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An Efficient Control Algorithm for Single Phase Power Factor Pre regulators to Achieve Fast Transient Response and Unity Power Factor

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An Efficient Control Algorithm for Single Phase Power Factor Pre regulators to Achieve Fast Transient Response and Unity Power Factor

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***Abstract*—In this paper, an approach to generate robust control algorithm for the single phase PFC boost converter is presented. This control rules provide fast output response while maintaining high power factor. This approach is based on derivation of the control functions for both current loop and voltage loop which is multi-loop control structure. Designing of the control parameters are based on the required transient and the steady-state responses. Due to application of feedback linearization the performance of the of this control scheme is robust under all practical conditions. This method eliminates the nonlinearity and the dependence of the error dynamics on the input disturbance. Experiments are conducted to evaluate the control performance.**

***Index Terms*—power quality, Current-mode control, AC–DC power conversion, power factor preregulator, feedback linearization.**

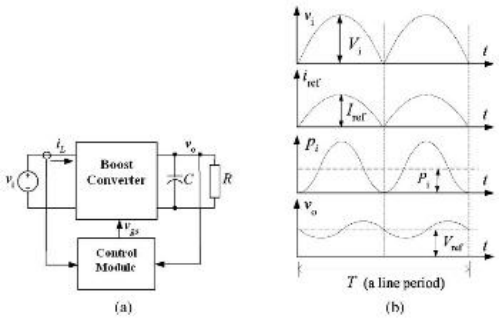

Fig. 1. (a) Block diagram of PFC converter (b) Ideal waveform.

I. INTRODUCTION

In recent years, there have been increasing demands for high power factor and low total harmonic distortion (THD) in the current drawn from the utility. Power Factor Correction is an active research topic in power electronics because of the high power quality requirement, and significant efforts have been made on the developments of the PFC converters[5]. In these converters, the main effort is devoted to the quality of the input current waveform, while, especially with simple single switch topologies like the boost one, the dynamic response of the output voltage is sacrificed[4].The preregulator is controlled by the fast control loop so that input current follows the sinusoidal path of the input voltage. Fig. 1 depicts the block diagram of the PFC and corresponding ideal waveforms, where v_i the rectified line voltage, i_{ref} is the reference current, p_i is the input power, and v_o is the output voltage.

The task of the boost converter is to step up the applied rectified line voltage to desired level by means of duty ratio.

There are two tasks of the control module, one is to maintain unity power factor and other is to regulate the output voltage across the capacitor. Output voltage contains the ripple because input power is the squared sinusoidal function[11].So, capacitor must be chosen such a way that it minimizes the ripple to a reasonable level. Size of the capacitor also affects the dynamic response of the system. Hence, voltage loop operates at the line frequency.

In order to improve the performance of this multi-loop control mechanism in terms of transient response of the output voltage and input current distortion, numerous methods have been proposed in the literature[2],[3],[10]. Instead of focusing on particular phenomena in each loop, we attempt to reduce the system error dynamics to a simple linear form based on the method of feedback linearization[9]. Feedback linearization is the technique for transforming the non linear system into equivalent linear system. Fig. 2 depicts the Boost PFCS with cascade control.

Section II describes the current control and Section III voltage control. Similation results are presented in Section IV and Finally conclusion is given in Section V.

II. CURRENT CONTROL LOOP

With the help of feedback linearization, generation of the current control is derived. Average model of the inductor current is given by (1) where $\bar{\alpha} = 1 - \alpha$ and α is the duty ratio.

$$\frac{di_L}{dt} = \frac{1}{L}\left(v_{in} - \bar{\alpha}\, v_{out}\right) \quad (1)$$

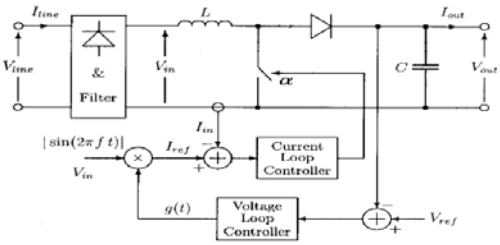

Fig. 2 Boost PFCS with cascade control

The current error e_c is given by

$$e_c = i_{ref} - i_L \quad (2)$$

By taking the derivation on the both side we have current error dynamics as

$$\frac{de_c}{dt} = \frac{di_{ref}}{dt} - \frac{di_L}{dt} = \frac{di_{ref}}{dt} - \frac{1}{L} v_{in} + \frac{v_{out}}{L} \bar{\alpha} \quad (3)$$

Using the feedback linearization (3) can be made linear if and only if we chose

$$\bar{\alpha} = \left(v_{i1} - \frac{di_{ref}}{dt} + \frac{v_{in}}{L}\right) \frac{L}{v_{out}} = \left(Lv_{i1} - L\frac{di_{ref}}{dt} + L\frac{v_{in}}{L}\right) \frac{1}{v_{out}} \quad (4)$$

Here, v_{i1} can be chosen as the linear PI controller to reduce the steady state error

$$v_{i1} = -K_{p1} e_c - K_{i1} \int e_c \, dt \quad (5)$$

And

$$\frac{de_c}{dt} = v_{i1} \quad (6)$$

Where v_{i1} is the equivalent input.

After combining (4),(5) and (6) we have finally current control as

$$\bar{\alpha} = \frac{1}{v_{out}} \left[v_{in} - L\frac{di_{ref}}{dt} - L\left(K_{p1} e_c + K_{i1} \int e_c \, dt\right)\right] \quad (7)$$

Which is shown in figure (3).

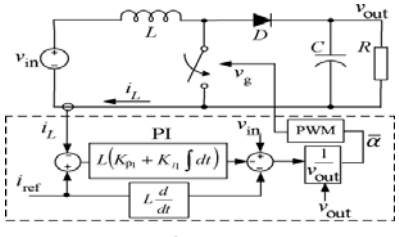

Fig. 3 Current Controller

III VOLTAGE CONTROL LOOP

Derivation of the voltage controller is carried out same way as the current controller using the feedback linearization technique. By taking into the consideration that converter has very high efficiency, average diode current is given as

$$i_D(t) = \frac{v_{in} i_L}{v_{out}(t)} sin^2 \omega t \quad (8)$$

where $i_D(t)$ is the diode current, V_{in} the peak input voltage, I_L the peak inductor current, and $v_{out}(t)$ the output voltage. the average of $i_D(t)$ over a rectifier line cycle $T/2$ is approximated as (9) with consideration of sufficient large storage capacitor.

$$i_D = \frac{V_{in} I_L}{2 v_{out}} \quad (9)$$

Average model of the voltage loop is given by

$$\dot{v}_{out}(t) = \frac{1}{C}(i_D - i_{out}) \quad (10)$$

On substitution of (9) into (10) we have

$$\frac{dv_{out}}{dt} = \frac{1}{C}\left(\frac{V_{in} I_L}{2 v_{out}} - i_{out}\right) \quad (11)$$

Under the ideal condition we assume that $I_L = I_{ref.}$ where, $I_{ref.}$ is the control input of the voltage controller

$$\frac{dv_{out}}{dt} = \frac{1}{C}\left(\frac{V_{in} I_{ref}}{2 v_{out}} - i_{out}\right) \quad (12)$$

I n the voltage controller output voltage along with the reference voltage. So, voltage error

$$e_v = V_{ref} - v_{out} \quad (13)$$

Where V_{ref} is the constant reference voltage.

By taking the derivation on the both side we have voltage error dynamics as

$$\frac{de_v}{dt} = \frac{dV_{ref}}{dt} - \frac{dv_{out}}{dt} = \frac{1}{C}\left(i_{out} - \frac{V_{in} I_{ref}}{2 v_{out}}\right) \quad (14)$$

I_{ref} is the amplitude of the reference current, which is the control output generated by the voltage controller. Using the feedback linearization (14) can be made linear if and only if I_{ref} is chosen as

$$I_{ref} = \frac{2 v_{out}}{V_{in}} (i_{out} - C v_{v1}) \quad (15)$$

v_{v1} is the equivalent input and that can be taken as the linear PI controller so that it can be represented as

$$v_{v1} = -K_{p2} e_v - K_{i2} \int e_v \, dt \quad (16)$$

Where, K_{p2} and K_{i2} are the gain of the controller

$$\frac{de_v}{dt} = v_{v1} \quad (17)$$

By combining (15),(16) and (17) we have the resulting voltage control rule as

$$I_{ref} = \frac{2 v_{out}}{V_{in}} (i_{out} - C(K_{p2} e_v + K_{i2} \int e_v \, dt) \quad (18)$$

Which is depicted in the figure (4).There are some disadvantages regarding to direct realization of the derived algorithm[10].

Distortion of the input current by the line frequency ripple in the feedbacked output voltage and feedfowarded load-current signal . This drawback can be ruled out by using Sample and Hold function to control output so that control output signal is sampled at every zero-crossing of the line voltage[6]. There are numerous advantages of this method. Like it ensures the unity power factor even though presence of the ripple in both the signals. It also provides flexibility regarding to design the control parameters. It has only one dis-advantage and that is susceptible to the noise at higher frequency. So, the filter is to be designed to reduce higher frequency noise[13].Fig.4 depicts the voltage controller with S/H function.

IV.SAMPLE DESIGN AND SIMULATION RESULTS

Both the open loop and close loop methods are applied to boost converter with the following values o f the power-stage elements V_{ac} =85–265 V_{RMS}, f_{line} =50 Hz, V_o =400 V,

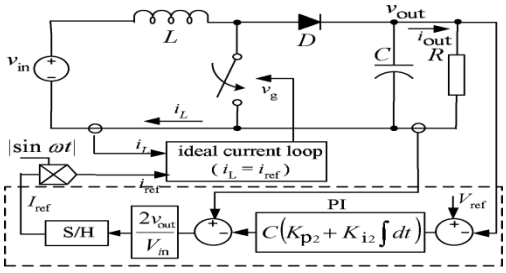

Fig. 4 voltage controller

P_o =250 W,L = 1 mH, C = 470 μF, $f_{switching}$ = 100 kHz. Simulation is carried out using the MATLAB. Here values of gains in each of the controller that is voltage loop or current loop are taken according to desired response. The cross over frequency of the current and voltage loop of about f_c = 15 kHz and f_v = 10 Hz respectively. The efficiency of the converter is worst at low line because the converter suffers from larger conduction losses.

Here, using the transfer function of boost converter the response is plotted. Corresponding values of settling time and peak values are measured as 0.938sec. and 793V.Step response for the open loop system using transfer function is shown in the Fig.5

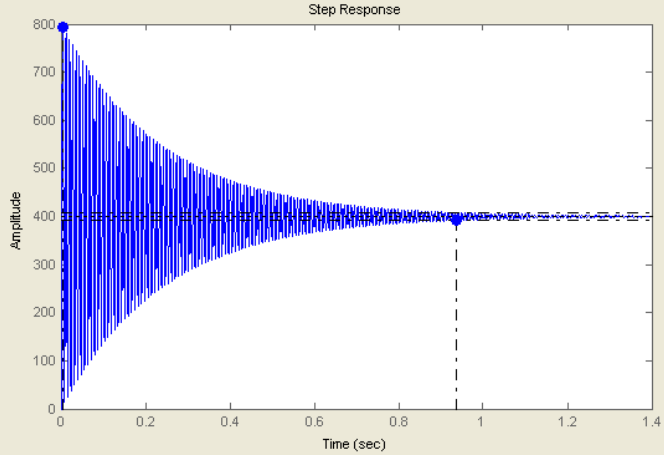

Fig. 5 Step Response for open loop system

With the open loop case the power factor is measured as 0.83. Now, to determine the performance of the derived control algorithm values of the controller gains are designed based on the desired response. The close loop simulation diagram is shown in Fig. 6.

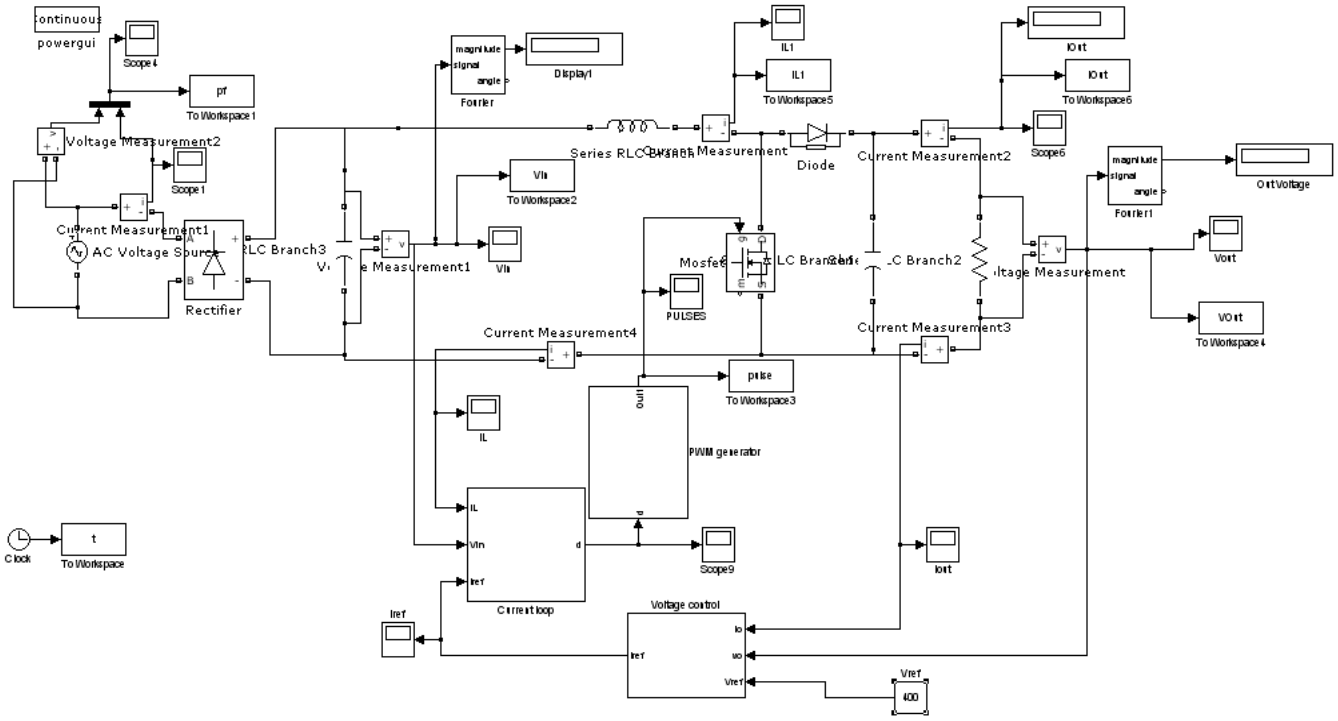

Fig.6 Simulation diagram for the close loop system.

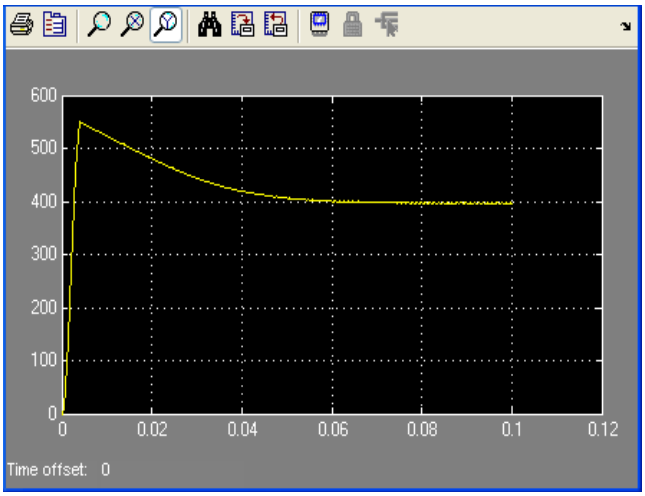

Fig. 7 Step response of the close loop system

After the close loop simulation we have the response as shown in Fig. 7. From that analysis can be done that settling time is around 60ms,While the peak value is not exceeding 550V. To check the performance of the controller we apply the disturbances to the system and observe that how the system is responding to the sudden changes. Fig. 8 shows step change in the load current.

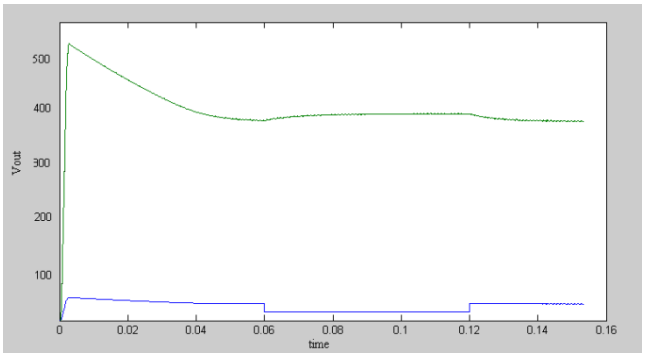

Fig.8 Step change in load current

Fig. 8 shows the effect on the output voltage when change in the load current occurs. From the simulation result, we can see that the output remains constant even though there is change in the load current at 60ms and 120ms.

Fig. 9 depicts the effect of the step change in the reference voltage. From the simulation result, we can see that the output follows the reference voltage within 50ms. So, output voltage tracks

the reference voltage not more than in time 50ms. By measuring the fundamental component of the supply current, RMS value of the supply current and the phase angle the power factor is calculated and for the close loop system the power factor is 0.978.

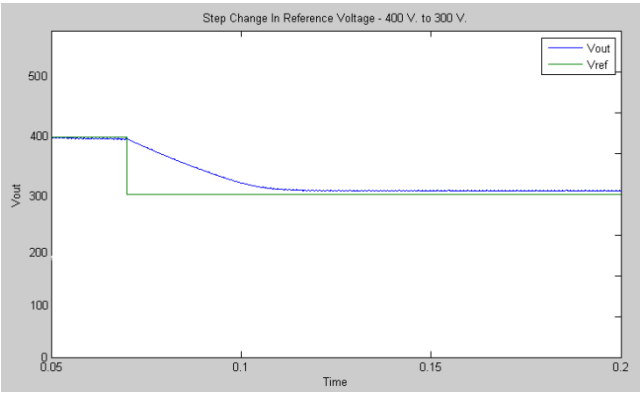

Fig.9 Step change in Reference Voltage

V. Conclusion

Derived control scheme has been analyzed and applied to a 250-W PFC rectifier. It has been shown that, by using the proposed algorithm fast response of the output voltage to large load steps is achieved, significantly reducing the voltage overshoots during load changes. Derived control rules introduces both feedback and feedforward effects. As a result of feedback linearization control technique removes the nonlinearity problem and the dependence of the error dynamics on the input disturbances. The derived control algorithm ensures better transient response, and the control performance is robust with the variations of loading condition Based on experimental data, the effectiveness and the robustness of the derived control rules are verified. The proposed technique can be easily implemented by using any standard control integrated circuit for PFC and some operational amplifiers, resulting in a cost-effective solution for the improvement of the dynamic response of modern converters.

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