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Research Article

CONTROLLING SPEED OF INDUCTION MOTOR USING THREE-PHASE BOOST CONVERTER

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ABSTRACT
Power inverters as electronic devices changing direct current (DC) to alternating current (AC), are widely used in various industries. With respect to their important role in the industries, the technology of manufacturing inverters must be developed as far as possible. In this paper, we have tried to control the speed of induction motors by using boost converters so that inrush current and input voltage harmonics are placed in their optimized position. To that end, we have applied PI controller for regulating the output voltage of boost converter by using the Particle Swarm Optimization (PSO). In the end the results of the proposed method after simulation were compared with the results of the classic boost converter (non controller) and it is shown that using PI controller in boost converter has an effective role on output voltage harmonics of the inverter and consequently on the overall performance of the induction motor.

Keywords: *Controlling, Motor, Three-Phase, Converter*

INTRODUCTION
One of the ways for controlling the speed of induction motors is the control of input frequency to the motor. This can be realized by the inverters. Inverter is an electronic device that is capable of changing DC voltage to AC voltage. During the recent years, with respect to the scientific progress in design and production of semi-conductive devices and due to reduction in production costs of these implements, inverters have been widely used in controlling the speed of induction motors. The classic structure of the inverter allows the device to generate alternating voltage equal to or less than the input voltage. However, given the significance of these devices during the recent years, many researches have been conducted into the field so that drastic changes have been made in the structure and way of control of these devices. An example could be Impedance Source Inverter that is made of an impedance network (comprising of a set of self and capacitors) placed in between input source and diode bridge. This will give us a buck–boost converter (Fang *et al.*, 2005).
Source (Caceres and Barbi, 1999) has reviewed a new structure of single phase boost converters. Using two boost converters it will be capable of generating AC voltage in the output. However, the starting and control of these devices have been doubly paid attention by the researchers during the past decade. For instance, source (Amarapur and Doddappa, 2013) has introduced a new control method based on bandwidth modulation for starting and control of the speed of induction motors. The paper has introduced a simple method for calculation of harmonic currents of an induction motor and optimized PWM switching patterns for minimization of the harmonic losses. Source (Arulmozhiyal *et al.*, 2011) has studied the speed control in induction motors by using fuzzy-PI controllers and source (Mohit *et al.*, 2013) has studied design and control of highly efficient boost converter. Sources (Sreekumar and Agarwal, 2008; Prudente *et al.*, 2008; Seeman and Sanders, 2008; Zhenyu and Prodic, 2008) have studied control methods in boost rectifiers.

Structure of Boost Converters
Inverter or electricity converter is an electronic device that changes DC voltage into the AC voltage. The converted AC voltage can be in any voltage or frequency based on the demands that are controlled by proper transformers and circuits. The application of these transformers in power systems and in changing or controlling one of the several features like frequency, voltage, number of phases, reactive power and power quality of electrical load. Figure (1) depicts a simple type of three-phase inverter.

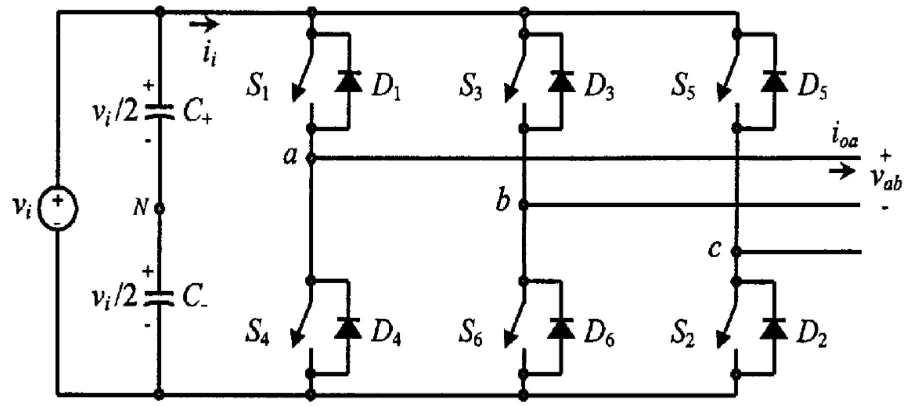

Figure 1: Basic configuration of three-phase inverter

It is made of six power transistors named IGBT or insulated gate bipolar transistor. The three-phase inverter has three arms and each arm has two switches (power transistor) and they are able to create the required waveform by coordinated turning on and off of the switches.
One of the greatest problems with three-phase inverters is this that they are only capable of generating alternating voltage with smaller domain in comparison with DC voltage. Therefore, in order to create a greater output voltage out of the input voltage boost rectifiers are used in the input segment. Figure (2) indicates the basic structure of three-phase boost converter.

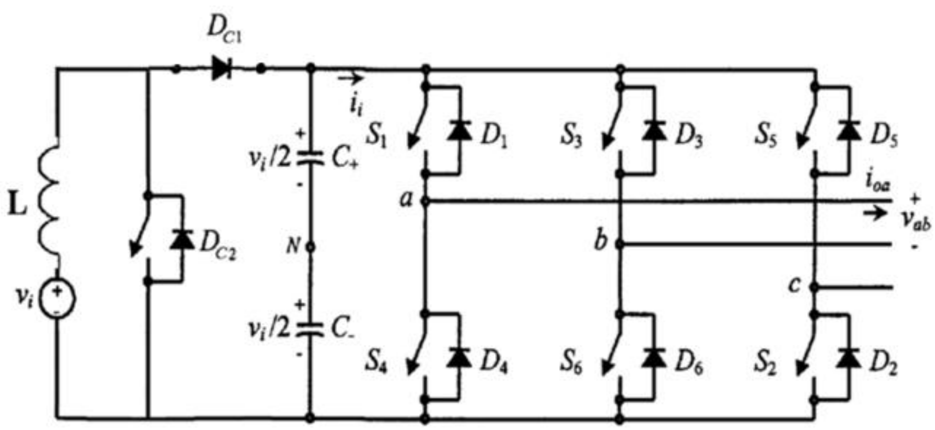

Figure 2: Basic configuration of three-phase boost converter

As it is shown, this inverter includes a DC voltage source (Vs), boost inductor (L), one diode (Dc1) and a controlled switch (DC2). The ratio between the input and output voltages of a boost converter can be displayed as the following (Panov and Jovanovic, 2001):

(1) $$\frac{V_o}{V_i} = \frac{1}{1-D}$$

In this equation, D represents the time of performance of the switch in an interval known as Duty Cycle.

Space Vector Modulation

In the majority of industrial uses it is often needed to calculate the output voltage of inverters for meeting the permanent demands. There are various methods for changing inverter gain. The most effective way for gain and output voltage control is using pulse width modulation or PWM control inside inverter. Using zero and 1 signals in power switches will turn them on and off and then the desirable waveform of the output voltage will be realized. Space vector modulation is one of the pulse width modulation methods (Jabbar *et al.*, 2004).

In this method the voltage vector is made by a proper time distribution between the neighboring voltage vectors (from among voltage vectors of V1 to V6 and two vectors of V0 and V7. In this method, the three borders of Vi+1 and Vi and V0 or V7 are indeed enforced in the motor in the time period.

In this method we need the source voltage with a fixed frequency 2fs, therefore,

(2) $$2f_s(t_1 V_i + t_2 V_{i+1}) = V_s{}^*(t)$$

(3) $$t = \frac{1}{2f_s} - t_1 - t_2$$

(4) $$t_1 = \frac{1}{2f_s} V_s{}^*(t) \frac{2\sqrt{3}}{\Pi} \sin(60 - \alpha)$$

(5) $$t_2 = \frac{1}{2f_s} V_s{}^*(t) \frac{2\sqrt{3}}{\Pi} \sin(\alpha)$$

To minimize the number of switch commutations for the space vector the source voltage in the first section of the starting switch will be like the following:

(6) $$V_0(t_0/2) \ldots V_1(t_1) \ldots V_2(t_2) \ldots V_7(t_0/2)$$

For all the odd cycles the above arrangement is used. Also the arrangement of switches for the even cycles will be like the following:

(7) $$V_7(t_0/2) \ldots V_2(t_2) \ldots V_1(t_1) \ldots V_0(t_0/2)$$

Other switching models are more or less developed by imaging voltage on the six basic vectors. Therefore, on this basis an appropriate switching table with high precision for determining appropriate voltage vector can be developed from among three vectors created in each area.

Total Harmonic Distortion (THD)

The output of inverters is an act of harmonic nature and the quality of an inverter is usually evaluated by the parameters named efficiency parameters, one of which is the total harmonic distortion or THD. This parameter is indeed a scale for measuring the similarity between the waveform and its principal component as the following:

(8) $$\mathrm{THD} = \frac{1}{\mathrm{V_1}} \left(\sum_{\mathrm{n}=2,3,\ldots}^{\infty} \mathrm{V_n^2}\right)^{\frac{1}{2}}$$

In which V1 of the effective quantity of the principal component and Vn is the effective quantity of the nth harmonic component.

In this paper, we have tried to get the total calculation and its minimum degree by using THD methods.

Controlling Induction Motor

The most important advantages of induction motors over DC motors are simpler structure, higher efficiency, less price, and higher range of power. There are various methods for controlling the induction motors that can be classified into two groups: the first method is vector control of induction motor that is highly complicated and more expensive but they can control the nominal speed of motor from zero to above precisely.

The second method is scalar control method that is relatively simpler and cheaper but it has limitation in speed range control. One method is the number of pole pairs, frequency and v/f.

(9) $$n_r = (1-s)n_s = \frac{(1-s)\times 120 \times f_s}{P}$$

In which fs is the motor feed frequency, P is the number of pole pairs of the engine and s is the motor slip. As it is shown in the above equation, the three parameters of fs, P and s are needed to change the speed of the motor. Since in this paper we have worked on changing source frequency method for controlling the speed of induction motor, the generalities will be brought hereunder.

Figure (3) shows changes in the speed-torque curve based on the frequency changes:

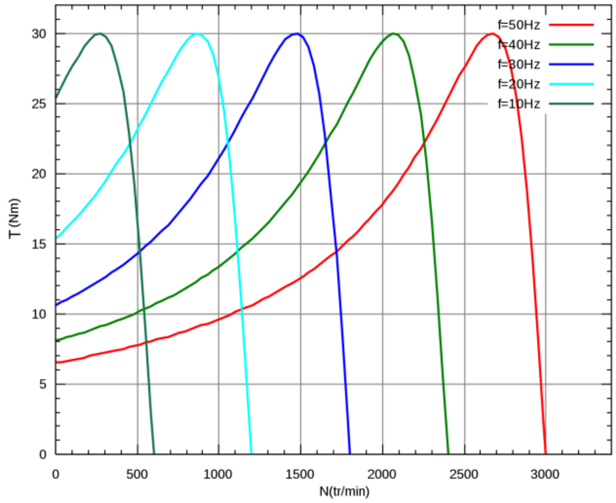

Figure 3: Changes in the speed-torque curve based on the frequency changes

As it was shown in the figure, the speed of induction motor has a direct link with the frequency. This means that with the reduction or increase of the frequency the speed of the induction motor will be increased or reduced. Another point worthy of attention in this figure is the maximum torque of the motor that is independent of the frequency of voltage source that will not change upon the change in frequency.

Proposed Control Method

In this paper we have proposed a PI (proportional-integral) controller method for controlling boost converter. PI controller is placed on boost converter circuit so that after measuring output DC voltage of the boost converter, it will be able to reduce fluctuations in output voltage to a great deal by changing switching pulses. Also in order to determine the optimum gains in this controller we have used the Particle Swarm Optimization (PSO) method. The stages of determining the optimum gains in this controller are the following:

1- In the beginning, particles as the initial population of PSO algorithm are created. This paper put the total number of these particles experimentally at 35. For initial numbering of these particles random figures within the defined limits of the variables are used. This range is for the first variable with the control proportional gain (KP) of zero to 0.1 and for the second variable with integral gain (Ki) between zero and 250.

2- Using SIM command in MATLAB software the quantities of the variables of each particle are referred to the Simulink environment. Upon placement of the variables in PI block (as controller gains) and implementation of Simulink, the quantities of output voltage of boost converter and the simulation time are calculated and returned to the program.

3- Using the defined objective function in equation (8) total THD is calculated for each particle and it is considered as the value of that particle.

4- After calculation of the value of each particle, Pbest and Gbest parameters are calculated for each particle. Pbest shows the best position each particle has had in the total iterations and Gbest shows the best position the particle has had until this moment. Then the parameters are placed in equation (10) so that new location of the particles are distinguished.

(10) $$v_{ij}(t+1) = v_{ij}(t)(c_1(r_1(pbest)_i(t) - x_{ij}(t)) + c_2[r_2(Gbest]_i(t) - x_{ij}(t)))$$

In which $v_{ij}(t)$ is the speed of particle in n*th*iteration, C1 is the inertia coefficient, *r* is the random figure, Pbest is the best answer by each particle, Gbest is the best answer among all particles, and $x_{ij}(t)$ is the location of each particle.

5- Since the particle quantities have been updated, we will go to the second stage and calculate the the output voltage quantity per updated variables.

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6- The above stages are implemented to the pre-determined number of iterations and in the end, the last Gbest is considered as the optimum answer. The number of iterations has been experimentally put at 10 here. The other parameters have been brought in Table (1).

Table 1: Quantities of PSO algorithm parameters for controller design

Quantity	Parameter
35	Popsize
2	C2
2	C1
0.9	Weight coefficient (w)
10	Iteration
2	Optimization variables (controller parameters)

Table 2: Shows the simulation results in two positions of with and nonPI controller.

Parameter	Kp	Ki	THD%
With controller	1	0	17.5
Non controller	6.5	151	8.7

The advantage of using PSO algorithm is in the speed of integration to the desirable answer along with finding optimum parameters for controller. In the end, the final results of PSO algorithm will be 0.65 and 151 for proportional gain (Kp) and integral gain (Ki) respectively. Placement of the optimized PI controllers will show that the output voltage features of boost converter will be improved outstandingly after using PI controller.

RESULTS AND DISCUSSION

Simulation Results

After studying the simulated results of the proposed method, we have first brought a schematic diagram of boost converter simulated in Simulink environment of MATLAB software.
Figure (4) depicts boost converter with PI controller. The input voltage is 220 V. This inverter converts the input voltage through one self with inductance of 100 micro-Henry and one 100 micro-Faraday capacitor with 204k Ohm resistance.

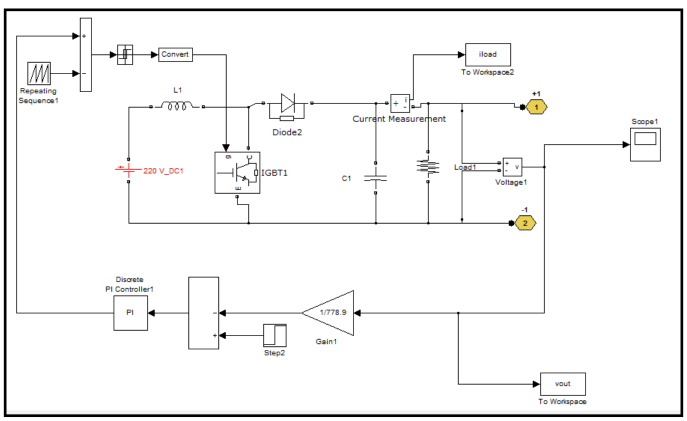

Figure 4: Simulated model of boost converter with result controller

Figure (5) shows a sample of three-phase boost converter. As it is seen, the function of boost converter in this figure is to control the three-phase induction motor connected to each other by LC filter to improve the output voltage of the inverter and to reduce the remaining harmonics in the output voltage to a great deal.

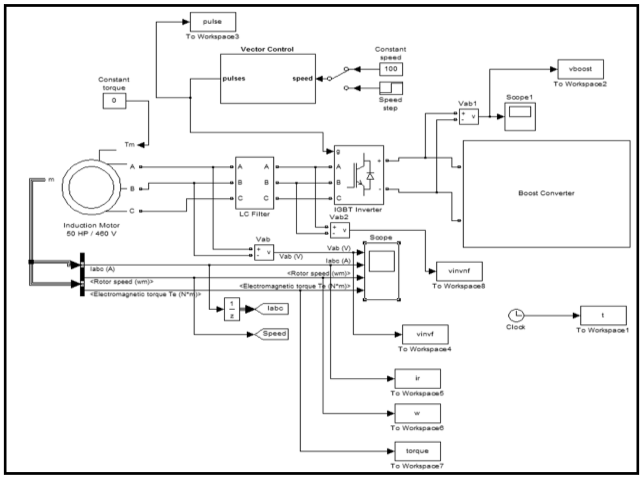

Figure 5: The general simulated model of the system under study in MATLAB software

The results of boost converter simulation have been shown in the figures (6) to (14).

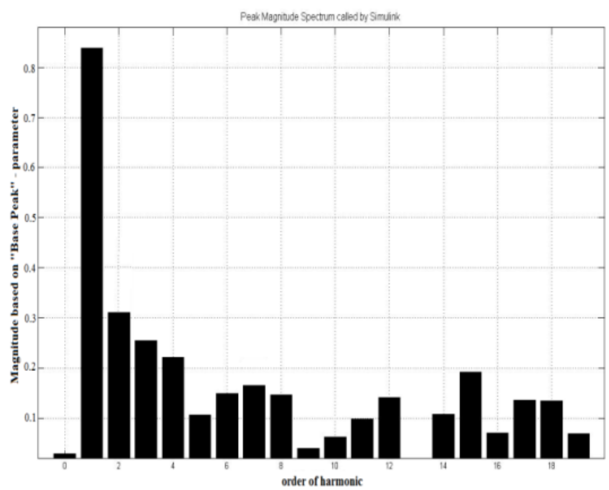

Figure 6: Output voltage harmonics of the inverter with PI controller

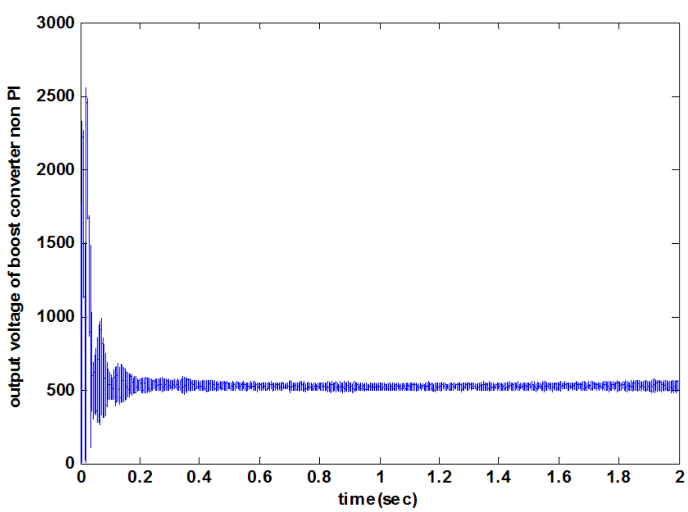

Figure 7: Diagram of output voltage of boost converternonPI

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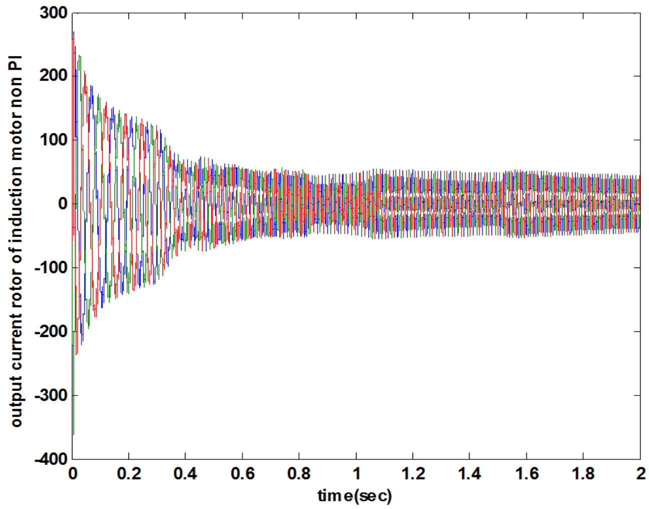

Figure 8: Diagram of induction motor current in amp.nonPI

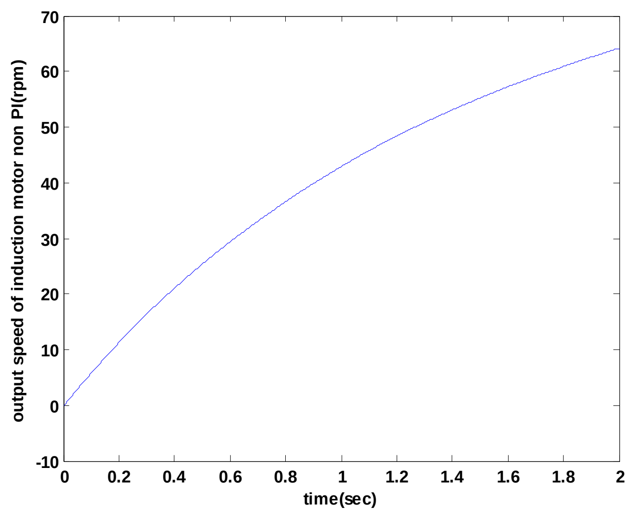

Figure 9: Diagram of output speed of induction motor non PI (*rpm*)

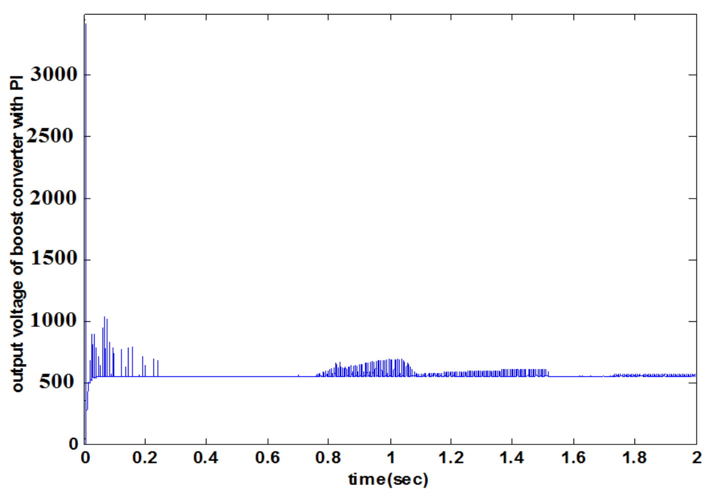

Figure 10: Output voltage of boost converter with PI

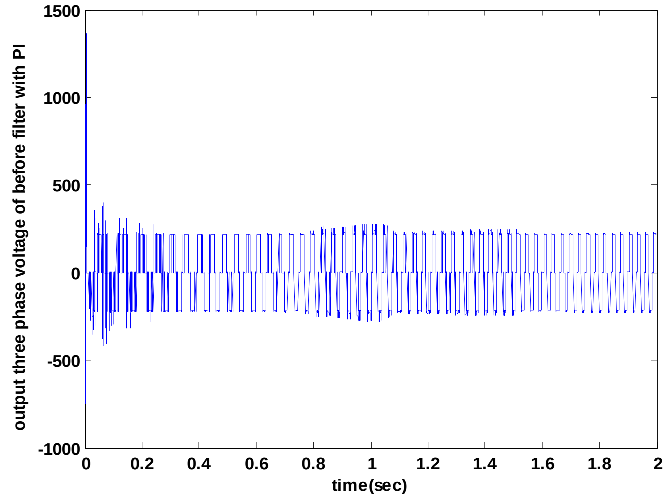

Figure 11: Output three-phase voltage to inverter phase before filter with PI

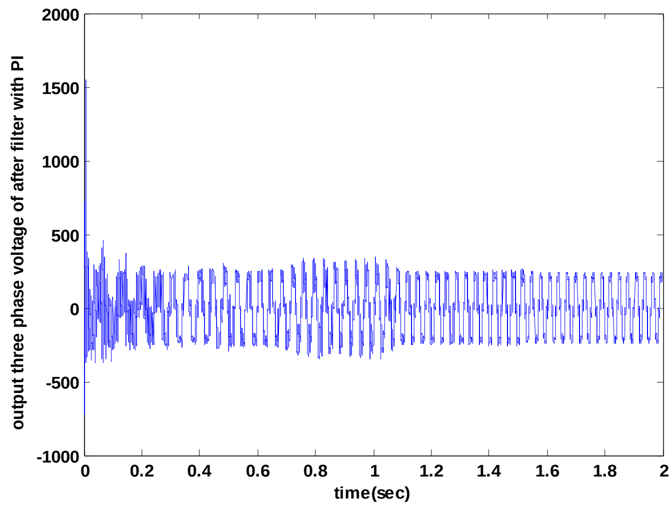

Figure 12: Output three-phase voltage to inverter phase after filter with PI

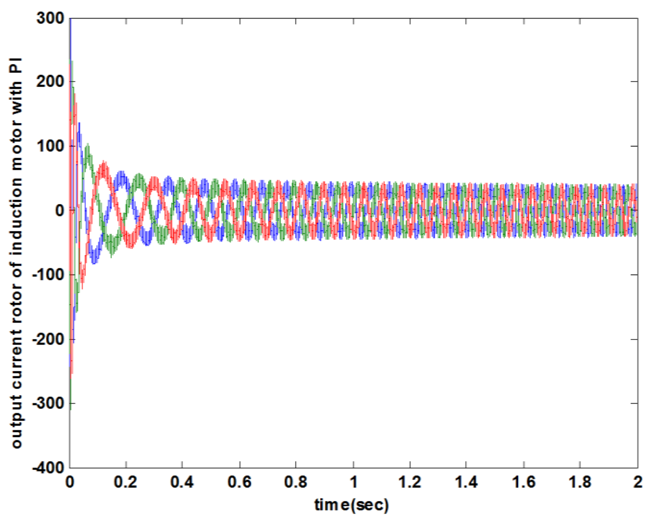

Figure 13: Output current rotor of induction motor with PI

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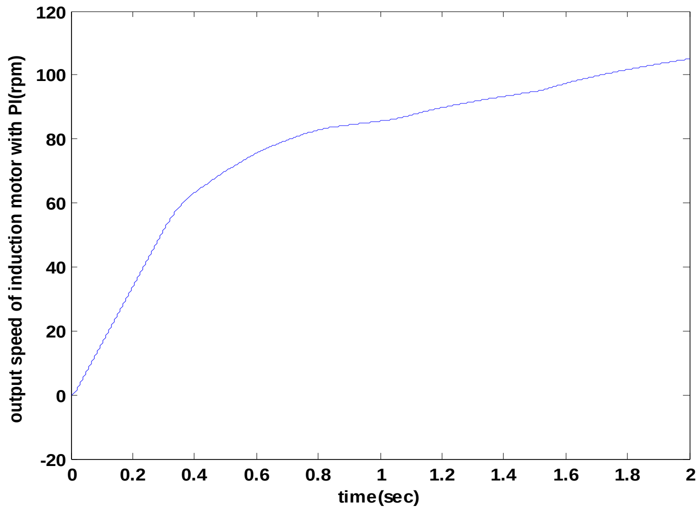

Figure 14: Output speed of induction motor with PI (*rpm*)

Conclusion

In this paper we used a boost converter to control the speed of an induction motor. Since the quantity of harmonics in output inverter can influence the performance and life expectancy of the motor, we used PI controller to reduce harmonics of the system and to boost efficiency of the motor. In order to determine the controller gains we used particle swarm optimization or PSO. With the placement of determined gains by optimization algorithms it was observed in controller that the voltage waveforms, current, torque and speed of the motor have had outstanding changes. Also, the determined gains have had notable impact on the inrush current of the motor.

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