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Simulation Performance of the Current Controller Converter by Using Matlab/Simulink

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ABSTRACT

This paper addresses the implementation and the performance of a current-controlled converter used in DC drive utilizing single phase controlled rectifier and unipolar switch-mode converter using Matlab /Simulink. Both of the converters are designed to be suitable for the PI controllers with appropriate close-loop bandwidth based on a small signal model analysis. The simulation results are then verified by using a large signal model. The results are compared that a response of the both system under influence of the step changes reference current and disturbance in the DC source.

Keywords: *Single phase controlled rectifier, PI controller, unipolar switch-mode converter, disturbance.*

1. INTRODUCTION

The current control of a DC drive can control the torque of DC drive. Besides that, current control can be used to eliminate the large damaging armature current during start-up process. In addition, a good control lead to fast current feedback when the steady state current signal should response exactly with the reference current. On another hand, the transient response should response to the step change in the reference current for fast and smooth damping signal after any disturbance [1]. This can be achieved by appropriate tuning of the PI controller [2].

The PI controller can be used to improve the control performance of variable-speed motor drives. Shin [3] introduced an new antiwindup PI controller for controlling the speed of motor drives. The PI controller is designed through the linear analysis in MATLAB using the average or linearized model. The objective of the model design is to tune the PI controller with appropriate close-loop bandwidth based on a small signal model analysis.

In this paper, a single phase controller rectifier and switch-mode converter is designed by using RL and DC source as the well as load design. The response of both systems with step changes in reference current and disturbances in DC source is compared.

2. CURRENT CONTROLLER CONVERTER MODEL

A. Single Phase Controlled Rectifier

The current-controlled converter consists of a conventional voltage-source converter fitted with current regulating loop to provide a controlled current output as shown in figure 1. For a good design, the DC output current signal should be with low ripple factor. Besides that, should has a good tracking capability with zero steady state error, constant switching frequency regardless of operating conditions and fast dynamic response. A large inductor at the armature circuit is required to ensure low ripple factor in the output voltage. The average output voltage response to a control signal is relatively slow, which is the delay angle. However, the assumption is only valid as the bandwidth of the control loop is much lower than the sampling frequency to ensure a continuous current mode [4].

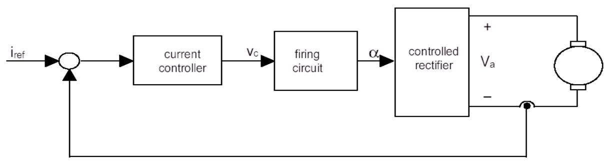

Fig. 1. Current controller converter.

The PID controller is one of the most popular controllers widely used in the industrial plants. Dan and Dale [5] implement PI/PID controller based on Disturbance Rejection . However, they shown that a proper designing of the parameters of the PID controller is an essential to guarantee closed-loop stability. It can be performed by using zero-pole cancellation method.

The PI controller is used as it gives smaller current ripple as compare to PID controller. For DC motor drive controller design, the PI controller is designed by using linear small signal model from SIMULINK with RL and DC source as shown in figure 2.

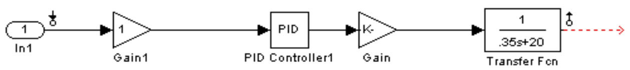

Fig. 2. Block diagram for small signal analysis.

The transfer function for the open loop of the load is given by equation 1.

$$T.F_{OL} = \frac{1}{sL + R} \tag{1}$$

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where, R= 20 and L = 0.35H, then, the controller transfer function can be calculated by equation 2.

$$T.F = \frac{1}{0.35s + 20} \quad (2)$$

PI Controller

$$TF = \frac{K_i\left(1 + \frac{S}{K_i / K_p}\right)}{S} \quad (3)$$

For a linear analysis of the PI controller, it is important to find the pole for the transfer function as calculated in equation 4.

$$S = \frac{20}{0.35} = 57.143 \quad (4)$$

By taking the proportional initial value as one with zero in integral value to determine the pole location of the system as shown in figure 3.

$$dB = 20\log Kp$$
$$15.3 = 20\log Kp$$
$$Kp = 10^{\frac{15.2}{20}} = 5.754$$

After that, If Ki is unity, then Kp is equal to 1/57.143 and the ration between Ki and Kp is given in equation 5. The plot will show a straight green line in figure 4.

$$\frac{Ki}{Kp} = 57.143 \quad (5)$$

In order to fix the bandwidth of current loop, it is required to shift the whole graph upward 15.2dB that it crosses exactly at 10Hz with the magnitude of 0dB as shown in the red line in figure 4.

Ki = 5.754*57.143=328.8

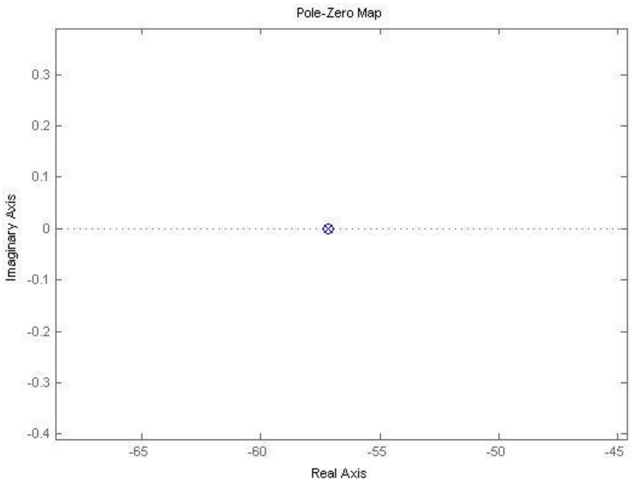

Fig. 3. Pole location at -57.143.

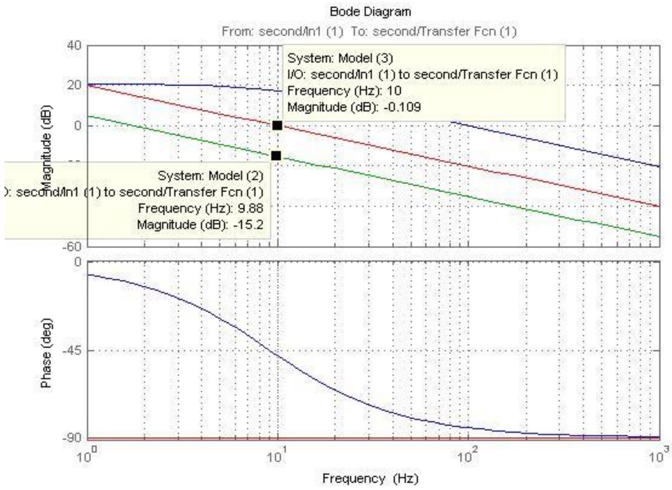

Fig 4. Bode plot for open-loop gain of the current loop.

B. Switch Mode Converter (Unipolar Switching)

The current controller can be achieved by using one-quadrant, two-quadrant and four-quadrant choppers [6]. Four-quadrant chopper is known as the most appropriate convertor for current control because the polarity of the armature voltage can be reversed, thereby allowing the maximum possible current-control capability [7]. Figure 5 illustrated the four-quadrant converter, which composed of two legs, Leg A and Leg B.

The immediate voltage Va can be swing between Vdc and –Vdc, Vdc and 0 or 0 and Vdc, which is determined by the switching scheme chosen. However the average value is depends on how long the upper and lower switch is on.

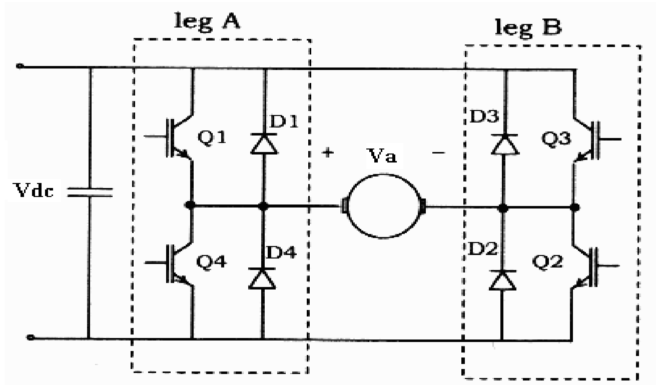

Fig 5. Four-quadrant converter.

Unipolar switching

The unipolar switching signals are shown in figure 6. The frequency for Leg B is obtained from the inverse of control signal for Leg A [8]. The resultant q and $\bar{q}$ is as shown in figure 7.

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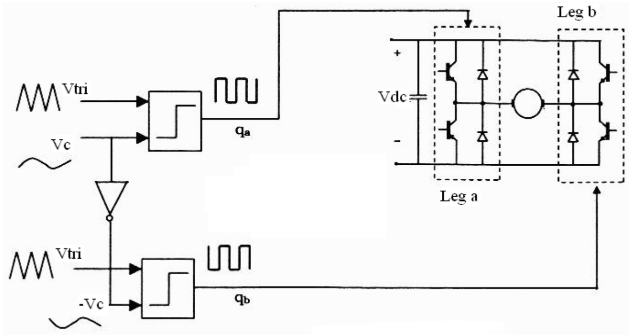

Fig 6. Unipolar switching with constant frequency.

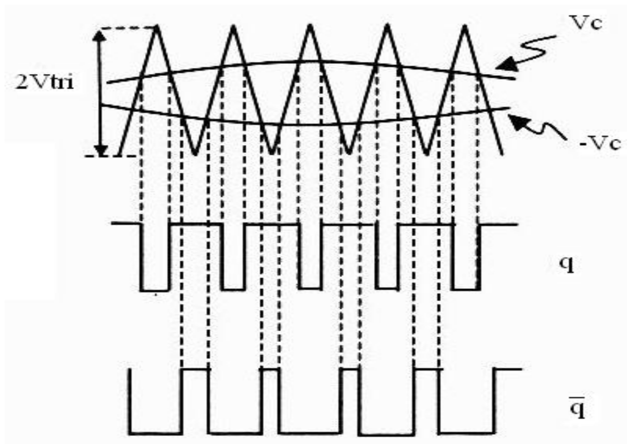

Fig 7. The two signal of q and $\bar{q}$.

NOTE: d is called duty ratio. The formula to obtained d is given in equation 6.

$$d=\frac{t_{on}}{t_{on}+t_{off}} \quad (6)$$

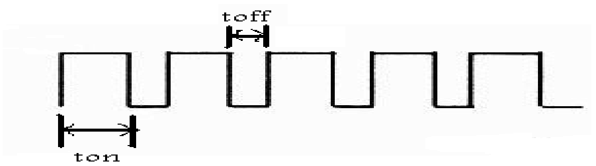

Fig 8. Signal of quadrant q.

The continuous duty ratio for Leg A, dA is given by equation 7. Since Leg B uses the inverse control signal, accordingly the continuous duty ratio for Leg B is given by equation 8.

$$dA = 0.5 + \frac{Vc}{2Vtri,p} \quad (7)$$

$$dA = 0.5 - \frac{Vc}{2Vtri,p} \quad (8)$$

This gives and average armature voltage as given in equation 9.

$$VAB = (dA\text{-}dB)Vdc = \frac{Vdc}{Vtri,p}Vc \quad (9)$$

The transfer function obtained for unipolar switching scheme is founded by equation 10.

$$VAB(S) = \frac{Vdc}{Vtri,p}Vc(s) \quad (10)$$

3. SIMULATION RESULT OF THE SWITCH-MODE CONVERTER

The small signal current loop for switch-mode converter is shown in figure 9. The transfer function is 0.35S + 20, which is same as the design for single phase controlled rectifier. However, the setting for the Gain is different from the setting where it is the same in the single phase rectifier. The number that chosen for the Gain is 100/15, where 100 is the value of Vdc and 15 represents Vtrip.

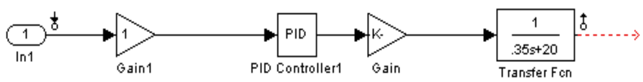

Fig 9. Linear small signal current loop for switch-mode converter.

The triangular frequency is 2 kHz. In order to fix the bandwidth of current loop, it is required to shift the whole graph upward 57.4dB. There is a good phase margin at the cross over frequency at 2 kHz as shown in the red line in figure 10.

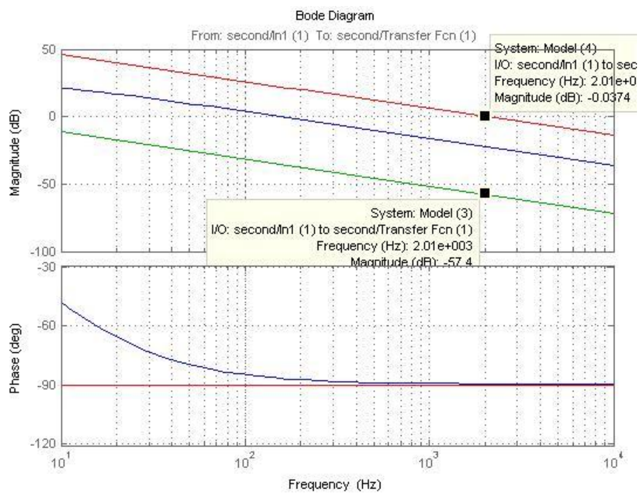

Fig. 10. Bode plot for open-loop gain of the current loop.

4. LARGE SIGNAL MODEL

A. *Single Phase Controlled Rectifier*

The designed PI controller for large signal simulation of single phase controlled rectifier took same parameter in the linear small signal model.

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These tuning parameters are verified by using large signal analysis. Closed loop of the thyristor rectifier circuit is established in figure 11.

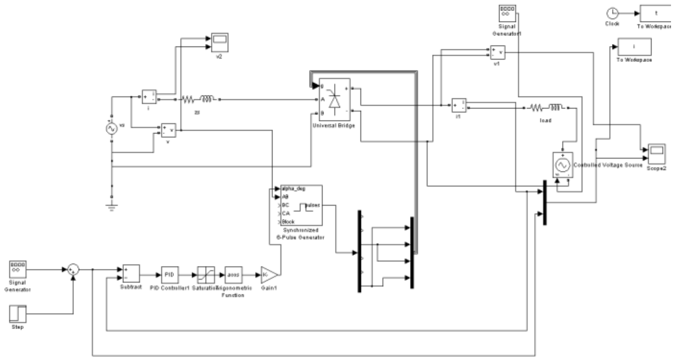

Fig 11. Thyristor rectifier circuit.

PI parameters are inserted in the controller in order to get the desired output response.

Amplitude = -4, fr = 5

With disturbance.

Amplitude = -4, fr = 5
Dis. value is
Amplitude = 80, fr = 4

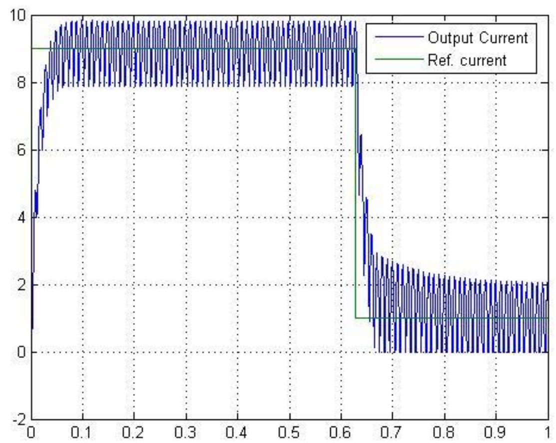

Fig 12.The output waveform (without disturbance).

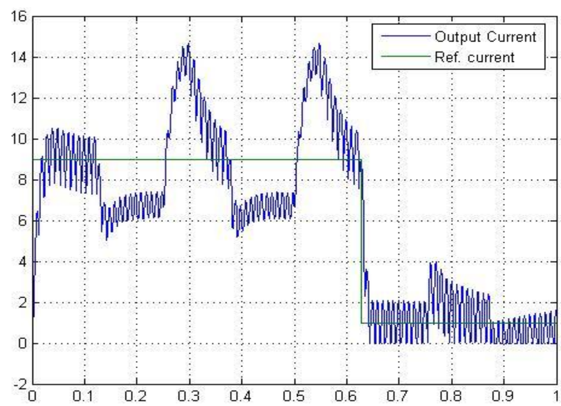

Figure 13. The output waveform (with disturbance).

The response of the system of output current and output voltage is verified by a step change in the reference current and disturbances in the DC source. The output waveform is shown in figure 12 when the steps changes in reference current (without disturbance).

B. Unipolar Switching Scheme Simulation

Similar method is applied to determine the suitable tuning parameter for unipolar switch mode converter. Average or lineaized model of the system is shown in figure 14.

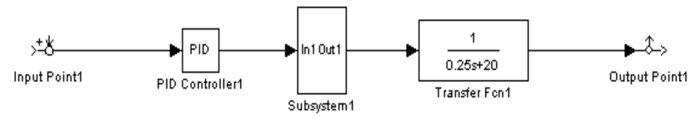

Fig 14. Linear large signal current loop for switch-mode converter.

By using the linearization analysis, bode plot that showing the approximate value of bandwidth as shown in figure 15. It is desired that the bandwidth of the current loop to be 2 kHz. The bandwidth is intentionally chosen to be lower than the triangular frequency. From the small signal analysis, parameters of proportional-integral control are defined as following:

Kp =741.3
Ki =741.3*57.134=42353.4

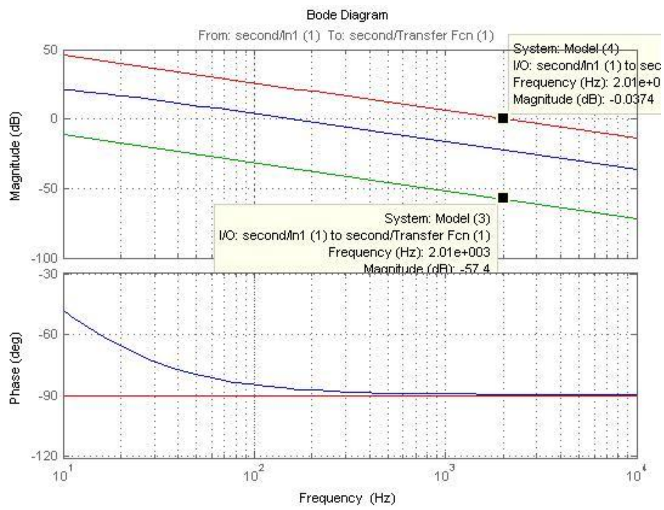

Fig 15. Bode plot for open-loop gain of the current loop.

The block diagram for unipolar switching scheme is shown in figure 16. Matlab/simulink was used to perform the schematic diagram.

The four-quadrant converter is composed of two leg, qA and qB, which each leg similar to that of the two-quadrant converter. The output signal current following the reference current without applying disturbance to the system as shown in figure 17. However there is some overshoot due to the fast response time.

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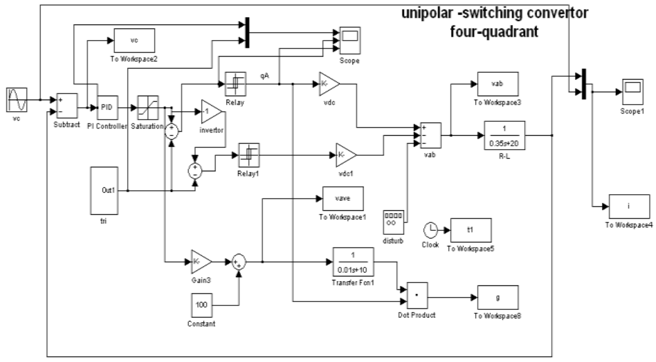

Fig 16. Unipolar switching schematic diagram.

Ref. Amplitude = -4, fr = 5
Dis. value is
Amplitude = 80, fr = 4

The output current signal is still following the reference current signal after the disturbance applied. There are some distortions in the transient but the output current remained a same value of the reference current at the steady state.

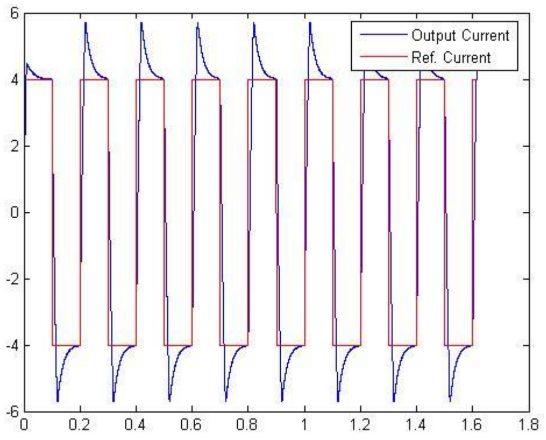

Fig 17. The output current and reference current without disturbance.

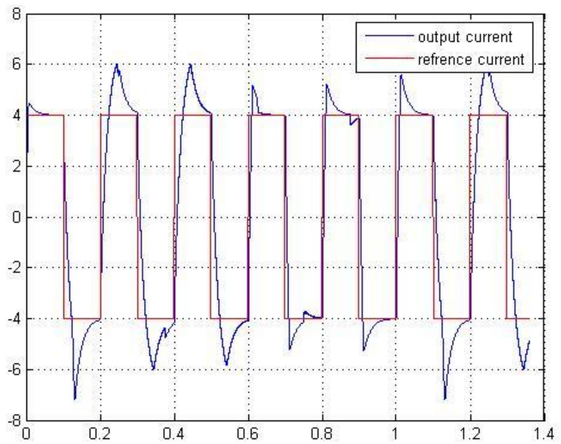

Fig 18. The output current and reference current with disturbance.

5. DISCUSSION AND COMPARISON

The performance of a current controlled converter used in DC drive by using single phase controlled rectifier and unipolar switch-mode converter using Matlab/Simulink was demonstrated. From the result obtained, it can be found that the performance of the unipolar switching scheme is better than single phase controlled rectifier in term of response and steady state error.

Switch mode converters normally operate at high frequency. As result of this it is clearly to see that the average output voltage response is significantly faster than the controlled rectifier. In other words the bandwidth of switch mode rectifier is higher compared to the controller. Moreover, the armature current ripple is relatively less than the controlled rectifier circuit when the same amount of inductance present in the armature circuit.

The plot of single phase controlled rectifier has ripple in the current waveform, whereas by using unipolar switching scheme, the waveform was not affected with current ripple.

For the output voltage response, the single phase controlled rectifier has lower frequency voltage ripple compared to the switch mode converter. However, the switch mode converter at very high frequency following the triangular wave frequency at 20 kHz.

6. CONCLUSION

This paper presents the comparison of the performance between two schemes for the current controlled converter in term of output voltage and current in response to the reference current as well as disturbances in the DC source. By using Matlab/Simulink, all the parameter of each scheme can be observe directly, and then produce the evaluation of theoretical analysis. The performance can be summarized as following:

- The single phase controlled rectifier change AC to DC while the switch mode converter is a DC-DC (chopper) device.
- With the help of the current controller, the output current is tracking the reference current, independent of the disturbance in the DC source (load disturbance).
- The switch mode converter has faster response. The output current follows the reference signal almost immediately.
- The integrating part of the PI controller leads to zero steady-state error for a step input and the proportional gain yield fast response and stability.
- The single phase controlled rectifier has low control bandwidth, low frequency voltage ripple and high frequency current ripple (due to sequence in firing of thyristor).
- The unipolar switch mode converter has high control bandwidth, high frequency voltage ripple but low current ripple.

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