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BRIDGELESS BOOST PFC CONVERTER CONTROLLED WITH FRACTIONAL ORDER-PI CONTROLLER

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Abstract- Analysis and simulation of bridgeless boost power factor correction (PFC) converter controlled with fractional order (FO) PI is presented in this paper. The bridgeless boost PFC circuit which provides a reduction of semiconductor switches compared with the conventional boost PFC circuit is the better circuit for improving power factor to design PFC circuit with lower size in medium/high power applications. FO controllers are based on fractional calculus and they have some advantages such as larger stable area, robust performance. The aim of the controller is the arrangement of the output voltage to a desired reference, irrespective of the behavior of load changes. A 600W/ 50 KHz bridgeless boost PFC converter controlled with FO-PI is analyzed and simulated via Simplorer simulation program. It is seen from the results that better power factor and lower total harmonic distortion (THD) can be obtained by using the proposed control strategy.

Keywords: Zero Voltage Transition, Dual-boost Converter, Closed Loop, PI controller.

I. INTRODUCTION

Different type PFC circuits which are used to satisfy the necessary requirements of power quality for drawing current have been popular research topics for decades. Since the conventional boost circuit with continuous conduction mode (CCM) has some benefits such as simple circuit and continuous mode of input current, it is generally used as a PFC pre-circuit among the different PFC circuits. However, the classical boost PFC circuit includes two diodes and one switch voltage drops through the current path due to input full bridge diode rectifier and boost switch. The circuit efficiency decreases due to conduction losses of the full-bridge diode rectifier. The bridgeless boost PFC circuits have been introduced to increase the PFC circuit efficiency [1, 2]. The conduction losses can be reduced with bridgeless boost PFC circuit due to less number of semiconductor switches which are used between that the source and load.

Literature shows many studies which use the digital and analog control methods for PFC applications [3, 4]. Generally, the analog method rules are used in digital methods in which the first compensator input error is obtained by comparison of the sensed output voltage and the output voltage reference. Then the output of the first controller and the input voltage are multiplied to obtain a scaling factor for the second compensator. The current compensator is used as inner loop and generally the average current control rules are used to force the average input current with the same as produced the reference current. Therefore, the average value of the input current is forced to become proportional to the input voltage shape [5]. Literature review shows that the applied PFC digital control methods are generally same as the classical average current control method which rules are based on sensed output/input voltages and input current. The input/output voltages are generally sensed by using voltage divider, a low-frequency transformer etc. The input current can be also sensed via simple methods.

Fractional-order PID (FO-PID) control method is also known as PI$^{\lambda}$D$^{\mu}$. Here, μ and λ can be selected as real numbers and are the degrees of integration and differentiation. The parameters of FO-PID must be determinate. This is an important problem for FO-PID. There are some researches papers in the literature to tune the parameters. Various methods are used to solve this problem. Some of these methods used for solutions use intelligent systems such as particle swarm optimization (PSO), genetic algorithm, PSO [6, 7]. There are other studies which based on stability and controller design based on fractional order.

A fractional-order PI (FO-PI) controller that is based on fractional calculus have some advantages such as larger stable area, robust performance is applied for bridgeless boost PFC circuit in this paper. A 600W/ 50 kHz bridgeless boost PFC converter controlled with FO-PI is analyzed and simulated via Simplorer simulation program. Simplorer simulation program gives an opportunity to design a circuit with component base platform. Except for total harmonic distortion (THD) and input power factor, output voltage is observed under different load changes. Also, the output voltage of the bridgeless boost PFC converter controlled with FO-PI is observed under variable input voltages.

II. CIRCUIT DESCRIPTION

In this part, the circuit description of the bridgeless boost PFC circuit controlled with FO-PI is given. Figure 1 represents the circuit configuration of the investigated the bridgeless boost PFC circuit controlled with FO-PI. The capacitor voltage and inductor current are taken as the state variables of the system. The input of the circuit can be modeled as a sinusoidal voltage with peak value of V_m and line frequency of f under normal operating conditions.

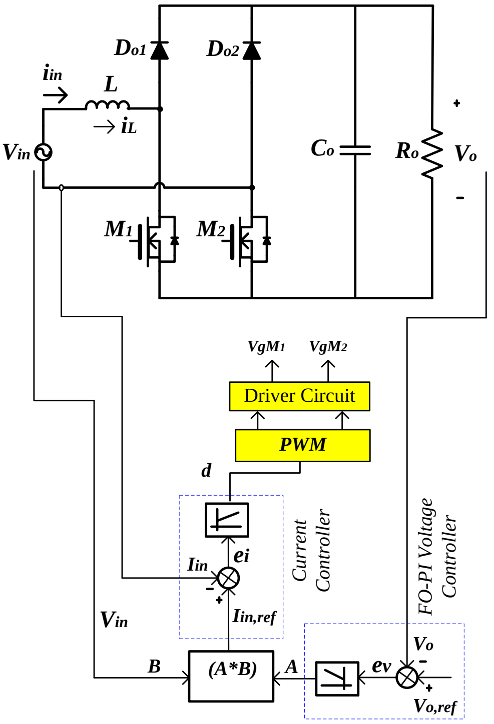

Figure 1. The proposed FO-PI controlled bridgeless boost PFC circuit

ON and OFF positions of the MOSFET and diodes of the circuit help us to derive the steady-state operating conditions of the circuit in continuous conduction mode (CCM). The peak value of the inductor current ripple is assumed as lower than the DC value of the inductor current in CCM. So, the current is always positive in total and when the MOSFET is OFF the diodes are forced to be ON. This condition can be ensured when the inductors are chosen such big enough for the quadratic boost converter. The instant value of the input voltage of the circuit is given as;

$$V_{in}(t) = V_m \sin \omega t \tag{1}$$

where, $\omega=2\pi f$ electrical rad/sec and t is instantaneous time in seconds. For analysis, the output filter capacitor and each inductor current is assumed as constant for a switching period due to large enough inductors of two cells very high switching frequency, f_s compared to the line frequency, f. The position of the switches can be determined via the relationship between the output voltage (V_o) and input voltage (V_{in}). The steady state relation of the bridgeless circuit can be given as below.

$$X_{ss} = \begin{bmatrix} i_L \\ V_o \end{bmatrix} = \begin{bmatrix} \dfrac{|V_{in}|}{R_o(1-d)^2} \\ \dfrac{|V_{in}|}{(1-d)} \end{bmatrix} \tag{2}$$

where, d is the duty ratio of the circuit.

The literature shows that the average current control method has been used as the well-known control method compared to different control strategies implemented to PFC topologies. The average current control technique both provides regulated dc output voltage and an input power factor with higher value. The outer loop controller is the output voltage controller and it generates a current signal. Then the output of the first controller is multiplied with the input voltage to obtain a current reference for the second compensator.

The output voltage is forced to close to its reference value due to this current reference. Also, this current reference is in phase with the input voltage. Then, the average value of the input current is sampled and it is compared with the reference value produced before via second compensator for an output to drive PWM. By this way, the inner loop current regulator can minimize the error obtained by using the average input current and its reference. In this paper, a FO-PI controller is used as the voltage control loop and the average control method is used as the current controller. The outer loop controller (voltage controller) regulates the output voltage despite of any variations in load and input voltage.

In fractional-order control method, the controller system has a non-integer order that can be changed according to system performance. Literature have some different fractional order control method such as fractional order PID, fractional-order sliding mode, fuzzy based fractional-order controller so on [8, 9]. Fractional-order PI controller has been studied in the literature. Fractional-order PI controller is look like to classic PI controller but order of integration is non-integer. Fractional-order PI equation is given as follow.

$$G(s) = K_p + \frac{K_i}{s^{\lambda}} \tag{3}$$

In Equation (3), $s^{-\lambda}$ is fractional order integrator that it can be transformed to transfer function according to fractional order Laplace method. Fractional order Laplace transform is given as;

$$L\left\{ \frac{d^{\lambda}}{dx^{\lambda}} f ; s \right\} = s^{\lambda} F(s) - \sum_{k=1}^{n-1} s^{\lambda-k-1} f^{(k)}(0+) \tag{4}$$

$$(n-1 < \lambda \le n)$$

$$s^{\lambda} \approx C \prod_{a=1}^{N} \frac{1 + \dfrac{s}{\omega_{z,a}}}{1 + \dfrac{s}{\omega_{p,a}}} \tag{5}$$

$$\omega_{z,a} = \omega_l \left(\frac{\omega_h}{\omega_l}\right)^{\frac{(2a-1-\lambda)}{2N}} \tag{6}$$

$$\omega_{p,a} = \omega_l \left(\frac{\omega_h}{\omega_l}\right)^{\frac{(2a-1+\lambda)}{2N}} \quad (7)$$

where, ω_h and ω_l are high and low frequency range [10]. It is seen that fractional system have to infinite memory but it has proven that error of the system at $N = 3$ is acceptable. Poles of classical control system must be in right side of s plan for stability, but fractional order controller this area is changed according to the order. Stability area is shown that Figure 2.

Fractional order PI controller has K_p, K_i and λ, and there are complex methods in order to determine the parameters and the order. Intelligent systems are fundamental of some of these methods. The FO-PI controller optimum parameters are given in Table 1.

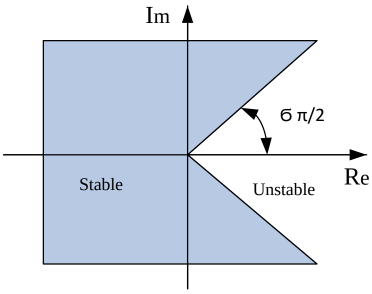

Figure 2. Stability area of fractional order system

Table 1. FO-PI controller parameters and order

Parameters	Value
K_p	2
K_i	50
Λ	0.9

III. SIMULATION RESULTS

Simulations are carried out by Simplorer in this section to observe the performance of the proposed FO-PI controlled bridgeless boost PFC circuit. Table 2 gives components and parameters of the simulations.

Table 2. Parameters of the dual boost converter

Components	Symbols	Parameters
Input voltage	V_{in}	220 V-rms
Output voltage	V_o	400 V
Main inductances	L	630 μH
Output capacitance	C_o	450 μF
Load Resistance	R_o	266 Ω

The simulation results related to input current and current harmonic analysis of the proposed topology are shown in Figure 3. The simulations have been done for 600 W-full load for 220 V-rms input voltage. The magnitude of the 3rd harmonic component is 0.1218 A and the input current *THD* is 6.18% for the full load. The value of input power factor is observed as 0.99 at full load for the proposed control strategy. Also, it is observed that the value of power factor is less than for light loads that for high loads. However, it is observed over 0.99 for different load values.

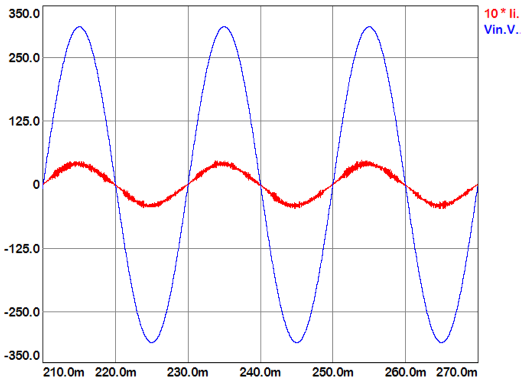

Figure 3. Simulation results of the input voltage-current waveforms for 600 W load

To show the dynamic response of the proposed FO-PI controlled bridgeless boost PFC converter, simulation studies have been done under variation of output load. Figures 4 and 5 show the input-current/input-voltage and the output voltage waveforms respectively for the variation of output load. As seen from the figures, the input voltage is 220 V. The load change is applied at 600 msec. In the transient state of the load change, the change in the output voltage is about 20 V (from 380-400 V) when the output power is increased from 300 W to 600 W at 220 V input voltage. The output voltage ripple increases during the load transient condition. However, the input current can maintain its sinusoidal waveform during this period.

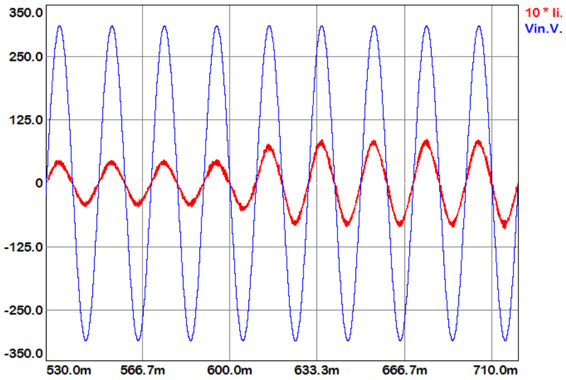

Figure 4. Transient response simulation results of input voltage and current for load change

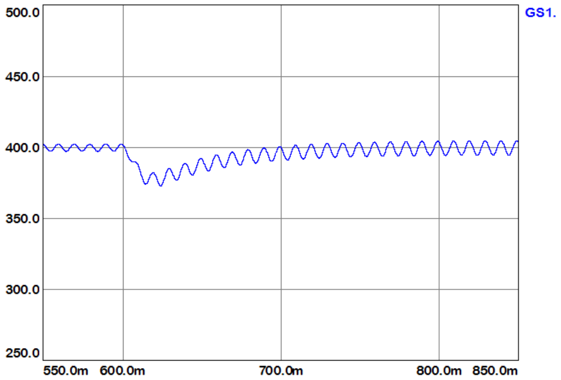

Figure 5. Transient response simulation results of the output voltage for load change

IV. CONCLUSION

This study presents simulation results of bridgeless boost power factor correction (PFC) circuit controlled with FO-PI controller. The dynamic-response for the bridgeless boost PFC circuit controlled with FO-PI controller is observed for different load values. The simulation results show that the outer loop FO-PI controller regulates the output voltage despite of any changes in load and input voltage. It will better to verify the proposed topology with experimental results. Experimental study of the bridgeless boost PFC converter controlled with FO-PI controller can be considered as a future work.

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BIOGRAPHIES

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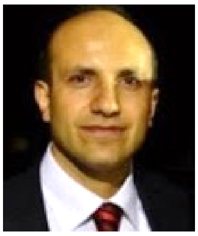

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