Resonant DC/DC ZVZCS Converter Implementation for Voltage Spike Reduction in a PMDC Drive

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***Absract*: This paper proposes a novel method for controlling a PMDC motor using a resonant zvzcs converter. The converter provides a full bridge output voltage without any spikes. The converter employs an auxiliary circuit to provide the reactive current for the full-bridge semiconductor switches, which guarantees zero voltage switching at turn-ON times for all load conditions.**

***Index terms*- ZVZCS converter, PMDC motor, PI controller.**

I. INTRODUCTION

The power conversion systems with wide load variations and hybrid electric vehicles are the areas where large fluctuations in the load occur. Efficient transfer of energy with the least of losses are highly desired. For such systems ,this project proposes a converter topology using ZVZCS switching . AC/DC converters, which are used for heavy load applications, usually consist of two stages: input power factor correction (PFC) for AC/DC conversion and DC/DC conversion for battery charging .The conventional full-bridge converter with the series inductor (zvs switching) loses its ZVS capability at light loads, and the converter with the parallel inductor loses its ZVS under heavy loads. Loss of ZVS implies extremely high switching losses at high switching frequencies and very high EMI. Hence , the proposed converter has the advantage that can overcome all these shortcomings and has proved better efficiency over varying load conditions. The applications of this converter also extends to switching power supplies, battery chargers, uninterruptible power systems, renewable energy generation systems, and telecom power supplies.

Full-bridge topology is the most popular topology used in the power range of a few kilowatts for DC/DC converters. Since the switch ratings are optimized for the full-bridge topology, this topology is extensively used in industrial applications. High efficiency, high power density, and high reliability are the prominent features of this topology.

For applications in the range of a few kilowatts, MOSFETs are mostly used to implement the full-bridge converters. In order to have robust and reliable operation, MOSFETs should be switched under zero voltage. Operation with zero voltage switching (ZVS) has numerous advantages including, for example, reduction of the converter switching losses and a noise-free environment for the control circuit. Zero voltage switching is usually achieved by providing an inductive current flowing out of the full-bridge legs during the switch turn-ON and by placing a snubber capacitor across each switch during the switch turn-OFF. The inductive current can be produced by inserting an inductor in series with the power transformer or by inserting an inductor in parallel with the power transformer.

In a practical full-bridge configuration, the internal drain-to source capacitor of the MOSFET is usually utilized as the snubber capacitor, the series inductor is usually the leakage inductance of the power transformer, and the parallel inductor is implemented by using the magnetizing inductance of the power transformer. Thus, external passive components are not required, which makes the power circuit very simple and efficient. However, the full-bridge converter with the series inductor loses its ZVS

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capability at light loads, and the converter with the parallel inductor loses its ZVS under heavy loads. Loss of ZVS implies extremely high switching losses at high switching frequencies and very high EMI due to the high di/dt of the snubber discharge current. Loss of ZVS can also cause a very noisy control circuit, which leads to shoot-through and loss of the semiconductor switches. The ZVS range can be extended by increasing the series inductance. However, having a large series inductance limits the power transfer capability of the converter and reduces the effective duty ratio of the converter. In battery charger applications, ZVS is vitally important since the converter might be operating at absolutely no-load for a long period of time. In this application, when the battery is charged, the load is absolutely zero and the converter should be able to safely operate under the zero load condition. Since ZVS in conventional full-bridge PWM converters is achieved by utilizing the energy stored in the leakage inductance to discharge the output capacitance of the MOSFETs, the range of the ZVS operation is highly dependent on the load and the transformer leakage inductance. Thus, this converter is not able to ensure ZVS operation for a wide range of load variations. A novel approach has been adopted to extend the ZVS range in the full-bridge converter. In this approach, an auxiliary inductor is put at the leading leg by deriving an auxiliary winding on the main transformer and confirms ZVS for the leading leg. Although the proposed scheme can effectively extend ZVS of the leading leg MOSFETs, it is not able to guarantee ZVS for the lagging leg of the converter. Thus, when the battery is fully charged, the lagging leg switches may not be switched under ZVS. Moreover, the voltage at the secondary side still suffers from the spikes due to the leakage inductance and voltage-fed rectifier, commonly seen in full-bridge converters[1]-[10].

A fundamental problem related to the conventional full bridge phase-shift DC/DC converter is the voltage spikes across the output diodes. It shows the schematic of the conventional full-bridge converter. Basically, the leakage inductance of the transformer causes the voltage spikes across the output diodes. Theses spikes are intensified by increasing the switching frequency of the converter. Thus, the diodes should be designed overrated to be able to withstand the voltage spikes, which leads to higher losses due to the higher forward voltage drop of the diodes and poorer reverse recovery characteristics. In addition, the spikes significantly increase the EMI noise of the converter. This fact makes the topology not very practical for high frequency, high voltage applications. There are quite a few references that proposed solutions for the voltage spikes across the output diodes. Some references tried to decrease the leakage inductance as much as possible though the transformer winding structures, which effectively decreases the peak of the voltage spikes across the output diodes. However, reducing the leakage inductance decreases the ZVS operating range of the full-bridge converter, which results in a very narrow range of ZVS operation. An R-C-D snubber circuit is used to mitigate the voltage spikes across the diodes. The main problem with the snubber circuit is the amount of losses in the snubber resistor, which considerably degrades the efficiency of the converter especially at higher power and it can only reduce the peak value of the voltage spikes. An active clamp circuit has been added to the converter to clamp the voltage across the output diodes. This method can effectively clamp the voltage spikes of the output diodes. However, the active clamp circuit increases the complexity of the converter and causes small losses in the clamp circuit. Several energy recovery clamp circuits (ERCCs) have been proposed. An improved ERCC method has been proposed to accommodate the effects of voltage spikes for a wide range of input voltage. Although the ERCC techniques are able to reduce the voltage stress of the output diodes, the amount of the voltage stress depends on the duty ratio and input voltage of the converter in most of the ERCCs techniques. In addition, using extra semiconductors is inevitable in all these aforementioned methods. The problem of voltage spikes is essentially related to the voltage-driven output rectifiers. This is due to the fact that the full-bridge inverter produces high frequency voltage pulses across the output diode rectifier, which is connected to the output inductor as shown. The voltage-driven rectifier works perfectly if there is no leakage inductance in between the output of the full-bridge inverter and the diode rectifier. However, the existence of the leakage inductance makes the rectifier connect two current sources, i.e., leakage inductance and output inductance, together. This connection creates high voltage spikes across the output diodes. In this project, a new topology is proposed based on a current driven rectifier, which effectively rectifies the voltage stress problems related to the full-bridge DC/DC converter[11]-[25].

II. BLOCK DIAGRAM DESCRIPTION

The block diagram consist of a DC voltage source, filter circuit, a resonant converter acting as an inverter, transformer stage, diode rectifier, PMDC motor and controller.

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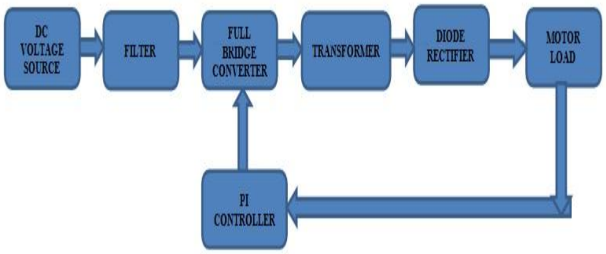

Fig. 1. Block diagram

Input source: The input voltage is provided as a regulated dc voltage from a steady source. A rectified dc voltage from an ac source can also be considered accordingly

Filter circuit: As per part of reducing the voltage stress across the switches one method is to reduce voltage across each set of switch of the zvzcs converter. So we provide a capacitive filter circuit after the voltage source.

The input supply will be divided and fed to the zvzcs converter . So the effective voltage experienced by the switch will be half than one without divider circuit.

Full bridge converter circuit: The converter is designed to satisfy the switching of a zvzcs topology. The switches are IGBT's and hence losses are reduced drastically in addition to the advantage of the zvzcs. The switching takes place at zero voltage crossing and zero current crossing .

Transformer stage: To transmit power from primary side to secondary side and to step up the voltage we use transformer. The transformer loss incurred will be very less and it is evident from very high efficiency of transformers.

Diode rectifier: The diode rectifier rectifies the ac voltage received at the secondary of the transformer ,producing a regulated dc voltage at the output with the help of a capacitive filter.

Controller: The controller helps to turn the switches on and off at instants of zero voltage. The controller is a PI (proportional integral) controller. The output of the controller will be given to the switches of the zvzcs converter. The controller helps to turn the switches on and off at instants of zero voltage. The controller is a PI (proportional integral) controller. The output of the controller will be given to the switches of the zvzcs converter.

PMDC motor: Permanent Magnet DC motors are useful in a range of applications, from battery powered de- vices like wheelchairs, welding equipments etc. They are frequently the best solution to motion control and power transmission applications where compact size, wide operating speed range, ability to adapt to a range of power sources are major considerations .Because of their linear speed-torque curve, they particularly suit adjustable speed and servo control applications

III. PI CONTROLLER

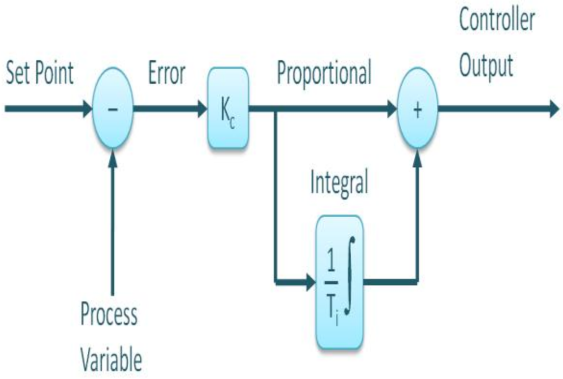

Fig 2 .Block of PI controller.

The block diagram for the PI controller is shown above. In the new topology , an auxiliary inductor is placed on the main transformer , and hence confirms zvs operation for leading leg thyristors of the converter .It also provides zcs switching for the output rectifiers which eliminates the reverse recovery losses of the output diodes . The direct supply from the rectifier is given to the motor load.

IV. CIRCUIT DESCRIPTION

Global energy crisis and increasing fuel costs demands the power electronic energy conversion equipments, which offering good conversion efficiency, high performance. Recently soft switching converters are providing good DC-DC energy conversion with reduced switching loses and EMI

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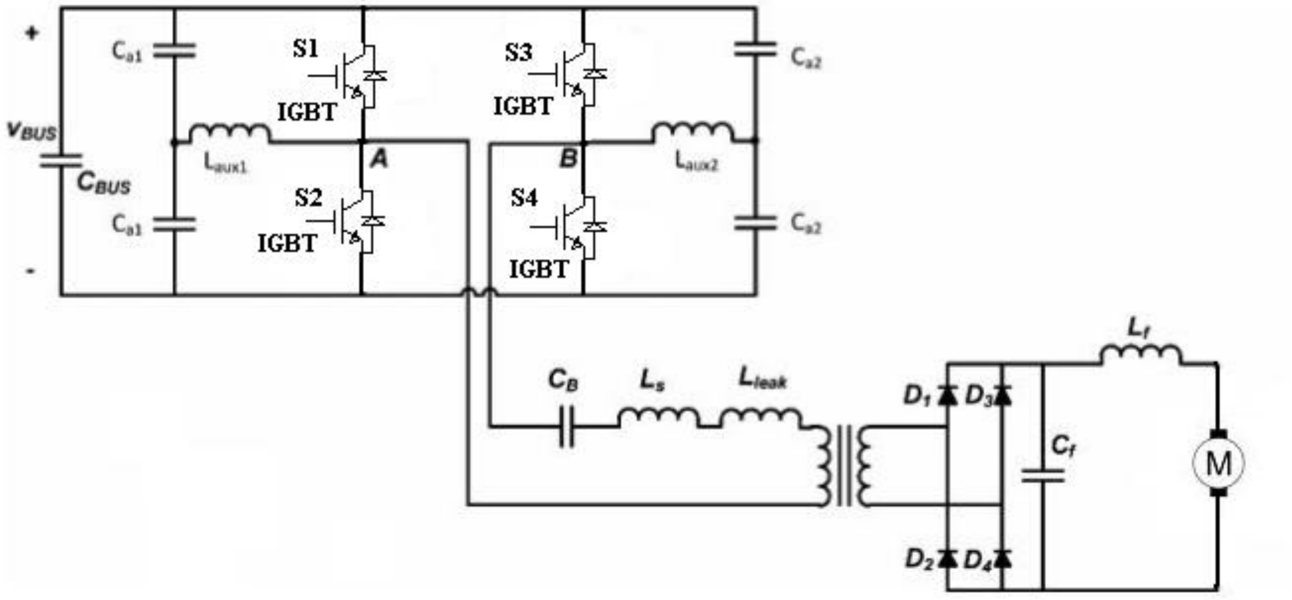

Fig 3. Circuit diagram of the proposed converter

Here Fig 2 shows the proposed converter circuit. Auxiliary inductors are designed based on the amount of reactive power required to guarantee ZVS for the MOSFETs. In other words, the reactive current should be enough to completely charge and discharge the MOSFET output capacitors. However, since there are substantial differences in operating modes for the leading leg, the design procedure is given accordingly. According to the operating modes of the proposed converter, the worst case for ZVS operation is no-load. Thus, ZVS should be guaranteed for no-load in order to make sure ZVS operation for all operating conditions. At absolutely no-load, the primary current is zero during the switching transitions of the leading leg. Therefore, the current through auxiliary circuit of the leading leg should only charge and discharge the output capacitors of the MOSFETs. The series inductor should be designed so that the converter full-load condition corresponds to the critical conduction mode of the series inductor. This series inductance *Lseq* plays a major role in the energy transfer from the primary to the secondary side of the transformer. This inductance by nature is an AC inductor. So regular design methods of an AC inductor with air-gap has to be followed if an external inductor is to be designed for the series inductor, *Ls*. This inductance can be integrated as the leakage inductor of the transformer too. Although in that case, a transformer with a precisely designed leakage inductance will be necessary but the advantage of having this integrated series inductance is immense including elimination of an actual physical inductor along with its core and copper losses and the adverse effects of its fringing flux on the EMI and the operation of the surrounding devices on the PCB of the converter

V. PRICIPLE OF OPERATION

The topology introduced in this project presents a novel yet simple solution to this problem. The proposed topology is essentially a ZVZCS type full-bridge converter with a current driven rectifier. Fig. below shows the power circuit of the proposed topology. In this topology, the full-bridge inverter converts the DC-bus voltage to a high frequency quasi-square wave voltage. Then there is an inductor in series with the transformer, which acts as a current source for a current driven rectifier. The current driven rectifier rectifies the output current of the transformer and transfers power to the output. In one switching cycle, the circuit has 14 modes during steady-state operation. Due to the symmetrical structure, the analysis is only given for half a switching cycle.

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***Mode I**: ($t0 \leq t \leq t1$):* At $t0$, $S2$ is turned OFF. The output capacitor of $S1$ is discharging and that of $S2$ is charging up with the reactive current provided by the auxiliary circuit. During this interval, the secondary-side diodes are reversed biased and are OFF. Therefore, the rising voltage *Vab* conducts a very small current through the DC blocking capacitor *Cb*, series inductance *Ls*, leakage inductance *Lleak*, and magnetizing inductance *LM* .

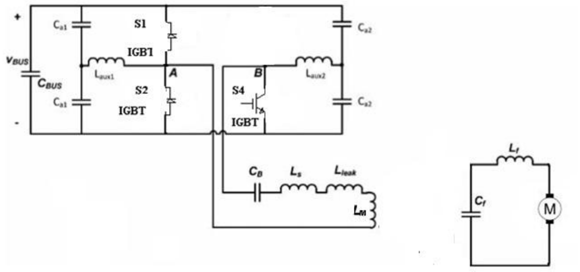

Fig.4. Mode 1 operation

***Mode II** ($t1 \leq t \leq t2$):* This mode starts once the output diodes get forward biased. According to this figure, the output capacitor of the MOSFET, $S1$ is still discharging to finally reach zero and that of $S2$ is charging up to *Vdc*. This mode ends once the voltage across this capacitor becomes zero.

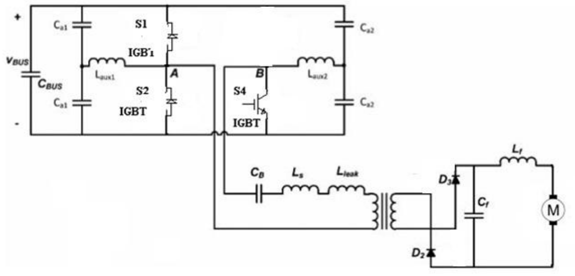

Fig. 5 Mode 2 operation.

***Mode III** ($t2 \leq t \leq t3$):* This mode starts once the MOSFET output capacitors have been charged and discharged completely. During this mode, the output diodes clamp the secondary voltage to the output voltage. Thus, there is a constant voltage across the combination of the series inductance and the leakage inductance. Therefore, the series current ramps up to its peak value.

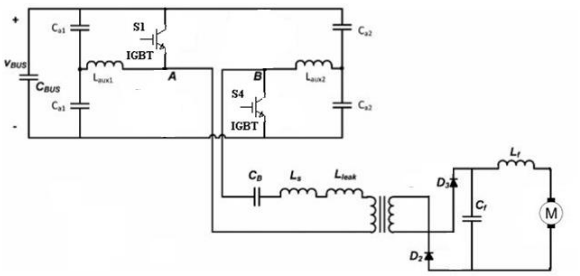

Fig.6 Mode 3 operation.

***Mode IV** ($t3 \leq t \leq t4$):* During this interval the output capacitor of $S3$ is discharging from and that of $S4$ is charging up to *Vdc*.

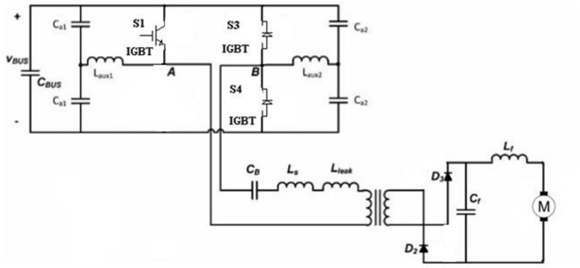

Fig.7 Mode 4 operation.

***Mode V** ($t4 \leq t \leq t5$):* Once this voltage *Vab*, becomes zero this mode commences. During this mode, the output voltage of the inverter is zero and the output diodes clamp the secondary voltage to the outputvoltage.

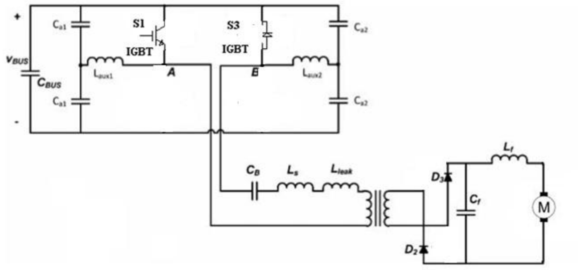

Fig.8 Mode 5 operation.

***Mode VI** ($t5 \leq t \leq t6$):* This mode starts when the gate pulse is applied to $S3$. The equivalent circuit is the same as the previous mode except $S3$ channel is conducting in this mode rather than the body diode of $S3$. Therefore, the series inductor current is still ramping down to reach zero at the end of this mode. It should be noted that $S1$ turns off under near zero current switching at the end of this mode. At the end of this mode, the current through the series inductor reaches zero, so that the output diodes $D2$ and $D3$ naturally turn off with zero current.

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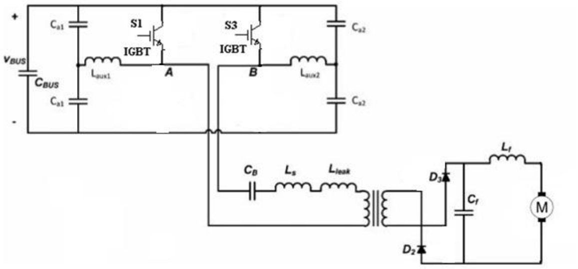

Fig.9 Mode 6 operation.

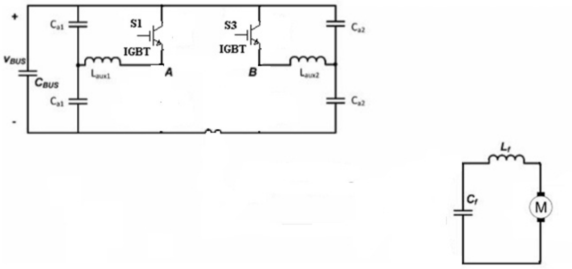

Fig.10 Mode 7 operation.

Mode VII *(*$t6 \le t \le t7$ *):* This interval starts once the current through output diodes reaches zero and the diodes naturally turn off with zero current .During this mode, the output capacitor *Cf* feeds the output load with its stored energy while on the transformer primary side there is no current.

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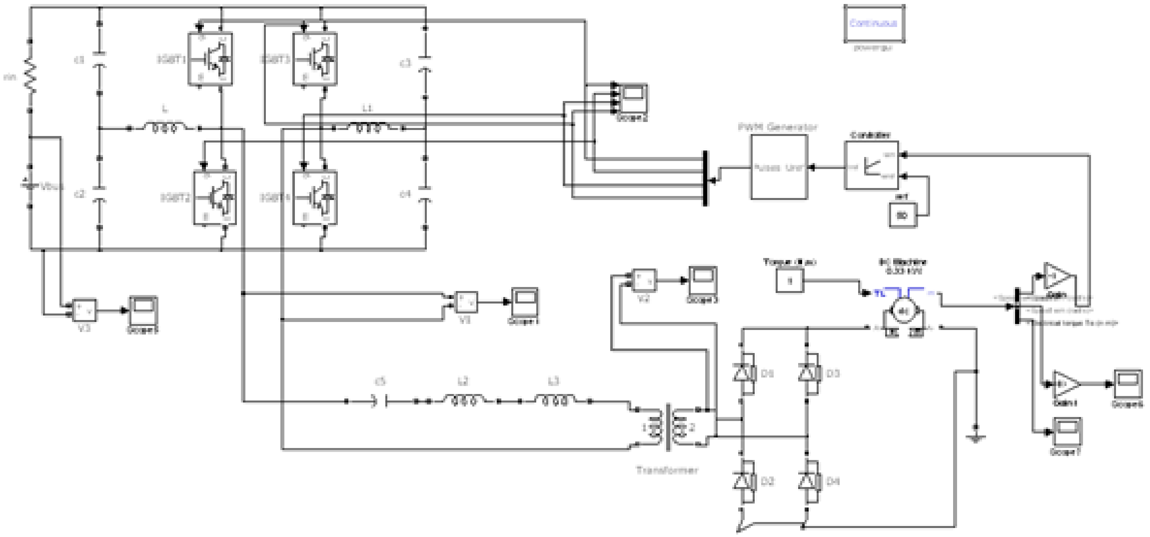

Fig..11 Main Simulation Circuit.

VI. EXPERIMENTAL RESULTS

The proposed circuit is developed and analyzed with MATLAB software.

MATLAB simulation circuit diagram for proposed full bridge ZVZCS converter is shown in fig 11

Resultant output waveforms after simulation is as given below

Resultant Waveforms :

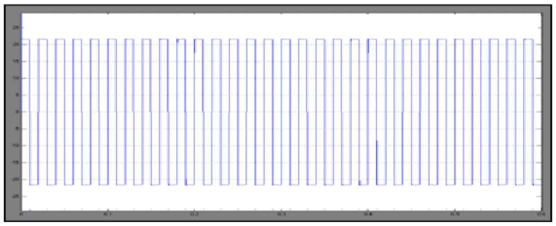

Fig 12 .Converter Output voltage

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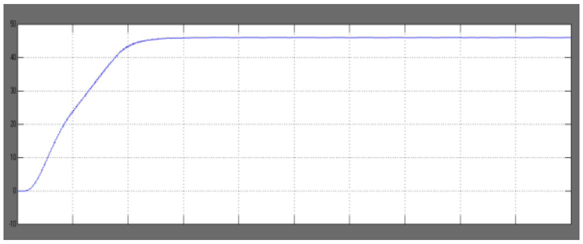

Fig 13 .Rectifier Output voltage

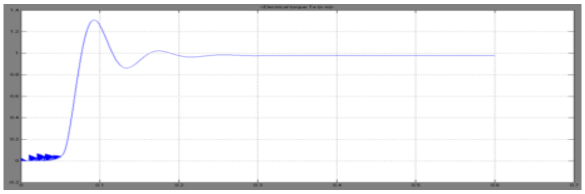

Fig. 14 Motor torque

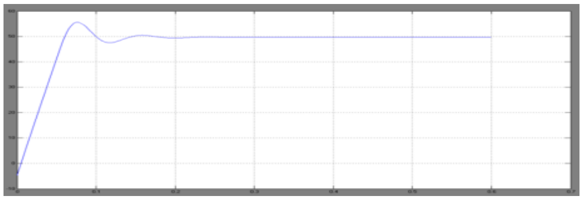

Fig. 15 Motor speed

VII. CONCLUSION

In this project, a novel yet simple full-bridge topology has been implemented on a PMDC motor. The proposed converter eliminates the adverse effects of the voltage spikes at the secondary side of the transformer, as well as the freewheeling mode of operation, which are intrinsic to the conventional full-bridge converters. Moreover, the proposed converter assures reliable operation at no load by applying the symmetric auxiliary circuits on both legs of the full-bridge converter. Better efficiency of the proposed converter over full range of operation not only validate the operation of the converter but also confirm the superiority of the proposed topology over the conventional full-bridge converter.

REFERENCES

[1] Enhui Chu, Xutong Hou, Huaguang Zhang, *Senior Member, IEEE*, Mengyang Wu, and Xiuchong Liu “Novel Zero-Voltage and Zero-Current Switching (ZVZCS) PWM Three-Level DC/DC Converter Using Output Coupled Inductor”, IEEE Transactions on Power Electronics, vol. 29, no. 3, March 2014

[2] H. Cha, L. Chen, R. Ding, Q. Tang, and F. Z. Peng, “An alternative energy recovery clamp circuit for full-bridge PWM converters with wide ranges of input voltage,” IEEE Trans. Power Electron., vol. 23, no. 6, pp. 2828– 2837, Nov. 2008.

[3] K. Raggle, T. Nussbaumer, and J. W. Kolar, “Guideline for a simplified differential-mode EMI filter design,” IEEE Trans. Ind. Electron., vol. 57, no. 3, pp. 1031–1040, Mar. 2010.

[4] Hyungjoon Kim, Changwoo Yoon, and Sewan Choi, *IEEE Senior Member* Seoul National University of Technology Dept. of Control and Instrumentation Eng. “A three-Phase ZVZCS DC-DC converter for fuel cell applications”

[5] J. G. Cho, J.W. Baek, D.W. Yoo, H. S. Lee, and G. H. Rim, “Novel zerovoltage and zero-current-switching (ZVZCS) full bridge PWM converter using transformer auxiliary winding,” in *Proc. 28th Annu. IEEE Power Electron. Spec. Conf., (PESC)*, vol. 1, St. Louis, MO, Jun. 22–27, 1997, pp. 227–232

[6] L. H. Mweene, C. A. Wright, and M. F. Schlecht, “A 1 kW 500 kHz front-end converter for a distributed power supply system,” *IEEE Trans. Power Electron.*, vol. 6, no. 3, pp. 398–407, Jul. 1991.

[7] R. Ayyanar and N. Mohan, “Novel soft-switching DC–DC converter with full ZVS-range and reduced filter requirement. I. Regulated-output applications, *IEEE Trans. Power Electron.*, vol. 16, no. 2, pp. 184–192, Mar.2001.

[8]Dr.T.Govindaraj, and M. Gunasegaran,“ PV Micro inverter System based Electric Drive , ” *International Journal Of Advanced and Innovative Research.*ISSN: 2278-7844, Dec-2012, pp 458-467.

[9] Dr.T.Govindaraj, and V.Purushothaman**, “**Simulation Modeling of Inverter Controlled BLDC Drive Using Four Switch,**”** *International Journal of Advanced and Innovative Research.*ISSN: 2278-7844,Dec- 2012*, pp* 554-559.

[10] Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli,”Design, Development and Control of an Axial Flux Permanent Magnet Linear Oscillating Motor using FE Magnetic Analysis Simulation Models,” Int. Journal of Electrical and Electronics Engineering, Oradea, Romania, October 2010

[11] R.Narmatha and T.Govindaraj, “Inverter Dead-Time Elimination for Reducing Harmonic Distortion and Improving Power Quality”, *International journal of Asian Scientific Research*, vol.3, April 2013

[12] Dr.T.Govindaraj, and A.Kanimozhi,“ Instantaneous Torque control of Small Inductance Brushless DC Drive,”*International Journal Of Advanced and Innovative Research.*ISSN: 2278-7844, Dec-2012 ,pp 468- 474.

[13] Dr.T.Govindaraj, and T.Keerthana,“ DFC And DTC Of Special Electric Drive Using PI And FLC, ” *International Journal Of Advanced and Innovative Research.*ISSN: 2278-7844, Dec-2012 ,pp 475-481.

[14]Dr.T.Govindaraj, and T.Sathesh kumar, “New Efficient Bridgeless Cuk Converter Fed PMDC Drive For PFC Applications,” *International Journal Of Advanced and Innovative Research.*ISSN: 2278-7844, Dec- 2012*, pp* 518-523

[15]Dr.T.Govindaraj, and B.Gokulakrishnan**, “**Simulation of PWM based AC/DC Converter control to improve Power Quality,**”**

International Journal of Advanced and Innovative Research.ISSN: 2278-7844, Dec-2012, *pp* 524-533.

[16] Dr.T.Govindaraj, and M.Jagadeesh, "Resonant Converter Fed PMDC Drive Using Soft Switching Techniques," International Journal of Advanced and Innovative Research ISSN: 2278-7844, Dec-2012, pp 535-541.

[17] T.Govindaraj, Rasila R,"Development of Fuzzy Logic Controller for DC – DC Buck Converters", International Journal of Engineering Techsci Vol 2(2), 192-198, 2010

[18]Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli," Design, Development and Finite Element Magnetic Analysis of an Axial Flux PMLOM," *International Journal of Engineering and Technology*, Vol.2 (2), 169-175 , 2010

[19]Govindaraj Thangavel, Ashoke K. Ganguli and Debashis Chatterjee,"Dynamic modeling of direct drive axial flux PMLOM using FEM analysis" *International journal of Elixir Electrical Engineering* Vol.45 pp 8018- 8022, April 2012

[20] G. Thangavel and A. K. Ganguli,"Dynamic Modeling of Directive Drive Axial Flux PM Linear Oscillatory Machine Prototype Using FE Magnetic Analysis", ***Iranian Journal of Electrical and Computer Engineering***, Vol. 10, No. 2, Summer-Fall 2011

[21**]** Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli,"FEA based Axial Flux permanent Magnet Linear Oscillating Motor**," *International Journal THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI F ASCICLE III, ELECTROTECHNICS, ELECTRONICS, AUTOMATIC CONTROL, INFORMATICS*** , July 2010

[22] Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli,"FEA Simulation Models based Development and Control of An Axial Flux PMLOM,"***International Journal of Modelling and Simulation of Systems***, Vol.1, Iss.1, pp.74-80, 2010

[23]Dr.T.Govindaraj, and S.Deepika, "Hybrid input Boost converter Fed BLDC Drive," *International Journal Of Advanced and Innovative Research.* ISSN: 2278-7844, Dec-2012, pp 444-451

[24]Govindaraj Thangavel, Debashis Chatterjee, and Ashoke K. Ganguli," Modelling and Simulation of Microcontroller based Permanent Magnet Linear Oscillating Motor,"*International Journal of and Modelling Simulation of Systems*, Vol.1, Iss.2, pp. 112-117, 2010

[25]Govindaraj Thangavel," Design, Development, Analysis and Control of an Axial Flux Permanent Magnet Linear Oscillating Motor suitable for short strokes using Finite Element Method," *International Journal of Electronic Engineering Research* Volume 2 Number 3 pp. 419–428, 2010

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