Unity Power Factor Correction Based on Ripple Cancellation with Predictive Controller and Fuzzy Controller

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Abstract: ***This thesis proposes a control of single phase power factor correction. This control is capable for obtaining a unity power factor. In this paper, first a ripple estimation circuit is used to eliminate the double line frequency component of sampled output voltage. Then the result of ripple estimation is controlled by predictive controller and fuzzy logic controller. Here boost converter is used as PFC converter. The duty cycle is calculated based on reference current, inductor current, input voltage and reference output voltage. By the use of this proposed control technique, reduce THD in the input current with the output voltage (vo) regulation. This strategy achieves a fast dynamic response and near unity PF.***

Keywords: Power factor correction (PFC), total harmonic distortion (THD), Power factor (PF)

1.Introduction

The switched mode AC to DC converter produce low power factor with high harmonic content in the input current. This led to the improving of power quality. Here boost converter is used for improving the power factor. Boost converter produce an output dc voltage which is higher than input voltage. The boost converter produce regulated dc output voltage and reduce total harmonic distortion of the input current. This improving the power factor. To get the power factor much better, ripple cancellation circuits with control techniques are used for boost converter. The boost converter is analyzed by using multiplier approach. Multiplier approach consists of two control loops, outer voltage control loop and inner current control loop. This multiplier circuit is used for regulating the output voltage. This multiplier controls the amplitude of input current reference signal accordance with the output voltage error.

In power electronics applications Conventional PI controllers are widely used. For intelligent controllers, fuzzy logic controllers (FLC) are adopted. Here fuzzy logic controllers are implemented in the voltage control loop. The predictive controller strategy is used for predicts the input error at the beginning of each modulation period. The predicted voltage is used for pulse generation at the next switching instant and hence minimizing the error. By the use of this techniques an accurate output response can be produced

Due to the pulsating nature of the input power, the output voltage of the load is ripple. In estimation / cancellation circuit, an estimated reproduction of a sampled output ripple is generated by using this additional circuit. Ripple estimator consists of amplitude tuner and phase shifter that reproduce a sampled output voltage ripple by the adjusting of amplitude and phase of template signal. Thus ripple estimation/cancellation with control techniques are capable of maintaining a near unity power factor and fast dynamics response.

2.Boost Converter Based AC to DC Converter

Here a single phase diode bridge is used to rectify the AC input voltage. For reducing the output voltage ripple, a capacitor is connected in parallel to the load resistor. In this circuit, the boost inductor (L) is connected in series. The boost converter operates in two modes, ON mode and OFF mode. In ON mode, the diode is reverse biased and switch S is ON state. In this ON mode the current flow through inductor L, diode bridge and switch S. Here the current in the inductor L increases. In OFF mode, the diode is forward biased and switch 'S' is OFF state and the current flow through inductor L, diode D and capacitor C. Here the inductor current L decreases and output voltage increases more than Vdc.

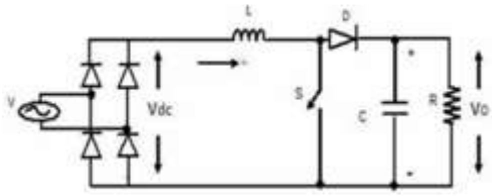

Figure 1: Boost converter

3.Proposed System of Ripple Estimation with Predictive and Fuzzy Controller

The block diagram of the proposed system is shown in figure (2). Ripple estimation/cancellation circuit is basically used to produce a ripple free signal. By the only use of the ripple estimation/cancellation circuit with boost converter a power factor of 0.93 is obtained. To obtain a near unity power factor, controllers are included with ripple estimation/ cancellation circuit. In this circuit predictive control for inner current control loop and fuzzy logic controller for outer voltage control loop.

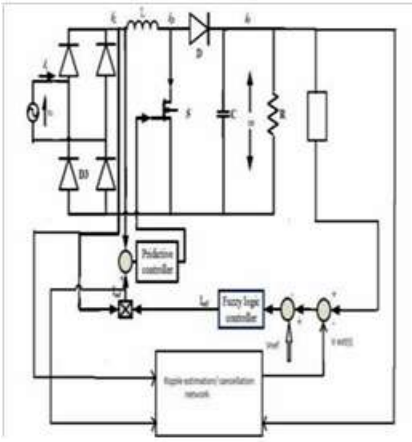

Figure 2: Proposed ripple estimation with predictive controller and fuzzy controller.

A. Ripple Estimation Circuit

The proposed ripple estimation circuit consists of the following three stages.

(i) Ripple Template Generation
(ii) Amplitude Tuner
(iii) Phase Shifter

(i) Ripple Template Generation

In ripple template generator, a ripple template is produced from the sampled rectified line voltage KmVin (t) and inductor current reference iLref (t).

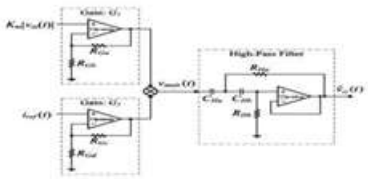

Figure 3: Block diagram of the proposed ripple template generator

The desired ripple template V ~ rt (t) is generated by multiplying KmVin (t) and iLref (t) followed by high pass filter. The high pass filter can be used to remove the dc component.

Since, assuming unity power factor,

$Vin(t) = Vp \sin(\omega line(t))$
$Iref(t) = I p \sin(\omega_{line}(t)) R_s$
$Km |Vin(t)| |Iref(t)| = KmVp \sin(\omega_{line}(t)) * I p \sin\omega_{line}(t))$
$Vrt = PinKmRsG1G2$
$Vmul(t) = [G1Km |Vin(t)| G2iref(t)$
$Vmul(t) = Vrt(1 \cos(2\omega line(t)))$
HPF
$V^{\sim} rt(t) = - Vrt(\cos 2\omega line(t))$

(ii) Amplitude Tuner

In Amplitude tuner, desired ripple template V ~ rt (t) and sampled output voltage ripple □V ~ o (t) is fed to the input of the amplitude tuner. Here equalizing the amplitude of sampled output voltage ripple with that of ripple template V ~ rt (t).

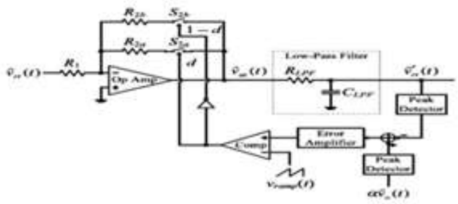

Figure 4: Schematic diagram of the proposed amplitude tuner.

The schematic diagram is shown in figure (3). It mainly consist of an inverting amplifier, two feedback resistors (R2a and R2b) each connected in series with a switch having a turn on time of dTs and (1-dTs) respectively, where1/Ts is the switching frequency. Here d is the duty cycle. Here a switching frequency of 20 KHz is chosen. According to error amplifier, from the pulse width modulator the duty cycle d is derived.

From the schematic diagram R1 is the input resistance of the amplitude tuner R2a / R1 and R2b / R1 are gains during dTs and

(1-d)Ts respectively. The instantaneous output signal V ~ at (t) is smoothened by low pass filter. The output of the low pass filter is shifted 180 ^{0} in Phase.

The amplitude of the modified ripple template is denoted as V ~' rt (t).It should be equal to the amplitude of the sample output voltage ripple. But its phase should be inverted compared to V ~ rt (t). Here LPF cutoff frequency is lighter than thedouble line frequency. After the amplitude equalization,

$V^{\sim'} rt(t) = \alpha Vr(\cos 2\omega line(t))$

Where Vr is the ripple template amplitude.

(iv) Phase Shifter

After the amplitude adjustment of ripple template, V~' rt (t) is fed to the input of phase shifter. Here phase adjustment can be obtained

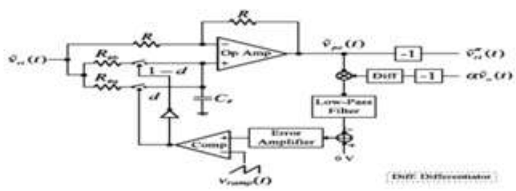

Figure 5: Schematic diagram of the proposed phase shifter

An input signal at frequency ω is pass through all pass filter. This phase shift depends on frequency. Here amplitude cannot be changed. For adjusting the phase shift, two resistors RIaand RIb arranged to switch alternately. Here switching frequency is changed to be 20

KHz. Here d is duty cycle of switch. When dis varied from 0 to 1, the amount of phase shift will also vary from 0 to 180.

The output of the phase shifter is $V^{\sim''}$ rt (t)

$$V^{\sim''}rt\,(t) = -\alpha V_r\,(\cos(2\omega_{line}\,(t) + \theta\varphi))$$
$$= -\alpha V_r\,(\cos(2\omega_{line}\,(t) + \theta_r\,))$$
$$= \alpha V^{\sim}o\,(t)$$

4.Controllers

A. Fuzzy Logic Controllers

Fuzzy Controller is used in the outer voltage loop. The fuzzy logic is a powerful tool to reduce the input current distortion and output voltage errors.FLC control rules can be applied to several preregulator topologies. According to converter parameters some scale factor must be tuned. A fuzzy control system can be explained as nonlinear control system. The analogue input for the fuzzy control system can be analysed in terms of logical variables. The three steps involved in fuzzy control are;

- Fuzzification
- Rulebased
- Defuzzification

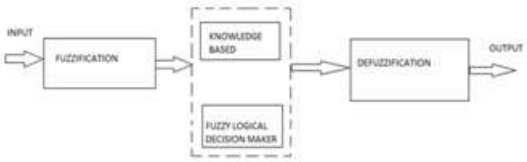

Figure 6: Structure of fuzzy logic controller

I. Fuzzy Logic Controller for Boost converter

Figure shows the block diagram of fuzzy logic controller for boost converter.

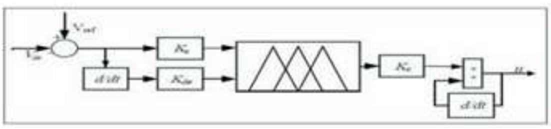

Figure 7: Fuzzy Logic Controller

The fuzzy logic controller is for controlling the output voltage Vo. Fuzzy controller have two input variables. They are error voltage and change in error voltage. The error voltage is obtained from the difference between the output voltage (Vo) and reference voltage (Vref).The change in error de is obtained from the difference between the error voltage and previous error voltage.

Error, $e=V_{ref} - V_o$

$de/dt = e_k - e_{(k-1)}$

$\Delta u = k_1 e + k_2\, de/dt$

II. Fuzzy logic membership function

The input error (e) and change in error (de/dt) has five membership functions. Fuzzy controller compares the two input membership function and produce one output membership function.

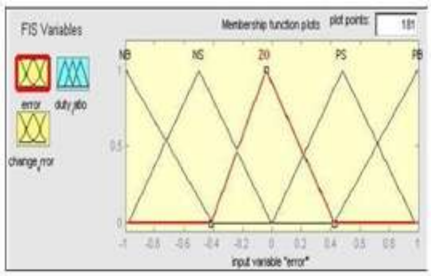

Figure 8: Shows the membership function of input error (e)

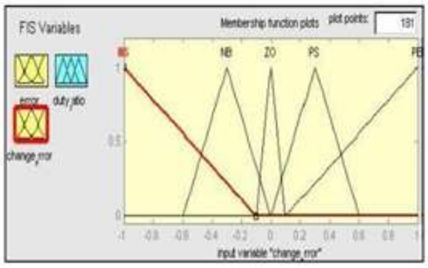

Figure 10: Shows the membership function of output variables

III. Fuzzy rules

The rules are collection based upon the knowledge and working of the system. The number of rules can be set as desired one. The rules based include twenty five rules which depend on five membership function of input variable.

Table 1: shows the fuzzy rule

e/de	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

B. Predictive Controller

Predictive control is used for control of converter switch.

If the case of converter switch ‘S’ is ON

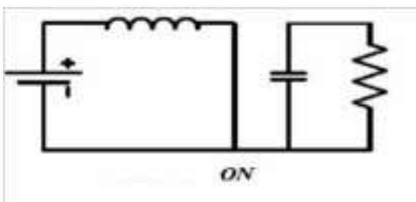

Figure 11: Shows the case of switch ‘S’ is ON

If the case of converter switch ’S’ is OFF

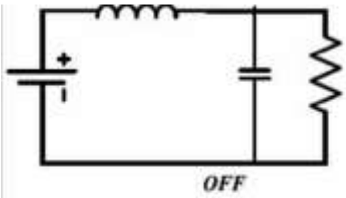

Figure 12: Shows the case of switch ‘S’ is OFF

n For switch ‘S’ is ON *diL*

r diL /dt =V_{in}(t) for $t(k) \leq t \bullet t(k) + d(k)T_s$ (1)

For switch ‘S’
is OFF

r diL /dt =V_{in}(t) – V_o(t) for $t(k) + d(k)\, T_s \leq t \bullet t(k+1)$ (2)

Where *t*(*k*)is the started time at k^{th} switching, *t*(*k*)is the started time at k+1 switching.*d*(*k*) is the duty cycle.

Ts is the switching period.

Since the switching period (Ts) is more than the input voltage. Then (1) and (2) can be rewritten as

$\underline{Li_L\,((t(k) + d\,(k)T_s) - i_L t(k)}$ = V_{in}(t(k))

$d\,(k)T_s$

$\underline{Li_L\,(t(k+1) - i_L\,(t(k) + d\,(k)T_s\,))}$ = V_{in}(t(k))-
V_o(t(k))

$(1 - d\,(k))T_s$

Figure (13) shows the inductor current for one switching cycle.

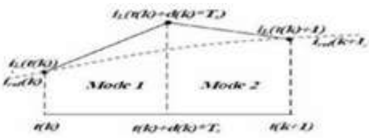

Figure 13: Inductor current during one switching cycle

For designed boost converter, the inductor current iL (k 1) has force to track the sinusoidal reference. To calculate the duty cycle.

$$d(k) = \frac{L}{T_s}\frac{i_{ref}(k+1) - i_L(k)}{V_{ref}(k)|} + \frac{V_{ref}(k) - V_{in}(k)}{V_{ref}(k)}$$

From the above equation the reference current.

$i_{ref}(k+1) = k_{fuzzy}. |\sin \omega_{line} t(k+1)$

where k fuzzy is the peak value of the reference current that given by the output of fuzzy controller.

Figure (14) shows a boost converter with predictive control and fuzzy controller.

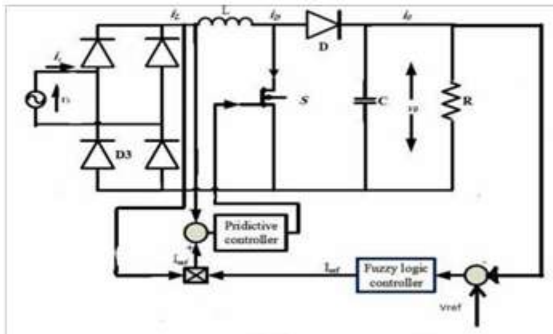

Figure 14: Boost converter with predictive control and fuzzy controller

Overall Simulation

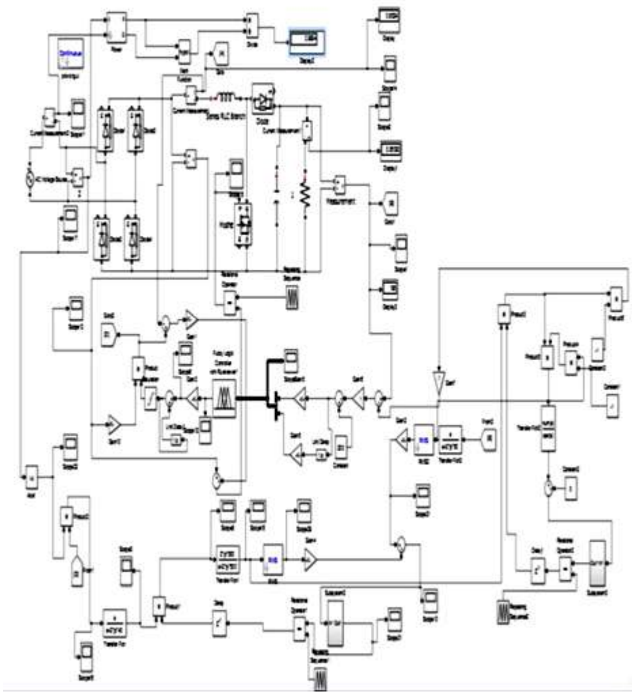

Figure 15: Overall simulation diagram

The simulation results are given below.

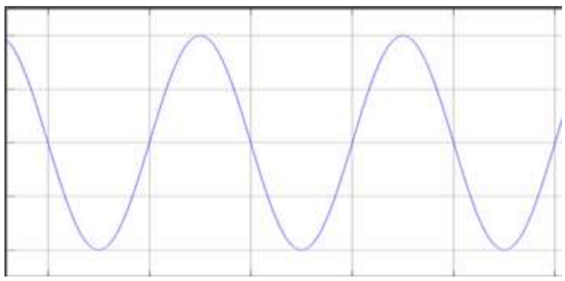

Figure 16: Shows the input voltage waveform.

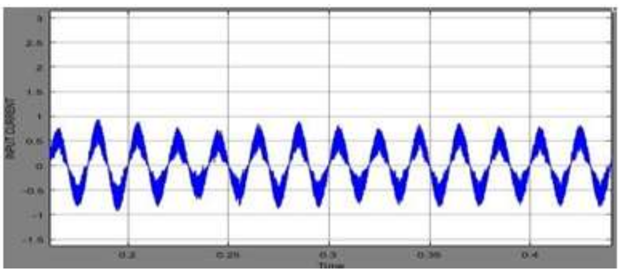

Figure 17: Shows the input current waveform.

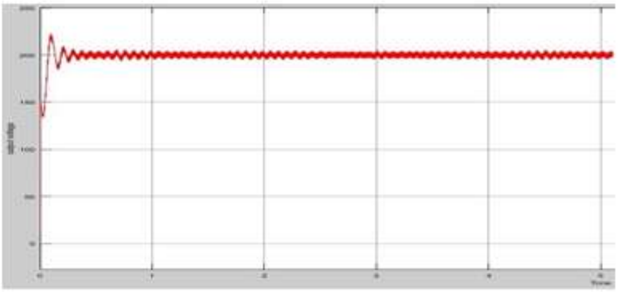

Figure 18: Output voltage waveform

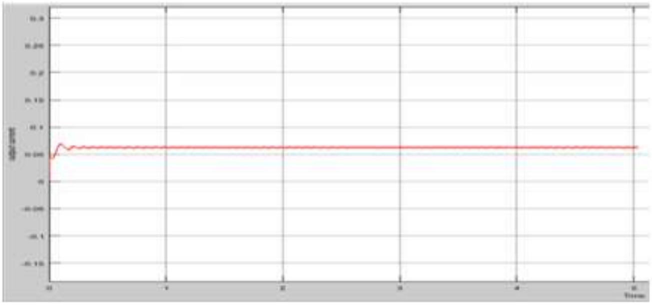

Figure 19: Shows the output current waveform

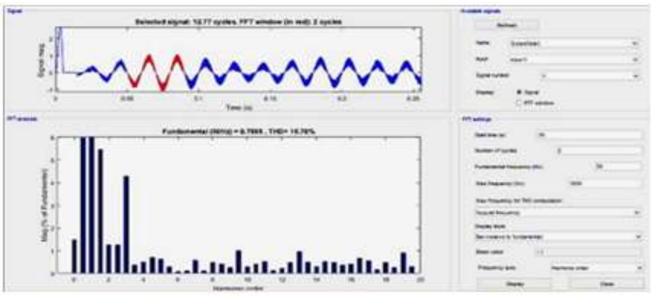

Figure 17: Shows the harmonic spectrum of the input current

5.Conclusion

Simulation is performed in MATLAB. Here the closed loop performance of PFC converter based on ripple cancellation with predictive control and fuzzy controller study is discussed. Here verification of the circuit is done through the simulation model and its analysis. By the use of this proposed control strategy, a closeness of unity power factor can be obtained. Here a power factor of 0.9815 is achieved. In this simulation, the THD of the input current is18.78%.

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