Generalized State Space Average Model for Multi-Phase Interleaved Buck, Boost and Buck-Boost DC-DC Converters: Transient, Steady-State and Switching Dynamics

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Abstract:

The GSSAM is used for the converters with dominant oscillatory behavior such as resonant converters, high current ripple converters, and multi-converter systems. The maximum current and voltage through the system can be predicted by modeling the switching behavior of voltage and current. This project present a generalized state space average model (GSSAM) for multi-phase interleaved buck, boost and buck-boost converters for DC loads. In this project we are using DC motor, LEDs as a load. And also pulse with modulation wave form plot on MATLAB.

Keywords:
Interleaved Multi-Phase DC-DC Converters, Generalized State Space Average Model, Buck Converter, Boost Converter, Buck-Boost Converter, PIC Microcontroller,LCD display,MATLAB.

1. Introduction:

Single-phase DC-DC converters have the maximum efficiency at the rated load conditions and it has low efficiency operation at partially loaded conditions. Thus, the multi- phase interleaved DC-DC converters are introduced to achieve high efficiency among the entire loading range so that the number of operating phases is proportional to the output load power.

There are four basic topologies for a non-isolated voltage amplification and suppression in a unidirectional DC-DC converter namely buck-boost, Cuk, Zeta and SEPIC [1]. In a distributed generation system utilising solar PV, they are normally employed for optimal operation at the generation side and for matching the load voltage requirements at the load side. Interleaving these converters at the load side offers a variety of advantages. Some of them are listed below.

1. Increase in the multiplicity of output ripple thereby reducing the filter requirements.
2. The input and output inductor and capacitor requirement is reduced to a large extent.
3. Overall reduction in the loss in the circuit compared to same rated single phase counterpart.
4. Faster transient response to load changes.

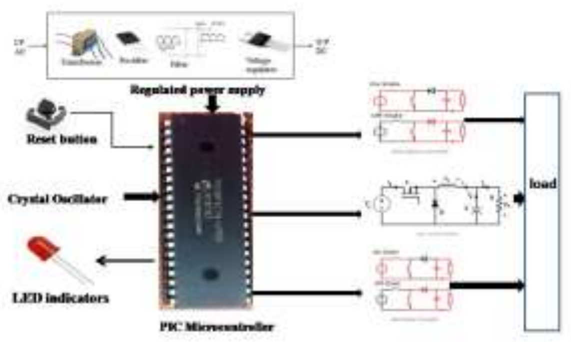
The interleaved converters are ideally suited for applications which require tight current regulation like VRM. Moreover, they have useful application in high power and load current dc motor drives circuit.

In this paper, GSSAM for multi-phase interleaved buck, boost and buck-boost DC- DC converters are introduced. PIC Microcontroller is used for soft switching operation. The main controlling device of the project is PIC Microcontroller which is interfaced to the input and output modules.
PL2303 along with PC is interfaced to the PIC Microcontroller. And the MATLAB code is running inside the PC to plot the pulse with modulation wave form on MATLAB. In this project we are using pot to change the reference voltage measured by PIC Microcontroller based on that the microcontroller trigger the MOSFETs and regulate the output voltage. The status of the project is display on LCD module.

2. Literature review:

DC-DC converters usually can be represented as a small signal model since the zero-order is the most dominant and
Effective value, except in the cases which have a dominant oscillatory behavior such as resonant converters, high current ripples converters, and multi-converter system.

3. Implementation:



3.1 Fig block diagram of Generalized State Space Average Model for Multi-Phase Interleaved Buck, Boost and Buck-Boost DC-DC Converters: Transient, Steady-State and Switching Dynamics

The proposed GSSAM can be used for any number of phases. Since the number of the operating phases in interleaved converters is proportional with the load, the proposed GSSAM can present the operation at any number of active phases. Furthermore, the proposed model can describe the switching dynamics of phases. The GSSAM is validated by comparing the steady-state and transient dynamics between the GSSAM and PLECS switching model of buck, boost and buck-boost converters.

4. Related Work:

The brief introduction of different modules used in this project is discussed below:

4.1. PIC Microcontroller:

4.1.1 Fig PIC Microcontroller.

The PIC16F72 CMOS FLASH-based 8-bit microcontroller is upward compatible with PIC16C72/72A and PIC16F872devices. It features 200 ns instruction execution, self-programming, an ICD, 2 Comparators, 5 channels of 8-bit Analog-to-Digital (A/D) converter, 2 capture/compare/PWM functions, a synchronous serial port that can be configured as either 3-wire SPI or 2-wire I2C bus, a USART, and a Parallel Slave Port.

Peripheral Features

• Timer0: 8-bit timer/counter with 8-bit prescaler

• Timer1: 16-bit timer/counter with prescaler, can be incremented during SLEEP via external crystal/clock

• Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler

• Capture, Compare, PWM(CCP) module

- Capture is 16-bit, max resolution is 12.5 ns

- Compare is 16-bit, max resolution is 200 ns

- PWM max resolution is 10-bit

• 8-bit, 5-channel Analog-to-Digital converter

• Synchronous Serial Port (SSP) with SPI (Master mode) and I2C (Slave)

• Heat sink/Source Current: 25 mA

• Brown-out detection circuitry for Brown-out Reset (BOR)

4.2. DC-DC Boost converter:

A boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

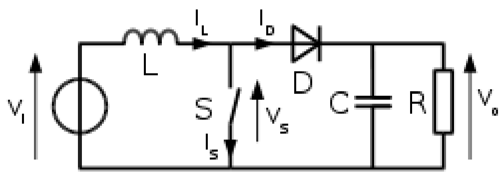
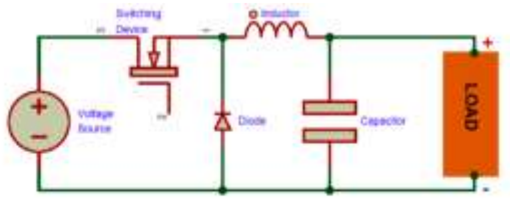


Fig: DC-DC Boost converter

4.3 BUCK converter:

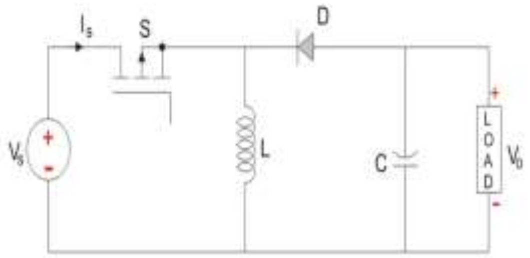
A **buck converter** (**step-down converter**) is a DC-to-DC power **converter** which steps down voltage (while drawing less average current) from **its** input (supply) to **its** output (load).



The **working of Buck converter** is slightly similar to that of PWM 'dimming'. We've all heard of lights being dimmed by a PWM signal. A small duty cycle means that the average voltage seen by the load is small and when the duty cycle is high the average voltage is high too.
But average voltage is not what we need – a raw PWN signal oscillates between high voltage level and ground, something no delicate load (like the microcontroller) would like. Of course, connecting an RC filter to a square wave source renders the output clean. The voltage level of the filter depends on the duty cycle of the PWM signal – the higher the duty cycle the higher the output voltage.

4.4 Buck-boost converters:

Buck-boost converters offer a more efficient solution with fewer, smaller external components. They are able to both step-up and step-down voltages using this minimal number of components while also offering a lower operating duty cycle and higher efficiency across a wide range of input and output voltages.



The input voltage source is connected to a solid state device. The second switch used is a diode. The diode is connected, in reverse to the direction of power flow from source, to a capacitor and the load and the two are connected in parallel as shown in the figure above.
The controlled switch is turned on and off by using Pulse Width Modulation(PWM). PWM can be time based or frequency based. Frequency based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage. Time based Modulation is mostly used for DC-DC converters. It is simple to construct and use. The frequency remains constant in this type of PWM modulation.

4.5 LCD display:

A liquid crystal display (LCD) is a thin, flat electronic visual display that uses the light modulating properties of liquid crystals. The 16×2 translates to a **display** 16 characters per line in 2 such lines. In this project we are interfacing LCD module to the PIC microcontroller to displays the status of the project.

4.6 MATLAB:

The name MATLAB stands for matrix laboratory. MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran.
MATLAB can be used in a wide range of applications, including control design, test and measurement, financial modeling and analysis, MATLAB is the language of technical computing.

5. CONCLUSION:

The generalized state space average models (GSSAMs) for multi-phase buck, boost and buck-boost DC-DC converters are investigated and simulated in SIMULINK GUI platform of MATLAB. The GSSAM has the advantage of describing the oscillatory behavior which is dominant in resonant Converters and high ripples DC-DC converters, where the AC signals in system dynamics cannot be neglected.

6. ACKNOWLEDGEMENT

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7. RESULTS:

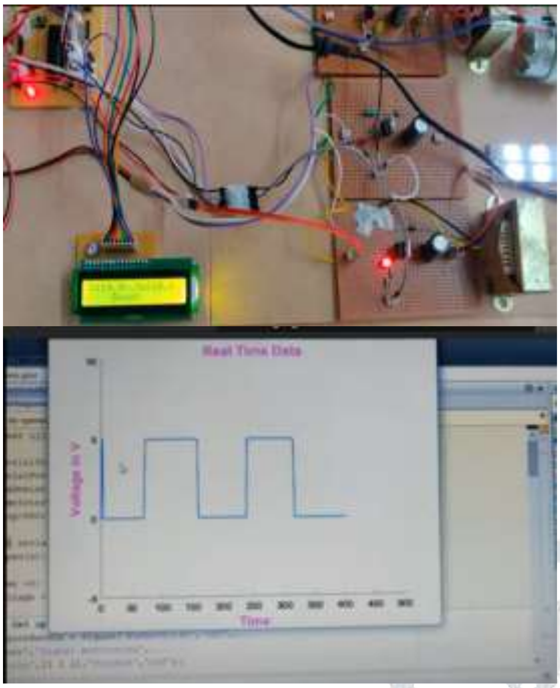


Fig:Boost mode

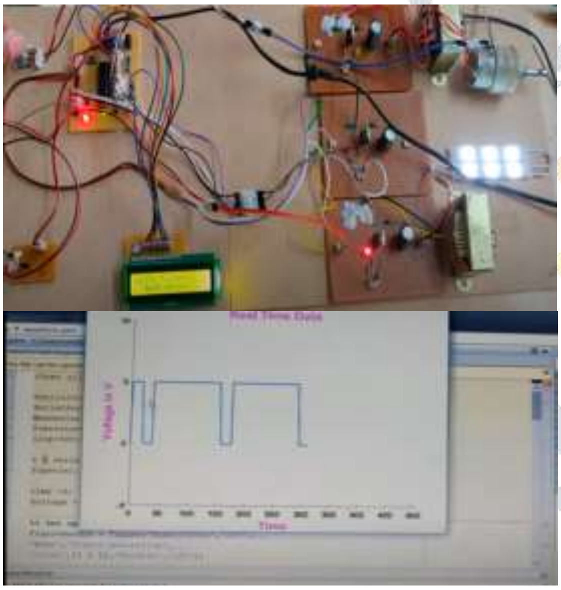
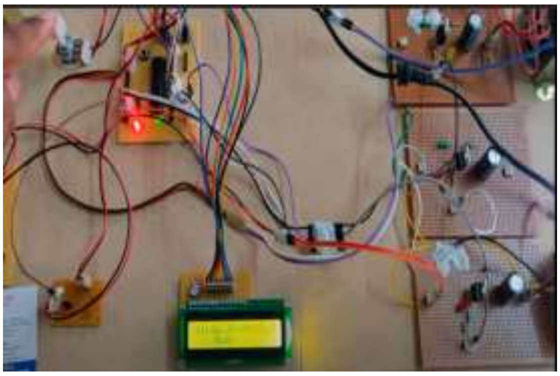


Fig: Buck-boost mode



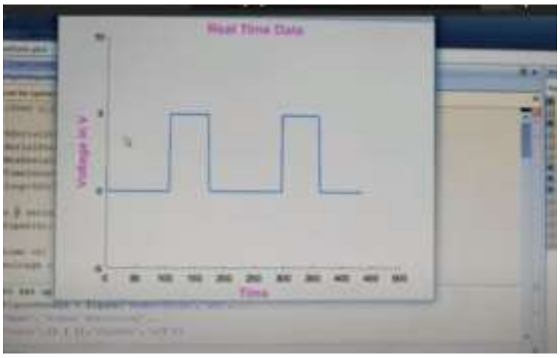


Fig: Buck mode

REFERENCES:

[1] H. Qiao, Y. Zhang, Y. Yao, Li Wei. " Analysis of buck-boost converters for fuel cell electric vehicles" IEEE International Conference on Vehicular Electronics and Safety, *Proc. IEEE* pp. 109-113, 2006.

[2] B. Ren Lin, C. Lan Huang, "Interleaved ZVS converter with ripple-current cancellation", IEEE Transaction on Industrial Electronics, vol. 55, issue. 4, pp.1576-585, April 2006.

[3] J. B. Wang, S. Chuang, "A study of the interleaved buck derived converters", IEEE International Conference on Industrial Technology, ICIT, Mumbai, December 2006.

[4] S. Ang, A. olive, Power Switching Converters, 3rd edition, Taylor and Francis, 2005, pp 42-51.

[5] R. W. Erickson, D. Maksimovic, Fundamentals of Power Electronics, 2nd edition, 2001.

[6] S Vijayalakshmil, E.Arthika, G. Shanmuga Priya, "Modeling and simulation of interleaved buck-boost converter with PID controller", IEEE Sponsored 9th International Conference on Intelligent Systems and Control (ISCO), October 2015.

[7] A. C. Schittler, D. Pappis, C. Rech, A. Campos, M. A. Dalla Costa, "Generalized state-space model for the interleaved buck converter" Power electronics conference (COBEP), Brazil September 2011.

[8] A. Joseph , S.P. Singh "Small signal modeling of non-ideal two phase interleaved buck converter" 1st National Conference on Power Electronics Systems & Applications (PESA), Rourkela, March 2013.

[9] N. Jantharamin , L. Zhang "Analysis of multiphase interleaved converter by using state-space averaging technique", 6th International conference on Electrical Engineering/Electronics, Computer, Telecommunication and Information Technology(ECTI-CON), Thailand, May 2009.

[10] M. Muhammad, M. Armstrong, and M. A. Elgendy, "A Nonisolated Interleaved Boost

Converter for High-Voltage Gain Applications", IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 04, No. 2, June 2016.

[11] J. Mahdavi, A. Emaadi, M. D. Bellar, M. Ehsani, "Analysis of power electronic converters using the generalized state-space averaging approach", IEEE Transaction on circuits and systems - I: Fundamental Theory and Application, Vol. 44, no. 8, pp 767-770, August 1997.

[12] Neacsu, D. O., Bonnice W., Holmansky, E. "On the small-signal modeling of parallel/interleaved buck/boost converters". IEEE International Symposium on Industrial Electronics (ISIE), Bari, July 2010.