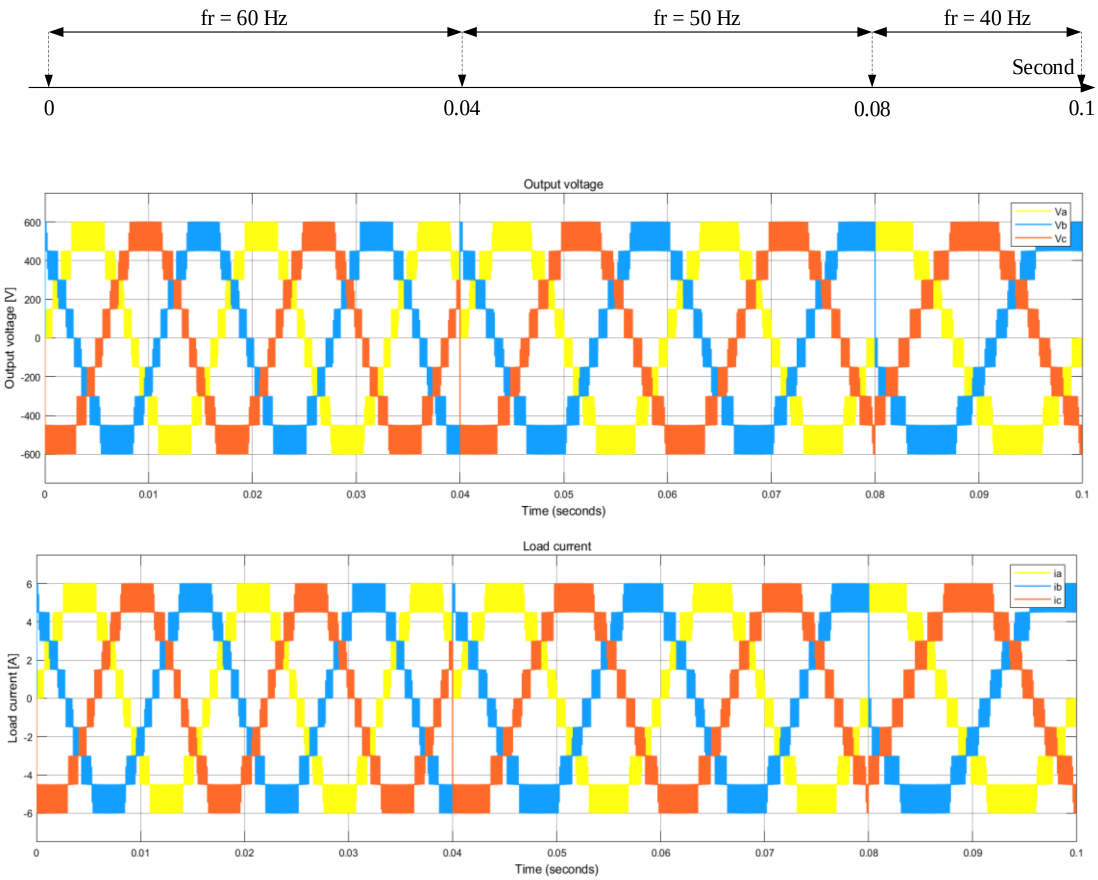

Figure 7. Waveform of output voltage and load current of three phase load when changing the modulation frequency

The decentralized modulation for the control of multilevel converters using LSC-PWM has the advantage of dynamic reconfiguration when the number of cells can be dynamically either deactivated or activated. It is demonstrated in Figure 8 the process of reconfiguration of a 4-cell system in per phase. At the beginning, the system had all active cells, there are 8 carriers arranged evenly in the range 0 to 1, the output voltage was 9 levels. At the time of 0.02s, cells 2, 6, and 10 are removed, the system left 3 cells per phase, there are 6 carriers arranged evenly in the range 0 to 1, output voltage was 7 levels. At the time of 0.04s, cells 3, 7, and 11 are removed, the system left 2 cells per phase, there are 4 carriers arranged evenly in the range 0 to 1, output voltage was 5 levels. At the time of 0.06s, cells 3, 7, and 11 are reinserted, the system had 3 cells per phase, output voltage was 7 levels. Finally, cells 2,7 and 12 are reinserted at 0.08s, the system had 4 cells per phase, output voltage was 9 levels. The results show that the output voltage meets the required dynamic reconfiguration. Based on the number of activated cells in the system after the refactoring process takes place, the power converter will operate at a limited voltage, increasing flexibility in operation and control to repair the system as needed.

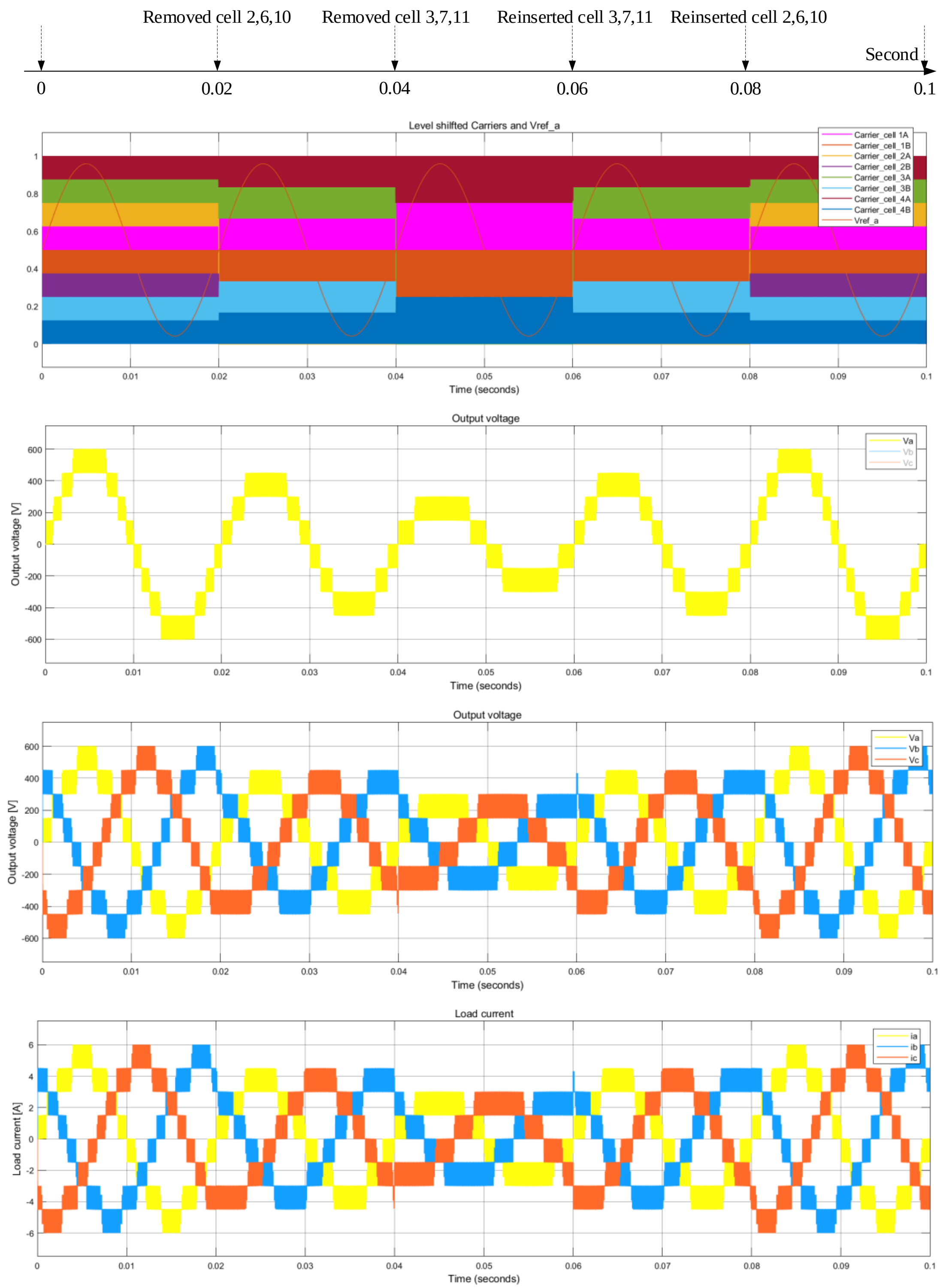

Figure 8. Output voltage and load current waveform in case of reconfiguration

3.3. Evaluation of output waveform

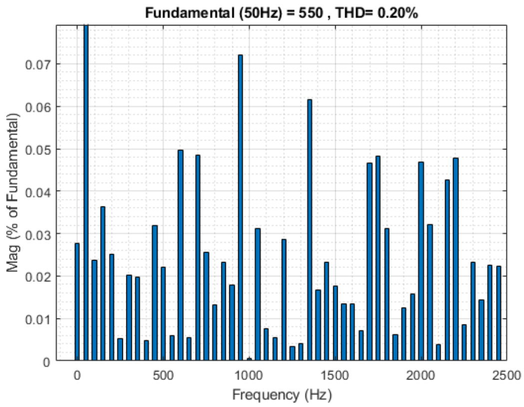

Figure 9. Analysis of THD (Total Harmonic Distortion) output voltage and load current of decentralized control

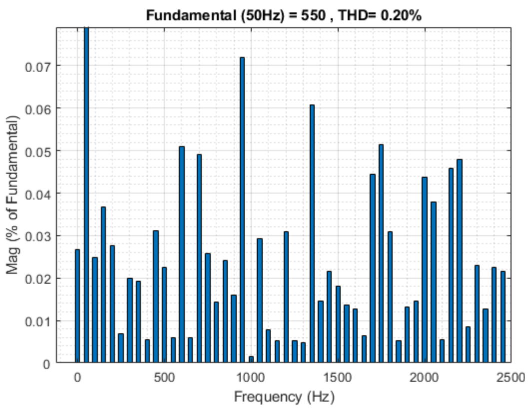

Figure 10. Analysis of THD output voltage and load current of centralized control

Comparing and evaluating the output waveform using LS-PWM and phase disposition pulse width modulation (PD-PWM) for the same system, the same control parameters, for 2 structures: centralized control and decentralized control. Figure 9 shows FFT (Fast Fourier Transform) for voltage and current on the load using a decentralized controller. Figure 10 shows FFT for voltage and current on loads using centralized control. From the results, the two control structures produce the same results. That shows the very good quality of the output voltage, ensuring the quality of the power.

4. CONCLUSION

This study has proposed the application of a multilevel three-phase inverter structure with an improved carrier level displacement control method. The results show the feasibility of the proposed method: low voltage harmonic quality. The simulation results demonstrate the efficiency and can be fully met in the case of dynamic refactoring, thereby increasing flexibility in the control and operation of power converters. The study just stopped at the simulation results on Matlab/Simulink, it is necessary to have experimental studies to verify. The experimental results will be conducted and announced in the near future.

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TÓM TẮT

ĐIỀU KHIỂN PHÂN TÁN BIẾN TẦN BA PHA ĐA BẬC
SỬ DỤNG PHƯƠNG PHÁP DỊCH MỨC SÓNG MANG

Nguyễn Phú Công[1*], Phan Quốc Dũng[2]
[1]*Trường Đại học Công nghiệp Thực phẩm TP.HCM*
[2]*Trường Đại học Bách khoa - Đại học Quốc gia TP.HCM*
*Email: *congnp@hufi.edu.vn*

Trong những năm gần đây, cấu trúc điều khiển phân tán trong bộ biến đổi công suất đa bậc ngày càng được quan tâm nghiên cứu, ứng dụng, triển khai trong thực tế bởi những đặc điểm và kỹ thuật vượt trội so với các phương pháp truyền thống. Một trong những tính năng chính của điều khiển phân tán là khả năng mở rộng và cấu hình lại hệ thống một cách linh hoạt. Nghiên cứu này trình bày việc ứng dụng cấu trúc điều khiển phân tán của bộ biến tần đa bậc sử dụng phương pháp điều chế độ rộng xung dịch mức sóng mang (LSC-PWM) làm thuật toán điều khiển. Đối với phương pháp điều khiển truyền thống, tín hiệu sóng mang được cung cấp bởi bộ điều khiển trung tâm. Phương pháp điều khiển phân tán cung cấp các kết nối cục bộ cơ bản để các sóng mang có thể tự sắp xếp theo cấu hình của hệ thống nối tiếp nhiều mô-đun. Hiệu suất, hiệu quả của điều khiển phân tán trong bộ chuyển đổi công suất thể hiện khả năng đáp ứng điện áp và truyền tải công suất phù hợp với nhiều loại ứng dụng, cũng như khả năng cấu hình lại hệ thống động khi cần thiết (thêm hoặc loại bỏ một mô-đun). Phương pháp điều khiển, thuật toán và cấu trúc được đánh giá thông qua kết quả mô phỏng trên Matlab/Simulink.

Từ khóa: Điều khiển phân tán, dịch mức sóng mang, bộ biến đổi công suất đa bậc, mạch cầu H nối tầng.