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Modelling of Single-Phase to Three-Phase Power Conversion System with Uncontrolled/Controlled Bridge at Input Side

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Abstract – This paper presents modelling of single phase to three phase conventional converter with uncontrolled and controlled bridge at input converter side. The input current of rectifier and output voltage of inverter is analysed. Initially single phase a.c power is converted into d.c power using diode bridge rectifier which is further converted into three phase a.c power with the help of three arms IGBT Inverter Bridge. A DC-link capacitor, is interlinked between the two stages of power conversion. The Pulse Width Modulation (PWM) control and Hysteresis Current Control (HCC) techniques have been used in rectification and inversion processes. The proposed topology permits to reduce the rectifier switch currents, the harmonic distortion at the input converter side, and improves the fault tolerance characteristics. The model is developed with the help of SIMULINK tool box of the MATLAB software.

Keyword – Power conversion, Power electronics converters, Parallel converter, Pulse width modulation.

1. INTRODUCTION

In the power distribution system, the single phase grid is considered as an alternative for rural or remote areas due to its lower cost, compared to the three phase grid. On the other hand, loads connected in a three phase arrangement presents some advantages when compared to single phase loads. Three phase motor system with variable–speed drives has advantage due to their constant torque characteristics.so there is a need for single phase to three phase power conversion system for above purpose.
The direct solutions for the single-phase to three-phase power converters is presented in Fig. 1.1.

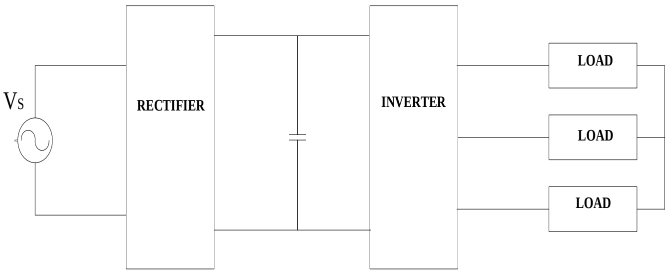

Fig. 1.1. Block diagram of single phase to three phase power converter

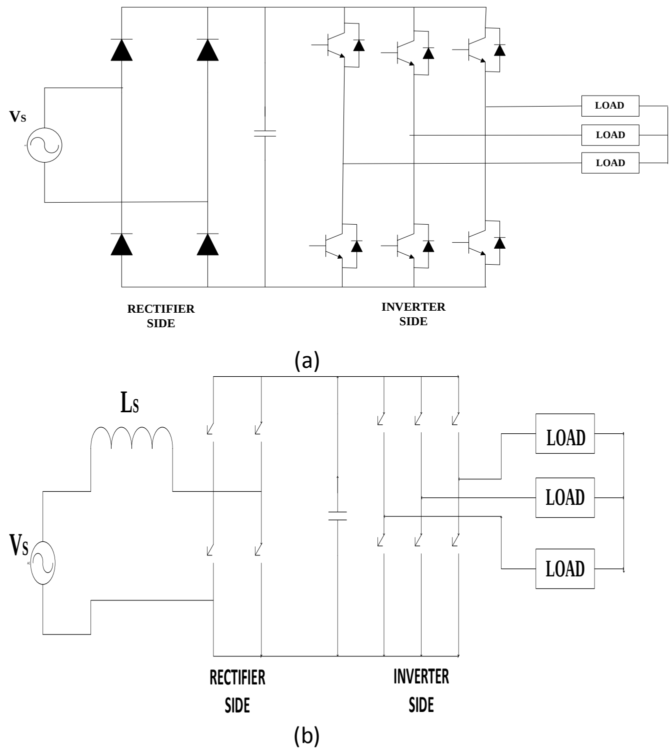

Fig. 1.2. Conventional single-phase to three-phase drive system with (a) uncontrolled (b) rectifier controlled rectifier

Standard Configuration with Conventional Controlled / Uncontrolled Switch are shown in fig. 1.2. Fig. 1.2 (b) shows a solution for single-phase to three-phase power

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conversion, in which all variables (e.g., input power factor and dc-link voltage) at input–output converter sides can be controlled, On the other hand, the configuration presented in Fig. 1(a) represents a cheaper solution but without any control of the input current and dc-link voltage. This is essential in some applications such as aerospace, wind turbine, or UPS for main frame computers and servers. the proposed system permits: to reduce the rectifier switch currents; the total harmonic distortion (THD) of the grid current with same switching frequency or the switching frequency with same THD of the grid current; and to increase the fault tolerance characteristics.

2. System Model

This section will present the model of the proposed configuration. Such a configuration is constituted by a single-phase grid, one open-end three-phase motor, inductor filters (L1a, L1b), converters 1, 2 and one dc-link capacitor banks (C12). If the legs are substituted by pulsed voltage sources, the proposed converter can be modelled as in Fig.2.1.

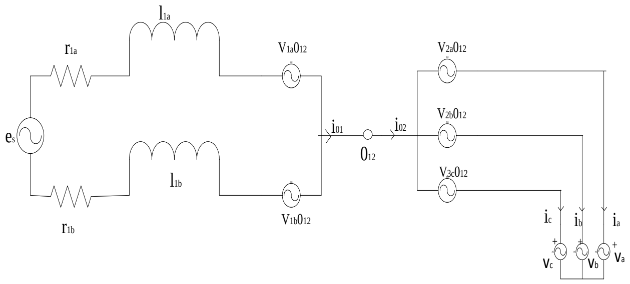

Fig. 2.1. Simplified model of the single-phase to three-phase conversion system C1 configuration

2.1. Source -Side Converter Model

From the system in Fig. 2.1, the following equations can be derived to converters 1 at the grid side:

$$e_g = r_{1a} i_{1a} + l_{1a}\frac{di_{1a}}{dt} - r_{1a} i_{1b} - l_{1b}\frac{di_{1b}}{dt} + v_1 \quad (1)$$

$$i_g = i_{1a} \quad (2)$$

With

$$v_1 = v_{1a}0_{12} - v_{1b}0_{12} \quad (3)$$

Where i_{1a} and i_{1b} are the input currents of the converter 1, the symbols r and l represent the resistance and inductance of inductors L_{1a}, L_{1b}. The voltages $v_{1a}0_{1\ 2}$ and $v_{1b}0_{1\ 2}$ are the pole voltages of the converter 1, and I_s is the source current.

2.2. Machine-Side Converter Model

From the system in Fig.2.1, the following equations can be derived to converters 2 at the machine side:

$$v_{ab} = v_{2a}0_{12} - v_{2b}0_{12} \quad (4)$$

$$v_{bc} = v_{2b}0_{12} - v_{2c}0_{12} \quad (5)$$

$$v_{ca} = v_{2c}0_{12} - v_{2a}0_{12} \quad (6)$$

Where $v_{2a}0_{12}$, $v_{2b}0_{12}$, and $v_{2c}0_{12}$ are the pole voltages of converter 2, and $v_{ab} = v_a - v_b$, $v_{bc} = v_b - v_c$, and $v_{ca} = v_c - v_a$ are line-to-line voltages of the machine. For the voltage control of the motor, the following relations are obtained:

$$v_{2ab} = v_{2a}0_{12} - v_{2b}0_{12} = \frac{v_{ab}}{2} \quad (7)$$

$$v_{2bc} = v_{2b}0_{12} - v_{2b}0_{12} = \frac{v_{bc}}{2} \quad (8)$$

$$v_{2ca} = v_{2c}0_{12} - v_{2a}0_{12} = \frac{v_{ca}}{2} \quad (9)$$

2.3. Circulating Current Model

Due to the series connection, the proposed system shown in Fig.2.1 has a circulating current among the converts. The model of this circulating current can be defined as following:

$$0 = v_{za} + v_{1a}0_{12} + v_{2j}0_{12} + v_j \quad (10)$$

$$0 = v_{zb} + v_{1b}0_{12} + v_{2j}0_{12} + v_j \quad (11)$$

With $j = a, b, c$ and

$$v_{za} = r_{1a} i_{1a} + l_{1a}\frac{di_{1a}}{dt} \quad (12)$$

$$v_{zb} = r_{1b} i_{1b} + l_{1b}\frac{di_{1b}}{dt} \quad (13)$$

The equations of the input circulating currents of the converters 1 i_{o1} and output circulating currents of the converters 2 i_{o2} are defined as

$$i_{01} = i_{1a} + i_{1b} \quad (14)$$

$$i_{02} = i_{2a} + i_{2b} + i_{2c} \quad (15)$$

However, the circulating currents io1, io2, can be represented by a single circulating current i_o, which means

$$i_0 = i_{01} = i_{02} \quad (16)$$

From (10) and (11), it is possible to write

$$v_0 = v_{01} + r_{1b} i_o + l_{1b}\frac{di_0}{dt} + \frac{2}{3}\sum_{j=a}^{c} v_j \quad (17)$$

With

$$v_{01} = (r_{1a} - r_{1b}) i_{1a} + (l_{1a} - l_{1b})\frac{di_{1a}}{dt} \quad (18)$$

$$v_o = \sum_{i=a}^{b} v_{1i}0_{12} + \frac{2}{3}\sum_{j=a}^{c} v_{2j}0_{12} \quad (19)$$

2.4. Three-Phase Motor Model

A typical three-phase machine has been used in this study. Selecting a fixed coordinate reference frame, the mathematical model that describes the dynamic behavior of the three-phase induction motor is given by

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$$v_{sdq} = r_s i_{sdq} + \frac{d\phi_{sdq}}{dt} \quad \text{...} \quad (20)$$

$$v_{rdq} = r_r i_{rdq} + \frac{d\phi_{rdq}}{dt} - j\omega_r \phi_{rdq} \quad \text{...............................} \quad (21)$$

$$\phi_{sdq} = l_s i_{sdq} + l_{sr} i_{rdq} \quad \text{...} \quad (22)$$

$$\phi_{rdq} = l_{sr} i_{sdq} + l_r i_{rdq} \quad \text{.......................................} \quad (23)$$

$$v_{s0} = r_s i_{s0} + l_{ls} \frac{di_{s0}}{dt} \quad \text{.......................................} \quad (24)$$

$$v_{r0} = r_r i_{r0} + l_{lr} \frac{di_{r0}}{dt} \quad \text{.......................................} \quad (25)$$

$$T_e = P l_{sr} (i_{sq} i_{rd} - i_{sd} i_{rq}) \quad \text{...................................} \quad (26)$$

where $v_{sdq} = v_{sd} + jv_{sq}$, $i_{sdq} = i_{sd} + ji_{sq}$, and $\varphi_{sdq} = \varphi_{sd} + j\varphi_{sq}$ are the voltage, current, and flux dq vectors of the stator, respectively; v_{so} and i_{so} are the homopolar voltage and current of the stator, respectively (the equivalent rotor variables are obtained by replacing the subscript s by r); T_e is the electromagnetic torque; ω_r is the angular frequency of the rotor; r_s and r_r are the stator and rotor resistances; l_s, l_{ls}, l_r , and l_{lr} are the self and leakage inductance of the stator and rotor, respectively; l_{sr} is the mutual inductance and P is the number of pole pairs of the machine. The dqo stator variables of the previous model can be determined from the abc variables by using the transformation given by

$$\omega_{sdq0} = A_s \omega_{abc} \quad \text{...} \quad (27)$$

With $\omega_{sdqo} = \begin{bmatrix} \omega_{sd} & \omega_{sq} & \omega_{s0} \end{bmatrix}^T$, $\omega_{abc} = \begin{bmatrix} \omega_a & \omega_b & \omega_c \end{bmatrix}^T$ and

$$A_s = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix}$$

3. Control Strategy

The control signals are obtained by comparing pole voltages with one (vt1), or more high-frequency triangular carrier signals. In the case of double-carrier approach, the phase shift of the two triangular carrier signals (vt1 and vt2) is 1800. The parameter μ changes the place of the voltage pulses related to Va and Vb. When Vx* = Vx*min (μ = 0) or Vx* = Vx*max (μ = 1) are selected, the pulses are placed in the beginning or in the end of half period (Ts) of the control block diagram of Fig. 3.1, highlighting the control of the rectifier. To control the dc-link voltage and to guarantee the grid power factor close to one. Additionally, the circulating current Io in the rectifier of the proposed system needs to be controlled.

the dc-link voltage vc is adjusted to its reference value v c* using the controller Rc, which is a standard PI type controller. This controller provides the amplitude of the reference grid current Is*. To control power factor and harmonics in the grid side, the instantaneous reference current Is* must be synchronized with voltage e.g., as given in the voltage-oriented control (VOC) for three-phase system. This is obtained via blocks Ge-ig, based on a PLL scheme Fig 3.1. The reference currents I a*and ib* are obtained by making Ia* = Ib* = Is* /2, which means that each rectifier receives half of the grid current. The control of the rectifier currents is implemented using the controllers indicated by blocks Ra and Rb. These current controllers define the input reference voltages Va*and Vb*. The homo polar current is measured (Io) and compared to its reference (Io* = 0). The error is the input of PI controller Ro, that determines the voltage Vo*. The motor there-phase voltages are supplied from the inverter (VSI). Block VSI-Ctr indicates the inverter and its control. The control system is composed of the PWM command and a torque/flux control strategy.

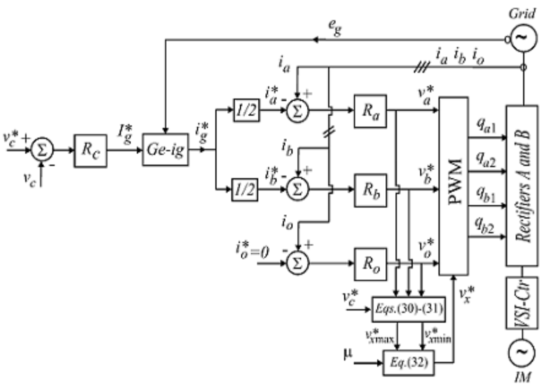

Fig. 3.1. Control block diagram

4. Harmonic Distortion

As we know that harmonic distortion of the proposed converter and its voltages had been analysed with the help of weighted THD (WTHD). It is solved by using

$$WTHD(p) = 100/a_1 \sqrt{\sum_{i=2}^{p} (a_i/i)^2}$$

Where is treated as amplitude of fundamental voltage and is treated as amplitude of Ith harmonic and also p may be number of harmonics in this consideration.

5. Simulation Model

To study the operation of the Three-Phase Drive System, it is implemented in MATLAB/SIMULINK environment. The model is shown in Fig.5.1

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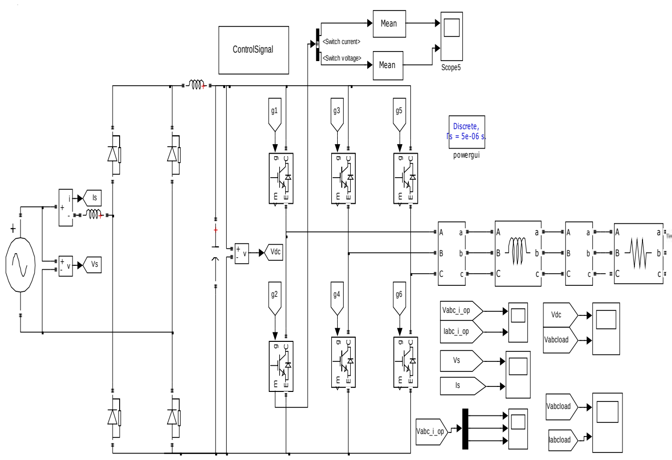


Fig.5.1. Simulation model of C1 configuration with uncontrolled bridge at input side for resistive load

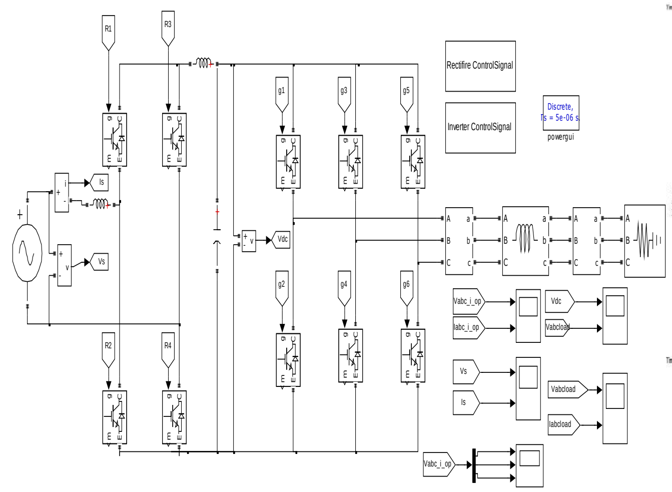
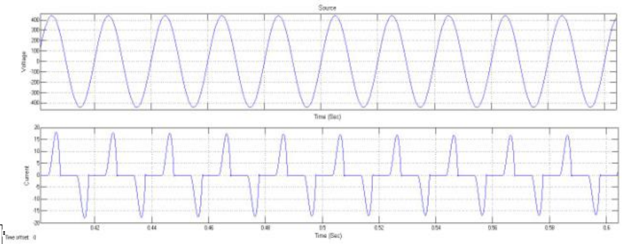


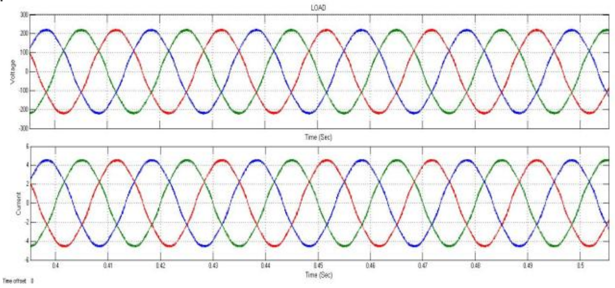
Fig.5.2. Simulation model of C2 configuration with controlled bridge at input side for resistive load

6. Result

The simulation results were obtained with the source and load -phase voltages equal to Vrms440/√2, dc-link voltage of 400 V, capacitance of 2200 μF, and input inductor filters with resistance and inductance given respectively by 0.1Ω and 2.6 mH. Fig. 6.1 (a) shows the ability of the conventional converter with uncontrolled bridge at input side to control the source current with a sinusoidal waveform and power factor close to one. While Fig. 6.1 (b) and (c) shows that wave form of Output Voltage and Output Current. And DC-link voltage for conventional system. Fig. 6.2 shows the wave form of source Voltage and source Current, Output Voltage and Output Current and DC-link voltage for with controlled bridge at input side



(a)



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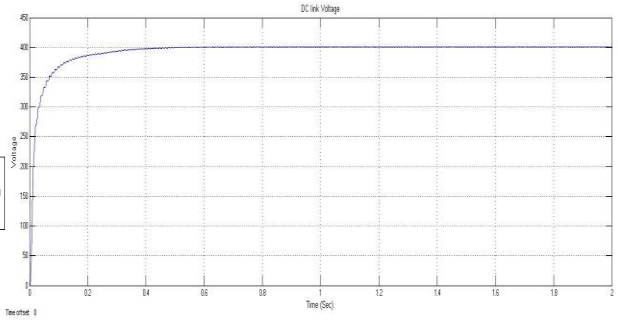
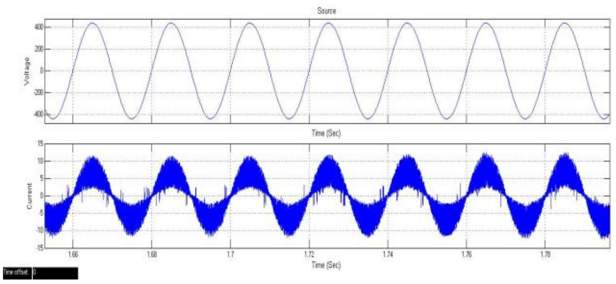
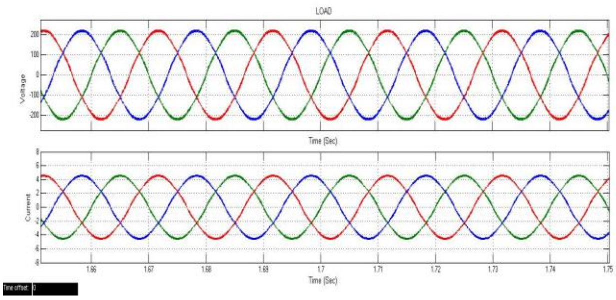


(c)

Fig. 6.1. Simulation results for conventional converter with uncontrolled bridge at input side: (a) voltage and current of the grid, (b) Output Voltage and Output Current, (C) DC- link Voltage



(a)



(b)

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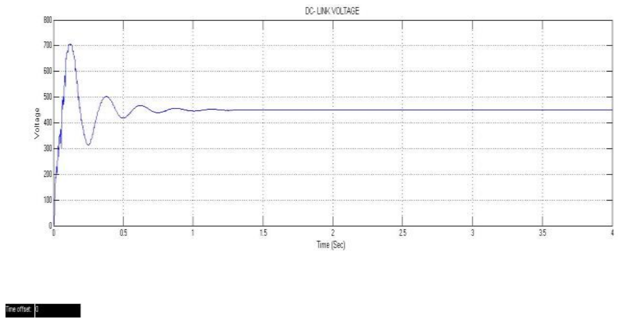

(c)

Fig. 6.2. Simulation results for conventional converter with controlled bridge at input side (a) voltage and current of the grid (b) Output Voltage and Output Current, (C) DC- link Voltage

7. Conclusion

A single-phase to three-phase drive system with uncontrolled/controlled bridge at input side and a three phase load was proposed. The system model and the control strategy, including the PWM technique, have been developed. The complete comparison between the proposed and standard configurations has been carried out in this paper. Compared to the conventional topology, the proposed system permits to reduce the rectifier switch currents, the THD of the grid current with same switching frequency or the switching frequency with same THD of the grid current and to increase the fault tolerance characteristics. In addition, the losses of the proposed system may be lower than that of the conventional counterpart. The initial investment of the proposed system (due to control of semiconductor devices) cannot be considered a drawback, especially considering the scenario where the cited advantages justify such initial investment. The experimental results have shown that the system is controlled properly, even with transient and occurrence of fault.

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