Different Control Method Approaches to a Non-Inverting Output Voltage Based Bridgeless PFC Cuk Topology Cascaded with Flyback Converter

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Abstract – A typical control system aims to generate a control output which has to force the system in order to keep it on desired level or position. In power electronics, control systems, are using to obtain a fixed steady state voltage or current on the output terminal. In general, there are two control methods: Open loop control and closed loop control. The most significant difference between these two methods is feedback, which provides an information to input of the control system and makes the system reactive for varied conditions. There are also different types of closed loop control. These two are PI and PR controlling systems. A PR controller has infinite gain at the fundamental frequency which makes it possible to achieve zero steady state error rather than a PI controller. In this study, the stability and transient time differences between these two control strategies are introduced on a modified cuk converter, which powered with an AC source and has no bridge at the input side. All the methods and propositions are verified on MATLAB Simulink environment.

Keywords – Closed loop control, PR controller, Cuk converter, PFC

I. INTRODUCTION

An exponentially increasing demand for renewable energy pushes electricity more into humanity life. Since fossil fuels are finite and electricity could be produced by renewable sources, electric vehicles (EVs) become more and more common for our planet. They also have some environmental and economic advantages such as reduced pollutants and transportation availability at less expensive rates [1]. On the other hand, the main power sources of EVs are the batteries and naturally, they have to be charged periodically. Additionally, they are DC power sources which causes their charger to show a non-linear characteristic and harmonic effects on the grid. Since these harmonic effect impacts decreases the power quality of the grid, there needs to be a PFC for becoming the input current shape and phase closer to the fundamental wave. For this reason, a controller design should contain and perform necessary PFC process. All the discussed above shows us that the importance of the control theory and strategy as much as power circuit when designing a converter. Focusing on this point, two different control mechanisms, PI and PR controllers, have been evaluated with their response time, transient time and steady state stabilities.

The performance of the PR controller is validated for PFC improvement through a Simulink simulation from starting to steady state including with transient time behaviours, sudden varying load and supply voltage scenarios.

II. PI AND PR CONTROLLER

The PI and PR controllers have the same working principle in the basic, but there is a restriction which makes the proper decision easier for the related topology, that is, the way that controllers achieve zero steady state error. Here is brief equations for both controllers to see the difference and how they work.

A. *PI Controller*

The transfer function of ideal PI controller is defined as below.

$$G_I(s) = K_p + \frac{K_i}{s} = \frac{K_p s + K_i}{s} \quad (1)$$

$$G_I(s) = K_p + \frac{K_i \omega_c}{s + \omega_c} \quad (2)$$

where K_p and K_i are proportional gain and integral gain, respectively, and ω_c is the cut-off frequency [2].

B. *PR Controller*

As discussed, a PR controller results the best for fundamental wave, which means it achieves an infinite gain at the AC frequency ω_0, and a simpler approximation to transfer function of a PR controller is [2]:

$$G_R(s) = K_p + \frac{K_i \omega_c s}{s^2 + 2\omega_c s + \omega_0^2} \quad (3)$$

The total gain difference between two control method PI and PR control can be clearly observed from the equations (2) and (3).

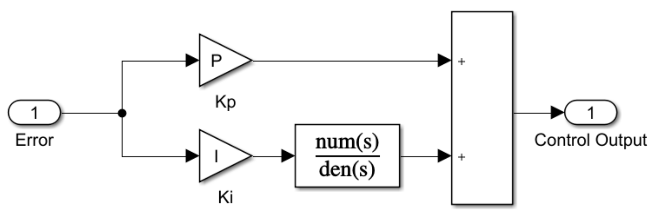

Fig. 1 Controller gain blocks

With the help of figure and equations above, the main factor that varies control output is the transfer function block, which is implemented as a division of numerator to denominator. This block represents different transfer functions for the PI and PR controllers, that is explained earlier.

III. INTRODUCING BL CUK TOPOLOGY

In this study, a modified cuk converter topology has been used, which has no bridge at the input, i.e. the input is connected to an AC power supply, and also constructed with reversing the semiconductor material polarities.

The converter can be shown on figure 3 [1], which claims the whole topology including control blocks. As observed, there is not any specified controller type implemented, however, PI and PR controllers will be introduced by the sense of this study.

Before control strategies, see and understand how the topology works.

A. *Mode 1*

The inductor L_{i2} is storing energy when the diode Dp and the switch S_2 are in conduction mode. At this interval, the output of the cuk converter is feeding by the capacitor C_2 and the output coil L_{o2}.

The current flowing loop in this mode is shown on figure 3-a.

B. *Mode 2*

In the second time interval, all the switches are cutted off, thus, input supply completes the path through D_{O2}, C_2 and L_{i2}. At this moment, output of

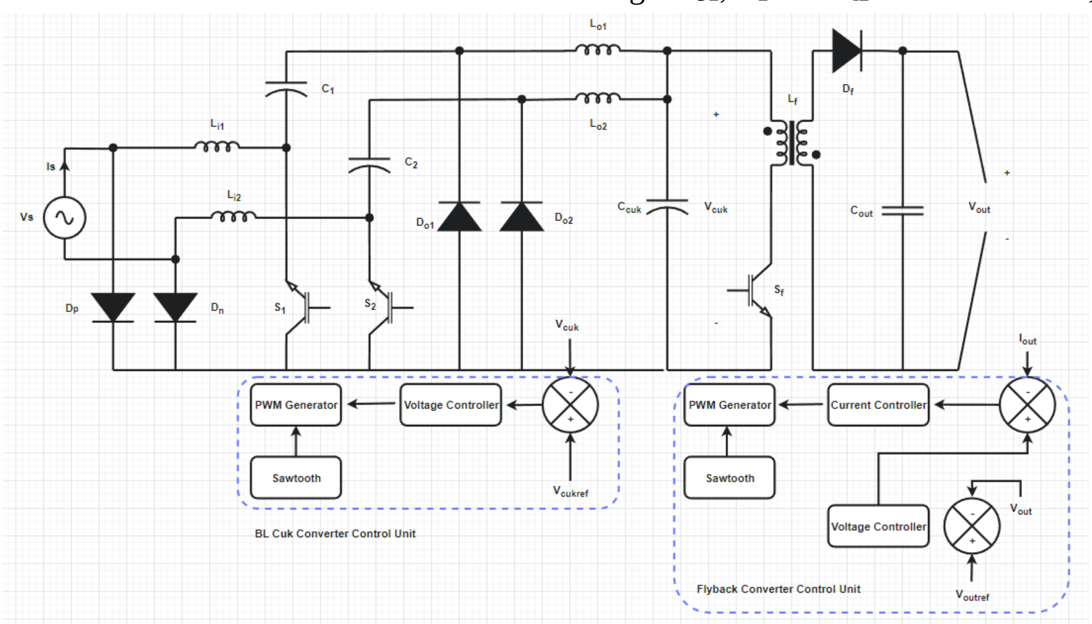

Fig. 2 Non-inverting Cuk converter topology [1]

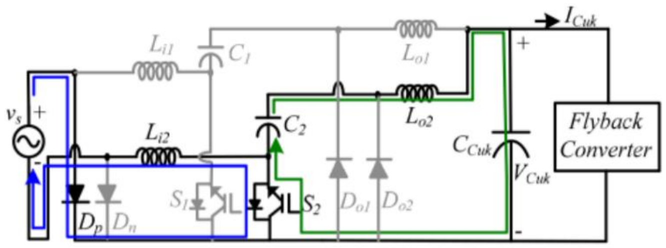

Fig. 3-a Operation in mode 1 [1]

the cuk converter is feeding by the output coil L_2. The related current flowing path is shown by figure 3-b.

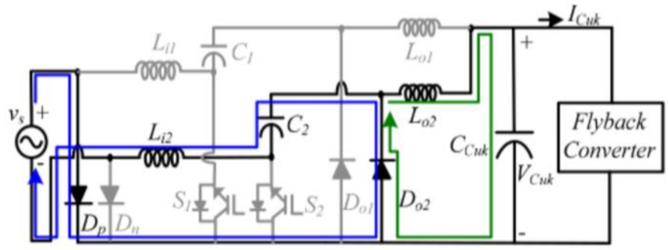

Fig. 3-b Operation in mode 2 [1]

C. *Mode 3*

This is the time interval which the circuit is in discontinuous conduction state. D_p provides a freewheeling from output to source and current flowing path is shown on figure 3-c.

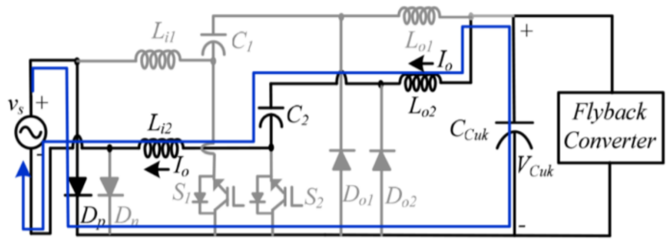

Fig. 3-c Operation in mode 3 [1]

IV. CONSTRUCTING CIRCUIT AND PI CONTROLLER

To achieve a successful PCB prototype without higher costs, they should be produced after being sure that they will work with a high probability. This precision can be satisfied by simulating the system before producing it.

In the light of this knowledge, a MATLAB simulation has been executed. The constructed circuit and related control systems are shown by the following figures. This is a fully mirrored construction of the topology, exists on figure 2. Since this is an AC input topology and works similar within two alternating cycles, thus, in order to show the symmetry of the circuit and to become it more understandable, the placement of the components are revised.

There are measurement instruments for almost every component on the circuit for sampling necessary outputs which then used in controller.

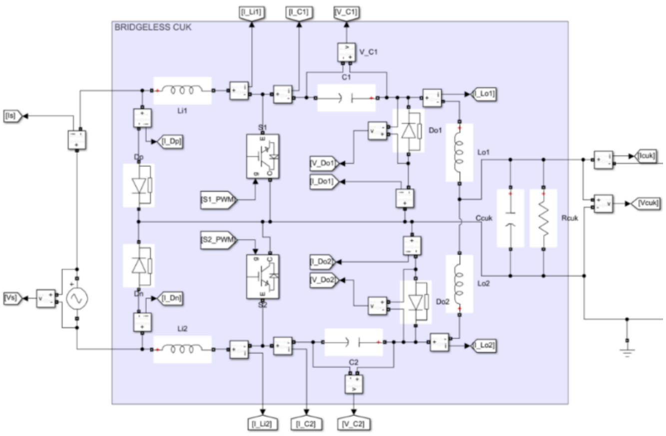

Fig. 4 Bridgeless Cuk converter with non-inverting output

On figure 6, controller of the cuk converter can be observed. Also from figure 2 [1], there is not any implementation for sampling input side, which make sense about concerning PFC process. Although an acceptable THD could be introduced with proper controller, anyway it is not sufficient to become it a more successful process.

In this study, a PLL has been used to detect phase angle, and combined with the output voltage error, in order to generate PWM signals which provides both voltage following and power factor correction.

To compare the difference, two figure, figure 5-a and figure 5-b, below should be considered. Both figures show us the input current, I_S, for a time interval.

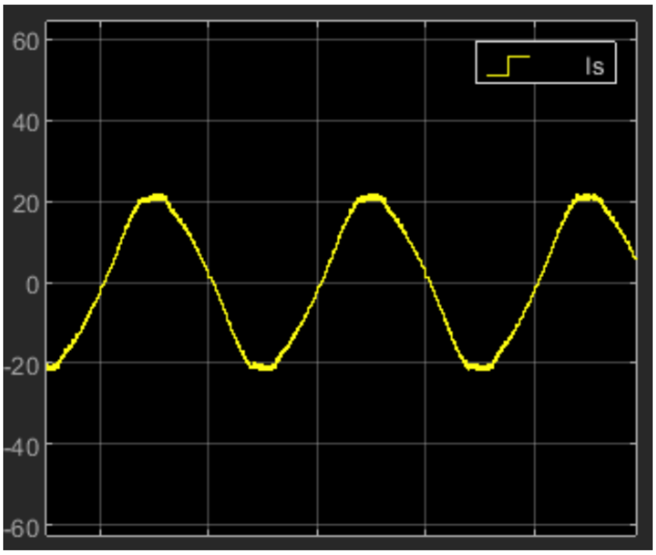

Fig. 5-a Source current I_S without PFC

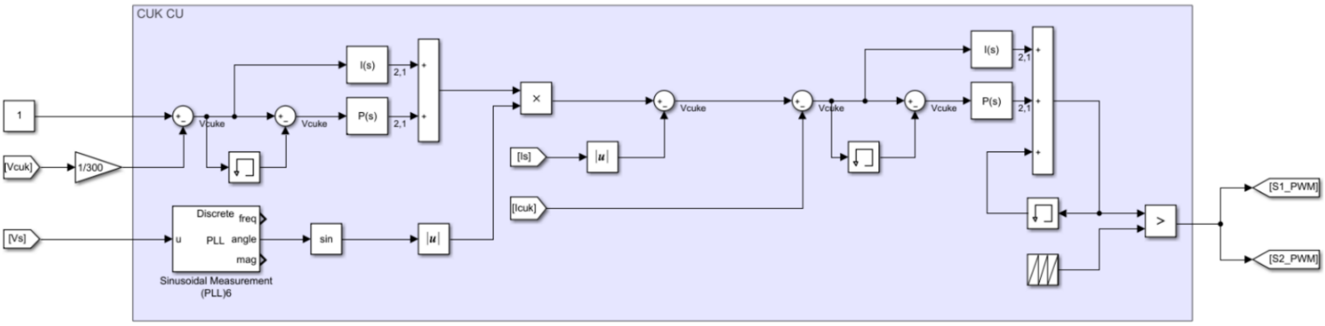

Fig. 6 PFC control unit of Cuk converter

According to figure 5-a, the input current is distorted by the load, and is lost pure sine wave shape.

With adding PFC components to controller, as shown in figure 6, it is clearly observing from figure 5-b that the input current shape is now more likely to pure sine wave.

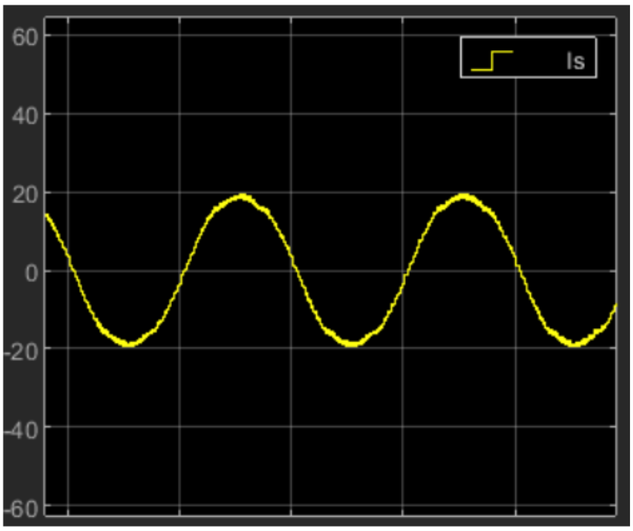

Fig. 5-b Source current I_S with PFC

A FFT analysis also executed for proving a lower THD in input current. The results are attached[1] to appendix.

The Cuk converter side of the topology has been described. Since this is a cascaded converter, next, have a look about flyback side of the converter.

There is not any improvement related with flyback converter, thus, this paper does not include analysis of current flows of flyback converter.

This flyback converter has a swiching frequency of 50 kHz. Output voltage of the converter must be around 65V with a very low ripple voltage, so there is another PI controller is also used for this side.

Figure 7 and 8 show the circuitry and controller of the flyback converter.

Next, the simulation is executed and got the results to see if it works or not as desired. So, as seen on the scope, there are 6 channels which show V_S, I_S, V_{CUK}, I_o, V_o and I_{CUK}, respectively.

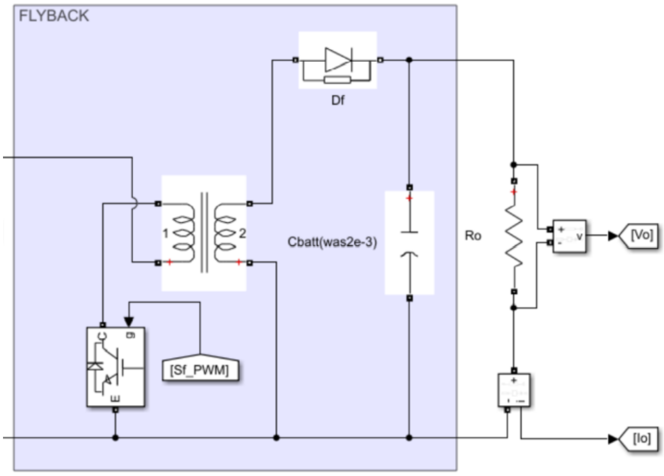

Fig. 7 Flyback converter side

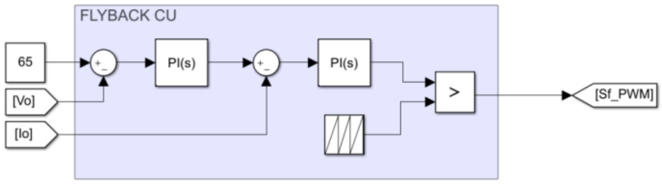

Fig. 8 Flyback converter controller blocks

From the channels, we can observe that the input signal has very similar shape to pure sine wave; output voltage of the cuk converter is oscillating around 300V with a maximum ripple of 10V and lastly flyback output is fixed at 65V. A FFT analysis applied to input current results a THD of 4.78%. There results are attached[2] to the appendix.

V. A DIFFERENT APPROACH TO ACHIEVE RESULT

In this study, a PR controller has introduced as a proposed control method, which fits more than PI and provides zero steady state error and infinite gain at the fundamental frequency ω_0. The transfer function of the system should be known for the best performance of the controller, but it can even work with little oscillations without the actual transfer function.

The PR controller, literally, needs a resonance to be performed. This makes PR controller not suitable for DC-DC converter applications.

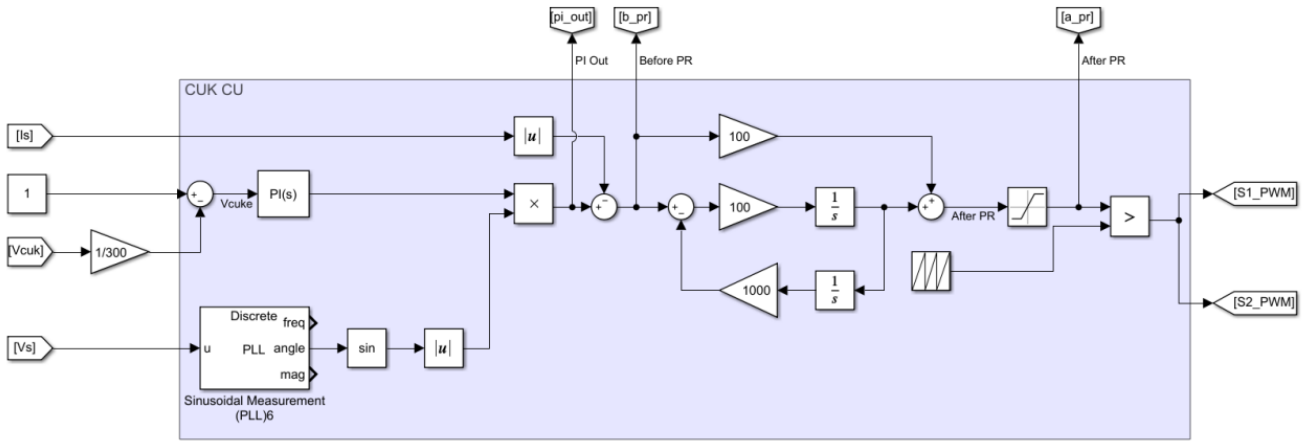

Fig. 9 PR controller blocks for the cuk converter

Besides, a cuk converter actually is a DC-DC converter. However, this is a modified version of cuk topology which used in this study, and it has an AC input, that contributes a compliance to this controller to be usable for a cuk converter.

Next, a scope output for the second control method case is attached[3] to appendix. The channels have the same order with the previous scope.

The input signal subjected to FFT analysis one more time and a better performance with PR controller has been proved with a THD of 1.4%, in this time.

VI. RESULTS

In this study, a modified cuk converter topology is reviewed by evaluating two different control theories, PI and PR controlling methods and a better result with a better THD has been achieved using PR controller for the topology.

VII. DISCUSSION

Since we try to achieve pure sine wave form for all the devices connected to grid, there should be improvements which corrects power factor of the devices, hence, lowers the demand of PFC systems and harmonic filters on distribution systems. This study shows the irrefutable affects on system with only differing the control method of the system. Contributions with this study, the devices that will be used this modified topology has no longer a worse effect to the grid when controlled with a PR controller, which supports to save the other grid connected devices from damage.

VIII. CONCLUSION

As a conclusion, the reviewed topology will work as desired with what it has been desinged for, as this study claims.

Finally, proper control method selection is as significant as designing a converter. Also a system can be controlled better with proper controller.

IX. REFERENCES

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X. Appendix

1.

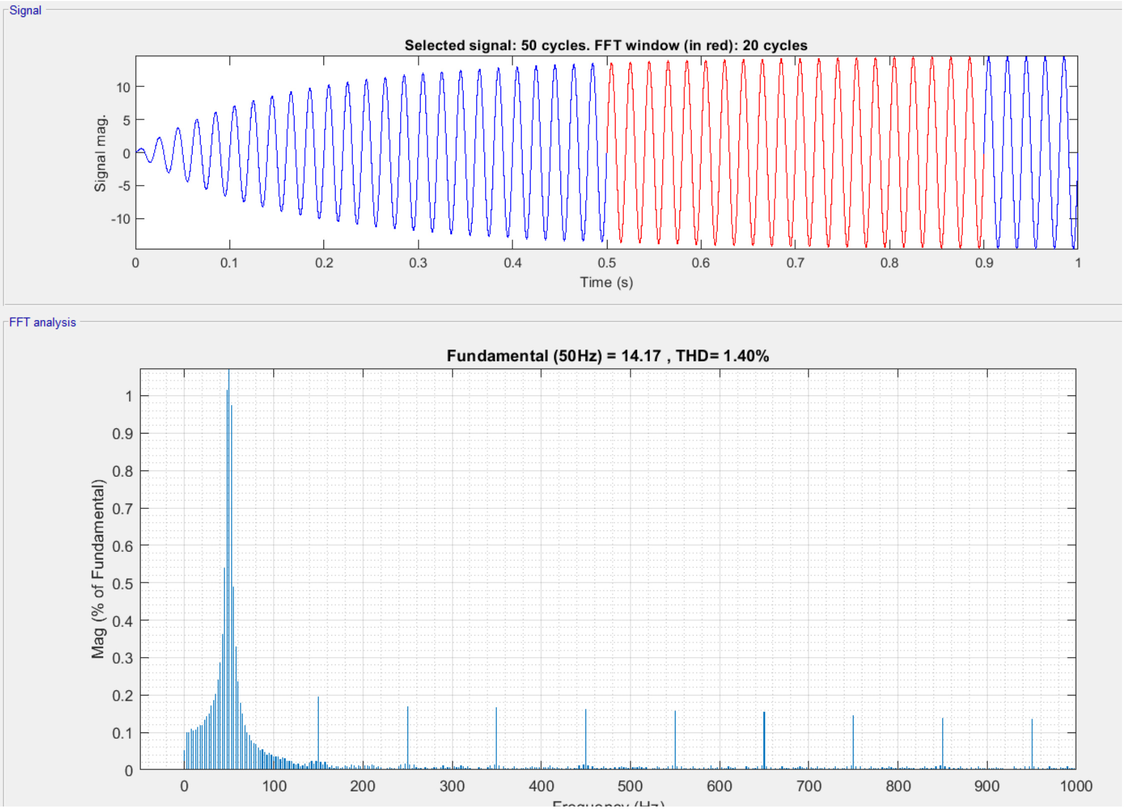

Fig. 10 FFT analysis of the PR controlled system

2.

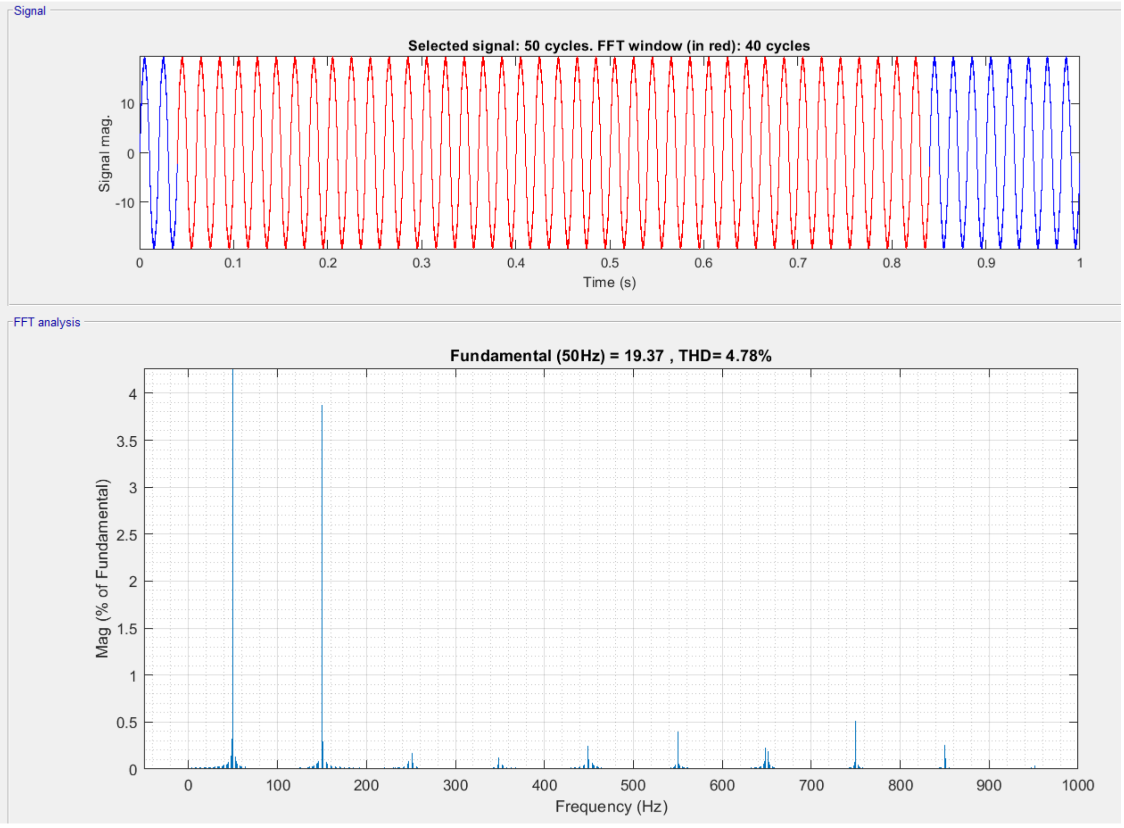

Fig. 11 FFT analysis of the PI controlled system

3.

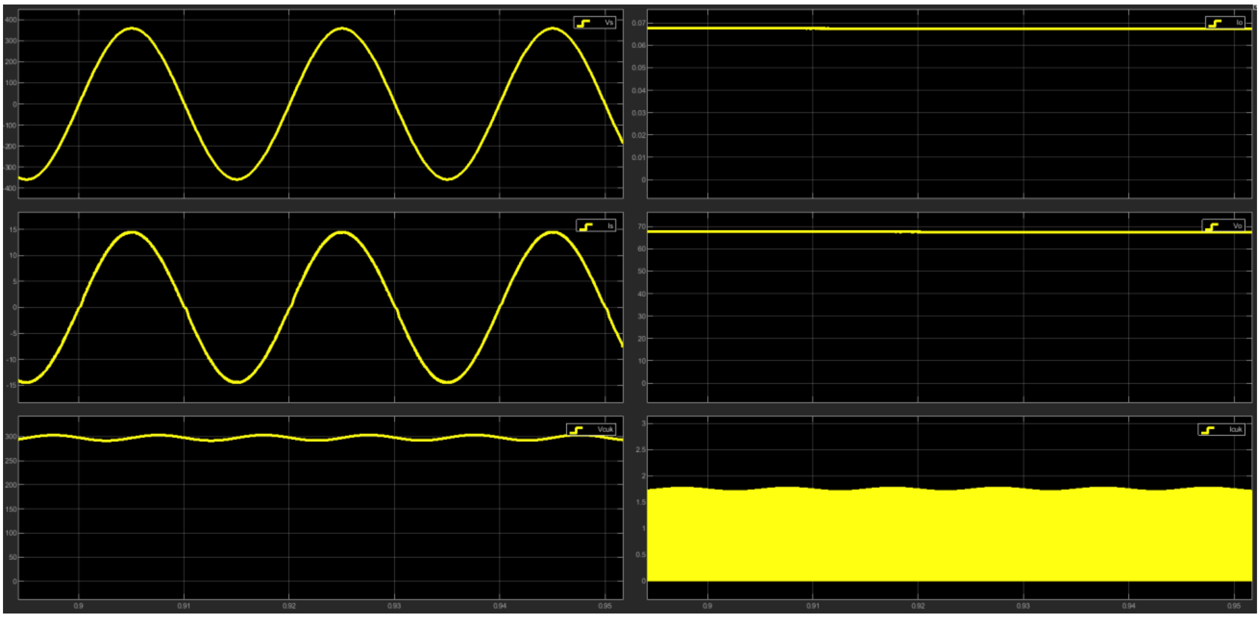

Fig. 12 Scope channels for second control method