ISSN (Online): 2349-7084
GLOBAL IMPACT FACTOR 0.238
ISRA JIF 0.351

INTERNATIONAL JOURNAL OF COMPUTER ENGINEERING IN RESEARCH TRENDS
VOLUME 1, ISSUE 6, DECEMBER 2014, PP 552-558

Single-Phase To Three-Phase Drive System Composed of Two Parallel Single-Phase Rectifiers

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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. Experimental results are presented as well.

Index Terms: AC-DC-AC power converter, drive system, parallel Converter, Fault Identification System (FIS).

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I. INTRODUCTION

Several solutions have been proposed when the objective is to supply a three-phase motor from single-phase ac mains [1]-[4]. 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. This 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 [5]-[6], uninterruptible power supplies (UPS) [7], fault tolerance of doubly fed induction generators, and three-phase drives [8]. 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 [9]. When an isolation transformer is not used, the reduction of circulating currents among different converter stages is an important objective in the system design [10]-[12].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. 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. METHODS TO CONNECT SINGLE PHASE TO THREE PHASE DRIVE SYSTEMS

2.1 Static Phase Converter:

Static Phase Converters operate by charging and discharging capacitors to temporarily produce a 3rd phase of power for only a matter of seconds during startup of electric motors, then it will drop out forcing the motor to continue to run on just 1 phase and only part of its windings. Due to their technology, Static Phase Converters do not properly power any class of 3 phase machinery or equipment. They will not in any way power 3 phase welders, 3 phase battery chargers, 3 phase lasers, or any type of machinery with 3 phase circuitry. Static Phase Converters also will not start delta wound 3 phase motors.

2.2 Rotary phase converter:

A rotary phase converter, abbreviated RPC, is an electrical machine that produces three-phase electric power from single-phase electric power. This allows three phase loads to run using generator or utility-supplied single-phase electric power. A rotary phase converter may be built as a motor-generator set. These have the advantage that in isolating the generated three-phase power from the single phase supply and balancing the three-phase output. However, due to weight, cost, and efficiency concerns, most RPCs are not built this way. Rotary Phase Converters Provide Reliable, Balanced, and Efficient Three Phase Power. Quick and Effective Three Phase Electricity. All converters can be mainly categorized into two groups: one is cascade type and another is unified type [2]. In cascade type, the PWM converter for power factor correction and the PWM inverter for speed control are connected in series with large DC-Link capacitor and two static power converters are operated and controlled in separate. In this type, specific number of switches, to compose the converter and inverter, are required. Therefore, the required number of switches cannot be reduced significantly. On the other hand, in the unified type, conventional concepts of PWM converter and inverter are merged together and same converter handles the functions of PWM converter (power factor correction) and PWM inverter(motor control) at the same time. As an added advantage, the input inductor, which is commonly used in the PWM? Converter for power factor correction can be eliminated and replaced by the existing motor inductor. Therefore, this new concept can significantly reduce the number of components, compared to any conventional cascade type topologies.

III. SYSTEM MODEL

The Conventional system single-phase to three phase system and the proposed system single phase to three phase systems are labeled as fig 1 and fig 2 respectively as shown below:

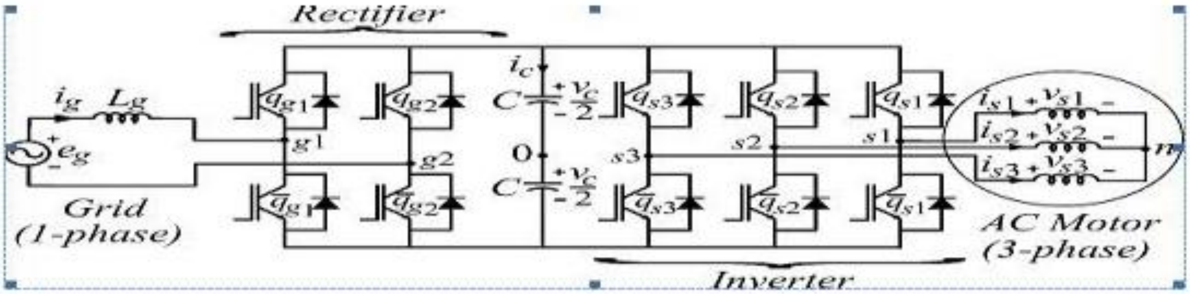


Fig 1 Conventional single-phase to three-phase system

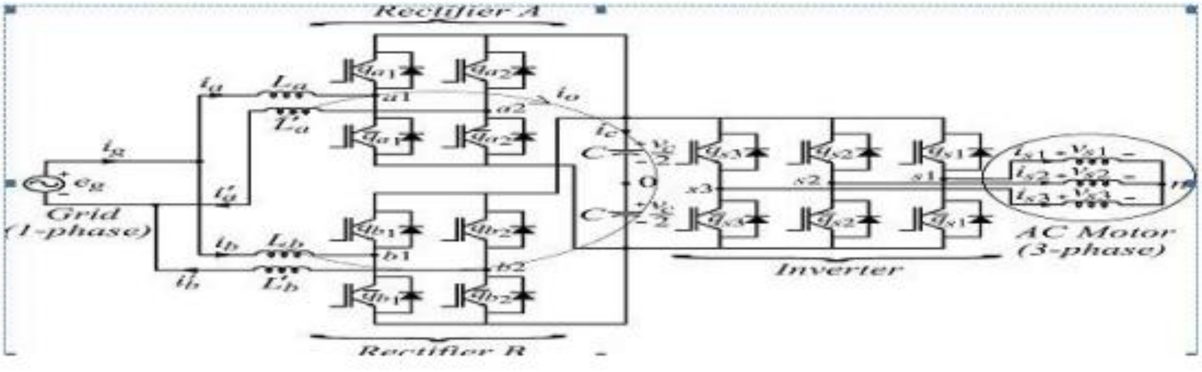


Fig 2 Proposed single-phase to three-phase drive system

IV. PWM METHOD

Considering that $va*$, $vb*$ and $vo*$ denote the reference voltages determined by the current

controllers. i,e,

$$va* = va10* - va20* \qquad (1)$$

$$vb* = vb10* - vb20* \qquad (2)$$

$$vo* = va10* + va20* - vb10* - vb20* \qquad (3)$$

The gating signals are directly calculated from the reference pole voltages $va10*$, $va20*$, $vb10*$ and $vb20*$.

Introducing an auxiliary variable $vx* = va20*$ and solving this system of equations,

$$V*a10 = va* + vx* \qquad (4)$$

$$V*a20 = vx* \qquad (5)$$

$$V*b10 = (va*/2) + (vb*/2) - (vo*/2) + vx* \qquad (6)$$

$$V*b20 = (va*/2) - (vb*/2) - (vo*/2) + vx* \qquad (7)$$

From these equations, it can be seen that, besides $va*$, $vb*$ and $vo*$, the pole voltages depend on also

of $vx*$. The limit values of the variable $vx*$ can be calculated by taking into account the maximum

$vc*/2$ and minimum $-vc*/2$ value of the pole voltages

$$V*xmax = (vc*/2) - v*max \quad (8)$$

$$V*xmin = (-vc*/2) - v*min \quad (9)$$

Introducing a parameter μ ($0 \le \mu \le 1$), the variable $vx*$ can be written as,

$$Vx* = \mu V*xmax + (1- \mu)V*xmin \quad (10)$$

Once $vx*$ is choosen, pole voltages $va10*$, $va20*$, $vb10*$ and $vb20*$.are defined from (4) to (7).The parameter μ changes the place of the voltage pulses related to va and vb. And also μ influences the harmonic distortion of the voltages generated by the rectifier.

V. SYSTEM DESIGN

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

1) Isolation. In this approach, the overall parallel system is bulky and costly because of additional power supplies or the ac line-frequency transformer.

2) High impedance. They cannot prevent a low frequency circulating current.

3) 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.2 . The following equations can be derived for the front end rectifier

$$Va10 - Va20 = eg - (ra+lap)\, ia - (r'a+l'ap)\, i'a \qquad (11)$$

$$Vb10 - Vb20 = eg - (rb+lbp)\, ib - (r'b+l'bp)\, i'b \qquad (12)$$

$$Va10 - Vb10 = (ra+lap)\, ia - (rb+lbp)\, ib \qquad (13)$$

$$Va20 - Vb20 = (r'a+l'ap)\, i'a - (r'b+l'bp)\, i'b \qquad (14)$$

$$ig = ia + ib = i'a + i'b \qquad (15)$$

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..

$$io = ia - i'a = - ib + i'b \quad (16)$$

By solving the above equations ,

$$Va = eg - [ra + r'a + (la+l'a)p]\, ia + (r'a+ l'ap) \qquad (17)$$

$$Vb = eg - [rb + r'b + (lb+l'b)p]\, ib + (r'b+ l'bp)\, io \quad (18)$$

$$Vo = - [r'a + r'b + (l'a + l'b)p]\, io - [ra - r'a + (la - l'a)p]\, Ia + [rb - r'b + (lb - l'b)p]\, ib \quad (19)$$

where

$Va = Va10 - Va20$ (20)

$Vb = Vb10 – Vb20$ (21)

$Vo = Va10 + Va20 - Vb10 – Vb20$ (22)

In order to both facilitate the control and share equally current, voltage, power between the rectifiers, the four inductors should be equal . i.e. r′g = ra = r′a = rb= r′b and l′g =la =l′a =lb =l′b.In this case the model (17)-(19)

can be simplified to the model given by

$Va + Vo/2 = eg – 2(r'g+l'gp)\ ia$ (23)

$Vb - Vo/2 = eg – 2(r'g+l'gp)\ ib$ (24)

$Vo = -2(r'g+l'gp)\ io$ (25)

$Vab = (Va + Vb)/2 = eg - (r'g+l'gp)\ ia$ (26)

$Va - Vo/2 = eg – 2(r'g+l'gp)\ i'a$ (27)

$Vb + Vo/2 = eg – 2(r'g+l'gp)\ i'b$ (28)

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

$Vo = Va10 + Va20 - Vb10 – Vb20 = 0$ (29)

When ia = 0 then ia = i′a and ib = i′b and the system model (17)-(19) reduced to

$Va = eg - 2(r'g+l'gp)\ ia$ (30)

$Vb = eg - 2(r'g+l'gp)\ ib$ (31)

VI. SYSTEM CONTROL

The gating signals are obtained by comparing pole voltages with one (vt1), two (vt1 and vt2) or more high-frequency triangular carrier signals [17]–[18]. In the case of double-carrier approach, the phase shift ofthe 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 begin or in the end of half period (Ts) of

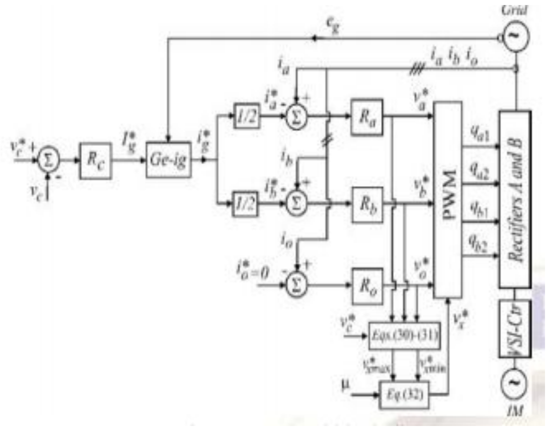


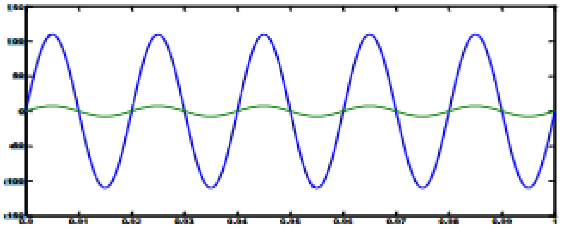
Fig. 3. Control block diagram.

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.

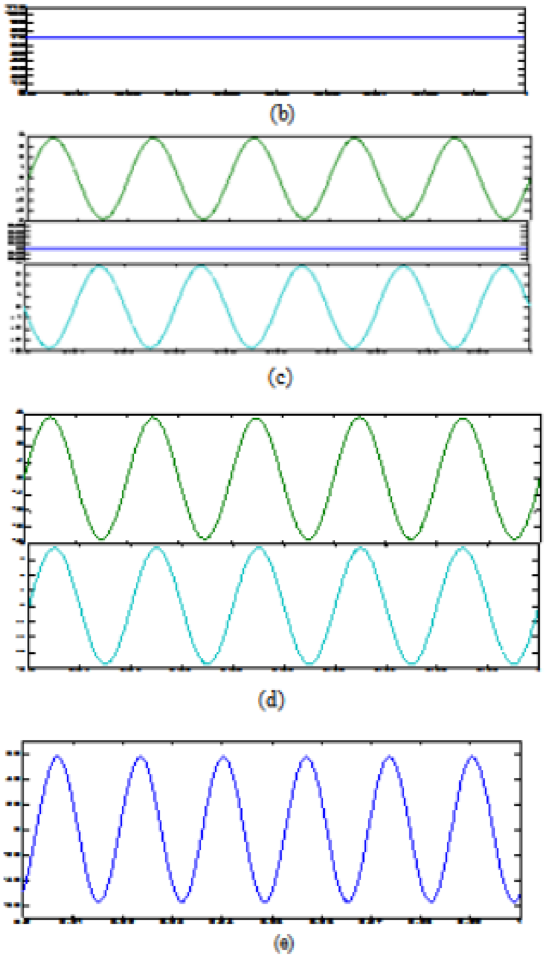
In this way, the dc-link voltage vc is adjusted to its reference value vc* using the controller Rc, which is a standard PI type controller. This controller provides the amplitude of the reference grid current Ig*. To control power factor and harmonics in the grid side, the instantaneous reference current Ig* must be synchronized with voltage eg , as given in the voltage-oriented control (VOC) for three-phase system. This is obtained via blocks Ge-ig, based on a PLL scheme. The reference currents ia*and ib* are obtained by making ia* = ib* = Ig* /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 homopolar 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 (e.g., field-oriented control or volts/hertz control).

VII. SIMULATION RESULTS

The steady-state simulation results are shown in Fig. 4. The waveforms in this figure are: (a) voltage and current of the grid, (b) dc-link voltage, (c) currents of rectifier A and circulating current, (d) currents of rectifiers A and B, and (e) load line voltage. Note that, with the proposed configuration, all control demanded for single-phase to three-phase converter has been established. The proposed configuration provides current reduction in the rectifier side (half of the current of the standard topology) [see Fig. 4(d)], which can provide loss reduction. Also, the control guarantees the circulating current close to zero [see Fig. 4(c)]. The same set of simulation results was obtained for transient in the machine voltages, as observed in Fig. 5 Simulation results presented in Fig. 6 show the behavior of variables of the proposed system when fault is detected in rectifier B. In this case, after fault detection given by the control system, the rectifier B has been isolated and the total flux of energy flows through rectifier A.



(a)



(b)

(c)

(d)

(e)

Fig 4. Steady-state simulation results. (a) Grid voltage (eg) and gird current (ig). (b) Capacitor voltage (vc). (c) Currents of rectifier A (i a and I *a)and circulating current (io). (d) Currents of rectifiers A (ia) and B (ib). (e) Line voltage of the load (vs 2 3).

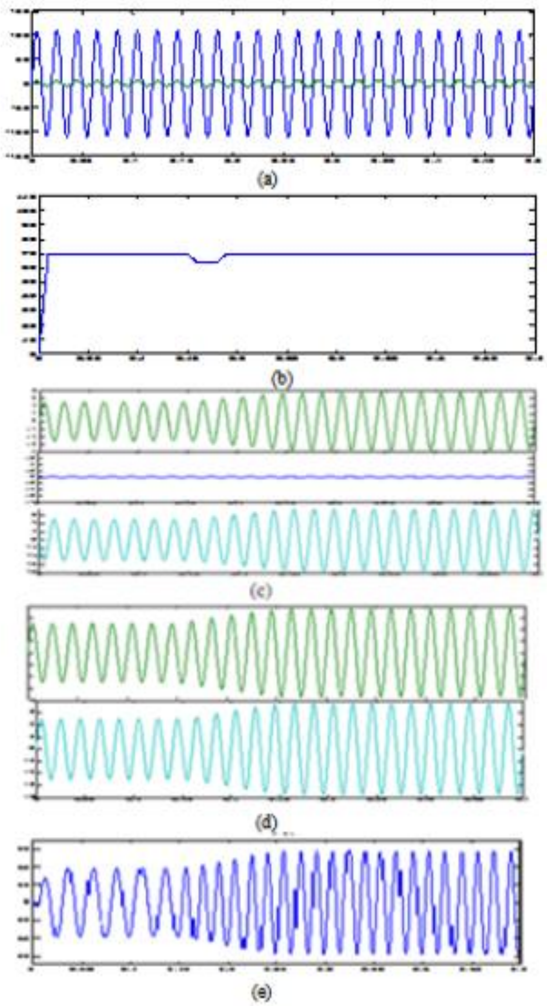


Fig 5 Fig. 8. Simulation results for a volts/hertz transient applied to the three-phase motor. (a) Grid voltage (eg) and gird current (ig). (b) Capacitor volt-age (vc). (c) Currents of rectifier A (ia and I * a) and circulating current (io).(d) Currents of rectifiers A (ia) and B (ib). (e) Line voltage of the load (vs 2 3).

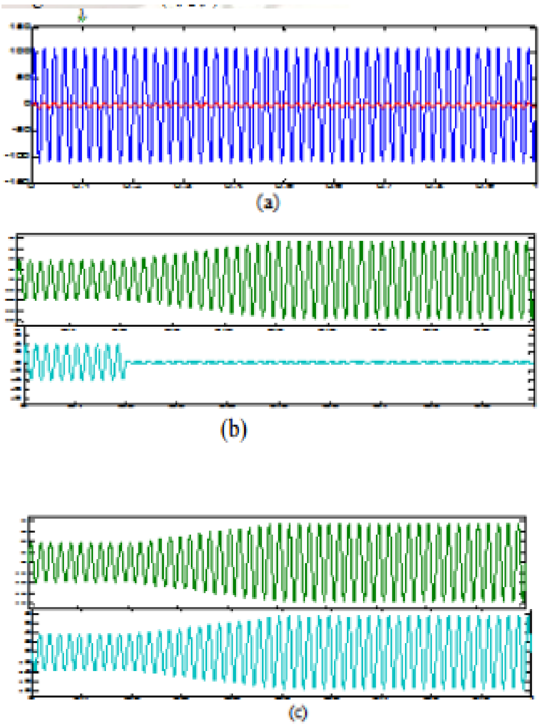


Fig. 6. Simulation results of the proposed configuration when a fault is identified at the rectifier B. (a) Grid voltage (eg) and grid current (ig).(b) Currents of rectifiers A (ia) and B (ib). (c) Currents of rectifier (ia and I * a).

VIII.CONCLUSION

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 proposed system permits to reduce the rectifier switch currents, the THD of the grid current and to increase the fault tolerance characteristics. The simulation results have shown that the system is con-trolled properly, even with transient and occurrence of faults

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