DESIGN AND IMPLEMENTATION OF PARALLEL MULTI STAGE DC –DC CONVERTER FOR WELDING APPLICATION

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Abstract: *This work focuses on the design and implementation of hybrid controller for parallel DC- DC converter intended for direct current (DC) Arc welding application. In this work Parallel multi phasing Topology of DC- DC converter is considered to ensure current sharing between the converters with reduced stress. The proposed hybrid controller combines the advantages of proportional integral controller at steady state and fuzzy logic controller at transient state. A complete comprehensive simulation of proposed controller is carried out and results indicate the dynamics of proposed system is robust with sudden variations in load. Experimental studies justify the application of hybrid controller for welding applications.*

Key words: *DC Arc welding, Fuzzy logic Controller, Hybrid controller, Parallel converter, PI controller*

1. Introduction.

The power source of welding decides welding quality, technical and economic characteristics of welding [1, 2]. The welding power supply with DC output provides high stability [3].Conventional dc welding sources employ uncontrolled diode bridge rectifier with a bulky dc-link capacitor in the front end followed by an inverter rectifier combination at the load end [3]. To improve the input power quality front end converter topology has been proposed in [3]. Detailed analysis of literatures highlight the merits of DC-DC converter for high current welding applications [4].

Parallel operated DC to DC converter have several advantages like low stress on semiconductor devices, reliable, high current carrying ability and good thermal conductivity. Researchers have explored the use of coupled inductor for parallel connected Single-Ended Primary Inductor Converter (SEPIC) topology [5]. In [6] interconnection concept of two (or more) series-parallel resonant converter suitable for parallel/series connected inputs is explained. It is in this perspective this work focuses on parallel multi stage converters for welding applications.

The controller design is vital for ensuring desired operation of the power converter. A dual-loop

Control scheme is utilized to incorporate over current protection and regulate dc voltage. The integration of voltage and droop current sharing controller with small signal modelling of parallel DC/DC converter system is discussed in [7]. The fault tolerant capability of parallel converters and their merits are discussed in detail in [8, 9]. A robust controller for parallel dc–dc buck converters by combining the concepts of integral-variable-structure and multiple-sliding-surface control is explained in [10]. The adaptive control of parallel DC to DC buck converter is discussed in [11].Bifurcation behavior in parallel-connected buck converter to enable stable current sharing is explained in [12, 13]. In [14] the implementation of PID and fuzzy logic controller for DC-DC buck converter using digital signal processor is explained. A new mixed modulator for parallel converter that combines interleaving and spread-spectrum techniques in order to achieve the lowest level of conducted EMI generation is discussed in [15]. The design of fuzzy controller to reduce the current ripples is discussed in [17, 18]. Control method for equal current sharing with linear and nonlinear load for three phase parallel converter is explained in [19]. An intensive analysis of various literature acknowledge that fuzzy Systems provide better response under transient conditions while a conventional PI controller works well in steady state. It is in this context this paper discusses a hybrid fuzzy PI controller for Parallel multi stage buck fed cuk Converter.

1. Description of Parallel Buck Fed cuk Converter

A. Description of Buck Fed cuk Converter

Parallel buck fed cuk converter block diagram is shown in Fig. 1 where output of first converter is given to second converter. Therefore two stage voltage reduction take place and range of controllable duty radio will increase. Voltage stress on IGBT under turn off condition reduces. Since buck fed cuk converter are connected in parallel entire load current get divided into number of parallel stage. Paralleling of converter will reduce current crowing under turn on condition and thermal stress.

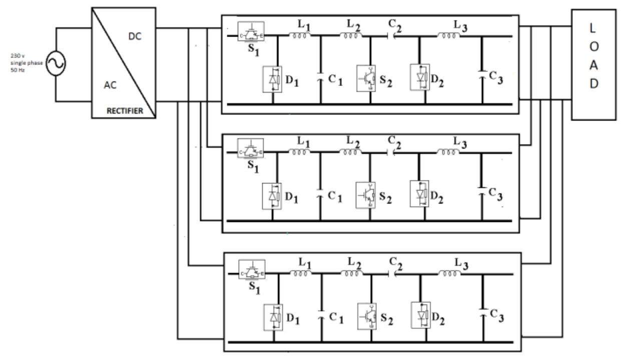

Fig. 1.Block diagram of the parallel buck fed cuk converter

The buck fed cuk converter consists of two IGBT named S1 and S2. Also two fast recovery diode D1andD2 used as freewheeling action when corresponding IGBT is in turn off condition. L1 C1 and L2 C2 of corresponding inductor and capacitor stage 1 and stage2 respectively which is shown in Fig. 2. There are five modes of operation under continuous conduction mode. Fig.2 (a), Fig.2 (b), Fig.2 (c), Fig.2 (d) and Fig.2 (e) shows the different mode of operations.

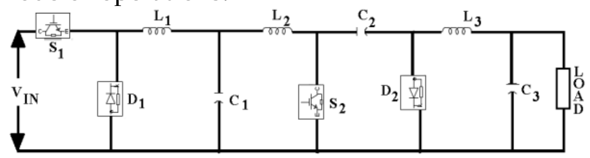

Fig. 2. Buck fed cuk converter

Mode I:

In this mode both S1 and S2 is turned ON. The current through the inductor L1 and L2 rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it. L is used to transfer energy from the input to the output of the converter.

$$V_{L1} = V_{in} - V_{c1} \quad (1)$$

$$V_{L2} = V_{c1} - V_{c1} \quad (2)$$

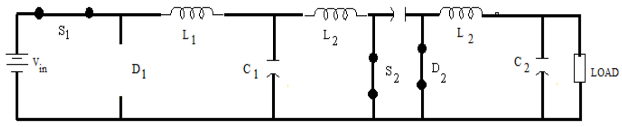

Fig.2(a) Mode I

Mode II:

In this mode S1 remains ON and S2 is turned OFF. The current to the load is only discharging of capacitorC2, L1 is connected to in supply, diode D1 is reversed biased and D2 is forward biased, L2 transfer energy to load.

$$V_{L2} = -V_{c1} \quad (3)$$

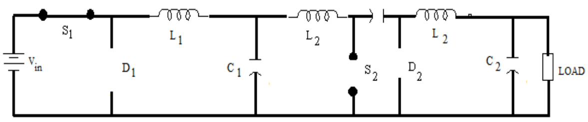

Fig.2(b) Mode II

Mode III:

In this mode both S1 and S2 is Turned OFF. This mode is continuous of mode II, with respect to load same condition continuous.

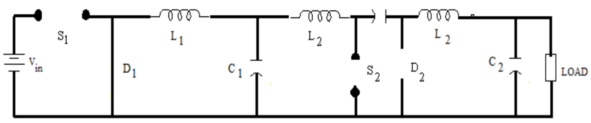

Fig.2(c) Mode III

Mode IV:

In this mode S1 is OFF and S2 is turned ON so what stored on L1 will be transferred to second stage. D1 forward biased an1d D2 is Reversed biased.

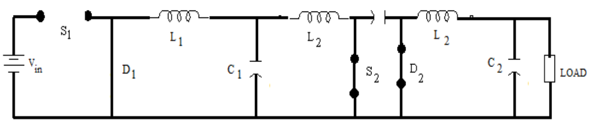

Fig.2(d) Mode IV

Mode V:

This is the last mode which is same as mode III, both S1 and S2 OFF and both D1 and D2 are forward biased. Only in MODE I source is connected to load, various switching pattern is shown in Fig.3.

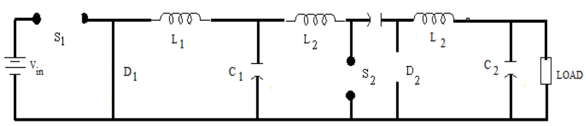

Fig.2(e) Mode V

B. Design of Buck fed cuk Converter:

The key parameters in design of buck converter are input voltage V in, output voltage V out, maximum output current I load, switching frequency of power IGBTs fsw.

(i) Inductor design:

The equation for the right inductor calculation is

$$L = \frac{V\_out \times (V\_in - V\_out)}{(I\_ripple \times f\_sw \times V\_in)} \quad (4)$$

After rearrange and substitute

$$L = \frac{D \times (V\_in - V\_out)}{(I\_ripple \times f\_sw)} \quad (5)$$

For the inductance, the appropriate wire diameter of the inductor should be selected. The maximum output current of the design, decides the wire diameter of the inductor. Equation to get the maximum output current is given by.

$$I_{\max} = I_{load} + \left(\frac{I_{ripple}}{2}\right) \quad (6)$$

To avoid the overload of the inductor, the current rating of the inductor is chosen with respect to the maximum current.

(ii) Capacitor design

The voltage ripple across the output capacitor is the sum of three parts. One is due to the Effective Series Resistance (ESR) of the capacitor, other is due to the Effective Series Inductance (ESL) of the capacitor and the third is the third is the voltage drop due to the load current that must be supplied by the capacitor as the inductor is discharged. The capacitor ESR value can be selected from data sheet. ESL value is taken as zero.

$$\Delta V = I\_ripple \times ESR + \left(\frac{I\_ripple \times ESL}{T\_on}\right) \quad (7)$$

$$T_{on} = \frac{D}{f_{sw}} \quad (8)$$

As mentioned before, assume ESL=0, Simplify the equation

$$V = I\_ripple \times ESR + \left(\frac{I\_ripple \times T\_on}{C\_out}\right) \quad (9)$$

Therefore

$$c\_out = \left(\frac{(I\_ripple \times D / f\_sw)}{(\Delta V - I\_ripple \times ESR)}\right) \quad (10)$$

Cout is the minimum output capacitor I ripple is the estimated inductor ripple current ΔV is the desired output voltage ripple D is Duty Cycle of the Buck converter Fsw is minimum switching frequency of the Buck converter, generated by drive circuit.

2. Hybrid FUZZY PI Controller for Parallel Converter

This section contemplates the application of hybrid Fuzzy PI controller for wilding application combining the advantages of PI controller at steady state and fuzzy controller during transient state. The block diagram of hybrid controller has been represented in Figure 5. A simple logical switching mechanism is employed which changes the control action from one controller to another controller based on the voltage error value. The conventional PI controller is operated at steady state condition while fuzzy is operated when the system undergoes transient or overshoot behavior. The input voltage error (e) and change in voltage error (ce) to the fuzzy logic controller are divided into seven linguistic variables: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), and Positive Big (PB) shown in table.1. The linguistic variables for the output are ZE, PS, PMS, PM, PLM and PL represent Zero, Positive Small, Positive Medium Small, Positive Medium, Positive Large Medium and Positive Large respectively.

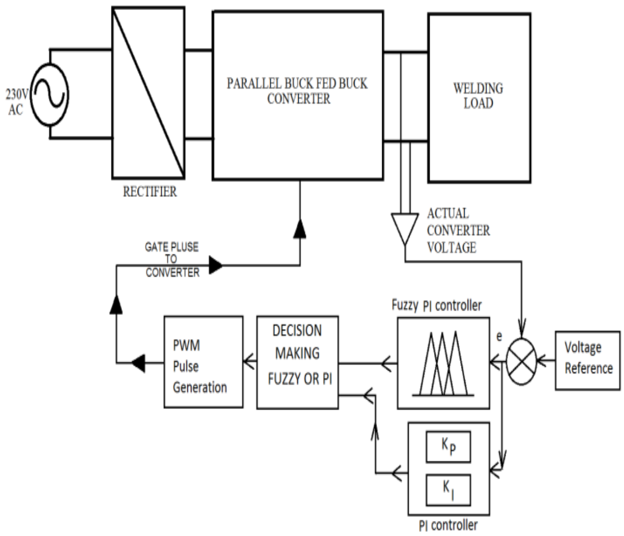

Fig. 5.Proposed hybrid system

A. Design of Fuzzy Logic Controller

Design of fuzzy controllers is based on expert knowledge of the Converter. There are two inputs for the fuzzy controller for the buck converters. The first input is the error in the output voltage given, where OV[k] is kth sample of the output voltage and VR is the desired output voltage. The second input is the difference between successive errors and is given by

$$e[k] = VR - OV[k] \quad (11)$$

$$ce[k] - e[k] - e[k-1] \quad (12)$$

The first step in the design of a fuzzy logic controller is to define membership functions for the inputs. Seven fuzzy levels or sets are chosen and defined by the following library of fuzzy-set values for the error e and change in error Ce.

The control rule for the dc-dc converter is shown in the Table.1. A typical rule can be written as follows. If e is NB and de is PS then output is ZE where the labels of linguistic variables of error (e) are, change of error (de) and output respectively, de and output represent degree of membership.

Table. 1 Rule Base for Membership Function

e \ de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	ZS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

B. Flow Chart

The process of Hybrid Fuzzy PI controller is based on the error voltage from the converter. The conventional PI controller is active when the voltage error is less than 5 volts whereas the hybrid controller is active when the error is greater than 5 volts. The working of the controller is depicted in figure 6.

4. Result and Discussion

MATLAB software is used to validate the performance of various controller on parallel buck fed cuk converter. Performance of proposed converter is simulated in open loop, closed loop with PI, fuzzy and hybrid systems. Steady state error, rise time and output ripple are considered as performance measure for evaluating the performance of various controller. Fig.7. shows output voltage waveform of converter operated under open loop. The point 'a' shows the instant at which load is applied and the disturbance in waveform that is voltage drop to zero. At point 'b' (15sec) change in load there is a drop in voltage is12V, steady state error is 3V.

The closed loop current response and voltage response with various controllers is depicted in Fig.8 and Fig. 9 respectively. The steady state and dynamic characteristics are analyzed with respect to the points 'a', 'b', 'c', d' and are tabulated in Table2.

From the simulation it is evident that the proposed hybrid controller is robust and has better steady state and fast dynamic response which is the requirement in DC welding application.

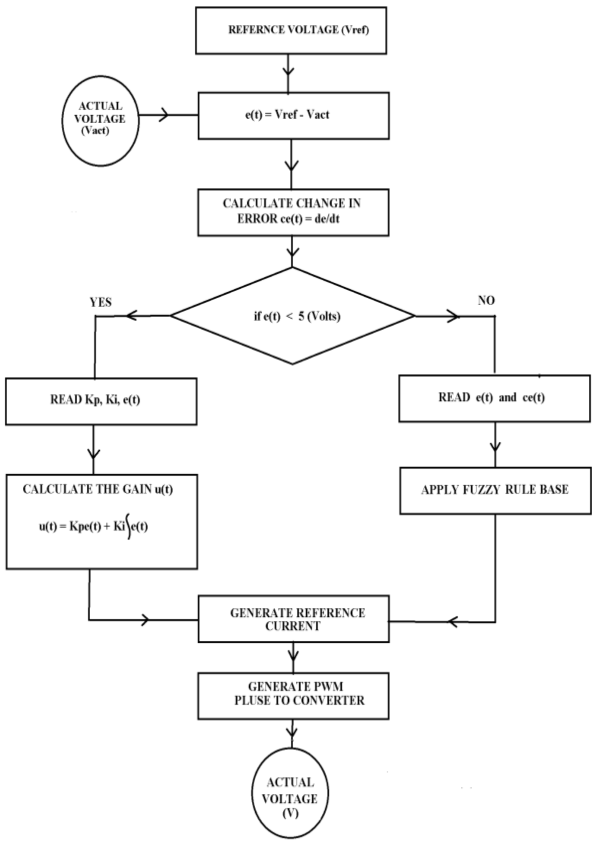

Fig.6. Flow chart of Hybrid system

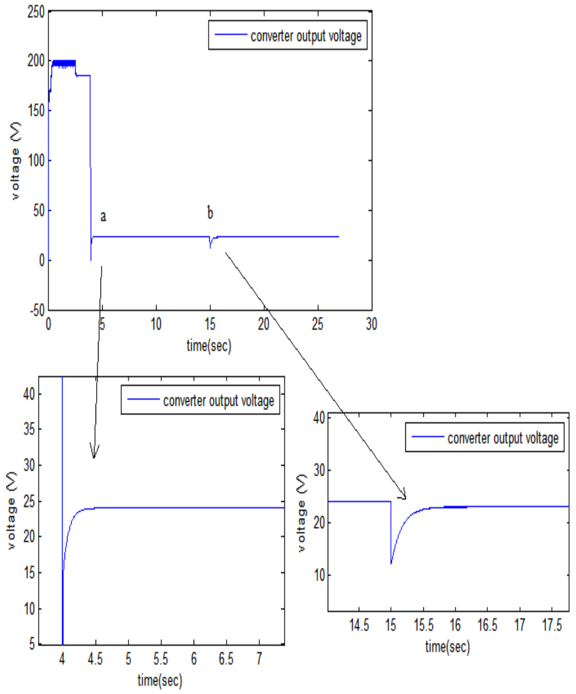

Fig.7.open loop output voltage

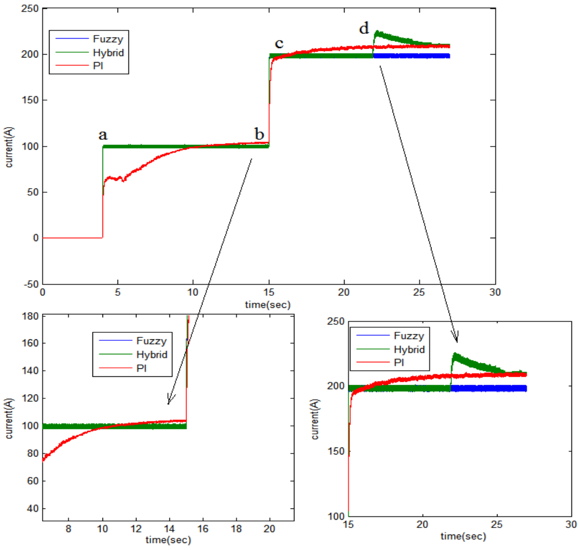

Fig. 8.current waveform due to various controller

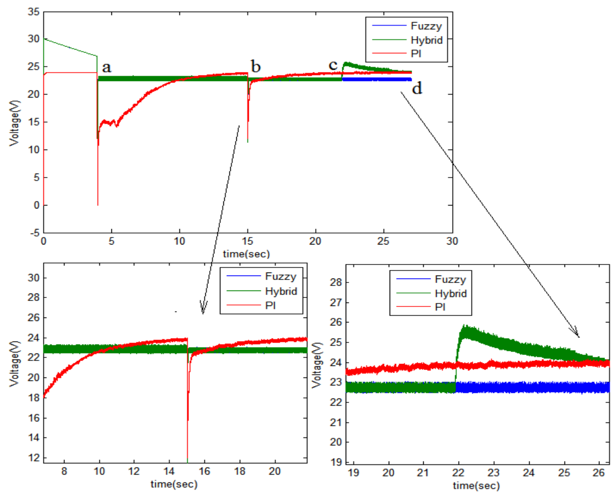

Fig.9. Output Voltage Waveform of various controller

PERFORMANCE PARAMETER	CONTROLLER TYPE		
	PI	FUZZY	HYBRID
Rise Time(sec) (output current)	0.2	.05	.04
Steady-State (sec) Value(current)	208	198.5	210.5
Steady-State (sec) Value(voltage)	23.9	22.75	24
Output Current Ripple(A)	3	5	2.5
Output Voltage Ripple(V)	0.3	0.5	0.25

5. Experimental Analysis

The experimental setup of Buck fed cuk converter is shown in Fig.10. Hybrid algorithm is implemented using PIC16F877A micro controller from microchip. The Voltage output from converter is taken as feedback and given to microcontroller through port A, with the code return in pulses are generated which is shown in Fig.11. The experimental voltage and current are scaled down version of simulations. Hardware model is designed for 1.4A which is shared by parallel converter as 0.7A. Input Voltage from diode rectifier of 45.6 V is passed to filter is given as converter input shown in Fig.12, output current waveform of converter is shown in Fig.13.

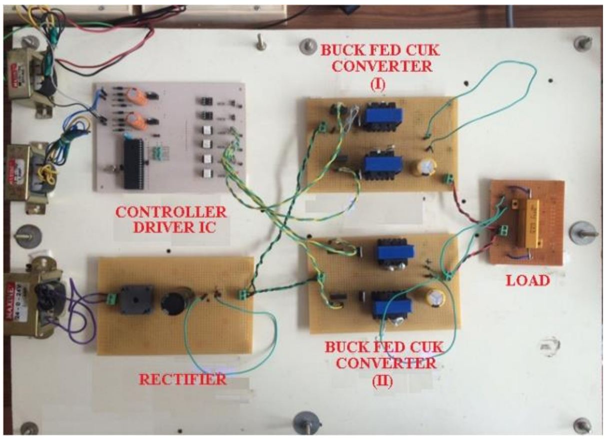

Fig.10. Hardware setup

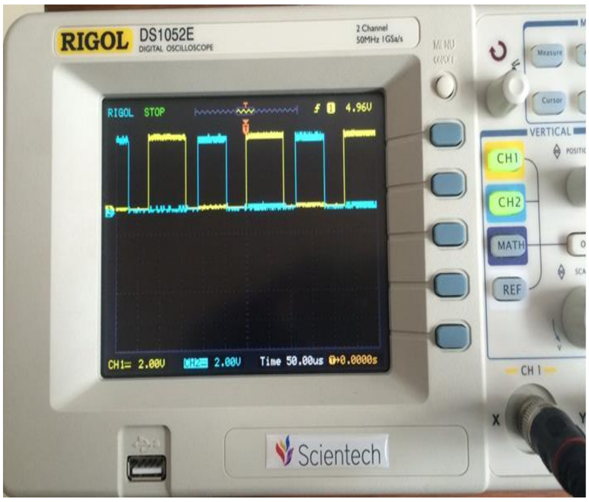

Fig.11. Pulse pattern before driver

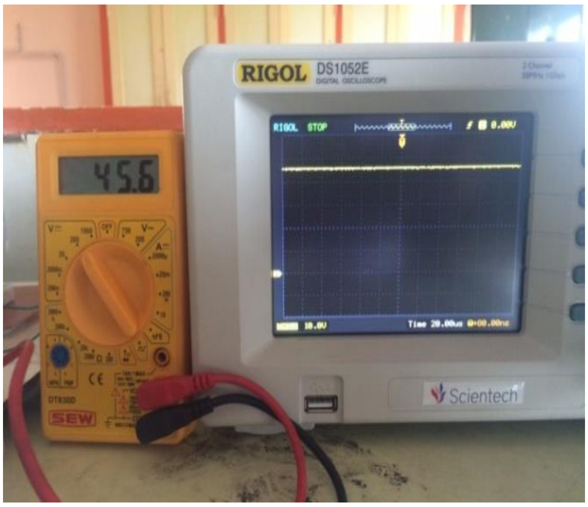

Fig.12.Input voltage to converter

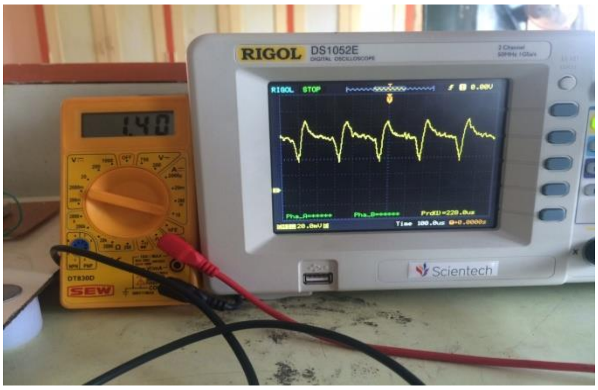

Fig.13.Output Current waveform

6. Conclusion

This paper proposes a hybrid fuzzy PI controller for parallel buck fed cuk converter for DC welding applications. The hybrid algorithm combines the merits of PI and fuzzy controller. The simulation results indicate the robustness of the controller. Hardware results validate the proposed controller for Parallel converter and justifies its application for welding application.

Appendix A

Parameter of the Simulation

STAGE	VALUES
I	F1=2.5 kHz, VIN=230V, VOUT=100V, IOUT=35A, VRDS,ON=3.5V,TON=177µs, IMIN=3.5A, L1=3.1994mH, C1=350µf
II	F2=5 kHz, VIN=100V, VOUT =24V,IOUT=35A,VRDS,ON=3.5V, TON=50.25µs, IMIN=3.5A L2=10mH, C2= 450µf C3=625 µf

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