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Research Paper

A SIMULATION MODEL FOR CONVERTING SINGLE-PHASE TO THREE-PHASE SYSTEM USING TWO PARALLEL SINGLE-PHASE RECTIFIERS

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The conventional methods of ac to variable voltage and frequency conversion such as ac voltage controller and Cycloconverter will gives the more harmonics and low input power factor. And also single phase ac to three phase variable ac conversion also very difficult. The above problems can be overcome by the proposed method in this project, i.e., single phase to three phase conversion with the two parallel connected rectifiers. With this method of conversion the input power factor will be improved. The Proposed Model consists 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.

Keywords: Ac-dc-ac power converter, Drive system, Parallel converter

INTRODUCTION

A wide variety of commercial and industrial electrical equipment requires three-phase power. Electric utilities do not install three-phase power as a matter of course because it cost significantly more than single-phase installation. Hence we need to conversion from single-phase to three-phase. Parallel converters have been used to improve the power capability, reliability, efficiency, and redundancy. Usually the operation of converters in parallel requires a transformer

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for isolation. However, weight, size, and cost associated with the transformer may make such a solution undesirable. When an isolation transformer is not used, the reduction of circulating currents among different converter stages is an important objective in the system design.

Several solutions have been proposed when the objective is to supply a three-phase motor from single-phase ac mains (Lee and Kim, 2007). 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 Figure 1. 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 (Chaer *et al.*, 2009), Uninterruptible Power Supplies (UPS) (Guerrero *et al.*, 2009), fault tolerance of doubly fed induction generators (Flannery and Venkataramanan, 2008), and three-phase drives (Jacobina *et al.*, 2008). 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 (Park *et al.*, 2008). When an isolation transformer is not used, the reduction of circulating currents among different converter stages is an important objective in the system design (Cheng *et al.*, 2008).

Figure 1: Block Diagram for Conventional Single-Phase to Three-Phase Drive System

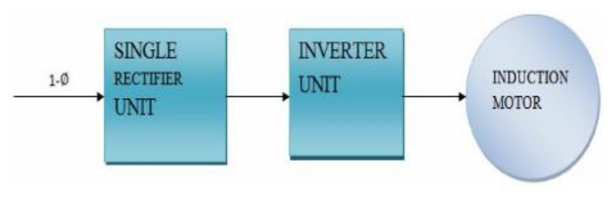
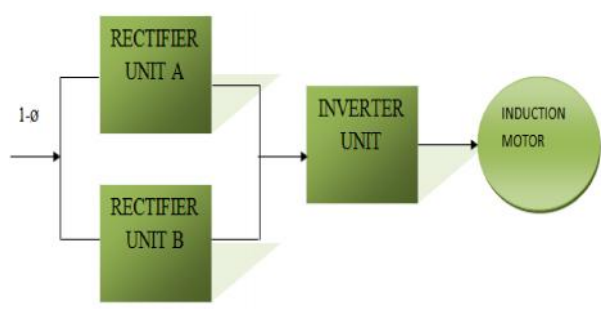


Figure 2: Block Diagram for Proposed Single-Phase to Three-Phase Drive System



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 Figure 2. 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.

METHODS TO CONNECT SINGLE PHASE TO THREE PHASE DRIVE SYSTEMS

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.

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. 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, this is commonly used in the PWM.

COMPONENTS IN THE PROPOSED CIRCUIT

Effect of Source Inductance

In the Figure 1, lg', la', lb, lb' are input side inductors these inductors are called source inductors. The input side bridge rectifier is a fully controlled rectifier. The presence of source inductance introduces an additional mode of operation of when firing angle is less than certain value. When there is an inductor in series with each input line, it is necessary to find out its effect. The effects are

1. The reduction in output voltage
2. The duration of commutation overlap.
3. The relationship between the firing angle and the commutation overlap.

DC Link Capacitor

A simple analytical expression for the current stress on the DC-link capacitor caused by the load-side inverter of a voltage DC-link-converter system is derived. The DC-link capacitor current RMS value is determined from the modulation depth and by the amplitude and the phase angle of the inverter output current assuming a sinusoidal inverter output current and a constant DC-link voltage.

Despite neglecting the output-current ripple, the results of the analytical calculation are within 8% of measurements made from digital simulation and an experimental system, even if the output-current ripple is relatively high as in the case of low-frequency IGBT inverter systems. The simple analytical expression provides significant advantages over simulation methods for designing the DC-link capacitor of PWM converter systems.

IGBT Fundamentals

The Insulated Gate Bipolar Transistor (IGBT) is a minority carrier device with high input impedance and large bipolar current-carrying capability. Many designers view IGBT as a device with MOS input characteristics and bipolar output characteristic that is a voltage-controlled bipolar device. To make use of the advantages of both Power MOSFET and BJT, the IGBT has been introduced. It's a functional integration of Power MOSFET and BJT devices in monolithic form. It combines the best attributes of both to achieve optimal device characteristics. The IGBT is suitable for many applications in power electronics, especially in Pulse Width Modulated (PWM) servo and three-phase drives requiring high dynamic range. Control and low noise. It also can be used in Uninterruptible Power Supplies (UPS), Switched-Mode Power Supplies (SMPS), and other power circuits requiring high switch repetition rates. IGBT improves dynamic performance and efficiency and reduced the level of audible noise. It is equally suitable in resonant-mode converter circuits. Optimized IGBT is available for both low conduction loss and low switching loss.

MODELLING AND CASE STUDY

Mathematical Analysis of the 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}, $\bar{q}_{a1}$, q_{a2} , and $\bar{q}_{a2}$, and q_{b1} , $\bar{q}_{b1}$, q_{b2} , and $\bar{q}_{b2}$, respectively. The inverter is constituted of switches q_{s1} , $\bar{q}_{s1}$, q_{s2} , $\bar{q}_{s2}$, q_{s3} , and $\bar{q}_{s3}$. 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.

From Figure 2. The following equations can be derived:

$$V_a10 - V_a20 = e_g - (r_a + l_a p)i_a - (r'_a + l'_a p)i'_a \quad ...(1)$$

$$V_b10 - V_b20 = e_g - (r_b + l_b p)i_b - (r'_b + l'_b p)i'_b \quad ...(2)$$

$$V_a10 - V_b10 = (r_b + l_b p)i_b - (r_a + l_a p)i_a \quad ...(3)$$

$$V_a20 - V_b20 = (r'_a + l'_a p)i'_a - (r'_b + l'_b p)i'_b \quad ...(4)$$

$$i_g = i_a + i_b = i'_a + i'_b \quad ...(5)$$

where $p = d/dt$ and symbols like *r* and *l* represents resistances and inductances of the input inductor L_a', L_a',L_b, and L_b'.

The circulating current can be defined from i_a and $\bar{i}_a$ or i_b and $\bar{i}_b$, i.e.,

$$i_o = i_a - \bar{i}_a = -i_b + \bar{i}_b \quad ...(6)$$

Introducing i_0 and adding (3) and (4), relations (1)-(4) become:

$$v_a = e_g - [r_a + r'_a + (_a + '_a)p]i_a + (r'_a + '_a p)i_o \quad ...(7)$$

$$v_b = e_g - [r_b + r'_b + (_b + '_b)p]i_b - (r'_b + '_b p)i_o \quad ...(8)$$

$$V_o = -[r'_a + r'_b + ('_a + '_b)p]i_o - [r_a - r'_a + (_a - '_a)p]i_a + [r_b - r'_b + (_b - '_b)p]i_b \quad ...(9)$$

where,

$$v_a = v_{a10} - v_{a20} \quad ...(10)$$

$$v_b = v_{b10} - v_{b20} \quad ...(11)$$

$$V_o = v_{a10} + v_{a20} - v_{b10} - v_{b20} \quad ...(12)$$

Relations (7)–(9) and (5) constitute the front-end rectifier dynamic model. Therefore, v_a (rectifier A), v_b (rectifier B), and v_o (rectifiers A and B) are used to regulate currents i_a, i_b, and i_o, respectively. Reference currents i^*_a and i^*_b are chosen equal to $i^*_g/2$ and the reference circulating current i^*_o is chosen equal to 0. In order to both facilitate the control and share equally current, voltage, and power between the rectifiers, the four inductors should be equal, i.e., $r'_g = r_a = r'_a = r_b = r'_b$ and $'_g = _a = '_a = _b = '_b$. In this case, the model (7)-(9) can be simplified to the model given by

$$V_a + \frac{V_o}{2} = e_g - 2(r'_g + '_g p)i_a \quad ...(13)$$

$$v_b - \frac{V_o}{2} = e_g - 2(r'_g + '_g p)i_b \quad ...(14)$$

$$V_o = -2(r'_g + '_g p)i_o \quad ...(15)$$

Additionally, the equations for i_g, i'_a, and i'_b can be written as

$$V_{ab} = \frac{V_a + V_b}{2} = e_g - (r'_g + '_g p)i_g \quad ...(16)$$

$$V_a - \frac{V_o}{2} = e_g - 2(r'_g + '_g p)i'_a \quad ...(17)$$

$$v_b + \frac{V_o}{2} = e_g - 2(r'_g + '_g p)i'_b \quad ...(18)$$

In this case (four identical inductors), the circulating current can be reduced to zero imposing

$$V_o = v_{a10} + v_{a20} - v_{b10} - v_{b20} = 0. \quad ...(19)$$

When $i_o = 0$, $(i_a = i'_a, i_b = i'_b)$ the system model (7)-(9) is reduced to

$$V_a = e_g - 2(r'_g + '_g p)i_a \quad ...(20)$$

$$v_b = e_g - 2(r'_g + '_g p)i'_b \quad ...(21)$$

Then the model of the proposed system becomes similar to that of a system composed of two independent rectifiers.

PWM Strategy

The inverter can be commanded by using an adequate Pulse Width Modulation (PWM) strategy for three-phase Voltage Source Inverter (VSI), so that it will not be discussed here. In this section, the PWM strategy for the rectifier will be presented. The rectifier pole voltages v_{a10}, v_{a20}, v_{b10}, and v_{b20} depend on the conduction states of the power switches, i.e.,

$$V_{j0} = (2S_{qj} - 1)\frac{V_c}{2} \quad \text{for } j = a_1 \text{ to } b_2 \quad ...(22)$$

where v_c is the total dc-link voltage. Considering that v^*_a, v^*_b, and v^*_o denote the reference voltages determined by the current controllers (see Section IV),we found

$$V_a^* = V_{a10}^* - V_{a20}^* \quad ...(23)$$

$$V_b^* = V_{b10}^* - V_{b20}^* \quad ...(24)$$

$$V_0^* = V_{a10}^* + V_{a20}^* - V_{b10}^* - V_{b20}^* \quad ...(25)$$

The gating signals are directly calculated from the reference pole voltages v^*_{a10}, $v^*_{a20,}$ $v^*_{b10}$and v^*_{b20}. However, (23)-(25) are not sufficient to determine the four pole voltages uniquely from v^*_a, v^*_b and v^*_o. Introducing an auxiliary variable $v^*_x = v^*_{a20}$, that equation plus the three Equations (23)-(25) constitute a four independent equations system with four variables ($V_{a10}{}^*, V_{a20}{}^*, V_{b10}{}^*, V_{b20}{}^*$). Solving this system of equations, we obtain

$$V_{a10}{}^* = V_a{}^* + V_x{}^* \quad ...(26)$$

$$V_{a20}{}^* = V_x{}^* \quad ...(27)$$

$$V_{b10}{}^* = \frac{V_a{}^*}{2} + \frac{V_b{}^*}{2} - \frac{V_o{}^*}{2} + V_x{}^* \quad ...(28)$$

$$V_{b20}{}^* = \frac{V_a{}^*}{2} - \frac{V_b{}^*}{2} - \frac{V_o{}^*}{2} + V_x{}^* \quad ...(29)$$

From these equations, it can be seen that, besides v^*_a, v^*_b and v^*_o, the pole voltages depend on also of v^*_x. The limit values of the variable v^*_x can be calculated by taking into account the maximum $v^*_c/2$ and minimum "$v^*_c/2$ value of the pole voltages

$$V_{xmax}{}^* = \frac{V_c{}^*}{2} - V_{max}{}^* \quad ...(30)$$

$$V_{xmin}{}^* = \frac{-V_c{}^*}{2} - V_{min}{}^* \quad ...(31)$$

where v^*_c is the reference dc-link voltages, v^*_{max} = maxg and v^*_{min} = ming with g = {v^*_a, 0, $v^*_a/2 + v^*_b/2 - v^*_o/2$, $v^*_a/2 - v^*_b/2 - v^*_o/2$}.

Introducing a parameter « (0 ≤ « ≤ 1), the variable v^*_x can be written as

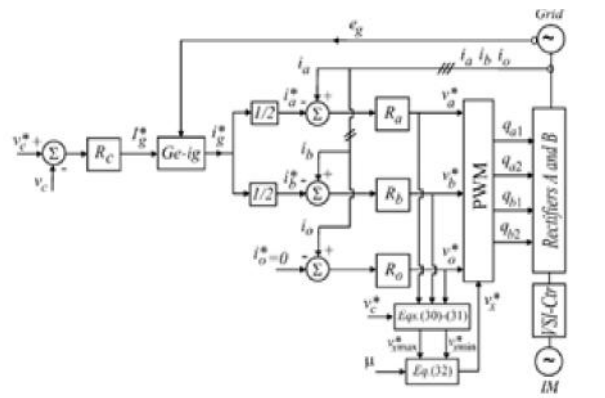
$$V_x{}^* = \mu V_{xmax}{}^* + (1-\mu) V_{xmin}{}^* \quad ...(32)$$

When « = 0, « = 0.5, and « = 1 the auxiliary variable has the following values $V_x{}^* = V_{xmin}{}^*$, $V_x{}^* = v^*_{xave} = (V_{xmin}{}^* + V_{xmax}{}^*)/2$, and $V_x{}^* = V_{xmax}{}^*$, respectively. When $V_x{}^* = V_{xmin}{}^*$ $V_x{}^* = V_{xmax}{}^*$ a converter leg operates with zero switching frequency. Once v^*_x is chosen, pole voltages v^*_{a10}, v^*_{a20}, v^*_{b10}, and v^*_{b20} are defined from (26) to (29). The gating signals are obtained by comparing pole voltages with one (v_{t1}), two (v_{t1} and v_{t2}) 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 180° [see Figures 5c and 5d]. The parameter *ì* changes the place of the voltage pulses related to v_a and v_b. When $v^*_x = v^*_{xmin}$ (« = 0) or $v^*_x = v^*_{xmax}$ (« = 1) are selected, the pulses are placed in the begin or in the end of the half period (T_s) of the triangular carrier signal [see Figures 5a and 5c]. On the other hand, when $v^*_x = v^*_{xave}$ the pulses are centered in the half period of the carrier signal [see Figures 5b and 5d]. The change of the position of the voltage pulses leads also to the change in the distribution of the zero instantaneous voltages (i.e., $v_a = 0$ and $v_b = 0$). With « = 0 or « = 1 the zero instantaneous voltages are placed at the beginning or at the end of the switching period, respectively, while with « = 0.5, they are distributed equally at the beginning and at the end of the half period. This is similar to the distribution of the zero-voltage vector in the three-phase inverter. Consequently, « influences the harmonic distortion of the voltages generated by the rectifier, as it will be shown in Section V.

CONTROL STRATEGY

Figure 3 presents the control block diagram of the system in Figure 2, highlighting the control of the rectifier. The rectifier circuit of the proposed system has the same objectives of that in Figure 1, i.e., to control the dc-link voltage and to guarantee the grid power factor

Figure 3: Control Block Diagram



close to one. Additionally, the circulating current i_o in the rectifier of the proposed system needs to be controlled. In this way, the dc-link voltage v_c 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^*_g. To control power factor and harmonics in the grid side, the instantaneous reference current i^*_g 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. The reference currents i^*_a and i^*_b are obtained by making $i^*_a = i^*_b = i^*_g/2$, 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 controllers can be implemented using linear or nonlinear techniques. In this paper, the current control law is the same as that used in the two sequences synchronous controller described in Jacobina *et al.* (2001). These current controllers define the input reference voltages v^*_a and v^*_b. The homopolar current is measured (i_o) and compared to its reference ($i^*_o = 0$). The error is the input of PI controller R_o, that determines the voltage v^*_o.

The calculation of voltage v^*_x is given from (30) to (32) as a function of ì, selected as shown in the Section V. 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).

SIMULATION MODELING AND RESULTS

In this chapter the work carried out on mathematical model of the system using MATLAB/SIMULINK software. The results of simulation have been discussed.

Figure 4: Matlab Model Using Conventional Control

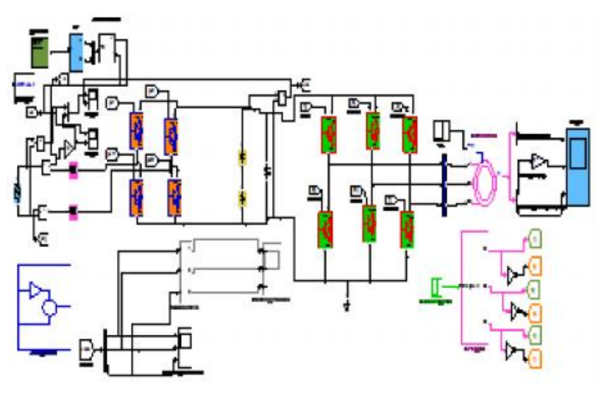
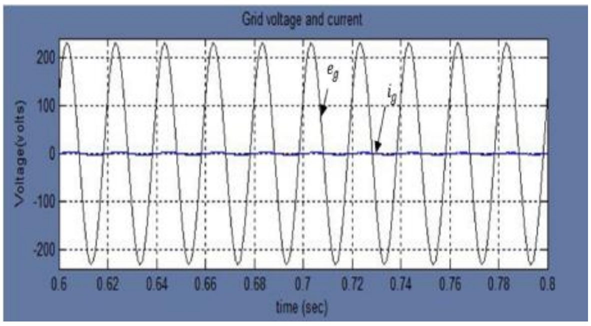
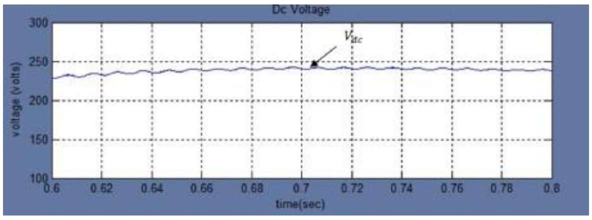


Figure 5: Output Waveforms

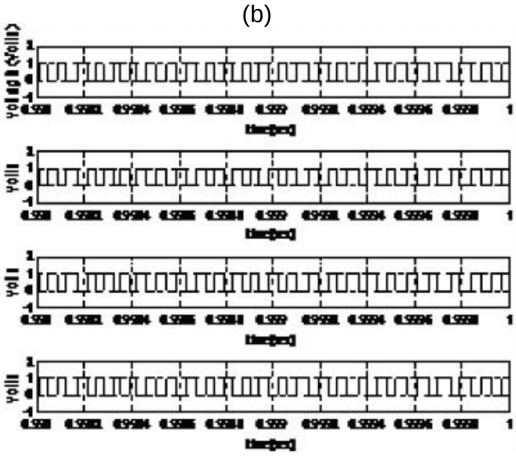


(a)

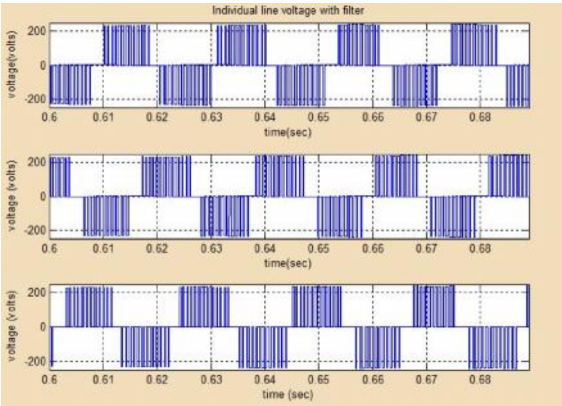
Figure 5 (Cont.)



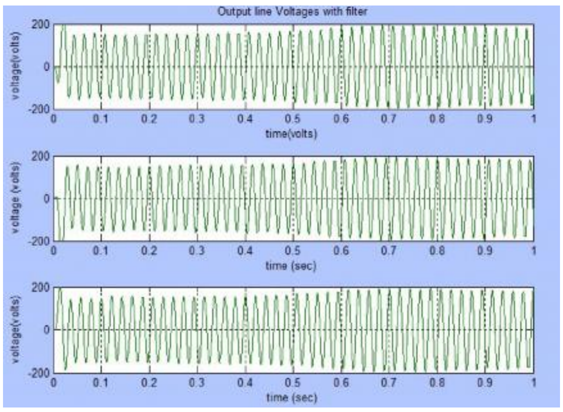
(b)



(c)

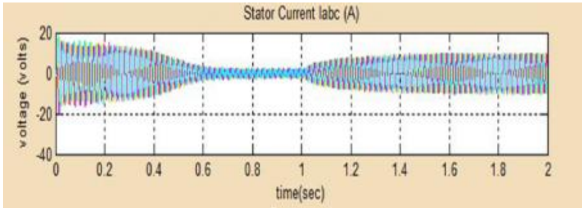


(d)

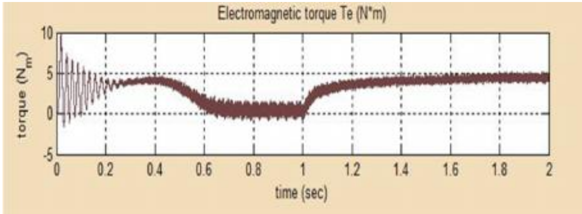


(e)

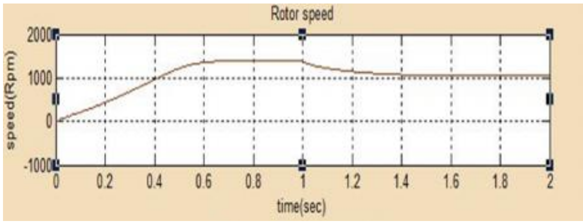
Figure 5 (Cont.)



(f)



(g)



(h)

Note: a) Waveform of both Grid voltage and current, (b) DC voltage, (c) Waveforms of Rectifier Pulses, (d) waveform for individual Line voltages without filter, (e) Waveform of Individual Line voltages with Filter, (f) Waveform for stator Current, (g) Waveform for ElectroMagnetic torque and (h) rotor speed.

Figure 6: Matlab Model Using Both Rectifier Combination

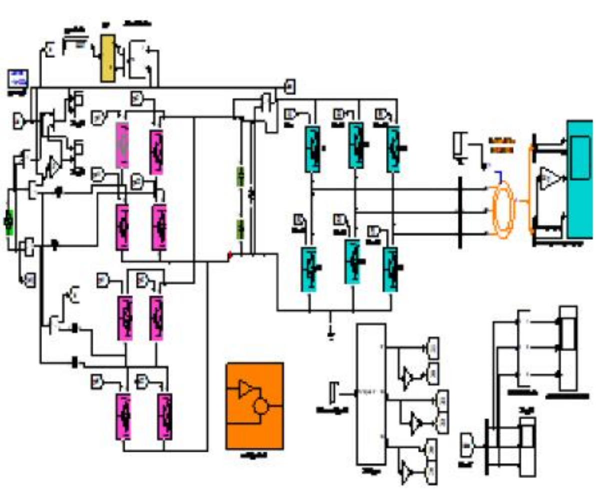
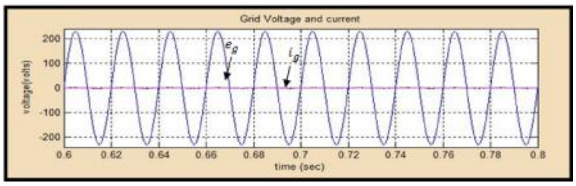
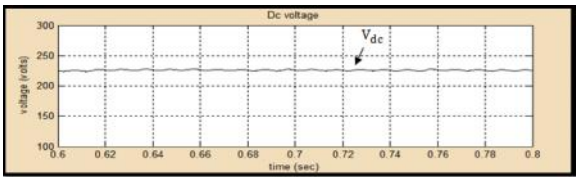


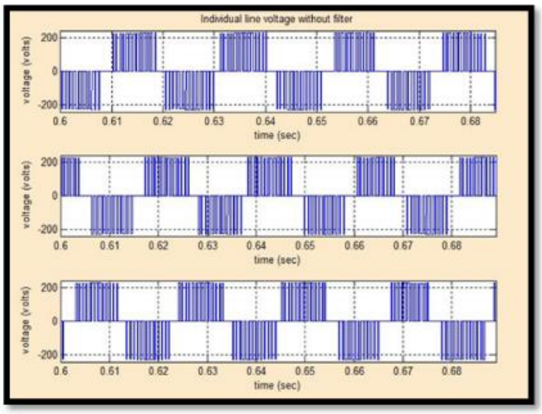
Figure 7: Waveforms



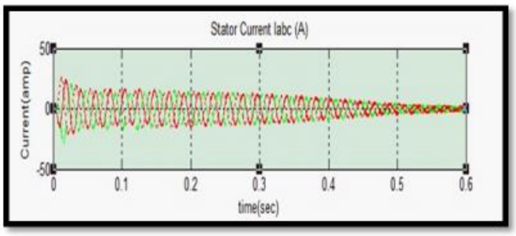
(a)



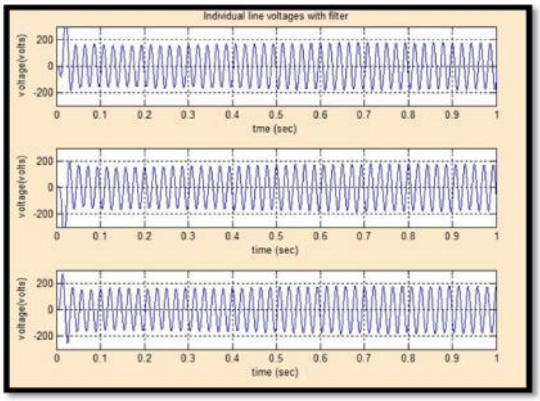
(b)



(c)

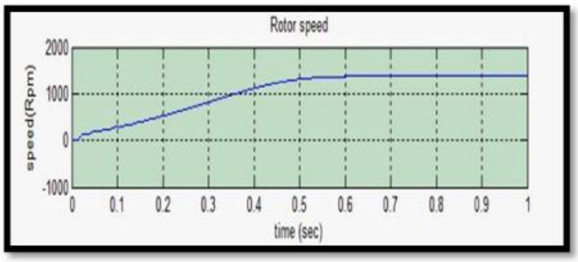


(d)

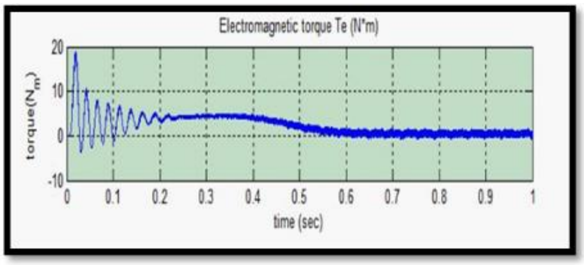


(e)

Figure 7 (Cont.)



(f)



(g)

Note: (a) Waveforms of both Grid current and voltage, (b) DC voltage (c) Waveforms of Individual Line Voltages without filter, (d) Waveform of Stator Current, (e) Waveforms of Individual Line Voltages with Filter, (f) Waveform for Rotor Speed and (g) Electromagnetic Torque.

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. 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.

FUTURE SCOPE

It is quite common to have only a single phase power grid in residential, commercial, manufacturing, and mainly in rural areas. At the solar power plant and industries it is convenient convert single phase supply to three phase supply. This system is very useful for agricultural to run three phase motor.

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