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Three-Level Back-to-Back Converter Simulation for Wind Turbine Energy Source

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Abstract

This paper presents the simulation of three-level back-to-back converter for wind turbine energy source. For this paper, it will be focused on wind turbine energy source and determined the voltage from wind turbine energy source being regular value. The operation of the converter can be simulated by using MATLAB/SIMULINK program. Moreover, the voltage and current of the converter can be properly controlled by SVPWM. The simulation results shown that the output current waveform have signal distortion less than the input current waveform, and also the output voltage waveform is more than the input as well. Therefore, this converter can convert the voltage and current from the AC to DC and from the DC to AC for more performance, and it can be connected to the grid.

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Keywords: Three-Level Back-to-Back Converter; Space Vector Pulse Width Modulation

1. Introduction

Nowadays, renewable energy sources can be increasingly utilized to supply them to the load, such as wind turbines, etc. by connecting to the grid system. However, the frequency of generator in wind turbine is very low, and the voltage must be controlled to a value closing to the grid system. The voltage and frequency, which are generated by the generator, cannot be connected to the grid system directly. Therefore, it is necessary to vary the voltage and frequency to the grid firstly. Recent studies have presented the simulation of three-level inverter using the space vector pulse width modulation method.

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The simulation results demonstrate the proposed three-level PWM rectifier that provides the excellent performance both in steady-state and dynamic load variations [1].

Further research presented the simulation of two-level inverter, which is compared sinusoidal pulse width modulation technique method and space vector pulse width modulation technique method. The simulation results show the control system with fast response and the stable dc voltage. Other, the voltage level is more than the sinusoidal pulse width modulation technique method [3]. Moreover, this research presented the comparison between the three-level inverter and two-level inverter simulations with using sinusoidal pulse width modulation technique method. A simulation result of three-level inverter has noise less than two-level inverter [4]. And the later research presented the simulation of three-level inverter using the space vector pulse width modulation method. The simulation results show feasibility of this strategy and excellent performance of this system [5]. From the above researches, the simulation of three-level back-to-back converter by using the space vector pulse width modulation shows that the voltage and current waveforms have an increasing value and a low noise value, respectively.

Therefore, this paper presents the mathematical model of three-level back-to-back converter with the space vector pulse width modulation control algorithm by using MATLAB/SIMULINK program to monitor performance and to develop for supporting the renewable energy utilization in the future.

2. Back-to-Back Converter

The main circuit of the back-to-back converter [2] is composed of renewable source, load, and switching devices. The switching devices or IGBT are divided into two sets that are equal to 24 pieces. The 12 switching devices will be operated as a rectifier, and the 12 switching devices will be performed as an inverter. It also has C_1 and C_2 , which is called DC-link, between the rectifier and the inverter.

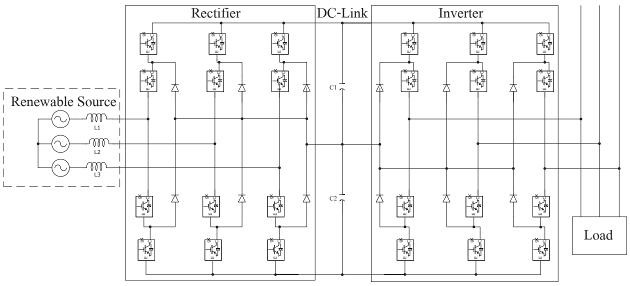

Fig. 1. Main circuit of three-level back-to-back converter

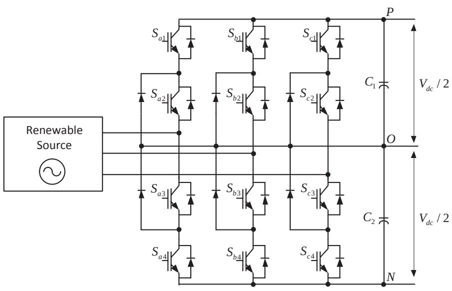

Fig. 2. Main circuit of three-level rectifier

2.1. Three-Level Rectifier

The three-level rectifier circuit [1], which is shown in Fig. 2, combines with 12 IGBTs, 6 diodes, and 2 capacitors C_1 and C_2

The nature of the three phase three-level PWM rectifier is the pure sinusoidal waveforms that can be achieved in grid currents with a unity power factor by optimizing the IGBTs switching status in each arm. Then the ending voltage of the three arms is equal to the three phase AC voltage sources. The power flows from the grid to DC-side load in converse condition while the power feedback from the DC-side to the grid in regeneration status working as a three phase PWM inverter.

Equations (1) and (2) are the mathematical model established in synchronous rotating reference frame (d-q frame) based on the topology of three-level PWM rectifier:

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -R/L & \omega \\ -\omega & -R/L \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L}\begin{bmatrix} e_d \\ e_q \end{bmatrix} - \frac{1}{L}\begin{bmatrix} V_d \\ V_q \end{bmatrix} \tag{1}$$

$$\frac{3}{2}\left(e_d i_d + e_q i_q\right) = v_{dc} i_{dc} \tag{2}$$

Where e_d and e_q denote the vector of grid voltage e_a, e_b and e_c in the d-q component vector of E_{dq} after rotation transform, V_d and V_q are the voltage vector component of V_{dq} in AC side of the rectifier.

The mathematical model in d-q frame of the PWM rectifier shows the simultaneous current component of d, q axis (i_d and i_q). Therefore, to figure out the problem for designing the current controller. This paper introduces the i_d and i_q feed-forward decoupling controller. The current-loop of the i_d and i_q is PI controller. The voltage instruction of the three phases VSR current control in synchronous rotating reference frame (d-q frame) is:

$$\begin{cases} v_d^* = -\left(K_{iP} + \dfrac{K_{iI}}{s}\right)\left(i_d^* - i_d\right) + \omega L i_q + e_d \\ v_q^* = -\left(K_{iP} + \dfrac{K_{iI}}{s}\right)\left(i_q^* - i_q\right) + \omega L i_d + e_q \end{cases} \tag{3}$$

Where, K_{iP} and K_{iI} are the proportionality coefficient and the integral coefficient in current loop, respectively. i_d^* and i_q^* are the current instruction of i_d and i_q, respectively. The topology of three-level PWM rectifier with the proportional and integral coefficients is expressed in Equation (4) by putting Equation (3) into Equation (1):

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\left[R - \left(K_{iP} + \dfrac{K_{iI}}{s}\right)\right]/L & 0 \\ 0 & -\left[R - \left(K_{iP} + \dfrac{K_{iI}}{s}\right)\right]/L \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} - \frac{1}{L}\left(K_{iP} + \frac{K_{iI}}{s}\right)\begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} \tag{4}$$

The whole circuit is composed of the DC voltage control loop, d-q current control loop, and the SVPWM part to fulfil the demand of the DC side voltage steady working and a unity power factor of the grid. Figure 2 shows the controlling system structure. The outer-loop is the current feedback controller, voltage PI controller feeds the i_d^*, the output of the current PI in inner-loop is the current feedback and the current controller. Moreover, the system has the current status feedback and the feed forward compensation of the distortion grid voltage to accomplish the complete control voltage. The voltage changes into the switching signal by PWM modulation to feed the main circuit to achieve the AC side control voltage.

2.2. Three-Level Inverter

Similar to the definition of two-level inverter switching function, three-level inverter [5] is as follows. In order to facilitate the analysis, the power devices are assumed as ideal switches; it is the symmetrical three phase for AC inverter side. The switching function for the three-level inverter is:

$$s_i = \begin{cases} 1 & \left(u_i = \frac{1}{2}E_d\right) \\ 0 & (u_i = 0) \qquad (i = a,b,c) \\ -1 & \left(u_i = -\frac{1}{2}E_d\right) \end{cases} \tag{5}$$

In other words, each bridge arm can be replaced by a switch, accordingly, a simplified model of main circuit of two-level inverter can be found (including load), as shown in Fig.4. And switching function S_i is decomposed as S_{ip}, S_{io} and S_{in} single switch. When the switching device is turn-on, it is equal to 1. When the switching device is turn-off, it is equal to 0. Because two switches in the same branch or arm cannot turn-on or turn-off at the same time, so that S_{ip}, S_{io} and S_{in} yield as $S_{ip} + S_{io} + S_{in} = 0$

As referring Fig.4, the differential equations of three-phase circuit are expressed in Equation (6):

$$\begin{cases} u_{AN'} = Ri_a + L\frac{d}{dt}i_a + E_a \\ u_{BN'} = Ri_b + L\frac{d}{dt}i_b + E_b \\ u_{CN'} = Ri_c + L\frac{d}{dt}i_c + E_c \end{cases} \tag{6}$$

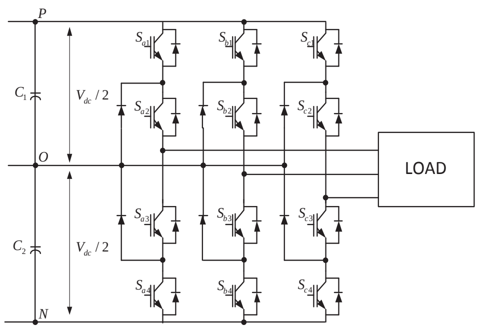

Fig. 3. Main circuit of three-level inverter

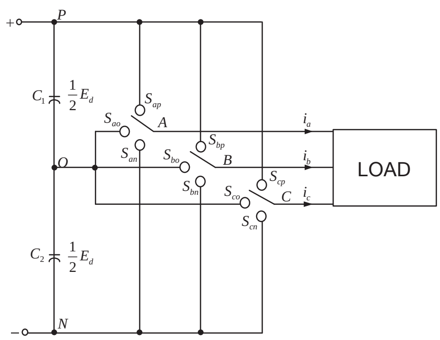

Fig. 4. Simplified mode of three-level inverter

It can be formatted as the matrix form in Equation (7):

$$\begin{bmatrix} u_{AN} \\ u_{BN} \\ u_{CN} \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \begin{bmatrix} \frac{d}{dt} i_a \\ \frac{d}{dt} i_b \\ \frac{d}{dt} i_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \quad (7)$$

Because the relationship between load-phase voltage and inverter output voltage can be expressed as follows:

$$\begin{bmatrix} u_{AN'} \\ u_{BN'} \\ u_{CN'} \end{bmatrix} = \frac{1}{6} E_d \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \quad (8)$$

So, Put (8) into (7), the main circuit mathematical model of the three-level inverter can be reformatted in Equation (9):

$$\begin{bmatrix} \frac{d}{dt} i_a \\ \frac{d}{dt} i_b \\ \frac{d}{dt} i_c \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 & 0 \\ 0 & -\frac{R}{L} & 0 \\ 0 & 0 & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \frac{E_d}{6L} \times (3S_a - S^*) - \frac{E_a}{L} \\ \frac{E_d}{6L} \times (3S_b - S^*) - \frac{E_b}{L} \\ \frac{E_d}{6L} \times (3S_c - S^*) - \frac{E_c}{L} \end{bmatrix} \quad (9)$$

Where $S^* = S_a + S_b + S_c$.

According to the definition of three-level inverter, each bridge arm four main control switch has three different types of on-off combination which corresponds to three different potential output P, O and N stands for each three, then define each phase's switch state as (5), by every phase of the switch state has three switch states (P, O and N), so three-phase three-level inverter totally has 27 different switch states.

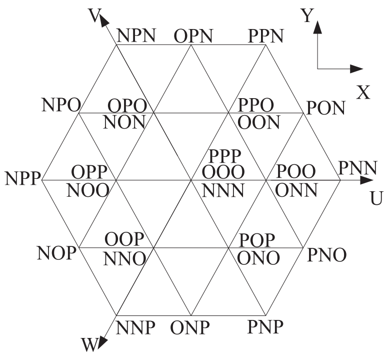

Fig. 5. Voltage space vector of three-level inverter.

3. Space Vector Pulse Width Modulation

Each phase of the circuit of the three levels has three states. Then, the three-level voltage space vector can be generated for all 27 states (3^3). The status of the switches can be shown in the hexagon as Fig.5. [1], [5], [6]

Table 1. Group of Voltage vector

Voltage Vector	Symbols
ZVV	(PPP), (OOO), (NNN)
MVV	(PON),(ONP),(NPO) (NOP), (ONP), (PNO)
LVV	(PNN), (PPN), (NPN) (NPP), (NNP), (PNP)
USVV	(POO), (PPO), (OPO) (OPP), (OOP), (POP)
LSVV	(ONN), (OON), (NON) (NOO), (NNO), (ONO)

In Fig.5, the vector can be divided into five groups that are summarized in Tab 1.

- Zero Voltage Vector (ZVV)
- Medium Voltage Vector (MVV)
- Large Voltage Vector (LVV)
- Upper Small Voltage Vector (USVV)
- Lower Small Voltage Vector (LSVV)

4. Simulation Results

The simulation parameters of the MATLAB simulation model are listed in Tab.2. The simulation results of the input voltage and current are shown in Figs.6, 7, 8 and 9, respectively.

Table 2. Parameter of Three-Level AC to AC

Parameter	Values
Voltage Source	380 V_{p-p}
Frequency	50 H_z
Capacitor	4,500 μF
Switching Frequency	2.5 kH_z
Load 50%,100%	½ kW , 1 kW

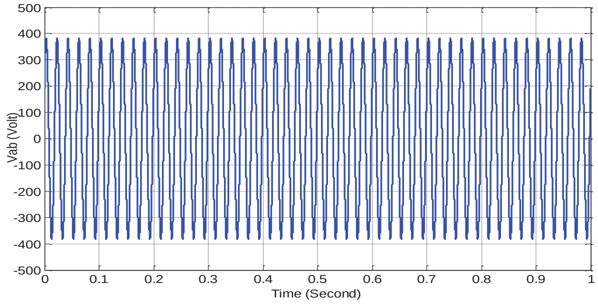

Fig. 6. Simulation result for input voltage

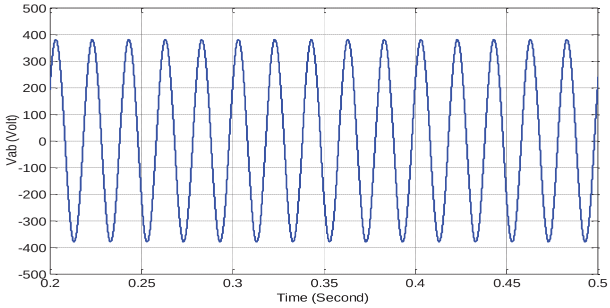

Fig. 7. Zoom as simulation result for input voltage at 0.2 to 0.5 seconds

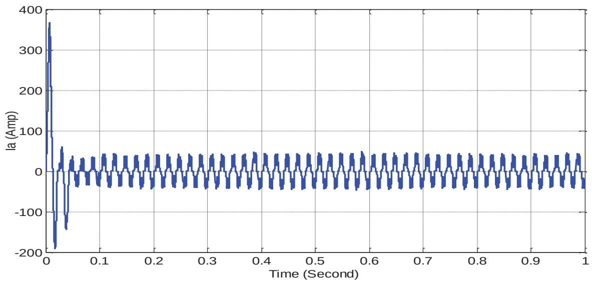

Fig. 8. Simulation result for input current

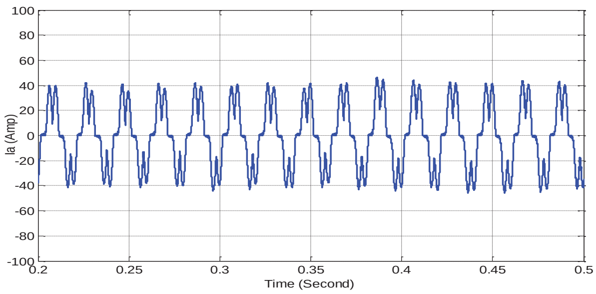

Fig. 9. Zoom as simulation result for input current at 0.2 to 0.5 seconds

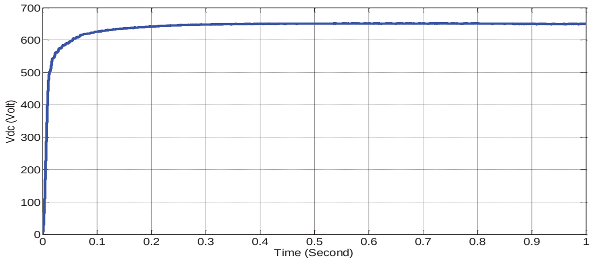

Fig. 10. Simulation result for DC-Link voltage

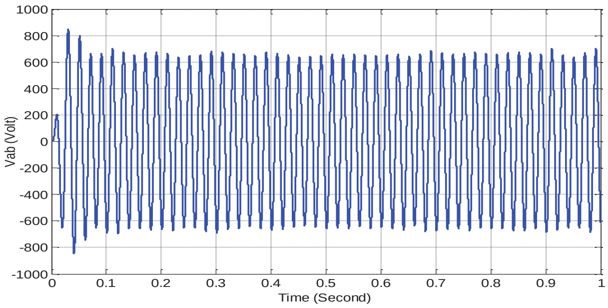

Fig. 11. Simulation result for output voltage

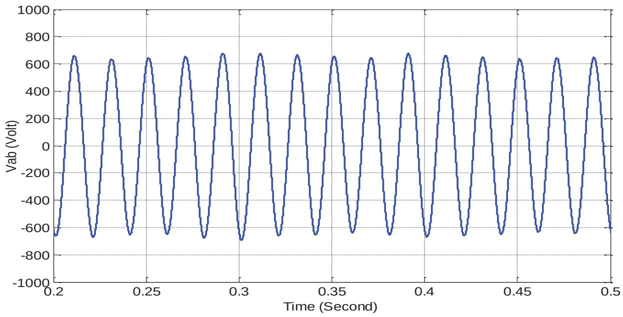

Fig. 12. Zoom as simulation result for output voltage at 0.2 to 0.5 seconds

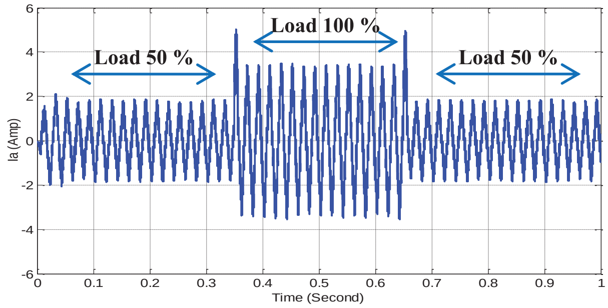

Fig. 13. Simulation result for output current

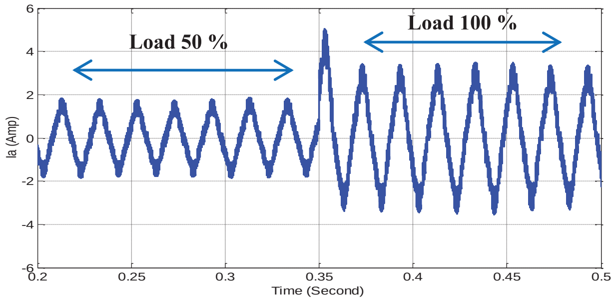

Fig. 14. Zoom as simulation result for output current at 0.2 to 0.5 seconds

In these results, the time of simulation is equal to 1 second. The constant DC-link voltage is approximately equal to 650 V as shown in Fig.10. The phase AB output voltage is approximately equal to 650 V. The 50% load current is about 1.5 A and 100 % load current is about 2.7 A. The simulation results are shown in Figs. 11, 12, 13 and 14, respectively.

5. Simulation Results

This paper presented the simulation of three-level back-to-back converter. The work is divided into two parts as the three-level rectifier and three-level inverter with the space vector pulse width modulation (SVPWM) to generate control signals. The simulation result of the three-level back-to-back converter has higher performance. Although, there are the changing of the load to increase and decrease, the control system can operate normally. In addition, the current waveform of the output signal has the signal distortion less than the current input waveform. The output voltage waveform can be increased and similar to the input voltage waveform. Therefore, the simulation results of three-level back-to-back converter are well. It can be developed to design and create the power converter for renewable energy further.

6. Conclusion

This paper presented the simulation of three-level back-to-back converter. The work is divided into two parts as the three-level rectifier and three-level inverter with the space vector pulse width modulation (SVPWM) to generate control signals. The simulation result of the three-level back-to-back converter has higher performance. Although, there are the changing of the load to increase and decrease, the control system can operate normally. In addition, the current waveform of the output signal has the signal distortion less than the current input waveform. The output voltage waveform can be increased and similar to the input voltage waveform. Therefore, the simulation results of three-level back-to-back converter are well. It can be developed to design and create the power converter for renewable energy further.

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