Zero Voltage Switching Technique for Bi-Directional Dc-Dc Converters

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Abstract- This paper proposes a zero voltage switching (ZVS) technique for bidirectional dc/dc converters. The dc/dc unit considered consists of two distinct bidirectional dc/dc cells paralleled at both input and output and whose two input bridges are coupled by means of passive inductive branches. A multi-angle phase-shift modulation method is proposed which simultaneously achieves bidirectional power control, power sharing, and ZVS of all the electronic devices over the full power range without the need for auxiliary switches. Single-phase grid connected fuel cell (FC) system offering low cost and compactness.

Index Terms- Bi-Directional DC-DC Converters, Resonant Conversion, and Zero Voltage Switching (ZVS).

I. INTRODUCTION

DC-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. DC/DC converters are widely used to transform and distribute DC power in systems and instruments. DC power is usually available to a system in the form of a system power supply or battery. This power may be in the form of 5V, 24V, 48V or other DC voltages. Further, the voltage may be poorly regulated and have high noise content. The dc-dc converters can be viewed as dc transformer that

delivers a dc voltage or current at a different level than the input source. Electronic switching performs this dc transformation as in conventional transformers and not by electromagnetic means. The dc-dc converters find wide applications in regulated switch-mode dc power supplies and in dc motor drive applications.

DC-DC converters are non-linear in nature. The design of high performance control for them is a challenge for both the control engineering engineers and power electronics engineers. In general, a good control for dc-dc converter always ensures stability in arbitrary operating condition. Moreover, good response in terms of rejection of load variations, input voltage changes and even parameter uncertainties is also required for a typical control scheme.

DC to DC converters are important in portable electronic devices such as cellular phones and Laptop computers, which are supplied with power from batteries primarily.

Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored power is drained.

Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

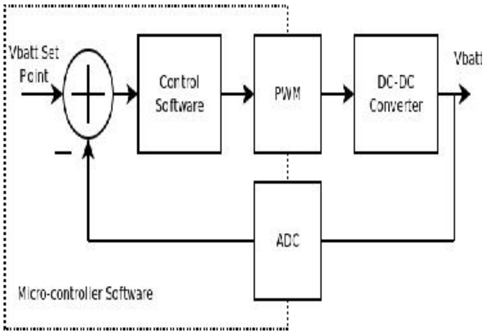


Figure: 1 block diagram of dc/dc converter

The buck converter is the most widely used dc-dc converter topology in power Management and microprocessor voltage-regulator (VRM) applications. Those applications require fast load and line transient responses and high efficiency over a wide load current range. They can convert a voltage source into a lower regulated voltage. For example, within a computer system, voltage needs to be stepped down and a lower voltage needs to be maintained. For this purpose the Buck Converter can be used. Furthermore buck converters provide longer battery life for mobile systems that spend most of their time in “stand-by”.In such scenarios, it becomes of strong practical interest to formulate advanced modulation strategies which, applied to the overall dc/dc unit, enable ZVS operation of the output devices as well, hence eliminating the need for additional semiconductor devices altogether.

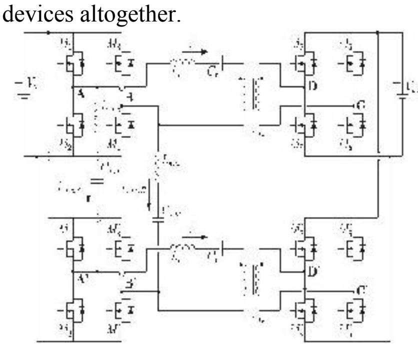


Fig. 1. DC/DC unit consisting of two paralleled DBSRC cells.

In this paper, these concepts are implemented via a multi-angle phase-shift modulation that simultaneously achieves bidirectional power control, power sharing among the cells, and ZVS of all the electronic devices over the entire power range [18]. The starting point of the proposed technique is the minimum current operation concept treated in [19], [20], here generalized into a method for controlling the amount of reactive power exchanged by the resonant tank with the output bridge. The approach is tested on the dc/dc unit detailed in Fig. 1, which consists of two bidirectional dual-bridge series resonant converter (DBSRC) cells paralleled at both input and output and with the two input bridges coupled by means of passive inductive branches.

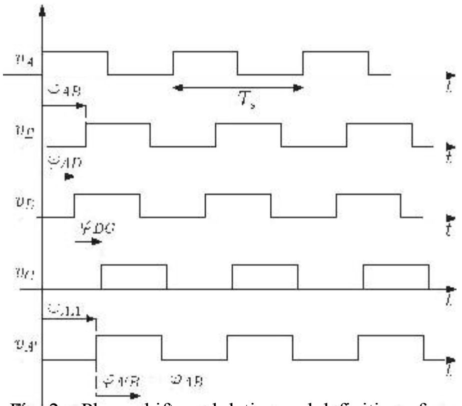


Fig. 2. Phase shift modulation and definition of control angles.

2.MODELING ANALYSIS OF DC-DCCONVERTERS

There are so many papers on modeling and analysis of DC-DC Converters. The most commonly used method is Large Signal Average Modeling method. This method is often used to obtain average state equations, from which an equivalent circuit model can be derived. Other methods can also be used, to

obtain the converter model, by replacing the converter with an equivalent circuit model. But these are typically restricted to few topologies.

BEHAVIORAL LARGE SIGNAL AVERAGED MODEL FOR DC/DCSWITCHING POWER CONVERTERS:

A general behavioral large signal modeling technique is presented in this. The model is applicable to DC-DC switching power converters working in both continuous (CCM) and discontinuous (DCM) conduction modes. The model is based on two PWM switch sub-models commutating between them as a consequence of the operating conditions. In the modeling technique, emphasis is made in the discontinuous conduction mode and in the determination of the instants to switch between the continuous and discontinuous conduction mode sub-models. The model is used in a multilevel simulator where behavioral descriptions are permitted. Results are obtained and compared with device level simulations. These results show good accuracy and significant reduction in the simulation time.

LARGE-SIGNAL MODELING AND SIMULATION OF DISTRIBUTED POWER SYSTEMS:

A PWM switch model has been shown to be a very good approach to simulate switched mode DC-DC power converters. In this model has been implemented in both continuous and discontinuous conduction modes.

ANALYSIS AND SMALL SIGNAL MODELING OF A NON-UNIFORM MULTIPHASE BUCK CONVERTER:

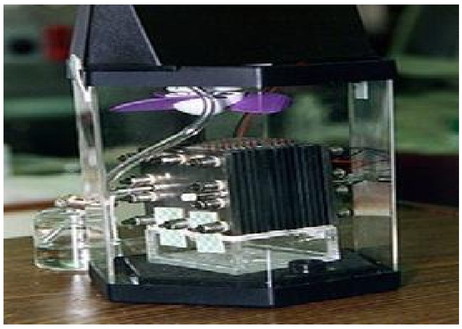
This presents steady-state analysis and dynamic modeling of a non-uniform multiphase buck converter. This type of converter architecture has been reported previously in the literature with non-uniform phase design with the utilization of dynamic non-uniform current sharing and phase picking schemes in order to improve the power conversion efficiency over a wide load range.

NUMERICAL STATE-SPACE AVERAGE-VALUE MODELING OF PWM DC-DC CONVERTERS IN DCM AND CCM:

State-space average-value modeling of pulse width modulation converters in continuous and discontinuous modes has received significant attention in the literature, and various models have been developed. This presents a new approach for generating the state-space average-value model. In the proposed methodology, the so-called duty-ratio constraint and the correction term are extracted numerically using the detailed simulation and are expressed as nonlinear functions of the duty cycle and average-value of the fast state variable.

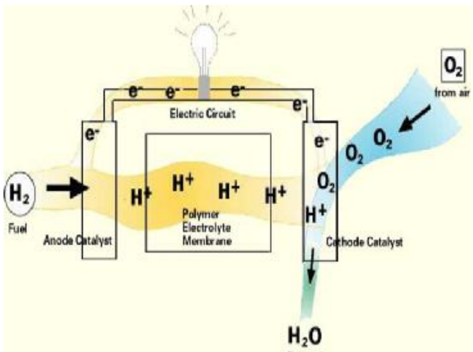
3.FUEL CELL TECHNOLOGY

The fuel cell concept was developed in 1839 by Sir William Grove, a Welsh judge and gentleman scientist. Fuel cell technology is a relatively new energy-saving technology that has the potential to compete with the conventional existing generation facilities. Among the various DG technologies available, fuel cells are being considered as a potential source of electricity because they have no geographic limitations and can be placed anywhere on a distribution system. Fuel cells have numerous benefits which make them superior compared to the other technologies. Benefits include high efficiency, high power quality and service reliability, few or no moving parts which leads to low noise, fuel flexibility, modularity and low maintenance.



The fuel cell is an important technology for new mobile applications and power grid distribution systems. For power distribution, fuel cell system requires a grid interconnection converter to supply power to the power grid.

FUEL CELL PRINCIPLE:

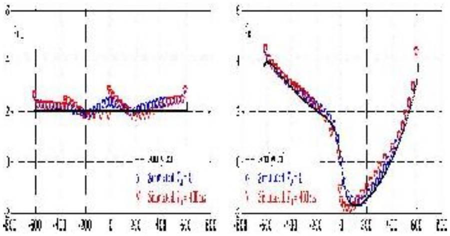


Encouraged by the catalyst , the hydrogen atom splits into a proton and an electron, which takes different paths to the cathode, the proton passes through the electrolyte, the electrons create a separate current that can be utilized before they return to the cathode, to be reunited with the hydrogen and oxygen in a molecule of water

Types of Fuel Cells:

The general classifications of fuel cells are based on the type of electrolyte used. There are many types of fuel cell such as alkaline fuel cells (AFCs), phosphoric acid fuel cells (PAFCs), proton exchange membrane fuel cells (PEMFCs), molten carbonate fuel cells (MCFCs) and solid oxide fuel cells (SOFCs). Fuel cells can further be classified based on operating temperature. Details on fuel cells based on type of electrolyte, operating temperature and fuel are shown in Table .

ZERO VOLTAGE SWITCHING TECHNIQUE FOR BIDIRECTIONAL DC/DC CONVERTERS



Output Power P(w) Output Power P(w)

Simulated steady-state turn-off currents of the output devices (a) and input leg B (b) as the control vector is swept along an I_{ZVS} = 2 A trajectory.

200 V, i.e., $M = 0.5$. Note that in these conditions the maximum available power is halved to □600 W, according to (3). Fig. 11(a) and (b) respectively report the turn-off current $i_{DC\downarrow}$ of the output devices and $i_{B\downarrow}$ of input leg B when the control vector $\mathbf{v}_\phi$ moves along an I_{ZVS} = 2 A trajectory. For each case, the analytical prediction is compared with two simulations done at $T_d = 0$ and $T_d = 400$ ns, respectively, in order to decouple the effect of the sinusoidal approximation from the dead time related dis-tortion. Overall the simulations point to a good accuracy of the presented models in terms of ZVS behavior along the analytical trajectories.

The stronger discrepancy, visible in Fig. 11(a), is related to the output ZVS current, which tends to slightly depart from 2 A. Although the detailed analysis of the phenomenon is beyond the scope of this paper, such behavior is explained by the harmonic content of the tank current.

B. Input ZVS

Fig. 12(a) reports the simulated currents through input devices $M_1$and M_3at a light-load operating point P_o=55 W on thesame I_{ZVS} = 2 A trajectory simulated in Section III-A and when no input ZVS correction provision is undertaken. As already suggested by Fig. 11(b), M_3 turns off at a negative current $i_{B\downarrow}$ ≈ -1 A, causing hard turn on of M_4 .

IV. EXPERIMENTAL RESULTS

A 2.4-kW dc/dc unit consisting of two paralleled 1.2-kW DBSRC cells was prototyped with the purpose of validatin

TABLE PARAMETERS OF THE EXPERIMENTAL PROTOTYPE.

f_s	100 kHz
Nominal V_g	500 V
Nominal V_{out}	400 V
$C_{r,p}$	33 nF
$C_{r,s}$	39 nF
Equivalent C_r	14 nF
L_r	2 x 220 μH
Turns ratio n	0.8
L_{mag}	220 μH
C_{out}	20 μF

the discussed ZVS approach. Parameters of the experimental setup are detailed in Table I, whereas the converter schematic is reported in Fig. 13.

Each DBSRC cell was designed with a split resonant inductor on the primary side with the purpose of reducing the criticality of the magnetics design by allowing a smaller air gap. Similarly, with the

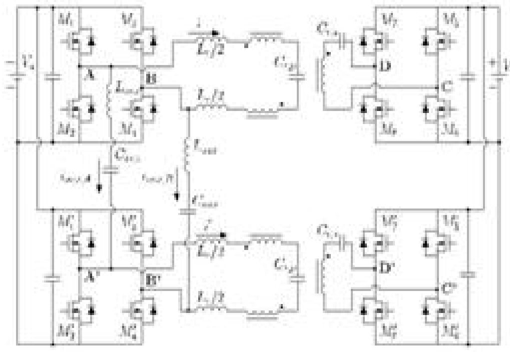


Fig. 13.Schematic of the 2.4-kW DBSRC converter prototype

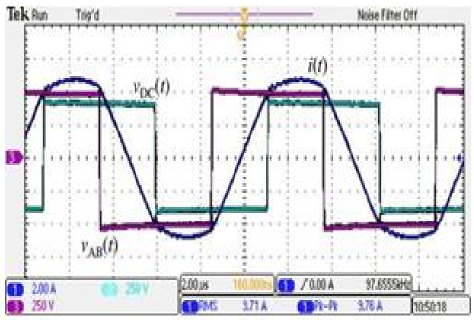


Fig. 14. Experimental waveforms at 1.1-kW forward power, V_g = 500 V,

= 400 V, $M = 1$; voltage scale: 250 V/div; current scale: 2 A/div; time

scale: 2 μs/div.

primary loop was organized symmetrically around the primary tank capacitor. In order to block the dc voltage component at both the primary and secondary sides of the transformer, the resonant capacitance itself was distributed between a primary-side and secondary-side components $C_{r,p}$ and $C_{r,s}$, with the two components chosen so as to be the subject to similar voltage stresses at full power. Furthermore, the two cells were equipped with 20 μF dc filtering capacitors at both input and output.

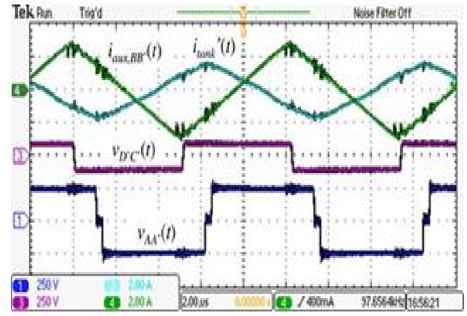


Fig. 15. Experimental waveforms for full ZVS operation with the proposed technique, P_{test} = 110 W; voltage scale: 250 V/div; current scale: 2 A/div; time scale: 2 μs/div

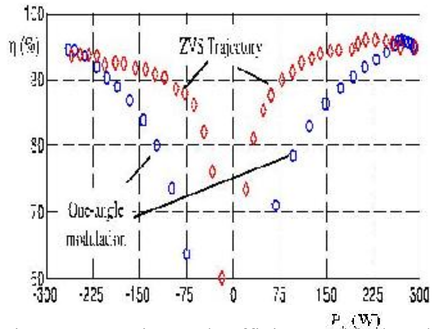


Fig. 16.Experimental efficiency of the dc/dc unit with the conventional one-angle modulation and with the proposed ZVS technique.

trajectories without physically harming the prototype due to hard switching-induced overheating.

Fig. 15 reports relevant experimental waveforms at a P_{test} = 110 W power level, i.e., less than one-twentieth of the nominal rating of the dc/dc unit and about one-third of the maximum available power pertaining to the selected operating conditions. The control vector $\mathbf{v}_{\phi} = (\phi_{AD} = 142^{\circ}, \phi_{AB} = 312^{\circ}, \phi_{DC} = 180^{\circ})$ was positioned for a 1-A output turn-off current, while

= 170° was adjusted for approximately I_{aux} = 2.7 A,

yielding an input turn-off current of about 2 A. All 16 devices in the dc/dc unit were found to operate in ZVS.

The experimental input and output turn-off currents along the ZVS trajectory are reported in Fig. 17 for one of the two DBSRC cells. All the four legs of the cell operate with positive turn-off currents as expected. The accuracy of the analytical trajectory.

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