IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 1, March, 2013
ISSN: 2320 - 8791
www.ijreat.org

Three Switch Control of Dual Output Synchronous Buck Converter

Bhuvanapriyan S[1], Ramamurthy S[2] and Hemalatha N[3]

[1] **Master of Power Electronics and Drives Engineering, Meenakshi College of Engineering, Chennai, 600078, India**
[2, 3] **Electrical and Electronics Engineering, Meenakshi College of Engineering, Chennai, 600078, India**

Abstract
The growth of portable electronic devices has been in rapid change towards more compatible and compact devices with much functionality such as wireless devices and mp3 players. The application, requiring power to be supplied from the batteries, needs more efficient converter to supply specific power with very high efficiency for long run time. The direct solution of dual output buck converter uses four switches. In this report a single input dual output synchronous buck converter is used to produce the two required output of 5V and 3.3V using three switches. In the converter maximum area is occupied by passive components such as inductor and capacitor. Operating converter in higher frequency reduces the size of passive components. The efficiency is improved by controlling converter so that ripple content is less. A PID controlled single input dual output synchronous buck converter is discussed in this work. Modulation, control strategy and Simulation result showing open and closed loop characteristics and stability of system is presented

Keywords: *Synchronous Buck Converter, High Efficiency, PID Controlled, Dual Output, High Frequency Operation*

1. Introduction

The portable electronic devices growth has been in rapid change towards more compatible and compact devices with multiple functionalities such as wireless devices, mp3 players which requires power to be supplied from the batteries needs more efficient converter to supply specific power with very high efficiency for long run time and also a converter which needs to adjust itself dynamically to supply voltage at different blocks.

Switched mode power supply (SMPS) is used as regulator for battery voltage. Single input dual output synchronous buck converter is used to produce the two required output of 5V and 3.3V. Synchronous buck converter with reduced conduction losses replaces normal buck converter, having a diode (Robert W. Erickson and Dragan Maksimovic, 2001). The direct solution of dual output buck converter uses four switches is reduced to three switches (dos Santos E.C Jr, 2012 and P Kumar etal. 2008). In the converter maximum area is occupied by passive components such as inductor

and capacitor. Operating converter in high switching frequency reduces the size of passive components.

Operating at high switching frequency is also used for mobile applications requiring high current for short duration Systems which require sudden increase of power from base level to peak needs very fast speed of response apart from good regulation from supplies.

2. Conventional Dual Output Buck Converter

Dual output power converter finds lot of application from medium power range power supplies to digital systems. Dual power output approach is to regulate dual outputs from a common dc bus. Forward converter with dual secondary windings and regulate only one output. This leads to poor load regulation in other outputs. The number of passive components will be increased to regulate each outputs separately.

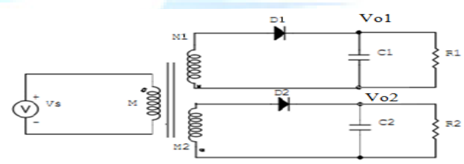


Fig. 1 Circuit diagram of basic dual output topology

The use of two transformers for dual output is commonly used because of its simple approach; however a transformer is needed even if isolation is not required. Use of two secondary windings in transformer leads to problem of cross regulation due to leakage inductance, forward voltage drop of diodes and series resistance of the windings. With this approach, the flyback configuration has least number of components but it too has the problem of cross regulation. Dual output forward converters have one transformer and either one or two inductors per output.

Conventional dual output synchronous buck converter has four switches shown in fig.2. In which two switches S1 S2 is controlled for first output Vo1 and switches S3 S4 is controlled for output Vo2 respectively by changing the duty cycle of switches we can change the output of Vo1 and Vo2 Depending on the increase and decrease of output duty cycle of respective switches of output is controlled. The switching condition ON and OFF state of switch pairs S1 S2 and S3 S4 does not depend on each other but switches S1 should be ON when S2 is OFF and vice versa. Also switch S3 ON and OFF state depends on switch S4.

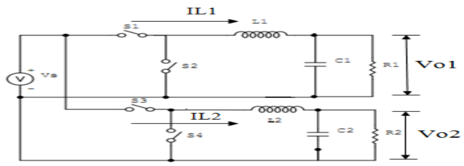


Fig. 2 Conventional dual output buck converter topology

3.Single Inductor Dual Output Buck Converter

The single inductor dual output topology shown in fig.3, which is having four switches and single inductor, reduces the use of two inductors supplying to two outputs. Instead, the inductor sharing the time with switches S3 and S4 of two outputs. Consider D1 D2 D3 D4 is the duty ratio of switches S1 S2 S3 S4 respectively. Depending on the duty ratio of two switches the output Vo1 and Vo2 varies.

If D3 > D4 then Vo1 > Vo2 (7)

If D4 > D3 then Vo2 > Vo2 (8)

Here since there is four switches all must be controlled for giving desired output. Initially when switch S1 is closed S2 is open thus allows current to flow through L1L2 and stores voltage in C1C2.we can use PWM or any control method to produce Output across Vo1 by making switch S1 S3 closed S2 S4 open and output Vo2 is produced when S2 S4 closed S1 S3 open.

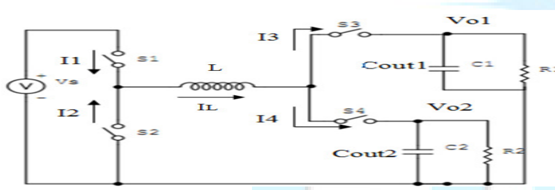


Fig. 3 single inductor dual output topology

In the above converter the inductor current IL is the sum of two output currents I1 and I2.A main duty cycle D1 can be defined respectively as follows

D1=Ton, S1/T (9)

D3=Ton, S3/T (10)

If the buck converter operates in the CCM from the inductor point of view, currents I3 and I4, delivered to the output capacitors Cout1 and Cout2, respectively, are discontinuous. Indeed, during the discontinuous periods, the output capacitors provide the current to two loads. Apart from its advantages due to four switches the control is little difficult.

4.Three Switch Topology

The conventional single output buck converter needs two switches in the case of replacing diode with switches shown in fig.4. So for the application of dual output synchronous buck converter conventional topology needs four switches. This four switch topology is reduced in to three switches by changing the topology. Which will in turn reduce switching losses thus improves efficiency of the buck converter. In this single input dual output buck converter having three switches of S1 S2 and S3 with two inductors and two capacitors. For implementing logic we assume 1 and 0 for ON and OFF state of conductor.

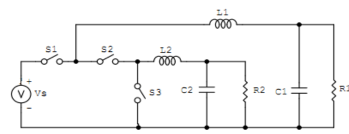


Fig.4 Three switch synchronous buck regulator

4.1 Converter Operation

Converter has three switches the combination will provide eight operating conditions. In which only three conditions possible to operate. In this we can note that the switching time of S1 is always higher than S2 and S3. When these switches operate there will be flow of current and voltage across the two inductors. The value of inductor and input voltage and current decides the charging and discharging time of current and voltages in the inductor L1 and L2. The waveform showing voltage VL1 VL2 and currents IL1 IL2 associated with the converter related to ON and OFF time of operating states is shown in fig.5.

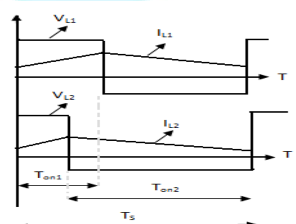


Fig. 5 Line voltage and Line current

4.2 Modes Of Operation

Mode1*:*

During S1=1 S2=1 and S3=0 switch S1 and S2 is ON and S2 is OFF

IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 1, March, 2013
ISSN: 2320 - 8791
www.ijreat.org

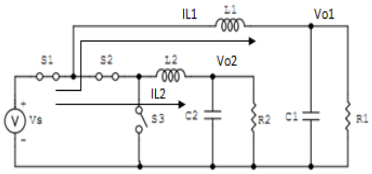


Fig.6 Mode 1

Current I1 flows through L1 and R1 and I2 flows through L2 and R2 and charges L1 and L2

Mode 2:

During S1=0 S2=1 and S3=1 switch S1 is OFF and S2 is ON and S3 is ON

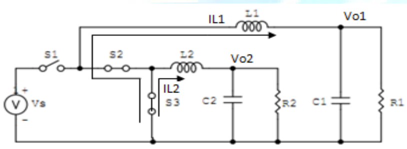


Fig.7 Mode 2

Current I1discharges through L1 and R1 and I2 discharges through L2 and R2.

Mode 3:

During S1=1 S2=0 and S3=1 switch S1 is ON and S2 is OFF and S3 is ON

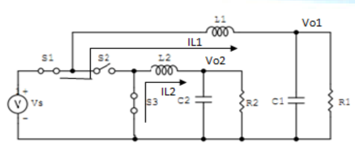


Fig. 8 Mode3

Current I1 charges through L1 and flows through R1.I2 Discharges through L2 and R2

4.3 Switching Signals

The gate pulse is produced by comparing the error obtained from ramp signal which is obtained by comparing reference voltage with the output voltage obtained. Vref1 is having the reference voltage which is equal to output voltage Vo1 and Vref2 will give reference voltage of the output voltage Vo2.The error signal when compared with ramp gives the gate pulse which has pulse width containing ON and OFF time required to control switch to maintain output voltage to be stable for the varying load condition and disturbances. The duty ratio directly depends upon the control signal. Duty ratio control is the technique used for the control of voltage. Gating signal Vg1 controls switch S1 and Vg3 controls switch S3. The waveforms of signals in pulse generator are shown in fig.9.

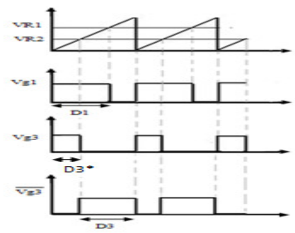


Fig. 9 Gating signal generation

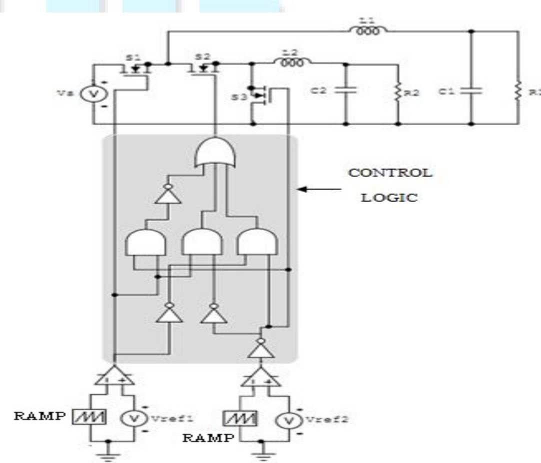
Depending on the gate signals produced for the switch S1 and S3 a gate pulse should be generated which should control the operation of switch S2. A non overlap control strategy should be used for synchronous rectification which will avoid the supply shunt currents which cause short circuits when three switches ON at the same time. A maximum of two switches can be ON at the same time for this three switch topology of dual output synchronous buck converter.

4.4 Operating Condition

Table 1: States Of Operation

S1	*S2*	*S3*
1	1	0
0	1	1
1	0	1

The table shows the possible operating states by which the three switch converter topology can work. According to the modes of operation of converter, switching signals should be generated. The design of control logic is shown in fig.10.



www.ijreat.org
Published by: PIONEER RESEARCH & DEVELOPMENT GROUP (www.prdg.org)

ISSN: 2320 - 8791
www.ijreat.org

Fig 10 PWM control strategy of three switch converter

The control strategy of three switch dual output buck regulator operating conditions can be noted from the table.I. The waveform shows the gate pulse Vg3 produced by the logic circuit using Vg1 and Vg2. Based on this switching signals switches are controlled as shown in fig.11

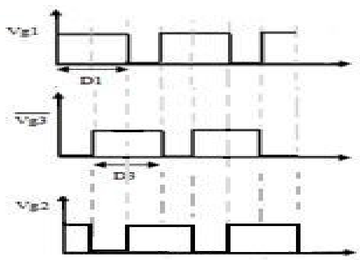


Fig. 11 switching signal

Output average voltage and current in given in both loop

Vo1= (D1/Ts) Vs (11)

Io1= Vo1/R1 (12)

Vo2= (D3/Ts) Vs (13)

Where,

D3=1-D3* (14)

Io2= Vo2/R2 (15)

These equations provide details of the duty ratio required for the output Vo1, Vo2 and average current are calculated.

5. PID Controlled Converter

For the varying load and disturbance in the converter, to work stable condition and to give the fixed output, it is necessary to control input based on the output. So the output is continuously monitored with the reference of the fixed output to be obtained and is controlled by P (proportional), PI (proportional plus integral) or PID (proportional plus integral plus derivative) based on the necessity. For the system to be stable with no disturbance we can simply add gain and compensate the system to give fixed output. But if the system is unstable integral is used. Here in this three switch dual output topology buck converter we are applying PID controller in order to make unstable output to stable output. Here Ziegler–Nichols tuning method is used for tuning PID controller.

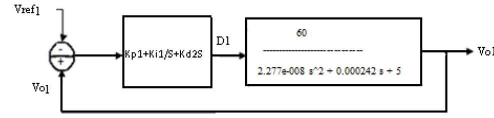


Fig.12 control block diagrams control of output Vo1

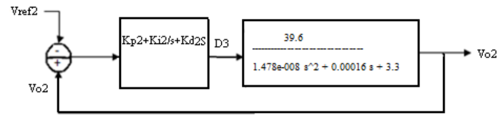


Fig.13 control block diagrams control of output Vo2

Transfer function of each loop is derived and compensated each loop separately. Fig.12 and Fig.13 shows the block diagram explaining the outline of how the system is compensated by adding PID controller.

6. Simulation Results

Here simulations of three switch single input dual output synchronous buck converter are performed in order to check its operation.Thus the performance of system is assessed in open loop and closed loop and results are given. The simulation is performed using MATLAB/SIMULINK

6.1 Open Loop Circuit Model

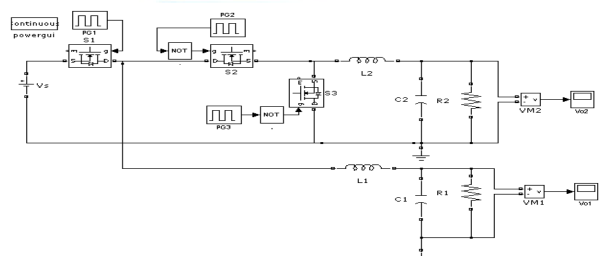


Fig. 14 Open loop model of three switch dual output buck regulator

The open loop simulation is based on the duty ratio calculation required for the two output based on the given input of 12V dc voltage and input frequency of 40Khz.Two output here is 5V and 3.3V. By using input voltage, output voltege and input frequency the duty ratio of three switches can be calculated.Switch S_1 ON time is greater than S_2 and S_3.

IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 1, March, 2013
ISSN: 2320 - 8791
www.ijreat.org

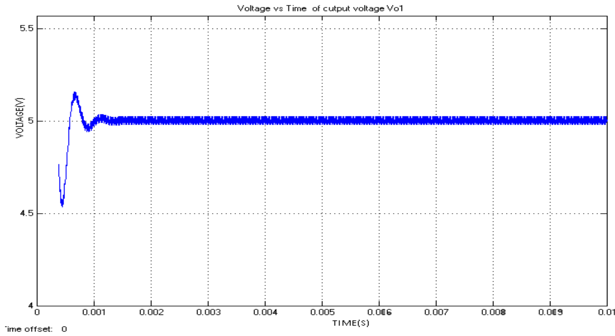


Fig. 15 output voltage Vo1 when V_s=12v

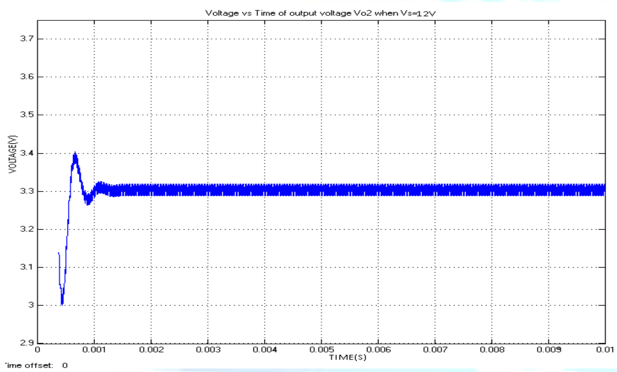


Fig.16 output voltage Vo2 when V=12v

The fig. 15 and fig.16 shows the output voltage of standard converter with standard output voltage thus obtained the required output voltage of V_{01} and V_{02} respectively.Here a slight supply voltage increase of V_s =13v is given to the same converter. The result obtained is not the required voltage. It shows that output is increased. It can be noted from the fig 17 and fig.18.

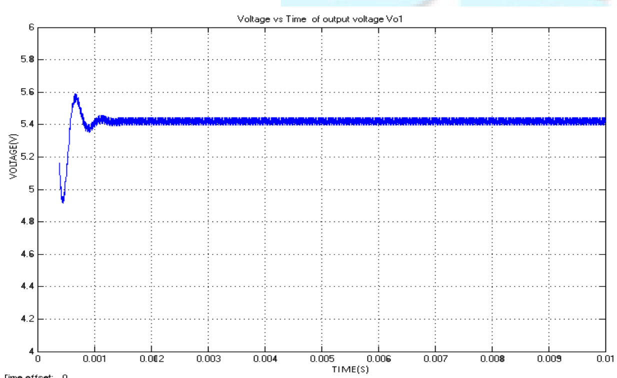


Fig. 17 Output Voltage V_{01} when Vs=13v

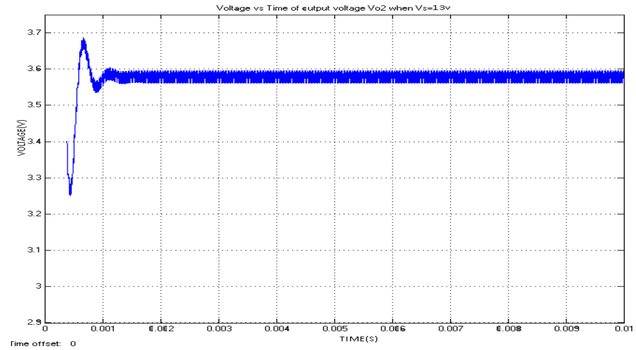


Fig.18 Output Voltage V_{02} when V_s=13v

The system should be compensated to improve the performance and closed loop converter is obtained through feedback control with a tuned PID controller.

6.2 Closed loop Model

The system with PID control implemented is shown in Fig.19 and control logic is as shown in Fig.20.The simulation parameters considered are shown in Table II.

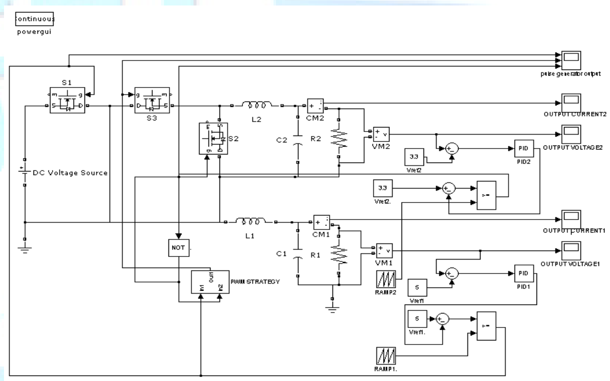


Fig.19 closed loop model of three switch dual output synchronous buck converter

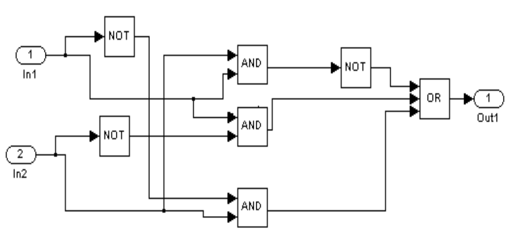


Fig. 20 subsystem – logic design

www.ijreat.org
Published by: PIONEER RESEARCH & DEVELOPMENT GROUP (www.prdg.org)

Table 2 Simulation parameters

Parameter	***Unit***
L_1	242e-6H
L_2	160e-6H
C_1	18.82e-6F
C_2	28.6e-6F
R_1	5Ω
R_2	3.3Ω
f	40khz

The parameters here used are for the simulation purpose only, which is a directly calculated values for output required. In the real time there are available only fixed set of values of components

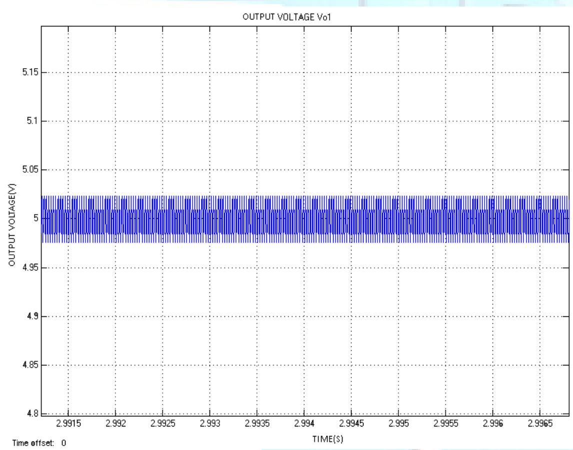


Fig.21 closed loop output voltage V_{o1}

Fig.21 shows the output voltage obtained in closed loop when input voltage is 12V. It shows there is bifurcation around the 5V output, which shows there, needs the PID tuning to settle down from the error

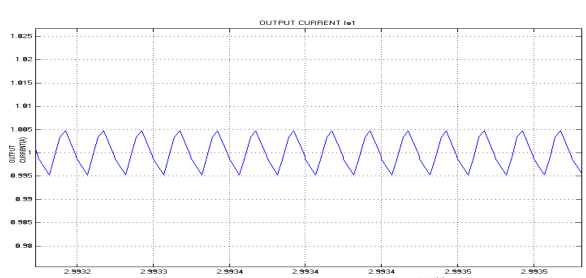


Fig.22 closed loop output current I_{01}

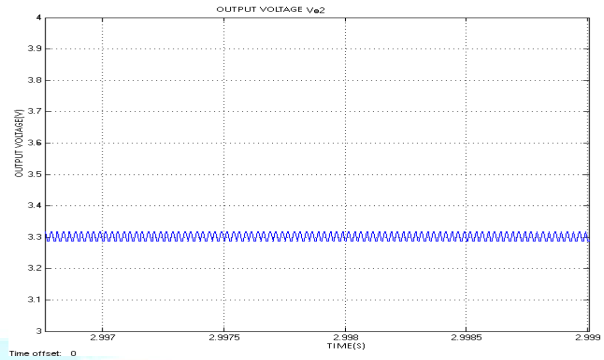


Fig. 23 closed loop output voltage V_{02}

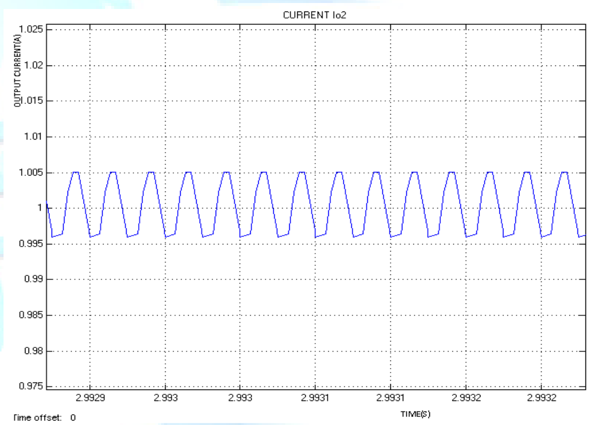


Fig. 24 closed loop output current I_{02}

In fig.22 we can notice the current ripple but it is less and gives a average current of around 1Ampere.The fig.23 shows the closed loop model second output voltage, In which we can observe the voltage gives an average output voltage of 3.3V which can give steady output of 3.3V after tuning. Fig.24 shows the output obtained for second loop output current. In which an average current of 1Ampere can be observed, which is less ripple and can be further reduced.It is observed from the results obtained that there is steady state error in each output as shown in above characteristics. In open loop we can see from figure 4.4 that for the given input voltage of 12V output voltage obtained is 5V and for same design value increase in input voltage to 13V, which is shown in fig.17 gives output of 5.4V. But closed loop can able to track 5V output. From the open and closed loop output we can see that, though closed loop can able to follow the output and advantageous compared to open loop, there is a steady state error which is to be compensated to reduce ripple and to obtain distortion less output voltage.

7. Conclusion

In this research, three switch topology of synchronous buck converter is presented. Various circuits, modes of operations, switching strategy are discussed. The model is designed to get peak voltage for particular time and gives very fast response. The conventional four switch topology is reduced to three switch topology for component count reduction.PID controller used here is approximately designed and are to be tuned in future for giving stable output to dynamic disturbances. Simulation results of the model are verified by MATLAB/SIMULINK and various outputs of voltage and currents are verified in open loop and closed loop by varying voltage inputs.

References

[1] Robert W. Erickson, Dragan Maksimovic, Fundamentals of Power. Electronics, Norwell, Mass.: Kluwer Academic Publishers, 2001
[2] Matlab/Simulink User's Guide , 2008R, www.mathwork.com.
[3] S. Baranwal, A. Patra, and B. Culpepper, "Self oscillating control of a synchronous dc-dc buck converter," *in Proc. of PESC, 2004*, vol. 5, pp. 3671– 3674, June 2004.
[4] P Kumar, M Rojas-Gonzalez, " Novel 3-switch dual output buck voltage regulator*", Applied Power Electronics Conference and Exposition*, APEC '06, 2006.
[5] S.Abedinpour, B. Bakkaloglu, S. Kiaei. "A Multistage Interleaved Synchronous Buck Converter With Integrated Output Filter in 0.18 μm SiGe Process," IEEE *IEEE Transaction on Power Electronics*, vol. 22, no. 6, pp. 2164–2175, Nov. 2007.
[6] S. Pattnaik, A. K. Panda, K. Aroul and K. K. Mahapatra, "A Novel Zero Voltage Transition Synchronous Buck Converter for Portable Application," *PROC WRLD ACAD SCI E Proceedings of World Academy of Science, Engineering and Technology*, Vol. 17, pp. 810 - 815, 2008.
[7] W. Li and X. He, "A family of isolated interleaved boost and buck converters with winding-cross-coupled inductors," *IEEE Transaction on Power Electron*ics, vol. 23, pp. 3164–3173, Nov. 2008.
[8] M. Belloni, E. Bonizzoni, and F. Maloberti, "On the design of single-inductor double-output dc-dc buck, boost and buck-boost converters," 15th *IEEE International Conference on in Electronics, Circuits and Systems,* vol. 31 pp. 626–629, Sept. 3 2008.
[9] E.C dos Santos Jr.,"Single Input Dual Output DC to DC Converter", 2012 *IEEE International Symposium on Industrial Electronics (ISIE)*,pp 496 – 502, 2012

.