Voltage Regulation of Cuk Converter Using Fire Fly Algorithm

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All of us need constant power supply for every application, but due to poor supplies, wiring issues and some natural causes it is not attended. This paper aims to provide a constant voltage across the load even if there is voltage fluctions at the supply. A cuk converter along with a PI controller is used in between input and load. In order to improve the effectiveness of the controller it is tuned manually and by artificial intelligence algorithm. This paper uses a firefly algorithm. The regulated voltage from both the method is compared with respect to different time domain specifications.

Keywords:Proportional controller, Firefly, Duty cycle, Maximum overshoot, Settling time, Proportional constant, Integral constant.

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1 Introduction

A converter converts one form of input to other form. A DC-DC converter converts a given magnitude of DC to a desired magnitude of DC. Depending upon the requirement of the application or load we can step down or step up the input given to the setup. The required DC voltage is first rectified from the available AC source and then it will be processed. The challenge arises when the input AC supply has fluctuations due to several reasons. The reasons included poor supplies, wiring issues, interferences, and some natural causes like thunder, lightning, fallen trees and heavy rains. This will affect the connected load. It may reduce the efficiency, longevity and poor power factor at the load side. In turn the voltage fluctuations at the supply will affect the entire co-ordinated system. Here a voltage regulation mechanism is employed in order to stabilise the voltage. A cuk converter is employed in between the supply and the load [1]. It will boost the voltage and regulates to a reference value provided by the load. The voltage regulation is done by a PI controller. The PI controller maintains the output of the cuk converter at a specified value for different supply voltage by controlling the duty cycle of the converter. Controller parameters are first tuned by conventional method and the results are analysed [2]. To improve the effectiveness a firefly algorithm is also used to tuned the controller parameters. The results for both the method are analysed in the later section.

2 Components used

Bridge rectifier: It converts Ac to dc and serves as the input to the cu converter. Fig 1. Shows a diode bridge rectifier. D_1-D_4 diodes used for rectification purposes. L and C is the filter circuit to filter out the ripples present in the output direct voltage. The output of the rectifier V_{DC}.

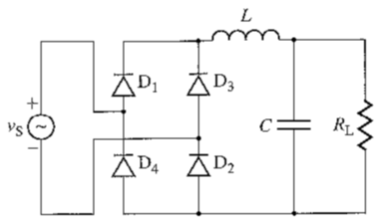

Fig. 1. Rectifier

Cuk converter: A cuk converter is a buck-boost converter. This consist of two inductors and two capacitors to perform the same. The circuit diagram is shown in Fig. 2. The output voltage equation is as follows:

$$Vo = \frac{DVs}{(1-D)} \quad (1)$$

Where V_o = output voltage, V_s= input voltage, D = duty cycle

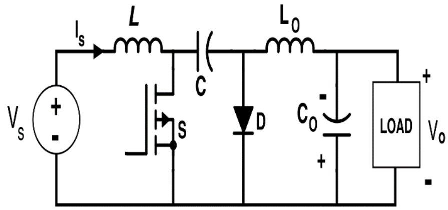

Fig. 2. Cuk converter

The design of Cuk converter is done using the following set of equations from equations.

$$L = L_0 = \frac{V_s D}{\Delta I_L f_s} \quad (2)$$

$$C = \frac{I_0 D}{\Delta V_c f_s} \quad (3)$$

$$C_0 = \frac{I_0 D}{\Delta V_{co} f_s} \quad (4)$$

Inverter: The output from the Cuk converter is converted to AC by a half bridge series resonant inverter [6]. It supplies the load. Fig. 3 shows inverter. A resistive load is connected to analyse the performance of the proposed system. The harmonics in the output are filtered by the capacitor C_b. The design parameters are calculated using equations from 6 to 10.

$$W_{starting} = W_{switching} = \frac{1}{\sqrt{L_r(\frac{C_b L_p}{C_b + C_p})}} \quad (5)$$

$$W_{running} = \frac{1}{\sqrt{L_r C_b}} \quad (6)$$

$$W_{switching} = 4W_{running} \quad (7)$$

$$C_b = 15\frac{V_l}{V_{ab}}(\frac{1}{R_L.W_{switching}}) \quad (8)$$

$$C_P = \frac{L_b}{15} \quad (9)$$

$$L_r = \frac{16}{C_b(W_{switching})^2} \quad (10)$$

where, C_b is blocking capacitor, C_P is parallel resonant capacitor and L_r is the resonant inductor.

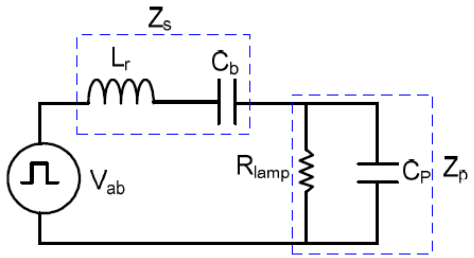

Fig. 3. Resonant inverter

3 PI Controller

A PI controller is used to regulate the output voltage of Cuk converter which is shown in Fig. 4.

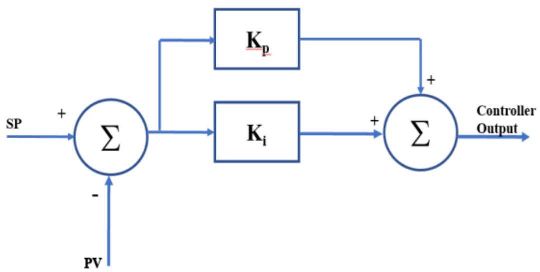

Fig. 4. PI controller

The transfer function of the controller is as given in equation 5.

$$u(t) = K_P + K_I \int e(t).dt \qquad (11)$$

The tuning of the controller parameter is done by two methods.

Ziegler-Nichols method: It follows the following rules [5]:

(i) Switch on the proportional controller only.
(ii) Tune it till desired result is achieved.
(iii) If (ii) do not achieved than switch on Integral controller
(iv) Decrease Kp to the half of original value resulted from step 1 and increase the integral controller.

FF based tuning:

The controller parameters are tune using a stochastic optimization algorithm. This is discussed in the following section.

4 Fire-fly Algorithm

Now a day's artificial intelligence is applied to optimize the results. This paper includes a swarm based fire-fly algorithm to tune the controller parameters. A firefly algorithm shown in Fig.5 is a nature inspired maximization or minimization solution to an objective function. It inspired from a tiny creature fire-fly who uses their flashing property to communicate. They emit the flashes as a biochemical process called as bio luminance to attract their mate and predators. The mates are attracted to their partner depending upon the brightness. If there are more fireflies than a mate will attracted to the brightest one. So only if a firefly is in the visible range it will be able to attract the mate or predator [8]. The light intensity reduces as the distance increases. The following assumptions are taken into considerations:

- Every fire-fly should attract to the other fire-fly: All fireflies in a given population are unisex.
- As the distance between any two fire-fly increases the brightness should decrease.
- A fire-fly should move in a random direction if it did not find a brighter fire-fly.
- The landscape of the objective function which is to be optimized should determine the brightness.

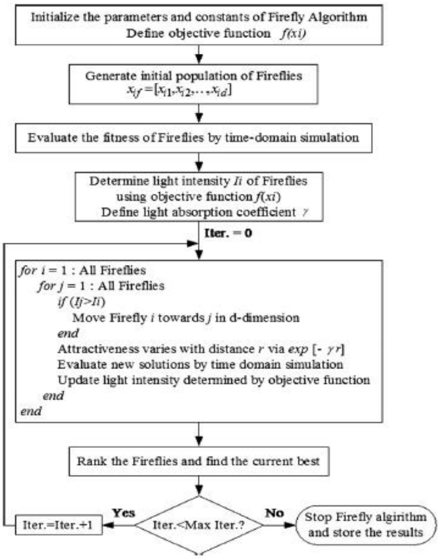

Fig. 5. Fire-fly algorithm

5 Simulations and Results

All the components are assembled and the simulation is done in MATLAB/SIMULINK environment. The final circuit is shown in Fig. 6.

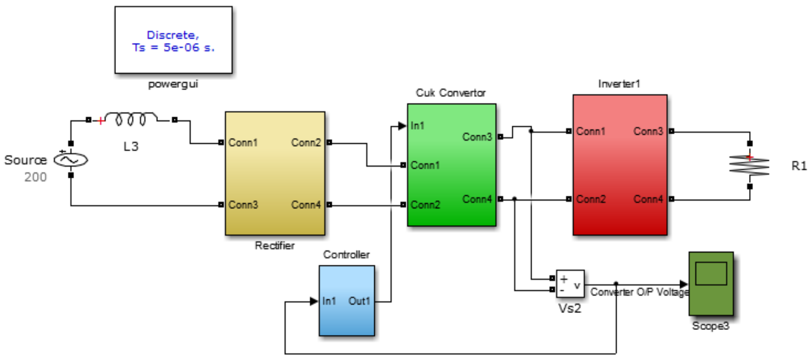

Fig. 6. Simulation diagram

The AC supply is converted to DC by a diode bridge rectifier. The rectified DC is step up to a reference voltage of 400 by a Cuk converter [6]. Inverter converts the DC into AC to be supplied to the load. Controller block contains a PI controller and setup for generating duty cycle for the Cuk converter. The design parameters are given in Table I and Table II. Fig.7 shows the controller block with conventionally tuned PI controller.

Table 1. Design Parameters

Parameter	**Values**
Rated load	18 W
rated load current	0.1454 A
Rated load voltage	110 V
switching frequency (f_s)	60 kHz
inductor (L)	25 mH
inductor (L_o)	25 mH
coupling capacitor (C)	2 nF
dc link capacitor (C_o)	18 µF
resonant inductor (L_r)	3.32 mH
Dc blocking capacitor (C_b)	45 nF
resonant capacitor (C_p)	3 nF

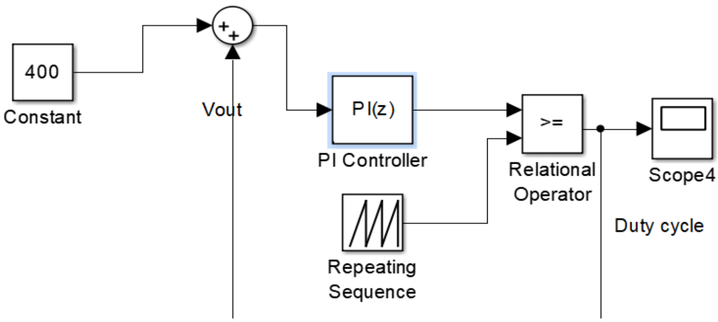

Fig. 7. Controller block

Table 2. Controller parameters

Method	Kp	Ki
Conventional	6	0.5
FF algorithm	1.8	1.72

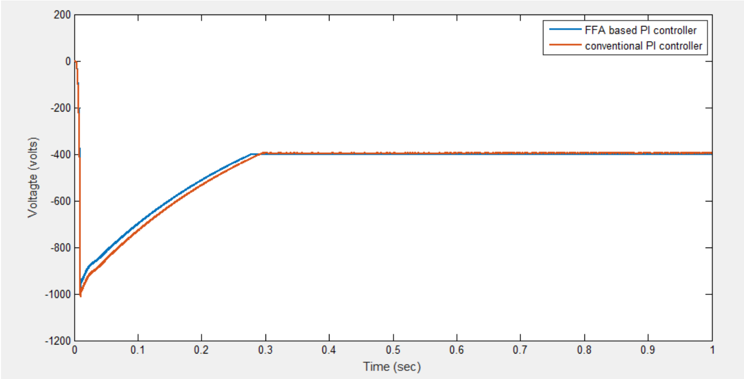

Fig. 8. Cuk converter output voltage for 230V input

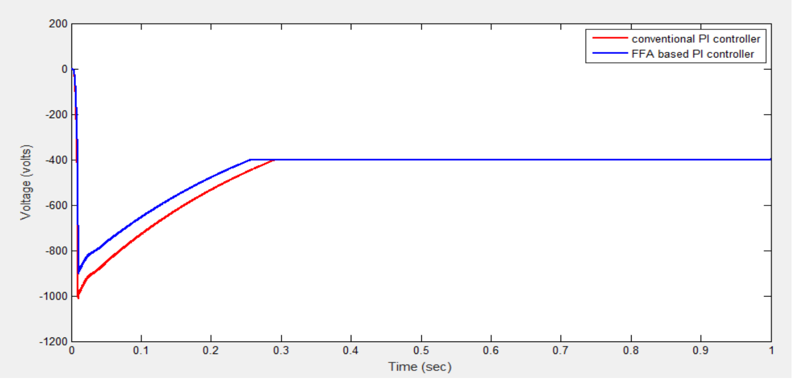

Fig. 9. Cuk converter output voltage for 200V input

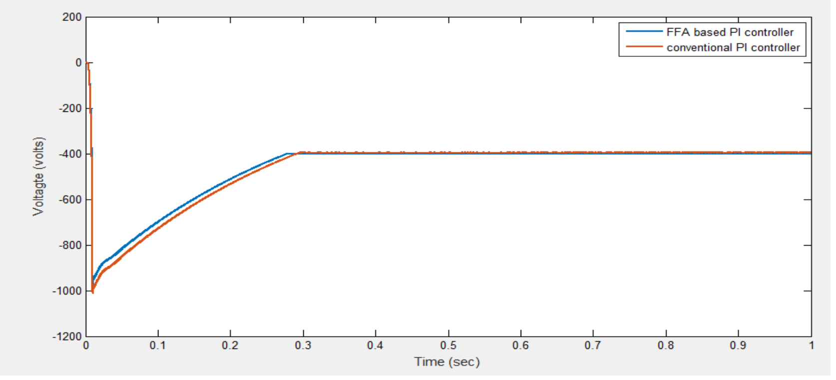

Fig. 10. Cuk converter output voltage for 180V input

A program is written in MATLAB programing for firefly algorithm. The optimized value of Kp and Ki are noted down for a generation of 20 and population of 30 fireflies. The converter output voltage is shown in fig.8, 9, 10 for a different input voltage. The results for both case is analysed for different input and arranged in table III.

Table 3. Output voltage

Supply Voltage	V_o conventional controller parameter	V_o with optimized controller parameter
150	396.7	398.6
180	397.2	398.9
200	397.6	399.4
230	398.7	400.1
250	399.9	400.7

It is very clear from the above table that the output voltages with optimised controller parameters are more effective to regulate the converter voltage. Also the output voltage is analysed with respect to the time domain specifications such as maximum overshoot and settling time and are listed in Table 4.

Table 4. Time domain specifications for 230V input

Specification	V_o conventional controller parameter	V_o with optimized controller parameter
Maximum overshoot	1012V	953.7V
Settling time	0.2993Sec	0.2765Sec

Table 5. Time domain specifications for 200V input

Specification	V_o conventional controller parameter	V_o with optimized controller parameter
Maximum overshoot	1009V	893V
Settling time	0.2887sec	0.2554sec

The table shows that for tracking the output voltage with both the controller are close to each other. But in response to the maximum overshoot and settling time is less with the proposed controller. It can be summarized that the FF based controller is effective compared to conventional controller. In order to check the robustness of the proposed controller also a variation in the reference voltage is changed from 400V to 200V. The output converter voltage is shown in fig. 11. It is efficiently tracks the new reference voltage.

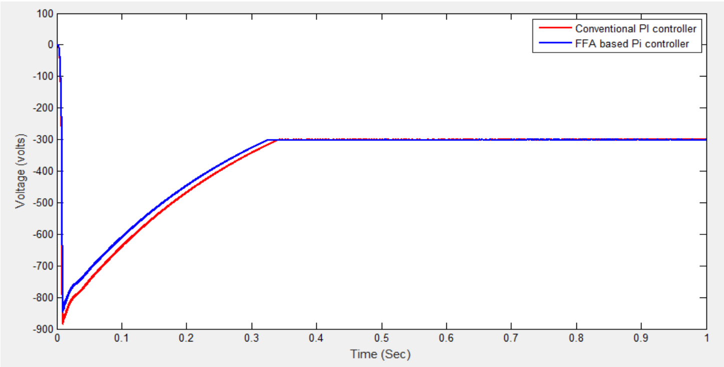

Fig. 11. Cuk converter output voltage with 300V reference and 230 V input

6 Conclusion

A multi-stage converter for voltage regulation of a resistive load is proposed in this paper. It uses a Cuk converter in CCM for boosting the input voltage. The converter employs a PI controller for the control purpose to provide a close loop control of the power factor corrector circuit. The results show that the converter regulates the output efficiently for wide voltage fluctuations. Also the proposed fire-fly algorithm based controller is more efficient compared to conventionally tuned controller. It is better in tracking the desired output as the same time has less maximum overshoot and settling time. Hence the voltage regulator circuit is efficient and robust.

References

[1] Erickson, R. W. *Fundamentals of power Electronics*. University of Colorado, Boulder.
[2] Bryant, B. and Kazimierczik, M. K. (2003). Derivation of the Cuk PWM DC To-DC Converter Circuit Topology. In ISCAS, 292-295.
[3] Mizoguchi, T., Ninomiy, T. and Harada, K. (1991). Analysis and design of voltage mode resonant Cuk converter. In IEEE, 480-487.
[4] Shrivastava, A. and Singh, B. (2010). PFC Cuk converter Based Electronic Ballast for an 18 W Compact Fluorescent Lamp. In *ICIIS*, 393-397.
[5] Mohan, N., Undeland, T. M. and Robbins, W. P. *Power Electronics, Converters, Applications, and Design*.
[6] Yang, Z. H. and Sen. P. C. (1998). Recent developments in high power factor switch -mode converters. In *IEEE*, 477–488.
[7] Copeland. B. R. (2008). The design of PI Controllers using Ziegler Nichols Tuning Brian R Copeland. http://educypedia.karadimov.info/library/Ziegler_Nichols.pdf
[8] Yang, X. S. (2009). Fire-fly algorithms for multimodal optimization. Stochastic Algorithms: Foundations and Applications. In *SAGA*, 169–178.