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Modeling of Single-Phase to Three-Phase Drive System

Boosharaju Ravikumar [α] & Dr.Y.R. Manjunath [σ]

Abstract- This paper presents single-phase to three-phase with dc-link converters with parallel rectifier and series inverter for reduction in the input current and reduction of the output voltage processed by the rectifier circuit and inverter circuit respectively. In this paper we proposed better solution for single phase to three phase drive system by employing 2parallel single phase rectifier stages, a 3-phase inverter stage. Parallel converters can be used to improve the power capability, reliability, efficiency and redundancy. An isolation transformer is not used for the reduction of circulating currents among different converter stages. It is an important objective in the system design. The complete comparison between the comprehensive model of proposed converter and standard configurations will be presented in this work. Simulation of this model will be carried out by using MATLAB/ Simulink.

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I. Introduction

Most power conversion applications consist of an AC-to-DC conversion stage immediately following the AC source. The DC output obtained after rectification is subsequently used for further stages. There by an ac to dc converter has become an integral part of mostly all the electronic equipments. Mainly, it is used as an interface between utility and most of the power electronic equipments[1]. These electronic equipments also form a major part of load on the utility. Two factors that provide a quantitative measure of the power quality in an electrical system are Power Factor (PF) and Total Harmonic Distortion (THD).The amount of useful power being consumed by an electrical system is predominantly decided by the PF of the system. Generally, to convert line frequency ac to dc, a line frequency diode bridge rectifier is used. To reduce the ripple in the dc output voltage, a suitable filter capacitor and/or an inductor is used at the rectifier output[2]-[3]. But due to these reactive components, the current drawn by this converter is peaky in nature, very much differed from asinusoidal shape. This input current is rich in lower order harmonics. Also, as power electronics equipments are increasingly being used in power conversion, they inject low order harmonics into the utility. Due to the presence of these harmonics, the total harmonic distortion is high when so many are put together in a huge electronic system. Additionally, the input power factor becomes poorer. Due to the disadvantages associated with low power factor and harmonics, utilities enforces (in some countries) harmonic standards and guidelines which will limit the amount of current distortion allowed into the utility. Looking into the serious effects generated by conventional converters, the simple diode rectifiers should not be used. There is a need to achieve rectification at close to unity power factor and low input current distortion.

Several solutions have been proposed when the objective is to supply three-phase motors from single-phase ac mains [8]–[16]. It is quite common to have only a single-phase power grid in residential, commercial, manufacturing, and mainly in rural areas, while the adjustable speed drives may request a three phase power grid. Single-phase to three-phase ac–dc–ac conversion usually employs a full-bridge topology, which implies in ten power switches, as shown inFig.1.

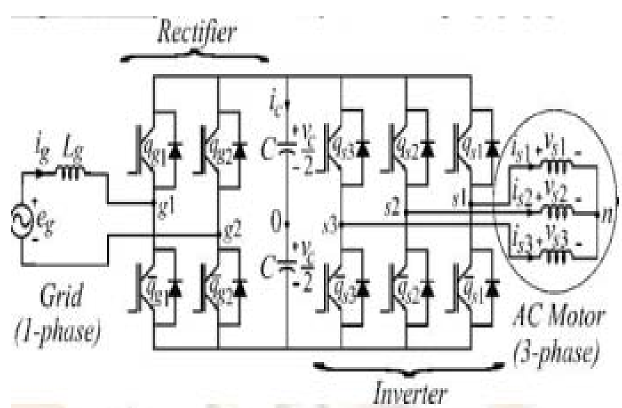

Fig. 1: Conventional single-phase to three-phase drive system

This converter is denoted here as conventional topology. In this paper, a single-phase to three-phase drive system composed of two parallel single-phase rectifiers and a three-phase inverter is proposed, as shown in Fig. 2.

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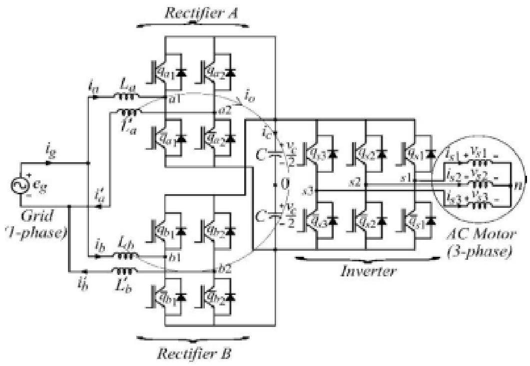
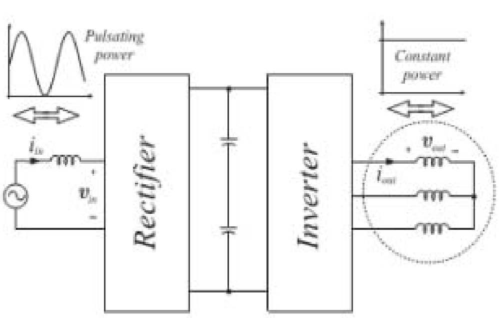


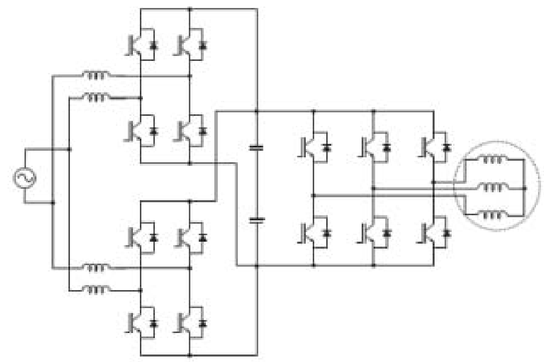
Fig. 2: Proposed single-phase to three-phase drive system

The proposed system is conceived to operate where the single-phase utility grid is the unique option available. Compared to the conventional topology, the proposed system permits: to reduce the rectifier switch currents; the total harmonic distortion (THD) of the grid cur-rent 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 aforementioned benefits justify the initial investment of the proposed system, due to the increase of number of switches.

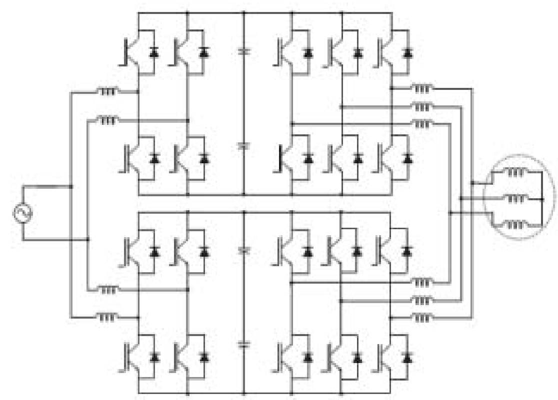
Fig 3. Shows the single-phase to three-phase power conversion with parallel configuration. Another important characteristic observed in the single-phase to three-phase power converters that also has been considered in this paper is the irregular distribution of power losses among the switches of the converter, as observed in Fig. 4.It means that, for a 600 V 50A class of insulated gate bipolar transistor (IGBT), 63% of the total losses measured in the single-phase to three-phase converter is concentrated in the rectifier circuit, while the rest 37% is observed in the inverter circuit. With those numbers, it is possible to measure the stress by switch, which means that each rectifier switch is responsible for 15.7% of the total converter losses, while each inverter switch is responsible for only 6.1%. The loss per switch gives an important parameter regarding the possibilities of failures in the power converters.



(a)



(b)



(c)

Fig. 3: Single-phase to three-phase power conversion. (a)Type of power processed by rectifier and inverter circuits.(b) Solution employed in [15]. (c) Solution employed in[16]

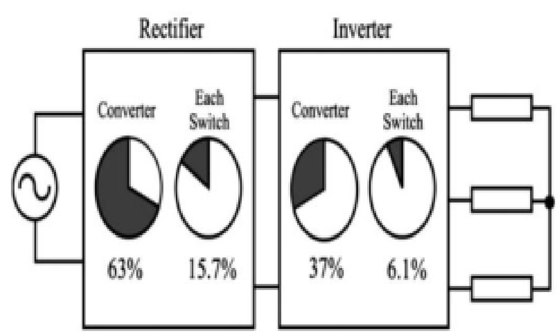


Fig. 4: Converter power losses distribution in both rectifier and inverter units:63% in the rectifier circuit and 37% in the inverter one. Power losses in each switch of the rectifier (15.7%) and inverter (6.1%)

II. System Model

This section will present the model of the proposed configuration. Such a configuration is constituted by a where $p = d/dt$ and symbols like r and l represent the resistances and inductances of the input inductors. The circulating current io can be defined from ia and i' a or ib and i'b i.e.

$$i_0 = i_a - i_a' = -i_b + i_b'$$

$$V_a = e_s - [r_a + r_a' + (I_a + I_a')p]i_a + (r_a' + I_a' p)$$

$$V_b = e_s - [r_b + r_b' + (I_b + I_b')p]i_b + (r_b' + I_b' p)i_0$$

$$V_0 = -[r_a' + r_b' + (I_a' + I_b')p]i_0 - (r_a - r_a' + (I_a + I_a')p]i_a + [r_b + r_b' + (I_b + I_b')p]i_b$$

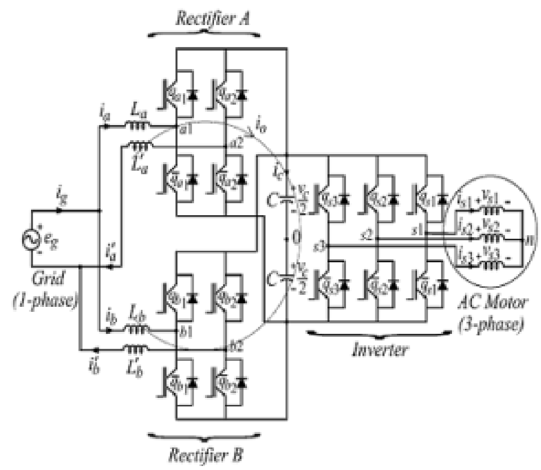


Fig. 5: Proposedsingle-phase to three-phase drive system.

To avoid the circulating current, the following three approaches are used commonly

i. Isolation. In this approach, the overall parallel system is bulky and costly because of additional power supplies or the ac line-frequency transformer.
ii. High impedance. They cannot prevent a low frequency circulating current.
iii. Synchronized control. This approach is not suitable for modular converter design. When more converters are in parallel, the system becomes very complicated to design and control.

In this proposed method the system is designed to reduce the circulating current (Io). From fig.5.the following quations can be derived for the front end rectifier.

$$V_{a10} - V_{a20} = e_s - (r_a + I_a p)i_a - (r_a' + I_a' p)i_a'$$
$$V_{b10} - V_{b20} = e_s - (r_b + I_b p)i_b - (r_b' + I_b' p)i_b'$$
$$V_{a10} - V_{b10} = (r_a + I_a p)i_a - (r_b + I_b p)i_b$$

In this ideal case, the circulating current can be reduced to zero imposing

$$V_0 = V_{a10} + V_{a20} - V_{b10} - V_{b20} = 0$$

When $I_a = 0$ then $I_a = I_a'$ and $I_b = I_b'$ and the system model reduced to the model given by

$$V_a + \frac{V_0}{2} = e_s - 2(r_s + I_s' p)i_a$$
$$V_b + \frac{V_0}{2} = e_s - 2(r_s' + I_s' p)i_b$$
$$V_0 = 2(r_s' + I_s' p)i_0$$

$$V_{ab} = \frac{V_a + V_b}{2} = e_s - (r_s' + I_s' p)i_a$$
$$V_a - \frac{V_0}{2} = e_s - 2(r_s' + I_s' p)I_a'$$
$$V_b - \frac{V_0}{2} = e_s - 2(r_s' + I_s' p)I_b'$$
$$V_a = e_s - 2(r_s + I_s' p)i_a$$
$$V_b = e_s - 2(r_s' + I_s' p)i_b$$

III. Control Strategy

The gating signals are obtained by comparing pole voltages with one (vt1), two (vt1 and vt2) 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 μchanges the place of the voltage pulses related to va and vb. When vx* = vx*min (μ = 0) orvx* = 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.2, 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.

In this way, the dc-link voltage vc is adjusted to its reference value v_c* using the controller R_c, which is a standard PI type controller. This controller provides the amplitude of the reference grid current I_s*. To control power factor and harmonics in the grid side, the instantaneous reference current I_s* 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 6. The reference currents I a*and ib* are obtained by making i_a* = i_b* = I_s*/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 R_a and R_b. These current controllers define the input reference voltages va*and vb*. The homo polar current is measured (i_o) and compared to its reference (i_o* = 0). The error is the input of PI controller Ro, that determines the voltage v_o*. 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(e.g., field-oriented control or volts/hertz control)

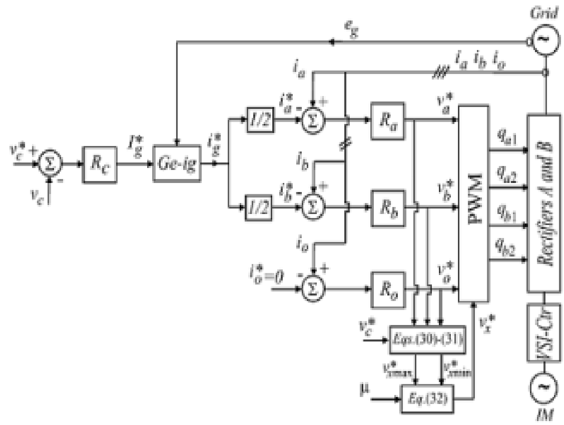


Fig. 6: Control block diagram

IV. Simulation Results

The simulink models of the Proposed converter system, its control strategy and fault diagnosis is also carried out. The simulation results were obtained with the grid- and machine-phase voltages equal to 127 Vrms, dc-link voltage of 225 V, capacitance of 2200 μF, and input inductor filters with resistance and inductance given respectively by 0.1Ω and 2.6 mH. The load power was of 5 kVA.

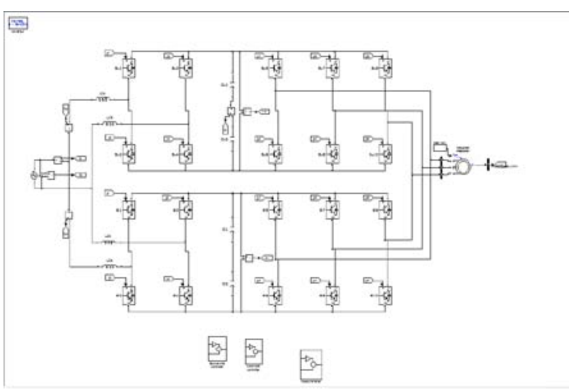


Fig 7: MATALB/SIMULINK diagram of proposed system

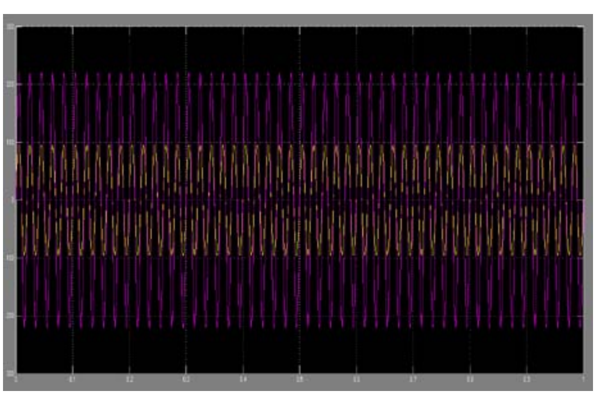


Fig. 8: voltage and current of the grid,

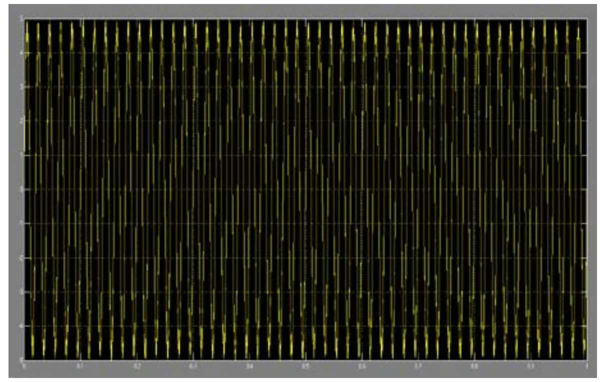


Fig. 9: Input current of the converter 1

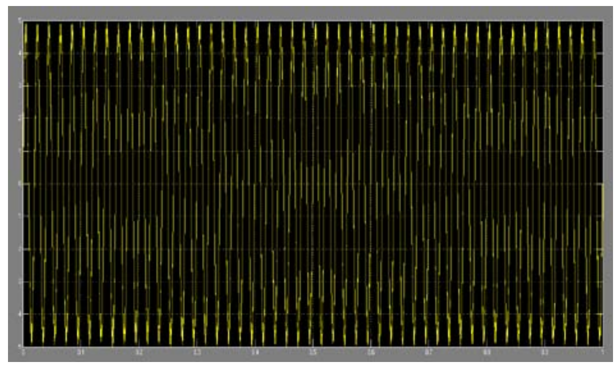


Fig. 10: Input current of the converter 2

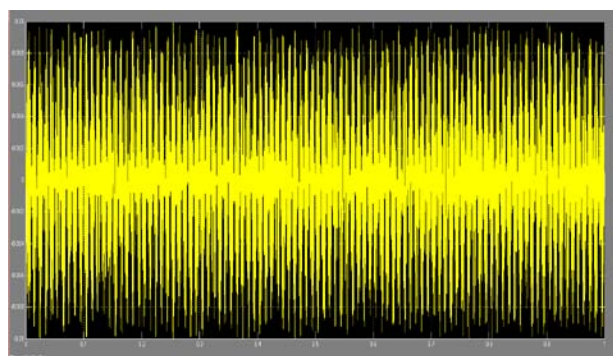


Fig. 11: Circulating current

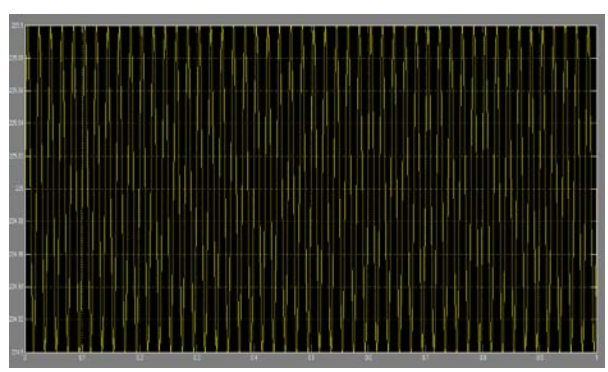


Fig. 12: dc-link voltage in C12

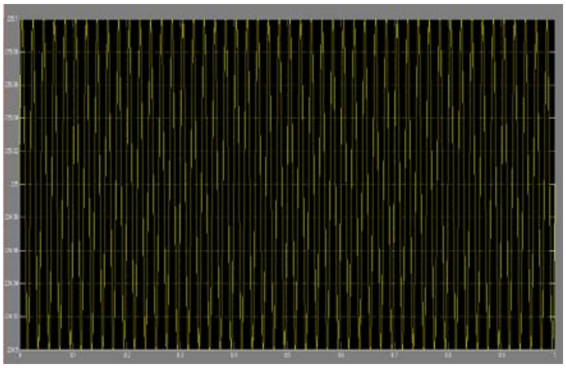


Fig. 13: dc-link voltage in C34

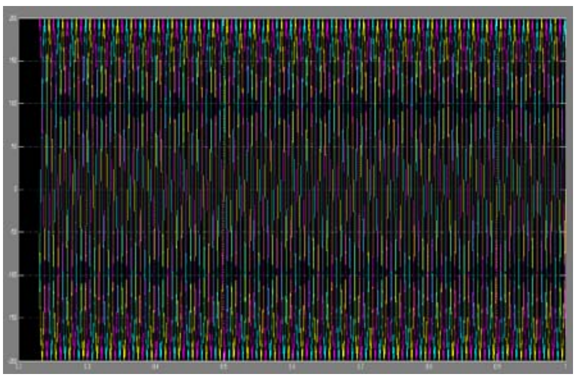


Fig. 14: load currents

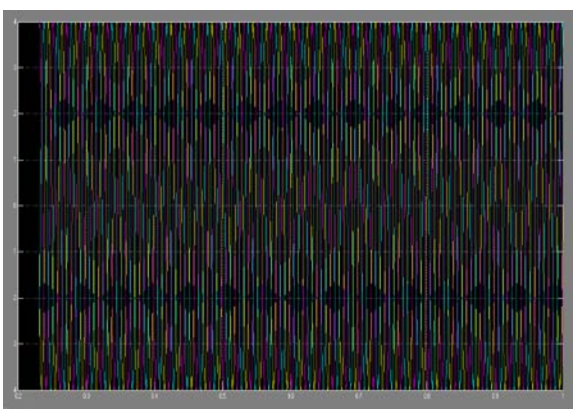


Fig. 15: load voltages

V. Conclusion

A single-phase to three-phase drive system composed of two parallel single-phase rectifiers, a three-phase inverter and an induction motor was proposed. The system combines two parallel rectifiers without the use of transformers. 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 high number of semiconductor devices) cannot be considered a drawback, especially considering the scenario where the cited advantages justify such initial investment.

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