Design of Controllers for Single-Input Dual-Output Synchronous DC-DC Buck Converter

S.Augustilindiya[#], S.Palani[*], K.Vijayarekha[#] and V.Sreenath[#]

[#] Department of Electrical and Electronics Engineering, SASTRA University
Tirumalaisamudram,Thanjavur,Tamilnadu 613401, India
[1]lindiya@eee.sastra.edu
[2]sreenathvenkatt@gmail.com
[*]Sudharsan Engineering College, Sathiyamangalam-622501,
Pudukkottai District, India

Abstract—**Design and control techniques for a Single Input Dual Output (SIDO) Synchronous DC-DC Buck Converter are presented. The advantage of this converter eliminates one MOSFET switch and its drive circuitry when compared to the conventional converter and in this system both output voltages are generated by the same integrated power converter. A Genetic Algorithm assisted PI controller is designed to maintain the output voltages to a constant value against load and line variations and compared with existing PI controller. The parameters of the controller are designed using various techniques like SISOTOOL (GUI), Internal Model Control and Binary Genetic Algorithm. The Discrete PI controller is also developed for the above converter. All the controllers are simulated using MATLAB and their performances are compared in terms of Peak overshoot, Rise time and Settling time. The system is also developed using real components and the results are obtained in open loop mode.**

Keywords— SIDO-Single Input Dual Output Synchronous DC-DC Buck Converter, SISOTOOL, IMC-Internal Model Control, Binary Genetic Algorithm, Discrete PI Controller

I. INTRODUCTION

DC-DC converters play an important role in the present day electronic systems and contribute the occupancy of the real estate of the Printed Circuit Board (PCB). Buck topology of DC-DC converters which reduce the supply voltage to a desired voltage contributes to the major number in an electronic system [1]. The size and weight of the PCB of the mobile electronic systems is to be minimized. Using few components with small size is desirable for compactness and low power consumption [1, 2]. In view of low voltage requirements of the electronic systems, synchronous converters are preferred for low losses [2]. An electronic gadget usually has more than one voltage rail and in many cases upto five. In this case number of Buck converters needed is equal to the number of voltage rails. The requirement of multiple voltage rails is due to different manufacturing technology and voltage specifications of different subsystems which has also reduced the power consumption of the overall system [3].To develop two output from single input,four switches are required in the conventional model as shown in Fig.1.SIDO type of Buck converters are used in low power applications like cell phone, microprocessors, wireless transceivers and PDA's etc [12] and also in high power applications like On-board distribution schemes where diverse dc voltages are required [5].The controller is essential to maintain the voltages constant against line and load variations.

This paper mainly considered the SIDO integrated power converter proposed in literature [5] with addition of Genetic Algorithm Assisted controllers, IMC tuned PI controller, Discrete PI controller and Hardware implementation.

II. CONVERTER MODEL

The SIDO buck [5] converter contains three MOSFET switches M_1, M_2 and M_s and two low pass filters are used (L_1, C_1 and L_2, C_2) as shown in Fig 2.

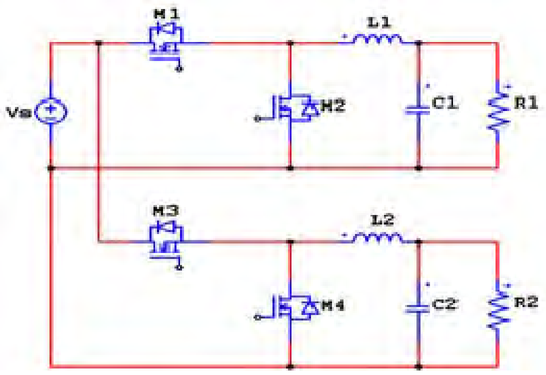


Fig.1 Conventional SIDO buck converter

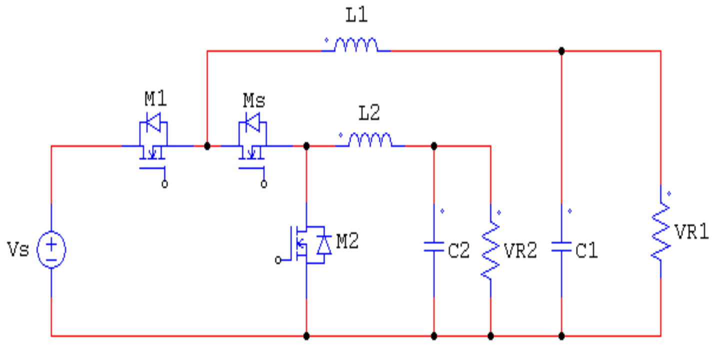
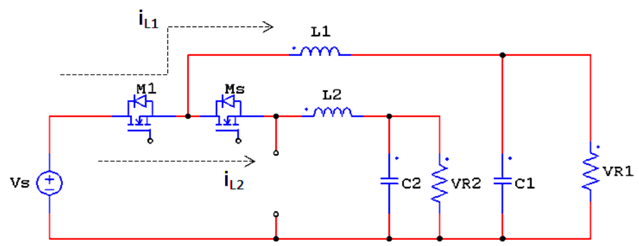


Fig.2 SIDO buck converter [5]

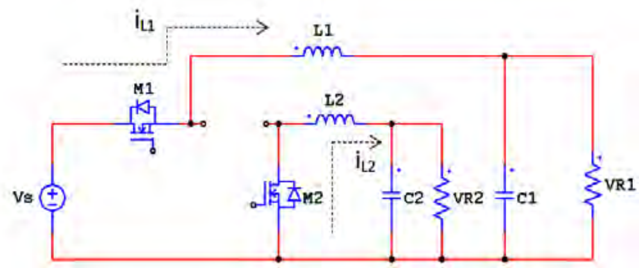
This converter has three modes of operation which is explained in Table 1:

TABLE I
Modes of operation [5]

Modes of operation	Switches in		Operation	Figures
	ON state	OFF state		
I	M_1, M_s	M_2	Both L_1 and L_2 are in charging condition	Fig.3(a)
II	M_1, M_2	M_s	L_1 is in charging condition and L_2 is in discharging condition	Fig.3(b)
III	M_s, M_2	M_1	Both L_1 and L_2 are in discharging condition	Fig.3(c)



(a)



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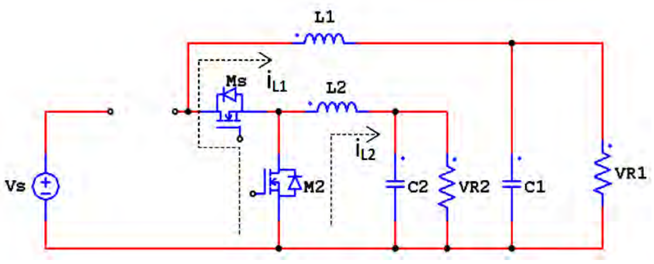


(c)

Fig.3 (a), 3(b), 3(c) Three modes of operation of the proposed converter [5]

From the operation of the converter, it is understood that the voltages V_{R1} and V_{R2} are controlled by the switches M_1 and M_2 respectively. The main purpose of the switch M_s is to avoid the source to be short circuited. The parameters of the converter are shown in Table.2.

TABLE II
Parameters of SIDO converter

S.No	Parameters	Ratings
1	Input voltage (Vin)	100V
2	Inductance (L_1 and L_2)	1mH
3	Capacitance (C_1 and C_2)	120µF
4	Load Resistance (R_1 and R_2)	10Ω
5	Switching frequency	50kHz
6	Duty cycle (D_1)	0.4
7	Duty cycle (D_2)	0.2
8	Output Voltage (V_{R1})	40V
9	Output Voltage (V_{R2})	20V

The converter is developed using PSIM® software and the output voltages are plotted in Fig.4 (a) and 4(b). The system is also expressed mathematically in S-domain and the open loop response is obtained in Fig. 5(a) and 5(b). This mathematical model is useful for obtaining the controller parameters.

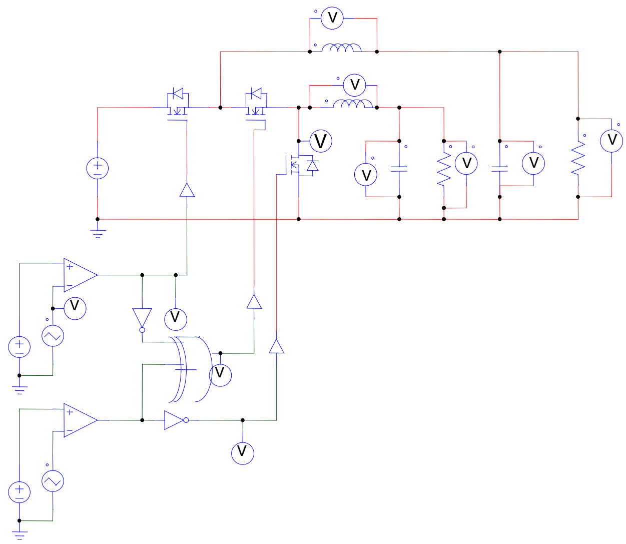


Fig.4 (a) Simulated circuit of SIDO converter using PSIM®

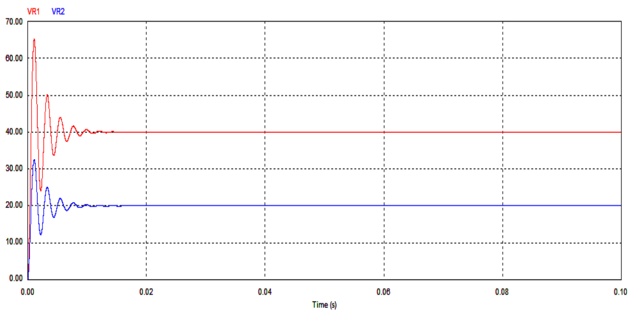


Fig.4 (b) Open loop output voltage waveform

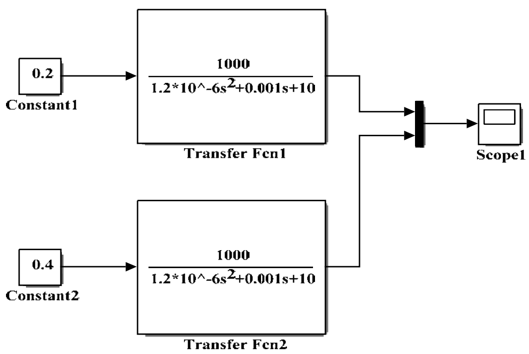


Fig. 5 (a) S - domain simulation model of SIDO converter

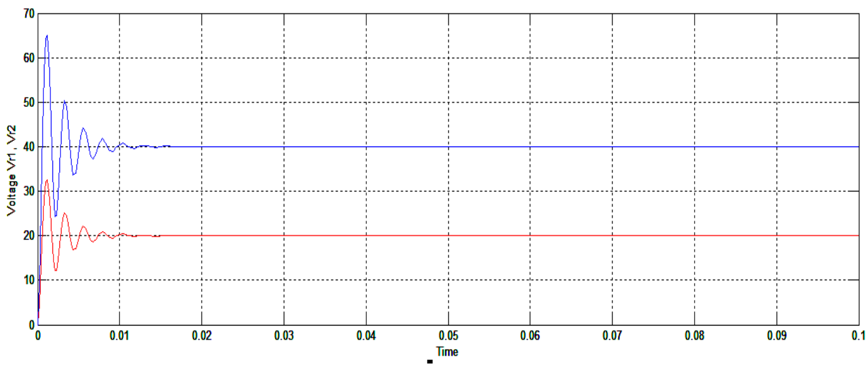


Fig. 5(b) Output voltage waveform of the S – domain simulation model

III. DESIGN OF CONTROLLERS

The PI controller is designed for the proposed single input dual output synchronous DC-DC buck converter to maintain these voltages constant against load and line variations. Here the parameters of the PI controller are designed using different techniques like SISIOTOOL® [6] in MATLAB®, IMC and Binary Genetic Algorithm. The Discrete PI controller is also developed for this SIDO buck converter. The performance of this different control techniques are analysed using the parameters like Peak Overshoot, Rise Time and Settling Time.

A. *SISOTOOL:* It is a Single Input Single Output (SISO) design tool available in the MATLAB® to tune the parameters of the controller using the Graphical User Interface (GUI). This controller design tool automatically designs the controller parameters for our plant or system i.e. the transfer Function of the system or plant has to be mentioned. The system is analysed with the design of controller using a variety of response plots like Bode plot, Root Locus plot and Nichols plot. These plots help to interactively adjust the design to meet our performance requirements and with this the controller parameters can be tuned for the PI controller of the power converter using the SISO feedback loops. The Fig.6 (a) and Fig.6 (b) show the root locus and Bode plots with the two output voltages of 40V and 20V waveform using SISOTOOL®.

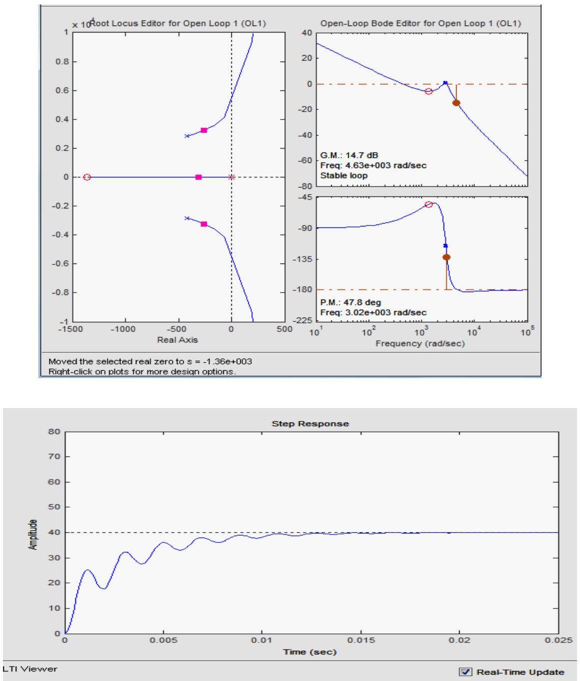


Fig.6 (a) Closed loop response of the SIDO conveter designedby SISOTOOL® using root locus and bode plots for output 40V

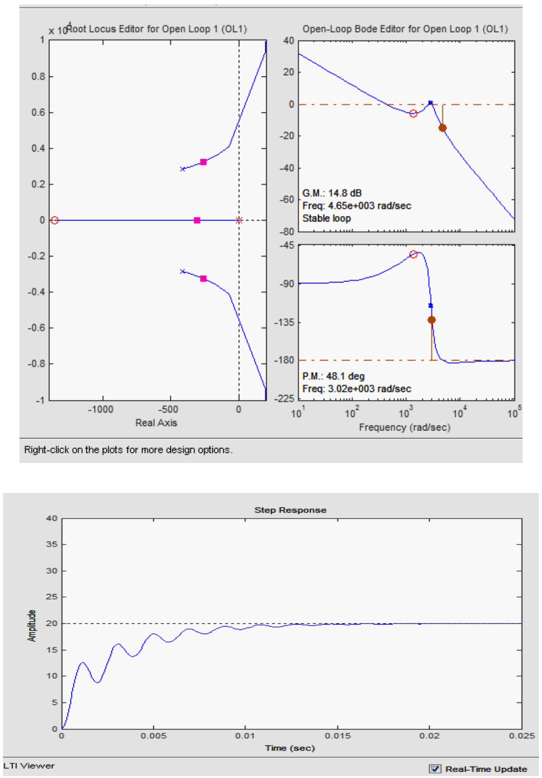


Fig.6 (b) Closed loop response of the SIDO conveter designed by SISOTOOL® using root locus and bode plots for output 20V

B. *Internal Model Control:* Here PI controller parameters are tuned by IMCTUNE algorithm available in MATLAB®. The inputs to the algorithm are the mathematical model of the converter, the portion of the model to be inverted by the controller and the filter time constant. The IMC filter time constant plays a major role. The filter time constant can be increased to a particular level in order to reduce the overshoot. The desired response is obtained, when IMC filter time constant is 0.002.

C. *Binary Genetic Algorithm:* The Binary Genetic Algorithm (BGA) is a global optimization technique which usually does not fall into local minimas in a minimization problem [8]. The design of PI controllers involve in minimization of rise time, peak overshoot, under shoot, ripples and settling time of the controlled system. BGA essentially searches for optimal parameters from an infinite solution space. In the search process, by Selection, Crossover and Mutation over generations finds the global optima [9]. The objective function of the system has to be initialised.

D. *Discrete PI controller:* The discrete PI controller is similar to the analog PI controller but it produce discrete signals with the required sampling time [10, 11]. The advantage of discrete PI controller is it will reduce the noise and disturbances in the signals so that the better results can be got and the efficiency is also increased.

IV.SIMULATION RESULTS

The Closed loop model of the Single Input Dual Output Synchronous DC-DC buck converter with the PI controller is simulated using MATLAB Simulink and it is shown in the Fig. 7.

The Fig. 8 (a), Fig.8 (b), Fig. 8 (c) and Fig.8 (d) show the SIDO converter output voltages using different techniques of PI controller like SISOTOOL®, IMC, Binary Genetic Algorithm and also the Discrete PI controller respectively.

The Transient response of the system is analysed by varying the input supply voltage. The Fig.9 (a) shows the behaviour of the converter under transients in the supply voltage, i.e., the first transient at t=0.06s with a step transient in supply voltage Vs from 100V to 120V, the second transient at t=0.12s with a step transient in Vs from 120V to 115V and the third transient at t=0.18s with a step transient in Vs from 115V to 100V. The Fig.9 (b) shows the step transient response for the load variation of R_1 in the transient period of t=0.04s, 0.08s and 0.12s respectively.

The comparative results of the various design of PI controller parameters is analysed with the performance parameters like peak overshoot, rise time and settling time are tabulated as in Table.III.

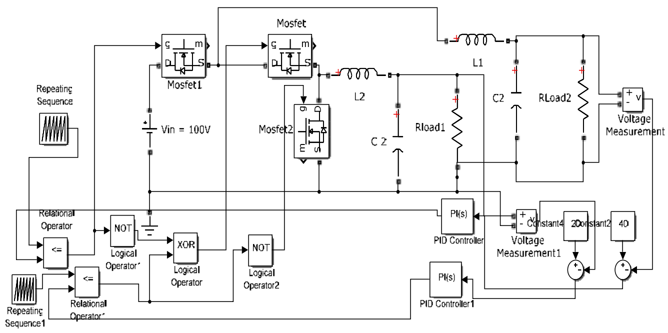
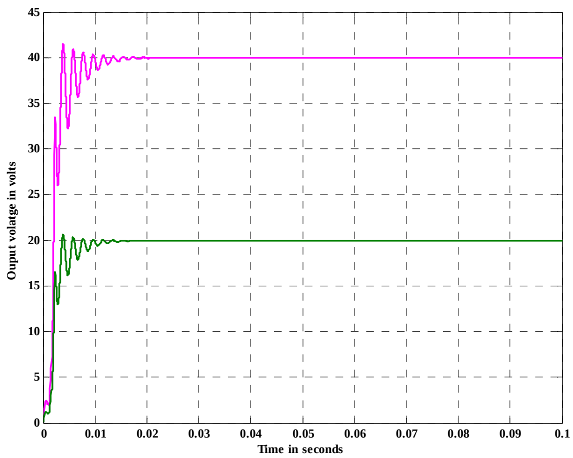
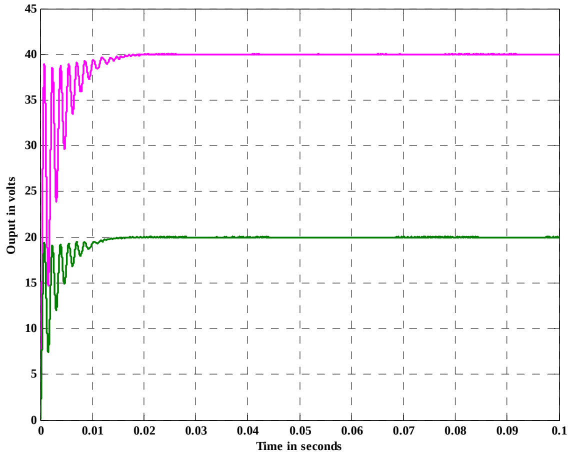


Fig.7 Closed loop circuit of SIDO converter



(a)



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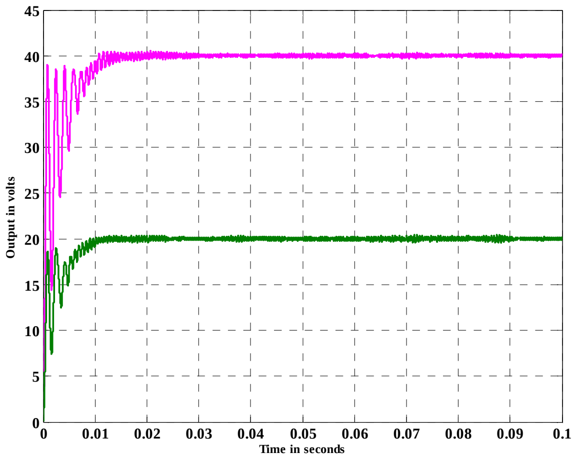

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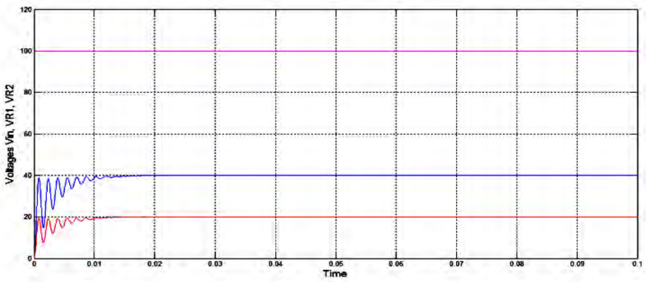
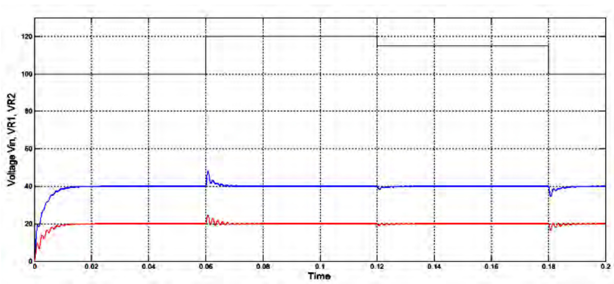
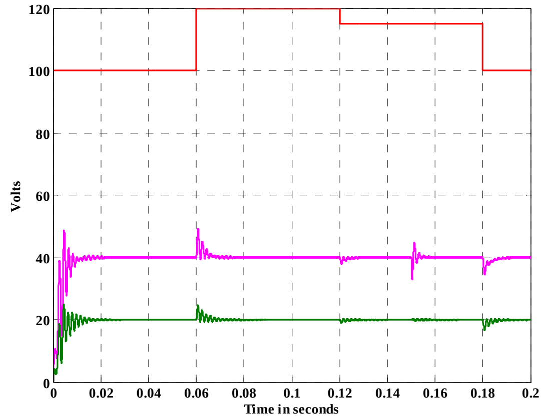


(d)

Fig.8. Simulation results of Input and Output voltages using (a) SISOTOOL, (b) IMC, (c) Binary Genetic Algorithm and (d) Discrete PI controller



(a)



(b)

Fig.9 Step transient response during the line and load variations

TABLE III
Comparison of results

Performance Parameter	**PI controller design using**						**Discrete PI controller**	
	SISOTOOL		**IMC**		**Binary Genetic Algorithm**			
	40V	**20V**	**40V**	**20V**	**40V**	**20V**	**40V**	**20V**
Peak overshoot (V)	41.52	20.63	48.5	20	39.05	18.64	38.90	19.36
Rise time (ms)	3.4	3.4	4.7	3.48	0.69	0.78	0.65	0.67
Settling time (ms)	9	9	10	10.2	9.75	8.8	9.7	9.7

IV. Experimental Results

The Fig. 10 shows the block diagram representation of the hardware circuit in open loop mode. The PIC microcontroller is used to obtain the gating pulses for the switches.

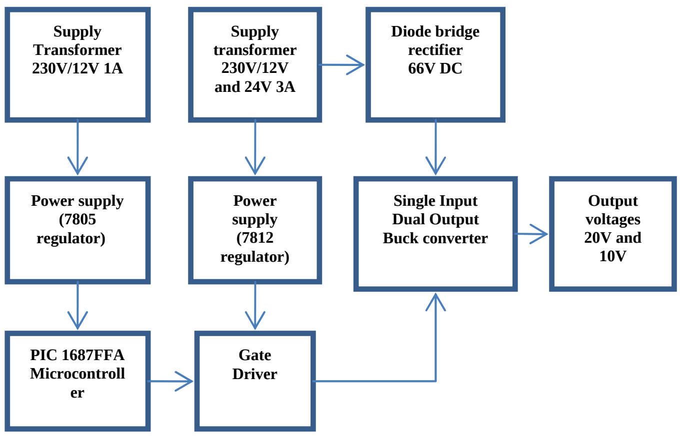


Fig.10. Block diagram representation of hardware circuit

The components used in the hardware circuit are displayed in the Table. IV.

TABLE IV
Hardware components

S.No	Components	Specifications
1	MOSFET	IRFP250N
2	Regulator	7805 and 7812
3	Diode Bridge Rectifier	GBJ2510
4	PIC microcontroller	1687FFA
5	Opto coupler	MCT2E

The schematic representation of the hardware is shown in Fig.11&12.The results of SIDO in open loop mode are shown in Table V.

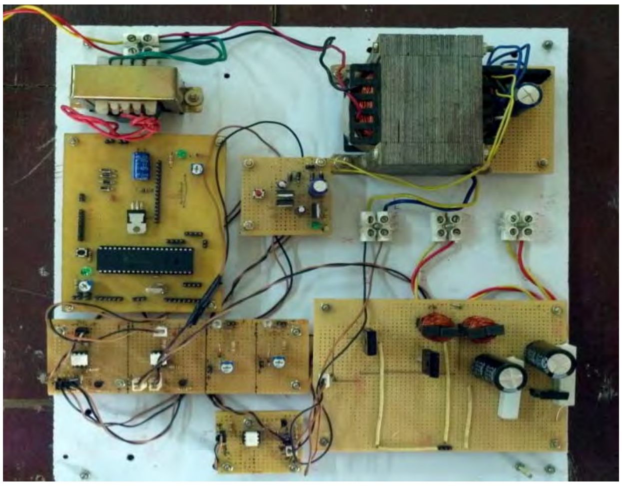


Fig.11. Hardware implementation of SIDO converter

Fig.12 Gating pulse for the switch

TABLE V
Hardware output

Input Voltage (Vin)	Output voltage (V_{R1})	Output voltage (V_{R2})
66V	20V	10.8V

V. CONCLUSIONS

This paper presented the controller design for the SIDO synchronous DC-DC buck converter. The design of PI controller is done for this power converter with various techniques of controller parameter design like SISOTOOL®, IMC and Binary Genetic Algorithm. The Discrete PI controller is also developed for this power converter. The comparative results of different controller parameter techniques are analyzed and also the transient step response is analyzed with the line and load variations The Simulated results are exposed to reveal the stability of this power converter. The experimental results in open loop mode are also observed.

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