Evolution in Electrical and Electronic Engineering Vol. 2 No. 2 (2021) 849-855
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Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Case Study on Cycloconverter with PI Voltage Control for Single Phase Induction Motor

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DOI: https://doi.org/10.30880/eeee.2021.02.02.102
Received 22 July 2021; Accepted 12 October 2021; Available online 30 October 2021

Abstract: This paper is to highlight several case studies in order to simulate a single phase cycloconverter for induction motor voltage control using MATLAB/Simulink, with a Proportional Integral (PI) control technique. The cycloconverter comprises of back-to-back connected controlled thyristor, where its output voltage and frequency can be controlled by tuning the PI gains in order to give reference firing angles to be adjusted to 60° switching cycle for thyristor voltage control. An AC voltage of 24V with a fundamental frequency of 50Hz source is applied for the motor operation. The simulation results show that, the output voltage feedback at the motor is changed accordingly to the reference voltage, set at the controller input where the PI controller can provide a required voltage for the induction motor. At the end it helps the authors to understand the concept of voltage control at power converter topologies.

Keywords: Cycloconverter, Induction Motor, PI Control, Voltage Control

1. Introduction

Induction Motors (IM) are not new in industries. They are reliable, relatively inexpensive, and robust in many domestic appliances such as vacuum cleaners, washing machines, and others [1]. Since speed control of induction motors plays a vital role in the industry, numerous research papers have suggested various methods to control the speed of induction motors. These include sliding mode control, fuzzy logic control, model predictive control, and others [2]. Since the rated frequency produces 50/60 Hz [3] as a main source, this frequency is not applicable for most of the motor applications because the speed of the motor is proportional to the frequency. Therefore, it requires variable frequency ranging from one-tenth to one-third of the supply frequency, like the induction motors used in AC traction, aircraft power supplies, mobile power supplies, and others [4] for variable speed application. This is where the cycloconverter came in handy, as it can generate variable frequencies or voltage by converting the input AC to the specific frequency and voltage without any intermediate DC link [5].

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At the meantime, it operates as a direct AC-AC frequency with an inherent to voltage control features [6]. In order to benefit the control strategy mechanism, its can be divided into two major types: scalar and vector control. Although the vector control method is excellent in handling transients, can operate with fast responses which satisfies the requirements of dynamic drives however high price and the complexity of the circuit are the factors that drive the industry to use scalar control because it is cheap and well-implementable method [7]. Due to the stability and efficiency of the semiconductor devices, it has presented an opportunity to control the frequency of the cycloconverter as needed and provide a considerable amount of controlled power with the help of switching devices such as thyristor [4] or others power electronics devices. Apart from that, steady-state analysis of an induction machine provides a more significant difference between the average and pulsating torque components of the instantaneous electromagnetic torque produced in the machine [8].

Here, a study to understand the concepts of a single phase cycloconverter circuit and it PI controller are designed and constructed in MATLAB/Simulink in this project is been tested. By applying a closed loop feedback control, the cycloconverter model with thyristor as the power converter devices, the voltage output feedback for induction motor can be varied with the help of a PI controller that acts as a voltage control for the cycloconverter.

2. Modelling of the System

Figure 1 illustrates the block diagram of this project. A 24V single phase AC supply with a rated frequency of 50 Hz is used to power the circuit, and the single phase induction motor acts as the load. A closed-loop model of a single phase cycloconverter is then constructed and been connected with the Pulse Width Modulation (PWM). The voltage output feedback is used to collect the voltage at the induction motor to be compared with the reference voltage to be compared. Here, the PI control technique is been used to control the motor voltage while at the same time changing the speed of the motor in closed loop mechanism.

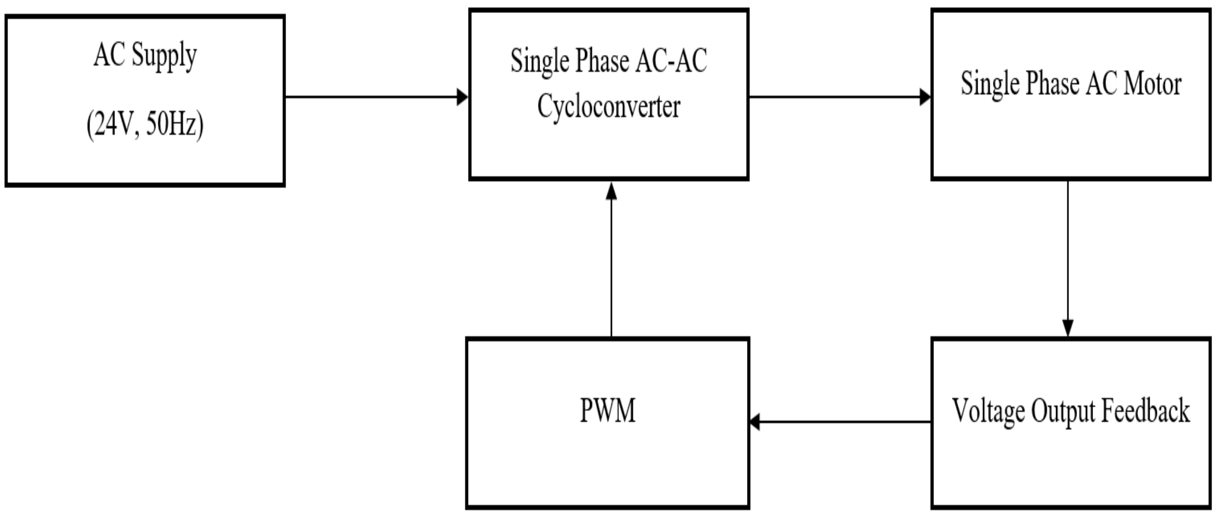


Figure 1: The block diagram of the single phase cycloconverter constructed

Figure 2 shows the entire circuit designing process for completing the simulation. This figure is to show the steps process in how to development of the cyloconverter, how to implement the PI control tehnique, what will be the expected output to voltage which fulfill the aims of the project and at the end, where is the repeating steps need to be taken if the results are not showing accurate answers.

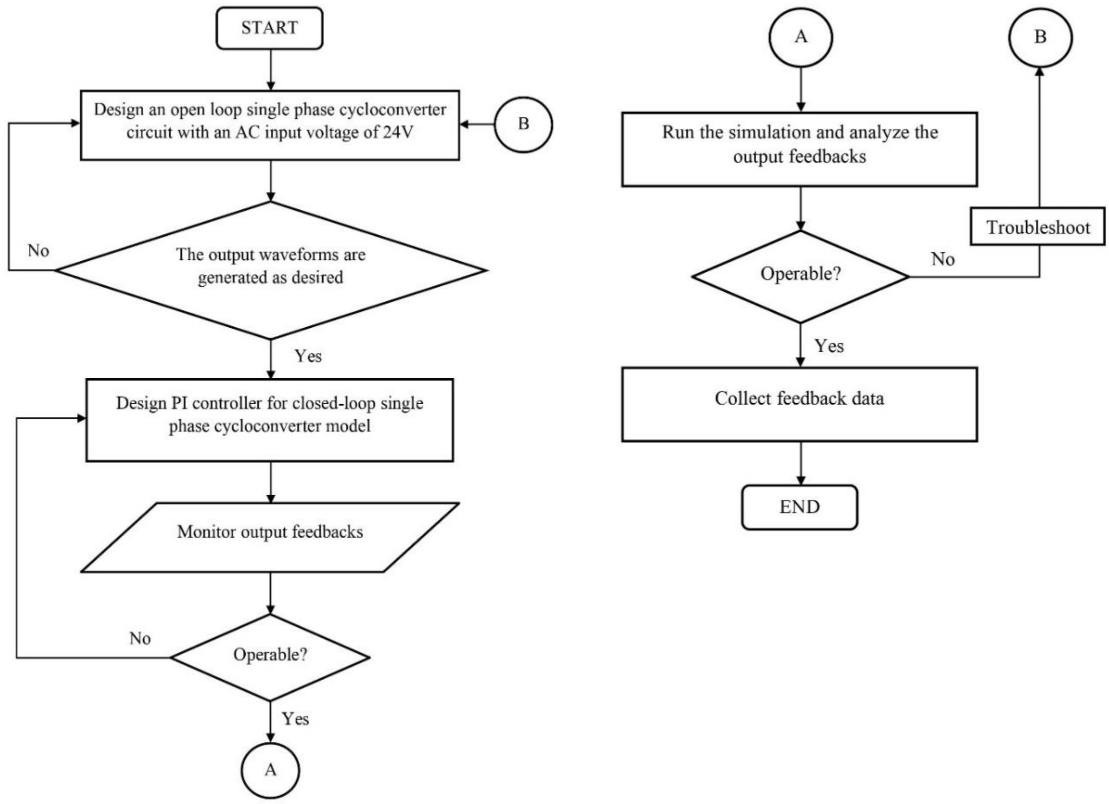


Figure 2: The designing process of a single phase cycloconverter

In this project, single phase cycloconverter consists of a back-to-back connection of two thyristor circuits was designed in MATLAB/Simulink for completed the simulation process as shown in Figure 3. The designing process of a closed-loop single phase cycloconverter circuit model is then further continued by constructing the PI controller for voltage feedback mechanism. The controller is designed using "trial and error" method for determine the PI gains. The values for P, kp and I, ki are obtained, as $kp = 0.185$ and $ki = 0.01$. This value can be achieved by varying the values of kp and ki of the PI controller while observed the motor output feedback until it gives the most suitable value of motor output voltage is the same as for reference voltage.

The voltage reference is ranged from 10V to 15V is been selected while motor voltage control block, V_o is used as a feedback with RMS value to be input to the PI control. All the thyristors are fired based on the reference signal output generated by the PI and then change to the firing angle based value at angle of $\alpha = 60°$ as shown in Figure 3. This angle is being used to fire the thyristor based on the PWM signal output. As known, the thyristor needs only the 'on' signal, while the 'off' signal is based on the AC voltage is when the source operated at negative cycle operation. This 'on' and 'off' signals give high harmonics value but it not been considered in this paper. The results obtained are monitored through Scope 1 and Scope 2.

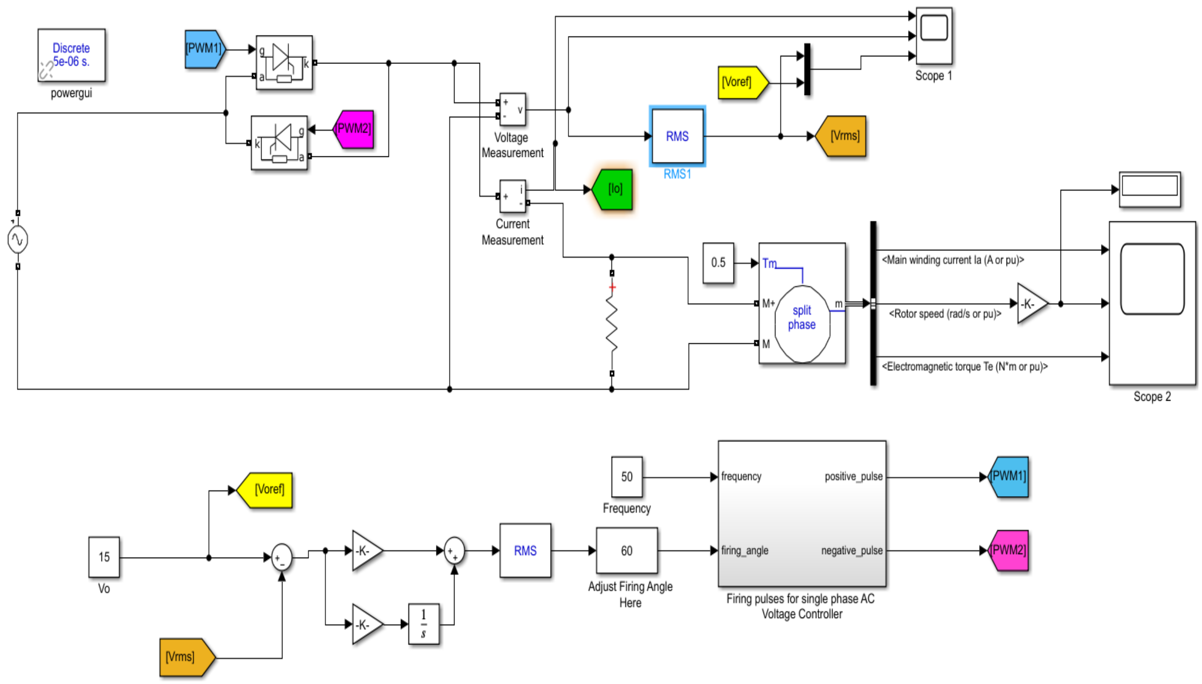


Figure 3: The closed loop model of single phase to single phase cycloconverter

3. Results and Discussion

This section presents the accumulated results obtained from simulating the cycloconverter model in MATLAB/Simulink during closed-loop operation. Data collections are obtained from the feedback output of the single phase cycloconverter and the feedback output of the induction motor. The single phase cycloconverter model, along with its PI control are acting as a voltage controller, where it can vary the motor voltage output by changing the reference voltage. Table 1 shows the specifications of the single phase cycloconverter model used for all the study cases.

Table 1: The specifications of single phase cycloconverter

Specification	Cycloconverter
AC voltage source	24V
Frequency, f	50Hz
Resistor, R	100
Mechanical torque, T_m	0.5Nm
Motor gain, K	$30/\pi$

The simulation results obtained from the closed-loop model single phase cycloconverter is divided into three cases: Case 1 is when the reference voltage is set at 10V, Case 2 is at 12.5V and Case 3 is when the reference voltage at 15V. All the cases are running with frequency at 50Hz while 50Nm Torque is given to indicated the load weight to the motor. The current and voltage at the motor have been measured for comparison purposes. Figure 4, shows the motor currents at different cases. Figure 4 (a) and (b) give the same profile due to equivalent firing angle from the PI controller due to same reference singal. However, the size of it switching is different based on the angle. As for Figure 4 (c), the output is almost sinusoidal because the firing angle of the thyristor is near to zero. This is happening when the output voltage is almost the same as the reference voltage.

Meanwhile, in Figure 5, the output voltage of the motor is showed the distorted waveform. This distorted waveform can create harmonics to the voltage input of the motor. Figure 5 (a) and (b) show both results are almost identical due to small range of firing angle. As can be seen in Figure 5 (c), the voltage is almost identical due to PI voltage control is able to tracking the output voltage to the reference voltage. Therefore, in Case 3, the RMS output voltage and its reference voltage, V_o, are closer to each other, will be contributing to the almost-similar sinusoid shape of the waveforms.

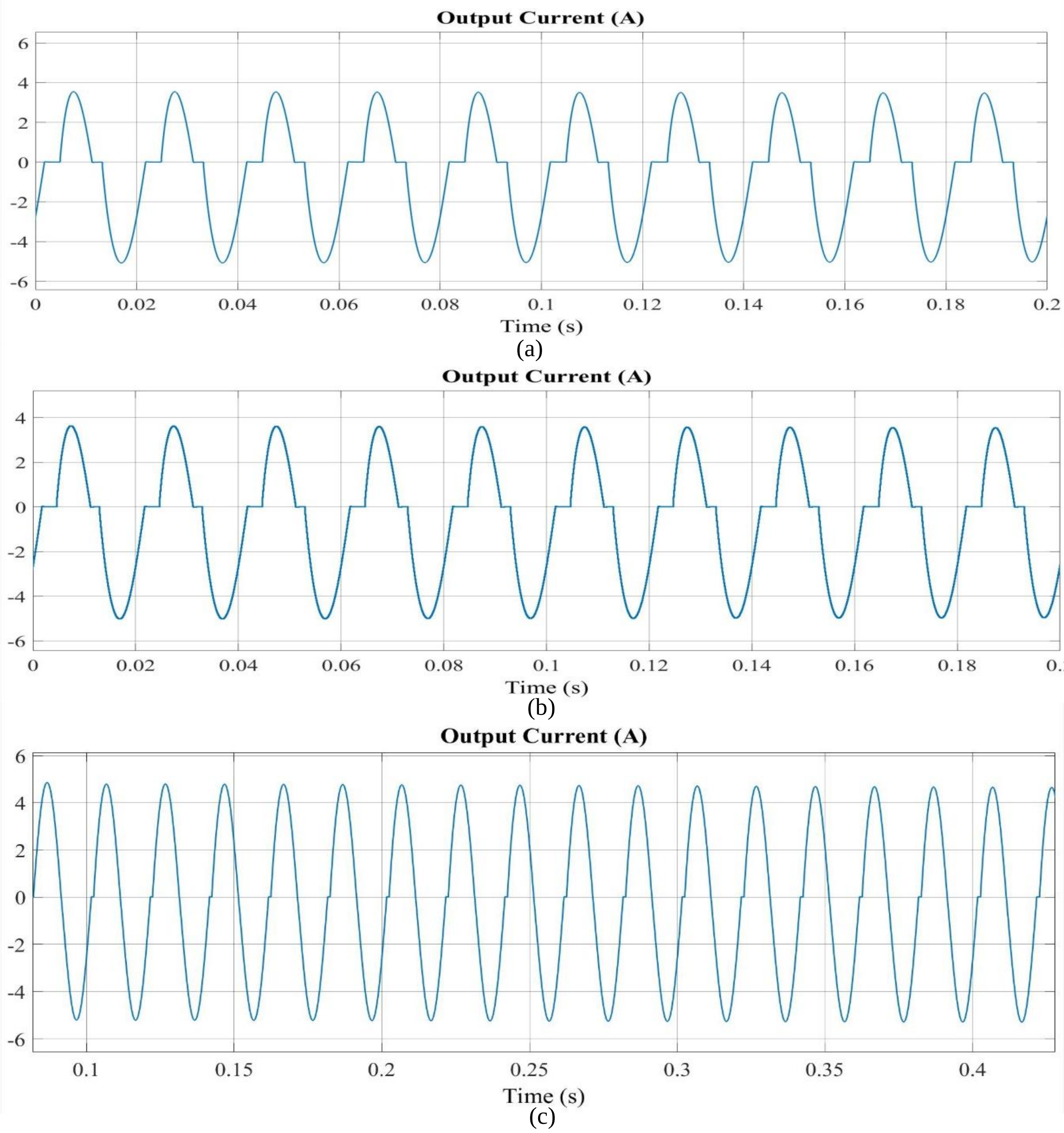
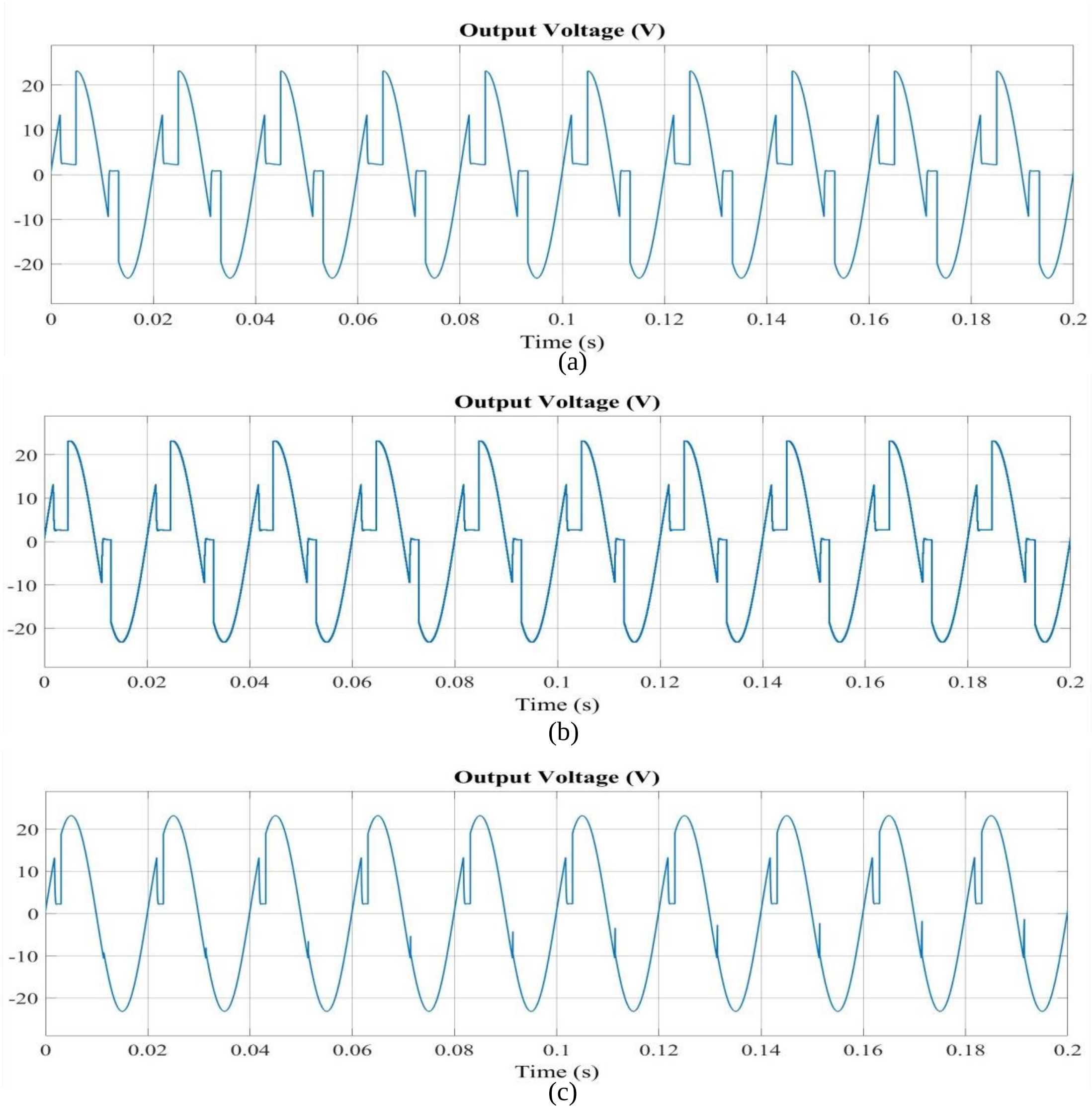


Figure 4 : Motor Output Current (a) Case 1, (b) Case 2, (c) Case 3



(a)

Figure 5 : Motor Output Voltage (a) Case 1, (b) Case 2, (c) Case 3

4. Conclusion

As a conclusion, the simulation of single phase cycloconverter for motor voltage control has been conducted to understand the control process. As for the voltage feedback control loop, it shows that the PI voltage control can maintain the output voltage with the given reference voltage. It is shows the feedback is able to give a suitable firing angle for thyristors switching operation. From all the results in case studies, the voltage at the motor able to maintain the motor speed at the meantime. At the end, it can be concluded that the closer the values of RMS output voltage with the reference voltage applied. At the end, it indicates that this cycloconverter is been able to control using PI voltage controller.

Acknowledgement

The authors would like to thank the Advanced Control on Power Converters (ACPC) team at Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, for its support.

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