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FUZZY REGULATED SWITCHED INDUCTOR CUK CONVERTER WITH IMPROVED POWER QUALITY FOR BATTERY CHARGING APPLICATION

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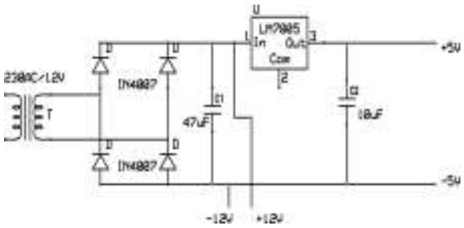
ABSTRACT
A boost converter for PFC is typically used in two-stage converters for charging electric bike batteries, followed by a dc-dc converter with a universal input voltage. These two-stage conversions involve a lot of parts and are inefficient. This article presents a power factor correction converter based on a single-stage switching inductor Cuk converter that has a high step-down gain, a low current stress, a high efficiency, and a small number of components. For the multiple components of the proposed converter, continuous current mode is used for operational analysis and design equations (CCM). The proposed 500 W, 48V/10.4A converter is the subject of mathematical modeling, analysis, simulation, and experimental in this paper. The suggested converter's performance is investigated in terms of power quality indices such as voltage THD, current THD, and total power factor with various types of loads such as resistiveload and battery load in both constant voltage (CV) and constant current (CC) (CC). Furthermore, the dynamic performance of the proposed converter with battery charging isexamined with Fuzzy Logic Controller and PIcontroller in constant voltage and constantcurrent modes under large supply fluctuations.

INTRODUCTION:

In the current situation, excessive usage of petroleum-fueled automobiles has resulted in emissions of greenhouse gases and other hazardous materials, which have significantly increased environmental risks, health problems, and price fluctuations [1]. Electric cars (EV) and electric hybrid vehicles (EHV) have recently become an alternative option for intercity transportation applications due to a number of benefit such cheap maintenance, high efficiency, and reduced noise and environmental pollution as well as cost effectiveness [2]. Pollution-free battery power, which can be recharged at battery charging stations, has become the most popular source for powering EVs and EHVs [3]. Yet, there is a chance that the current grids might have power quality issues owing to the exponential expansion of electric vehicles in the future [4]. In view of extensive usage of power electronics technology for battery charging stations, there is a raise in concern of power quality problems, particularly harmonic pollution in the distribution system [5]. There is an increased risk of harmonic level in power distribution systems which reduce the life of distribution transformers with the increasing installation of battery charging stations in urban areas [6]. Conventionally, a diode bridge rectifier followed by bulky filter capacitor draws a highly distorted non-sinusoidal and peaky supply current with high harmonic current THD of 70-80%, from the single phase ac mains with low power factor ofthe order of 0.75–0.8 lagging, and high crest factor[6].As per international standards for Power Quality (PQ) like IEEE Standard 519- 1992, IEC 61000-3-2, it is becoming essential for any product to satisfy load demand for power factor above 0.9 and current THD below 5% for Class-D (under 600W, <16A, single-phase) applications [7,8]. To meet the guidelines of recommended international standards for Power Quality (PQ), various ac-dc converter topologies are reported in the literature [10, 11]. Usage of two stage PFC converters is widely practiced in which the power factor correction is carried out in the first stage and voltage/current regulation is done in the second stage.

POWER SUPPLY UNIT:

All invention of latest technology requires source power. So, we need proper power source which will be suitable for a particular requirement. All theelectronic components require DC supply ranging from +5v to +12v. We are using the same cheapestand commonly available energy source 230V- 50Hz.



CUK CONVERTER:

The CUK or step down-step up regulator regulatesthe average DC output voltage at lower and higher level than the input or source voltage and there is apolarity reversal on the output this is accomplished through a controlled switching where the DC inputvoltage is turned on and off periodically, resulting in a higher and lower average output voltage.

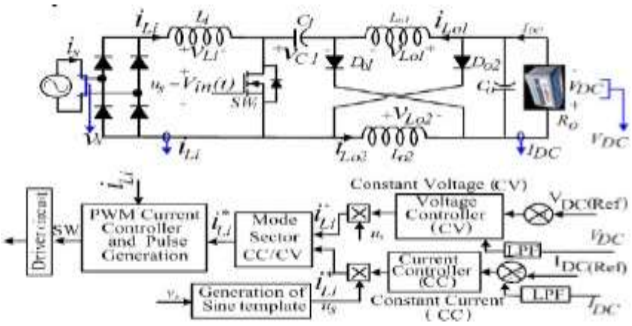
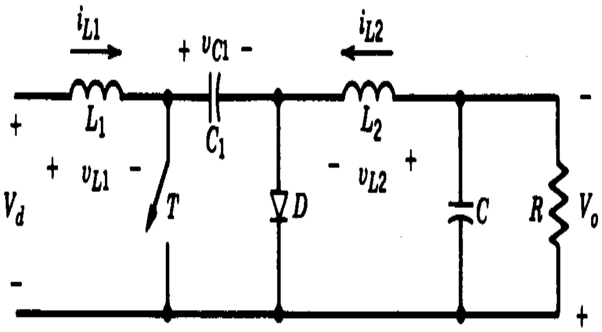
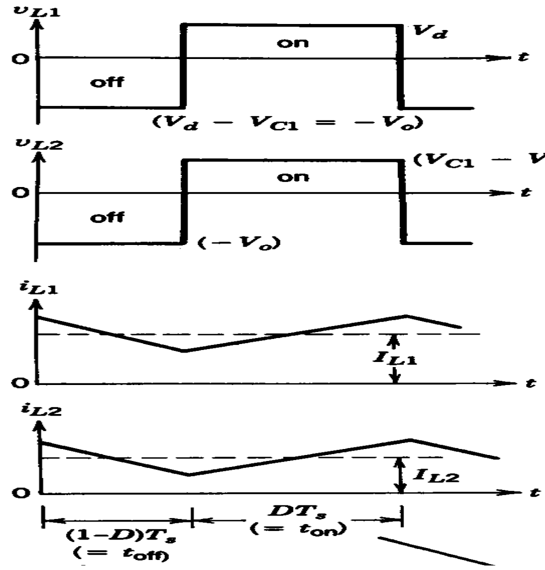


Fig. Switched inductor Cuk converter and schematic diagram of controller shows schematic of proposed power factor correction converter with its control system. A single-phase diode bridge rectifier (DBR) followed by a switched inductor Cuk converter is used for controlling the output voltage feeding the load. The PFC converter is opera ted in CCM mode using current multiplier approach, i.e. current flowing in input inductor Li, is continuous in a switching period. The converter is designed and simulation is done with resistive load and battery load.

CUK DC-DC Converter:

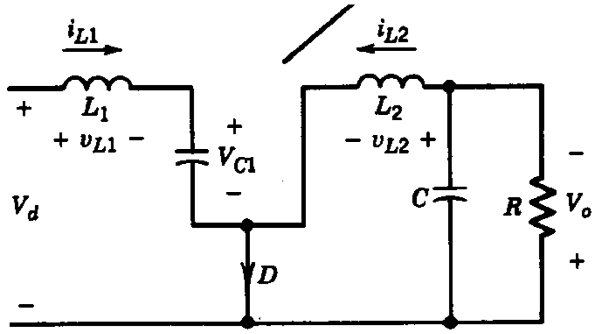


The output voltage can be higher or lower than theinput voltage the output voltage is negativeCapacitor C1 stores and transfers energy in steady state average inductor voltages VL1, VL2 are zeroVC1 is larger than Vd and Vo:



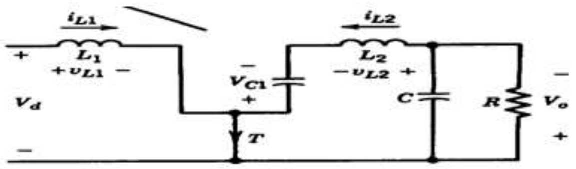
CUK DC-DC Converter: Waveforms (2)When switch T is on:

CUK DC-DC Converter: Waveforms (1)When switch T is off:



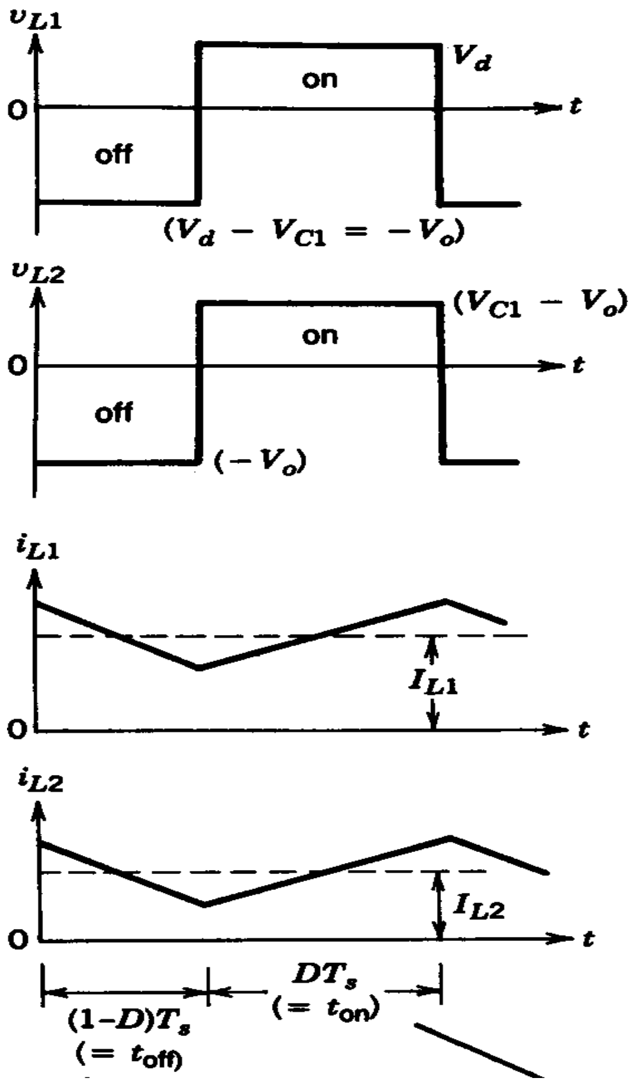
(a) VL1=Vd-VC1

(b) VL2=-VO



(a) VL1=Vd

VL2=VC1-Vo



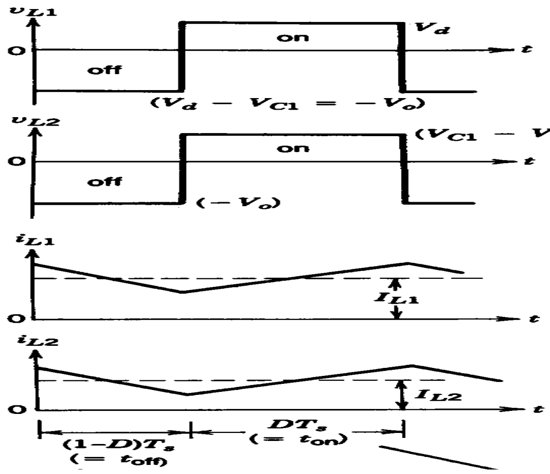
CUK DC-DC Converter: Waveforms (3) Equating the integral voltages of L1, L2 over oneperiod:

$$L1: \quad (V_d - V_{C1})(1-D)T_s + V_d D T_s = 0$$

$$\therefore V_{C1} = \frac{1}{(1-D)} V_d$$

$$L2: \quad (-V_o)(1-D)T_s + (V_{C1} - V_o) D T_s = 0$$

$$\therefore V_{C1} = \frac{1}{D} V_o$$



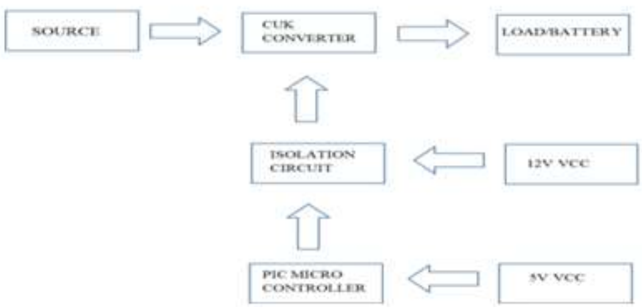
Load\Battery:

An electric battery is a device consisting of one or more electrochemical with external connections provided to power electrical devices such as lights and electric bike battery has two nodes positive is said to cathode and negative is said to be anode. The terminal marked negative is the source of electrons that will flow through an externalelectric circuit to the positive terminal.

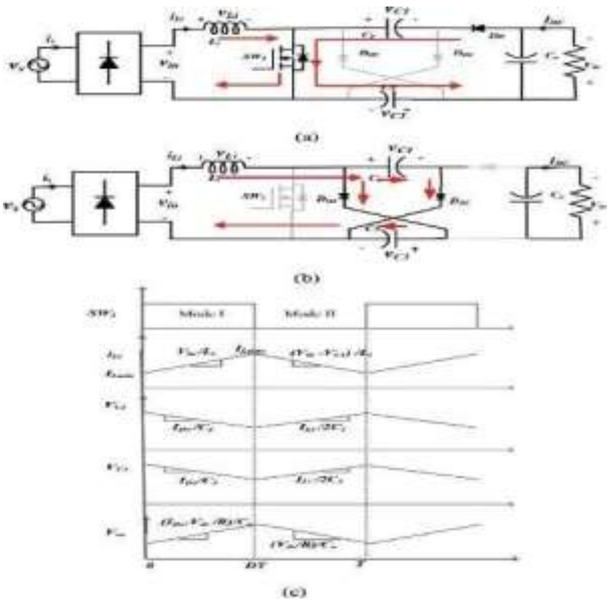
OPERATION OF PFC CONVERTER:

The operation of converter depends on switching state of switch SW1. The connection of intermediate capacitors (C1, C3) changes from series to parallel connection as switching state of switch SW1 changes from ON to OFF. The equivalent circuit during ON and OFF state of the switch SW1 are depicted in Figure and Figure. The Cuk-derived PFC converter is designed to operate in continuous conduction mode i.e. the current through inductor (iLi) is continuous over one switching period. Figure shows the voltage and current waveforms over one switching cycle. The detailed mode-wise analysis is carried out with assumptions that all the circuit elements are ideal. The output filter capacitor (Co) is assumed to be large such that theoutput voltage ripple is neglected.

MODE I: When the switch SW1 is turned ON, the output diode Do is forward biased. Power diodes (Do1, Do2) are in reversed biased by the negative voltage (VC1 + Vdc) that appears across them. The equivalent circuit during this mode is shown in Figure. During this mode, the input inductor current (ILi) increases gradually from its minimum value (ILmin) and stores energy as shown in Figure. The intermediate capacitors (C1, C3) start discharging in series through path indicated in Figure and charge the output capacitor as shown in Figure. At the end



of the mode-I, inductor current reaches to its maximum value (I_{lmax}) as shown in Figure.



CONTROL ALGORITHM FOR PFCCONVERTER:

In order to achieve unity power factor control, the current multiplier or voltage multiplier based approach for CCM and DCM are used. In this section a brief description of the control scheme is presented. The reference voltage $V_{dc}^*(k)$ is compared with the sensed dc-link voltage V_{dc} (k) to generate a voltage error $V_e(k)$, where voltage error $V_e(k)$ at any instant „k" is given as,

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k)$$

The voltage error $V_e(k)$ is fed to proportional- integral (PI) controller for generation of a controlled output V_c (k) as

$$V_c(K)=V_c(k-1)+k_{pv}\{V_e(k)-V_e(K-1)\}+k_{iv}V_e(k)$$

Where, kpv, kiv are the proportional gain and integral gain of the voltage PI controller. The reference current $i_{Li}^*(k)$ is generated by multiplying the controller output V_c (k), with the unit template of supply voltage u_s (k) as follows

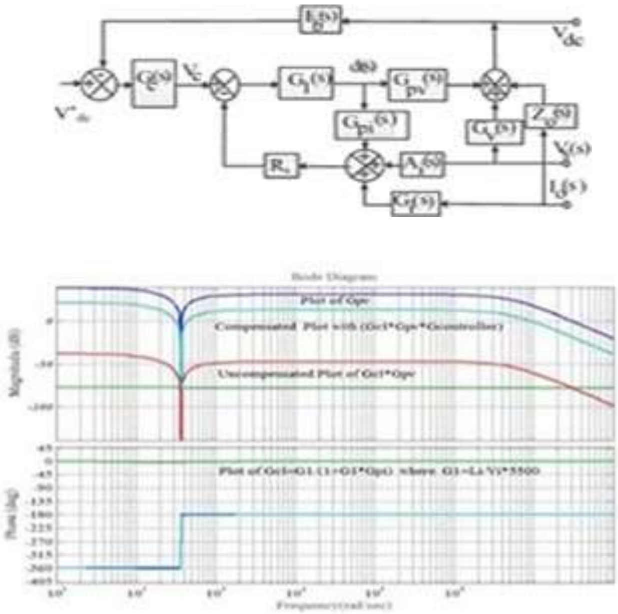
$$u_s(k)=\left|\frac{v_s(k)}{V_m}\right|; \quad i_{Li}^*(k)=u_s V_c(k); \quad i_{Li}^*(k)=u_s I_c(k)$$

Where U_s (k) is the unit template of supplyvoltage V_s (k) represents the amplitude of supply voltage at any instant k. This reference current i_{Li}^* (k) is compared with the sensed input current i_{Li} (k) to generate the PWM signal for PFC converter switch (SW_1). Based on state of battery charge, the selection of constant current (CC) or constant voltage (C V) mode is carried out. The charging cycle of a Li-ion battery(or a similar battery) consists of a constant- current mode and a constant-voltage mode. To reflect these two modes, the design of control block contains two feedback paths as shown in Fi g.1. One feedback path regulates the battery voltage in the CV mode. The voltage obtained is compared with the reference to regulate the loop. The second feedback path regulates the battery current in the CC mode. At a time one method isimplemented via mode selector block which depends on the state of battery charge. Small signal model is obtained by state space averaging, perturbation and linearization ofconverter. Accordingly we get,

$$\frac{\hat{i}_L(s)}{\hat{d}(s)} = \frac{2V_{in}[m_3s^3 + m_2s^2 + m_1s + m_0]}{(1-D)^2 C_1 L_i L_{o1}[b_4s^4 + b_3s^3 + b_2s^2 + b_1s + b_0]}$$

$$\frac{\hat{v}_{DC}(s)}{d(s)} = \frac{24V_{in} L_i L_{o1} C_1 R_o^2 C_o^2 [a_3s^3 + a_2s^2 + a_1s + a_0]}{(1-D)[b_4s^4 + b_3s^3 + b_2s^2 + b_1s + b_0]}$$

where(ao,a1,a2,a3,bo,b1,b2,b3,b4,mo,m1,m2,ma re the coefficients. The block diagram describing the closed loop current mode control is given by Fig.



Block Diagram of current mode controlled converter (a) Control block diagram (b) Bode plot of compensated and uncompensated system Where, Gpv(s) is the duty-cycle to output voltage transfer function given by equation (4), Gpi(s) isthe duty-cycle to inductor current transfer function given by equation (5), G1(s) is called the current error to duty cycle transfer function given by,

$$G_1(s) = \frac{Li}{V_i T_s R_s}$$

Where, Rs is the sense resistor. The control voltage to duty cycle transfer function Gd(s) generated by the internal current loop is given by following equation,

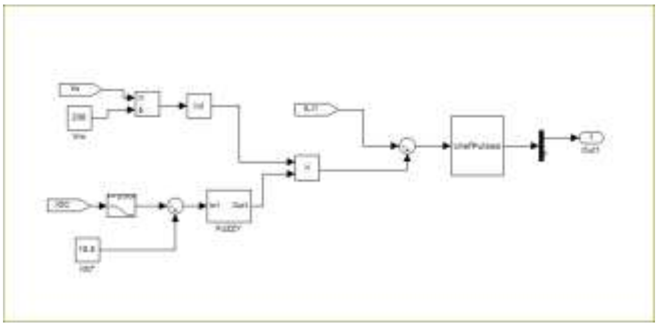
$$G_d(s) = \frac{\hat{d}(s)}{\hat{v}_c(s)} = \frac{G_1(s)}{1 + G_1(s).G_{Pi}(s).R_s}$$

The transfer functions of other blocks in the block diagram are Gc(s): transfer function of the compensator; Ai(s): input voltage to inductor current transfer function; Gi(s) output current to inductor current transfer function; Zo(s) output impedance. Gv(s) is the audio susceptibility. The change in input and output voltage is assumed tobe negligible over a switching cycle neglecting the feed-forward gains. Thus the compensator transfer function Gc(s) is designed based on the open loop gain given by Gc(s).Gd(s).Gpv(s).Fb(s). The design of Gc(s), to the meet the transient and steady state response is carried out by frequency response method meeting the sufficient phase margin with gain cross over frequency of 600 radians/secondas shown Fig. by the bode plot.

Proposed System:

Fuzzy Logic System:

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problemswith many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra. This paper contains a basic overview of the principlesof fuzzy logic. Today control systems are usually described by mathematical models that follow the laws of physics, stochastic models or models which have emerged from mathematical logic. A general difficulty of such constructed model is how to move from a given problem to a proper mathematical model. Undoubtedly, today"s advanced computer technology makes it possible; however managing such systems is still toocomplex.

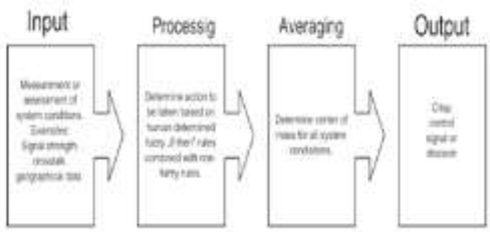


FUZZY LOGIC CONTROLLED SIMULINK DIAGRAM

The fuzzy logic analysis and control methodsshown in Figure can be described as:

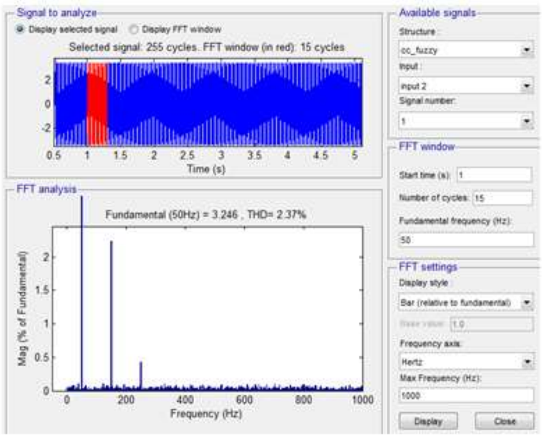
1. Receiving one or large number of measurements or other assessment of conditions existing in some system that will be analyzed or controlled.
2. Processing all received inputs according to human based, fuzzy "if-then" rules, which can be expressed in simple language words, and combined with traditional non- fuzzy processing.
3. Averaging and weighting the results from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The result output signal is a precise defuzzified value.

The following is Fuzzy Logic Control/AnalysisMethod diagram.

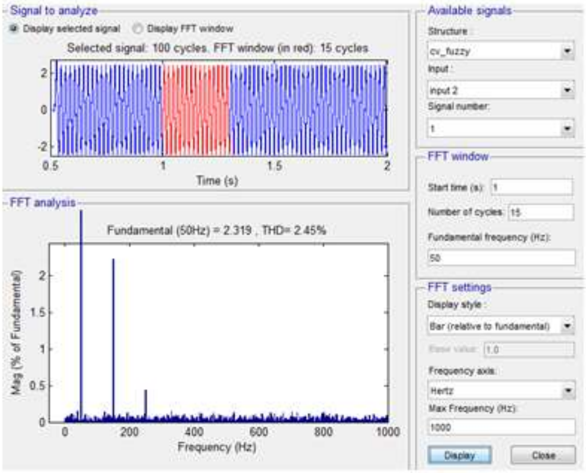


STIMULATION RESULTS:

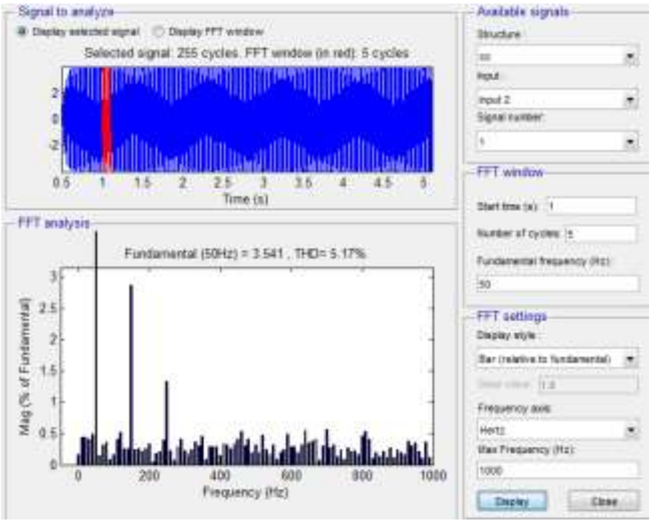
Constant current THD with Fuzzy



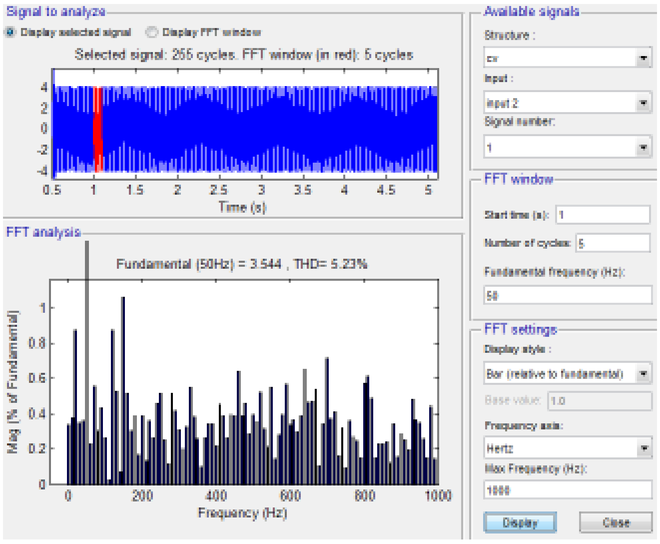
Constant voltage THD with Fuzzy



Constant current THD with PI



Constant voltage THD with PI



CONCLUSION:

The switched inductor CUK converter basedimproved power quality AC-DC converter isproposed for battery charging application. The design, simulation and hardware implementation of proposed converter are carried out. The simulation results are obtained under various loading conditions and results demonstrate that theproposed converter is able to provide regulatedoutput voltage irrespective of supply and load variations. The power quality indices like THD and PF at ac side are evaluated to assess the powerquality performance of the converter. Theconverter is evaluated both under steady state and transient conditions. In battery charging application, the power quality indices are also evaluated both in CV and CC mode of batterycharging and recorded. The simulation results showed good steady state and transient performance under load and source voltage disturbances. Therefore, it is well suited for various applications requiring power at high current at reduced output voltage such as battery charging for electric vehicles / EHV.

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