Various approaches to a bidirectional single-stage single-phase control method PFC-equipped isolated AC-DC converter for EV chargers

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Keywords
PFC, PI Controller, PR Controller, THD, Converter

Abstract
In this study, bidirectional single phase single stage isolated AC-DC converters are controlled using the propotional-resonant (PR) and propotional-integral (PI) control methods. One of the most crucial techniques needed for a system to achieve the ideal circumstances is control. The types of controllers used in power electronics differ depending on the system's structure. Controllers mostly use the open loop and closed loop approaches. For the system to function effectively, closed loop controllers like fuzzy, PI, PID, PR, etc. are typically employed. One of the most widely used controllers for grid-connected inverters to manage the current fed into the grid and reject harmonic disturbances is the PR control approach. The steady state error that occurs while following or rejecting high frequency signals can be completely eliminated by the PR control approach since it has a large gain near the resonant frequency. The Matlab Simulink application is used to compare and verify the PR and PI control strategies that were employed in this investigation.

Research Article
Submission Date : 17.04.2023
Accepted Date : 15.05.2023

1. Introduction

People have started concentrating on technological studies in this direction as the demand for renewable energy sources rises. The trend toward electric cars (EVs) has grown as these studies have as well (Ebrahimi, Taghavi, Tahami and Oraee, 2014). Electric vehicle chargers are prepared to transport both active and reactive power between the grid and EV batteries (Baharom, Salleh, Seroji and Hamzah, 2015), (He, Lu, Wu, Yang, Li and Liu, 2020). Moreover, the non-linear characteristics of DC power sources demonstrate larger harmonic distortions (Prasanna, Singh and Rajashekara, 2017). This leads to numerous issues. Whole harmonic distortion can be fixed as a result of these issues by adjusting power factor (Kisacikoglu, 2013). The outcome of using PFC demonstrates that the choice of controller and the method used are equally crucial to the success of the topology design (Afonso, Freitas and Martins, 2004), (Ortatepe and Karaarslan, 2018), (Karaarslan and İskender, 2011), (Karaarslan and İskender, 2012). The switching elements in the system are switched by utilizing both PI and PR controllers without the use of additional circuits, and when PI and PR controllers are compared, significant system differences appear (Liu and Lee, 1986), (Prasanna, Rathore and Mazumder, 2013), (Jauch and Biela, 2012), (Busarello, Pomilio and Simoes, 2018), (Lin, Liu and Meng, 2023), (Hornik and Zhong, 2012). In this study, Matlab Simulink was used to observe the performance of the PR and PI controller behaviors using the same topology.

2. Introducing Bidirectional Converter Topology

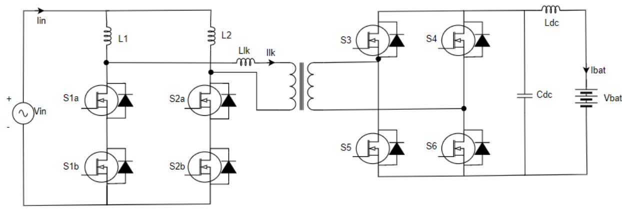

Figure 1. Topology of a single-stage Bidirectional Converter

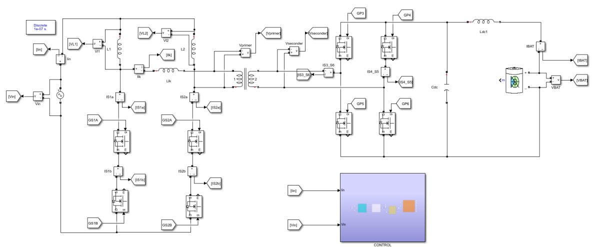

Figure 2. Single-phase Single-stage a Standalone AC-DC converter Topology in Matlab

The polarity of the input voltage and the positive and negative directions of the input current determine the four quadrant modulation. This circumstance leads to the conclusion that the system is acting in both the charge-discharge state and the inductive-capacitive state.

2.1. Four Quadrant Modulation Stage:

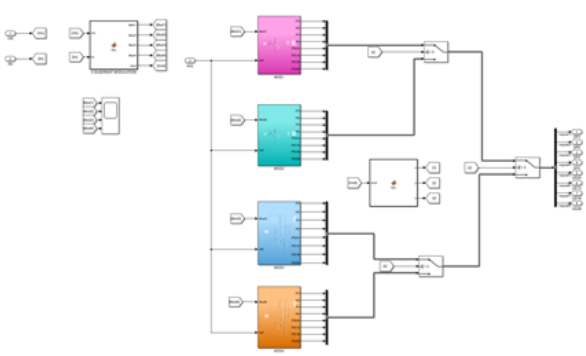

Figure 3. Four Quadrant Modulation Stage

In this section, the polarity of the input voltage and the direction of the input current are used to determine the system's mode of operation. To provide ZVS and ZCS techniques, each mode is configured in its own subsystem.

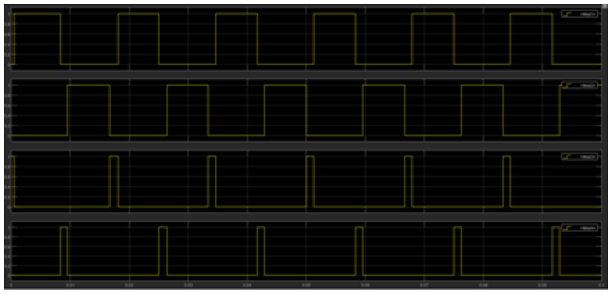

Figure 4. Switching In Mode Transitions

The system's mode of operation is established in this section based on the polarity of the input voltage and the direction of the input current. ZVS and ZCS techniques are provided by each mode, which is configured in its own subsystem.

3. Constructing Circuit and PR Controller

The proposed circuit topology is used to configure the simulation circuit. A PR controller is that the combination of a proportional term and a resonant term given by

$$CPR(s) = Kp + 2Ki\frac{s}{s^2 + \omega^2} \quad (1)$$

The controller transfer function is denoted as CPR(s), where is the resonant frequency. Such a controller can monitor or reject sinusoidal signals with no steady-state error since it has a high gain area around the resonant frequency. The proportional gain (kp) is used with a resonant route to create the digital PR controller. The resonant gain (ki) and transfer function make up the resonant path. Proportional resonant digital control has been used up until this point. In order to provide small steady-state error in the regulated variable, the PR controller operates at such a frequency. As a result, the PR controller works to maintain the current amplitude and frequency at the modified resonance frequency while also responding swiftly to faults.

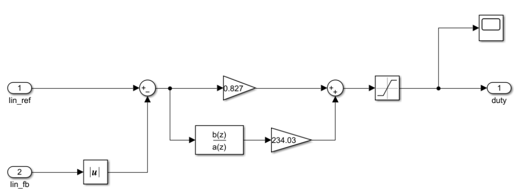

Figure 5. PR Control Topology Matlab Implementation

Input current and output current were taken into account when applying the pr control method. The calculation method of these currents (Iin_ref and Iin_fb) was applied according to the formulas below.

$$\theta = tan^{-1}\left(\frac{Pref}{Qref}\right) \tag{2}$$

$$Ic = \left(\frac{Pref}{V_S * \cos(\theta)}\right) \tag{3}$$

$$Ic = \sqrt{2} * Ic * \sin(\omega t + \theta) \tag{4}$$

The reference values for active and reactive power, as well as the angle between them, are determined. Ic is calculated as the rms value using this angle's value. The angle between the input voltage and current and the first angle value discovered is then added, and its sinus is taken in order to make PFC and determine the Ic reference value.

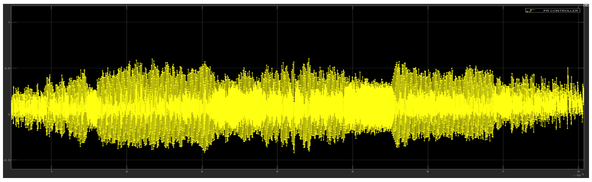

Figure 6. Duty of PR Controller (The PR controller's duty ratio ranges from -1 to -1)

When the PR controller is activated, PWM values are displayed at the output.

3.1. PR Controller Simulation Results:

1- Active power:1000W

Reactive power:-500Var

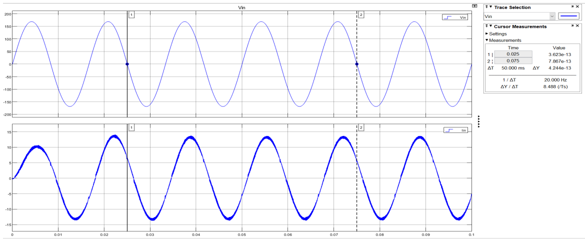

Figure 7. Vin-Iin Graph (Input voltage from Vin and source Iin's current draw)

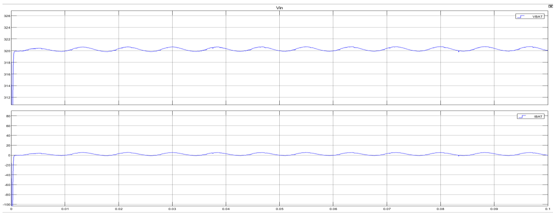

Figure 8. Vbat-Ibat Graph (Simulation results demonstrating battery-side reactive power adjustment)

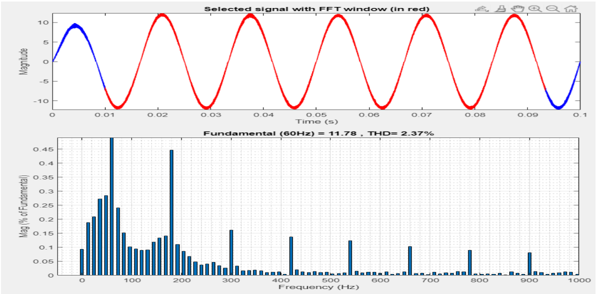

Figure 9. Proposed Converter THD with PR Controller (Input current is controlled to maintain THD at 2.37 percent and be in phase with the voltage)

Even though there is reactive power, the PFC required to adequately charge the battery is carried out as indicated in Figure 8.

4.Constructing Circuit and PI Controller

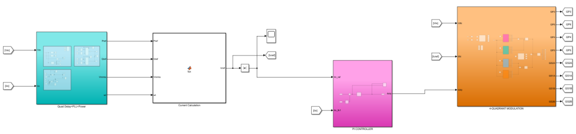

Figure 10. Control Circuit With PI Topology

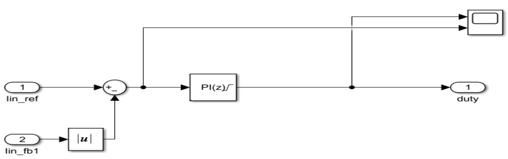

Figure 11. PI Control Topology Matlab Implementation

Non-integrating processes, or processes that eventually produce the same output given the same set of inputs and disturbances, require PI control. The most effective controller for integrating processes is P-only. Integral action, which may be viewed of as an adjustable bias voltage, is employed to eliminate offset. The determined current reference and the feedback reference obtained from the input are compared, and the PI controller is used to compute the PWM duty.

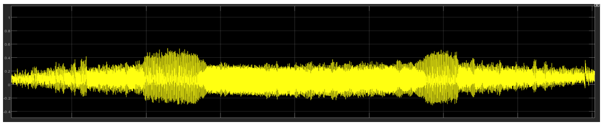

Figure 12. Duty of PI Controller (The duty ratio in the PI controller varies between -1 and -1)

4.1. PI Controller Simulation Results:

1- Active power:1000W

Reactive power:-500Var

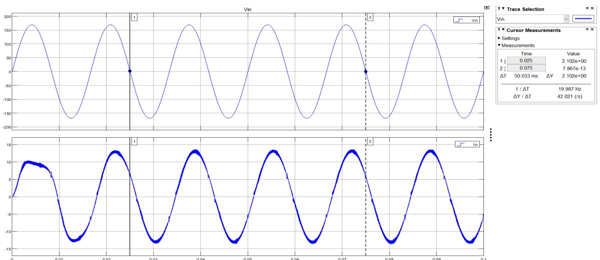

Figure 13. Vin-Iin Graph (Input voltage from Vin and source Iin's current draw)

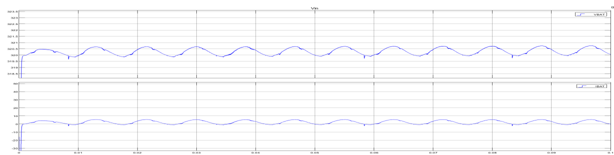

Figure 14. Vbat-Ibat Graph(Simulation results demonstrating battery-side reactive power adjustment)

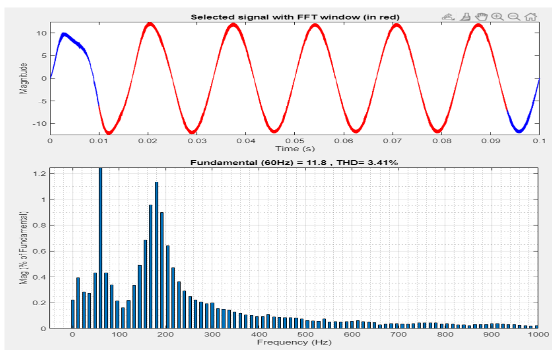

Figure 15. Suggested Converter THD with PI Controller (Input current is controlled to maintain THD at 3.41 percent and be in phase with the voltage)

In Figure 15, the input current is controlled so that it is in phase with the voltage and that the THD remains at 3.41%, which is less than the 5% mandated by IEEE 519.

5. Conclusion

When the output signal is not sent back into the system's input, the control system is said to be in an open loop. As a result, a non-feedback control system is another name for an open loop control system. On the other hand when the output signal is fed back into the system's input, the control system is said to be in a closed loop. As a result, the control action in a closed loop control system depends on the desired output signal. Although open loop controllers are simple, their reliability is lower than closed loop controllers. Because open-loop systems behave according to calibration, while closed-loop systems behave according to feedback signal. A bidirectional single-phase single-stage isolated AC-DC converter topology is studied by comparing and contrasting the two closed loop approaches as a consequence of the comparison.

Yet, PR control is superior to PI control in terms of effectiveness. Because in systems connected to the grid, the frequency and amplitude of the PR controller can be adjusted more stable than the PI controller.

	PI Controller	PR Controller
Complexity	Simple	Complex
Response	Slow	Fast
THD(%)	High	Low
Simulation Time	High	Low
Soft Start	Practicable	Practicable
ZVS	Practicable	Practicable
ZCS	Practicable	Practicable

Table 1. Table of Comparison between PI and PR Controllers

Conflict of Interest

Authors declare that there is no conflict of interest.

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