Comparison of Three-Phase Drive System Using Three Phase Rectifier and Two Parallel Single-Phase Rectifiers on Input Side

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Abstract- This paper proposes a single-phase to three-phase drive system composed of two parallel single-phase rectifiers, a three-phase inverter, and an induction motor. The proposed topology permits to reduce the rectifier switch currents, the harmonic distortion at the input converter side, and presents improvements on the fault tolerance characteristics. Even with the increase in the number of switches, the total energy loss of the proposed system may be lower than that of a conventional one. The model of the system is derived, and it is shown that the reduction of circulating current is an important objective in the system design. A suitable control strategy, including the pulse width modulation technique (PWM), is developed. Three Phase Rectifier is compared with Two Parallel Single Phase rectifiers on the input side and Performance of a three phase induction motor is to be observed. Finally a Matlab/Simulink based model is developed and simulation results are presented.

Index Terms—Ac-dc-ac power converter, drive system, parallel converter.

I. INTRODUCTION

Power consumption is rising day by day. In developed countries, power has been the fastest growing energy for the last decade. Many technologies are arising to develop power from various sources, which in turn produces a very high power using the advanced technologies. One of the methods to develop power from a source is “Single phase to three phase converter using inversion technique”. It is one of the advanced techniques to develop power. This technique involves power electronics which is an advanced method to produce or control the voltage or current from the supply.

Several solutions have been proposed when the objective is to supply a three-phase motors from a single-phase ac mains [1]–[9]. 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 in Fig. 1.

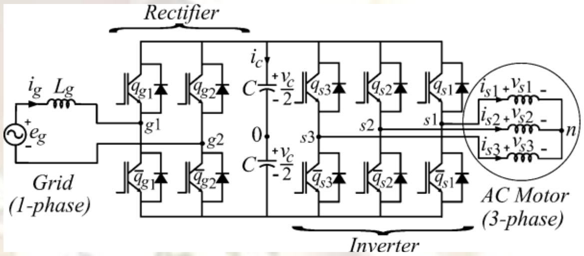


Fig. 1. Conventional single-phase to three-phase drive system.

is converter is denoted here as conventional topology. Parallel converters have been used to improve the power capability, reliability, efficiency, and redundancy. Parallel converter techniques can be employed to improve the performance of active power filters [10]–[13], uninterruptible power supplies (UPS) [14]–[16], fault tolerance of doubly fed induction generators [17], and three-phase drives [18], [19]. Usually the operation of converters in parallel requires a transformer for isolation. However, weight, size, and cost associated with the transformer may make such a solution undesirable [20]. When an isolation transformer is not used, the reduction of circulating currents among different converter stages is an important objective in the system design [21]–[26]. 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.

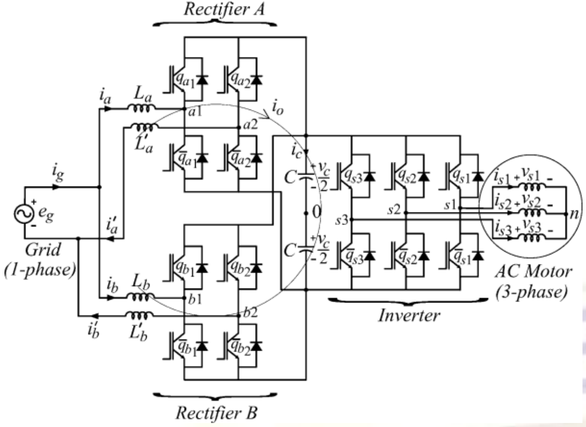


Fig. 2. Proposed single-phase to three-phase drive system.

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 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 aforementioned benefits justify the initial investment of the proposed system, due to the increase of number of switches.

II. SYSTEM MODEL

The system is composed of grid, input inductors (L_a , L_a^{-} , L_b , and L_b^{-}), rectifiers (A and B), capacitor bank at the dc link, inverter, and induction machine. Rectifiers A and B are constituted of switches q_{a1} , q_{a1}^{-} , q_{a2} , and q_{a2}^{-} , and q_{b1} , q_{b1}^{-} , q_{b2} , and q_{b2}^{-}, respectively. The inverter is constituted of switches q_{s1} , q_{s1}^{-}, q_{s2} , q_{s2}^{-}, q_{s3} , and q_{s3}^{-}. The conduction state of the switches is represented by variable s_{qa1} to s_{qs3} , where $s_q = 1$ indicates a closed switch while $s_q = 0$ an open one.

III. DYNAMIC MODEL OF INDUCTION MOTOR

The induction machine d-q or dynamic equivalent circuit is shown in Fig. 3 and 4. One of the most popular induction motor models derived from this equivalent circuit is Krause's model detailed in [5]. According to his model, the modeling equations in flux linkage form are as follows:

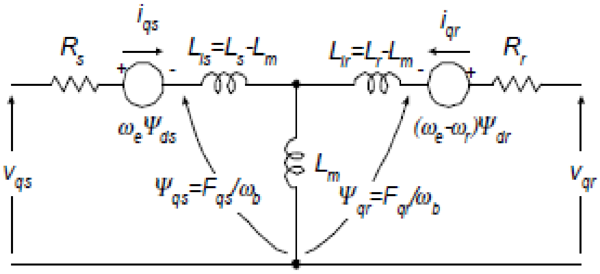


Fig. 3 Dynamic q-axis model

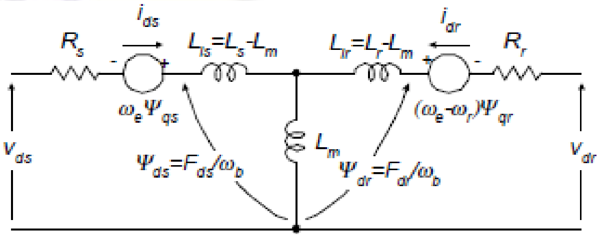


Fig. 4 Dynamic d-axis model

$$\frac{dF_{qs}}{dt} = \omega_b\left[V_{qs} - \frac{\omega_e}{\omega_b}F_{ds} + \frac{R_s}{X_{ls}}\left(F_{mq} + F_{qs}\right)\right] \quad (1)$$

$$\frac{dF_{ds}}{dt} = \omega_b\left[V_{ds} + \frac{\omega_e}{\omega_b}F_{qs} + \frac{R_s}{X_{ls}}\left(F_{md} + F_{ds}\right)\right] \quad (2)$$

$$\frac{dF_{qr}}{dt} = \omega_b\left[V_{qr} - \left(\frac{\omega_e-\omega_r}{\omega_b}\right)F_{dr} + \frac{R_r}{X_{lr}}\left(F_{mq} - F_{qr}\right)\right. \quad (3)$$

$$\frac{dF_{dr}}{dt} = \omega_b\left[V_{dr} - \left(\frac{\omega_e-\omega_r}{\omega_b}\right)F_{qr} + \frac{R_r}{X_{lr}}\left(F_{md} - F_{dr}\right)\right. \quad (4)$$

$$F_{mq} = X_{ml} * \left[\frac{F_{qs}}{X_{ls}} + \frac{F_{qr}}{X_{lr}}\right] \quad (5)$$

$$F_{md} = X_{ml} * \left[\frac{F_{ds}}{X_{ls}} + \frac{F_{dr}}{X_{lr}}\right] \quad (6)$$

$$i_{qs} = \frac{1}{X_{ls}}\left(F_{qs} - F_{mq}\right) \quad (7)$$

$$i_{ds} = \frac{1}{X_{ls}}\left(F_{ds} - F_{md}\right) \quad (8)$$

$$i_{qr} = \frac{1}{X_{lr}}\left(F_{qr} - F_{mq}\right) \quad (9)$$

$$i_{dr} = \frac{1}{X_{lr}}\left(F_{dr} - F_{md}\right) \quad (10)$$

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{1}{\omega_b}\left(F_{ds}i_{qs} - F_{qs}i_{ds}\right) \quad (11)$$

$$T_e - T_L = J\frac{2}{p}\frac{d\omega_r}{dt} \quad (12)$$

For a squirrel cage induction machine, as in the case of this paper, v_{qr} and v_{dr} in (3) and (4) are set to zero. An induction machine model can be represented with five differential equations as shown. To solve these equations, they have to be rearranged in the state-space form, In this case, state-space form can be achieved by inserting (5) and (6) in (1–4) and collecting the similar terms together so that each state derivative is a function of only other state variables and model inputs. Then, the modeling equations (1-4) of a squirrel cage induction motor in state-space become

$$\frac{dF_{qs}}{dt} = \omega_b [v_{qs} - \frac{\omega_e}{\omega_b} F_{ds} + \frac{R_s}{X_{ls}} \left(\frac{X_{ml} *}{X_{lr}} F_{qr} + Xml*Xls-1Fqs \right] \quad (13)$$

$$\frac{dF_{ds}}{dt} = \omega_b [v_{ds} - \frac{\omega_e}{\omega_b} F_{qs} + \frac{R_s}{X_{ls}} \left(\frac{X_{ml} *}{X_{lr}} F_{dr} + Xml*Xls-1Fds \right] \quad (14)$$

$$\frac{dF_{qr}}{dt} = \omega_b [- \left(\frac{\omega_e - \omega_r}{\omega_b} \right) F_{dr} + \frac{R_r}{X_{lr}} \left(\frac{X_{ml} *}{X_{ls}} F_{qs} + Xml*Xls-1Fqr \right] \quad (15)$$

$$\frac{dF_{dr}}{dt} = \omega_b [- \left(\frac{\omega_e - \omega_r}{\omega_b} \right) F_{qr} + \frac{R_r}{X_{lr}} \left(\frac{X_{ml} *}{X_{ls}} F_{ds} + Xml*Xls-1Fdr \right] \quad (16)$$

$$\frac{d\omega_r}{dt} = \left(\frac{P}{2J} \right) (T_e - T_L) \quad (17)$$

Where

d : direct axis

q :Quadrature axis

s : stator Variable

r : rotor Variable

F_{ij} *is the flux linkage(i=q or d and j=s or r)*

V_{qs}, V_{ds} *: q and d-axis stator voltages,*

V_{qr}, V_{dr} *: q and d-axix rotor voltages,*

F_{mq}, F_{md} *: q and d axis magnetizing flux linkages,*

R_r *: rotor resistance,*

R_s *: stator resistance,*

X_{ls} *: stator leakage reactance(*$\omega_e L_{ls}$*),*

X_{lr} *: rotor leakage reactance(*$\omega_e\ L_{lr}$*),*

$X_{ml} *= 1 / \left(\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}} \right)$,

i_{qs}, i_{ds} *: q and d-axis stator currents,*

i_{qr}, i_{dr} *: q and d-axis rotor currents,*

P : number of poles,

J : Moment of inertia,

T_e *: Electrical output torque,*

T_L *: Load torque,*

ω_e *: Stator angular electrical frequency,*

ω_b *: motor angular electrical base frequency,*

ω_r *:rotor angular electrical speed*

IV. CONTROL STRATEGY

Fig. 5, presents the control block diagram of the system in Fig. 2, high lighting the control of the rectifier. The rectifier circuit of the proposed system has the same objectives of that in Fig. 1, i.e., to control the dc-link voltage and to guarantee the grid power factor close to one. Additionally, the circulating current i_o in the rectifier of the proposed system needs to be controlled.

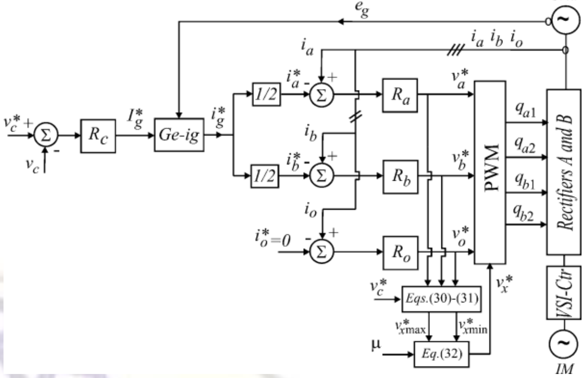


Fig. 5. Control block diagram.

V. Matlab/Simulink Model and Simulation Results

Simulation is carried out for two cases. In case 1, two single phase rectifiers are connected in parallel. In case 2, single three phase rectifier is used.

A. CASE 1

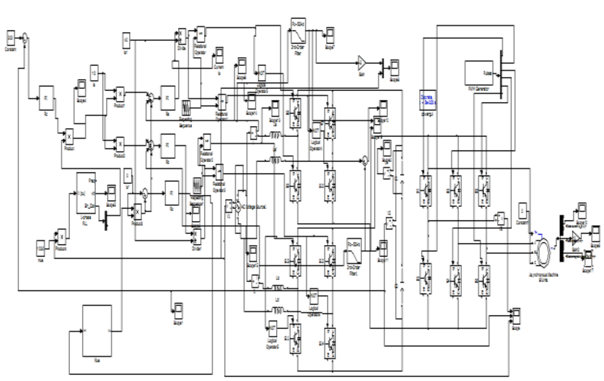
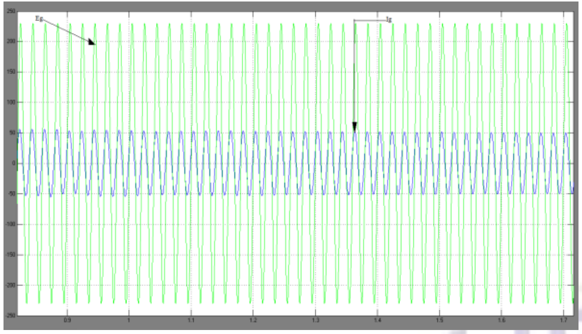


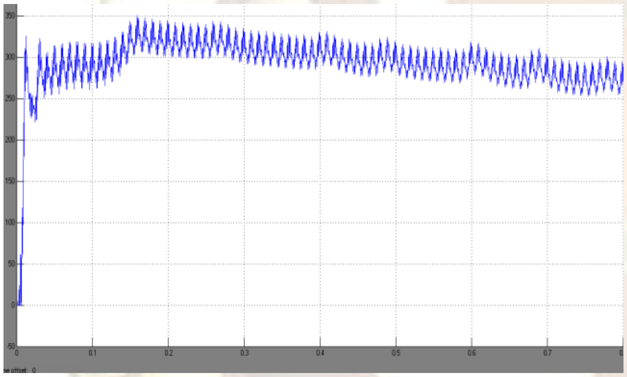
Fig. 6. Matlab/Simulink Model

Fig. 6 shows the matlab/simulink model of the two single phase rectifiers connected in parallel which is controlled by a control strategy which helps in controlling the DC link voltage, controls the circulating current i_o in the rectifier and guarantee's the grid power factor to be close to unity. The system is connected to a three phase drive system with the help of an inverter.

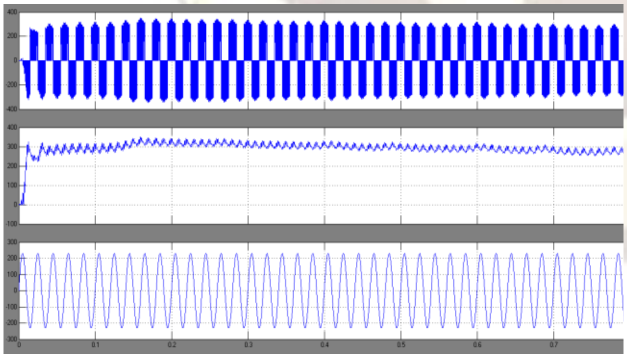


X-axis : time/div; Y-axis : V&A/div
Fig.7 Supply voltage and supply current

In fig.7, the Supply voltage and supply current is shown which shows the power factor on the supply side is close to unity. Fig. 8 shows the DC link voltage which is controlled by the control strategy used in the proposed system.



Y-axis: V/div ; X-axis: (time/div)
Fig. 8 DC link Voltage



Y-axis: V/div ; X-axis: (time/div)
Fig.9 Inverter output voltage, DC link Voltage and Supply Voltage

Fig.9 shows the Inverter output voltage, DC link voltage and Supply voltage. Fig. 10 shows the performance of a 3ph induction machine. Stator current increases gradually, Motor speed and motor torque positive is shown in the below graph.

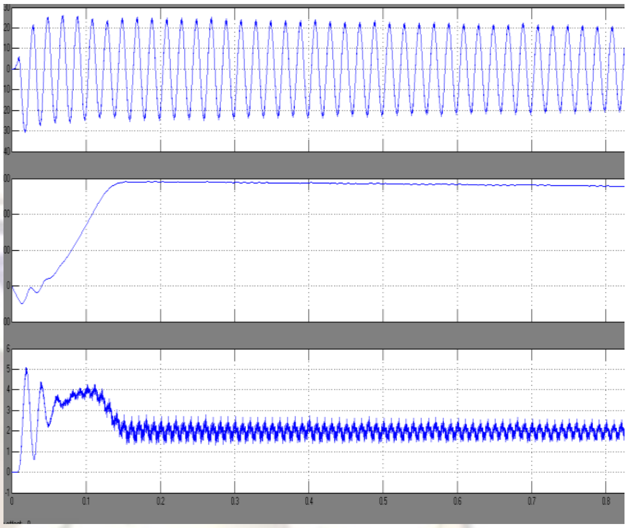


Fig.10 Stator Current(Y-axis :A/div) , Speed(Y-axis :rpm) and Motor Torque (Tm/div) ; X-axis: time/div

B. *CASE 2*

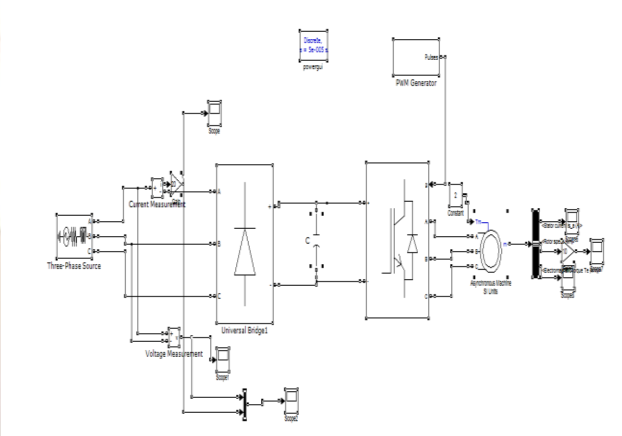
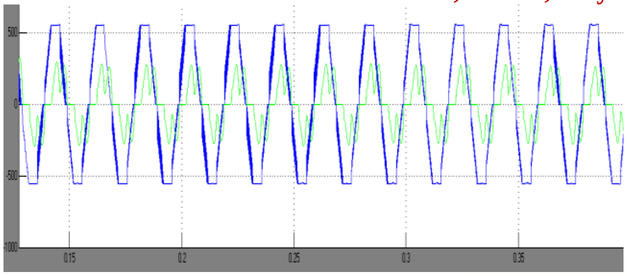


Fig. 11. Matlab/Simulink Model

Fig. 11, shows the Matlab/simulink model of the single three phase rectifier system connected to a drive system which is being compared with the drive system in fig.6. Fig. 12 shows the grid power factor. It can be clearly seen that the power factor is not unity. Supply voltage and current is non sinusoidal.



X-axis : time/div; Y-axis : V&A/div
Fig.12 Supply voltage and supply current

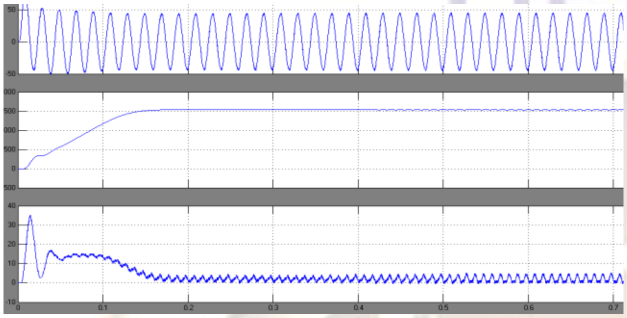


Fig.13 Stator Current(Y-axis :A/div) , Speed(Y-axis :rpm) and Motor Torque (Tm/div) ; X-axis: time/div

Fig. 13 shows the performance of a 3ph induction machine. It shows that the motor torque is fluctuating near zero.

VI. CONCLUSION

A single-phase to three-phase drive converter composed of two parallel single-phase rectifiers and a three-phase inverter was presented. The system combines in parallel two rectifiers without use of transformers, and it is optimized when the load frequency is equal to that of grid voltage. The system model and the control strategy, including the PWM technique, have been developed. The proposed topology permits to reduce the current and consequently to reduce the power ratings of the power switches of the rectifier. Finally a Matlab/Simulink based model is developed and simulation results are presented.

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