

Simulation of Bridgeless Boost Rectifier for Low Voltage Energy Harvesting Applications

Vrinda Vijayan, Vinida K.

Abstract— The conventional power converters for low voltage energy harvesting consist of two stages-diode bridge rectifier stage and dc-dc boost conversion. This paper presents an efficient AC-DC power converter that avoids the bridge rectifier stage and directly converts low AC voltage to a required high dc output voltage. The circuit is a unique integration of boost and buck-boost converter to condition the positive and negative half portions of the input AC voltage, respectively. The topology uses only a single inductor and capacitor to reduce the size of the converter. The input AC voltage of 0.4V amplitude is rectified and boosted to 3.3V dc which could be used to power wireless sensors, electronic devices and bio-medical implants. This topology provides an efficiency of 71% and is designed with the purpose of minimizing the size, weight and power losses. The closed loop simulation has been carried out in power electronic simulation software PSIM©.

Index Terms— Ac-dc conversion, Bridgeless, Buck-boost, Energy harvesting, Low-voltage rectification.

1 INTRODUCTION

ENERGY harvesting is the process by which small amounts of energy are extracted from the ambient surroundings. It has been a research focus for many years. The idea that energy can be harvested from the ambient environment and a device can operate without a battery is very attractive for low power electronic applications. The slow growth of battery technology and development of low power semiconductor technology has positioned, energy harvesting as a feasible option for low power applications. From a broader perspective, the systems for energy harvesting may be based on several sources, like the kinetic energy (wind, waves, gravity and vibrations), electromagnetic energy, thermal energy, atomic energy or biological energy [1].

Currently, all portable electronic devices are powered only by batteries. However, energy harvesting from human or environmental sources has proven to be an effective alternative or complement. As the electronics' scale decreases, so does the energy consumption. In this sense, batteries were also produced in smaller size providing more energy storage availability. However, due to technical and technological issues, the batteries have not been followed by the same evolutionary trend limiting the operational time and performance of portable devices as it need to be recharged or replaced periodically. Moreover, it has problems related to its weight and volume [2], [3].

In the present scenario of global warming, such self-powered devices play a very important role. They can perform operations without any external supply by scavenging energy from the environment. With the ever reducing power requirements of both analog and digital circuits, power scavenging approaches are becoming increasingly attractive. Fabrication of

such power sources using MEMS (Micro Electro Mechanical Systems) technology is attractive in order to achieve small size and high precision [4]. The power requirement of these electronic devices is the order of a few milliwatts, which can be harvested from the ambient energy in the form of heat, light, vibration by using various types of micro generators. The types of micro generators for harvesting energy include electromagnetic, electrostatic and piezoelectric [5]. Since electromagnetic micro generators have higher energy density, they are being considered in this paper.

The electromagnetic micro generators are mass-spring damper based arrangement (as shown in Fig. 1) in which the ambient mechanical energy is converted to electrical energy by electromagnetic coupling [6]. The output voltage of this micro generator is of AC type, whereas the electronic loads require DC voltage. Hence, the micro generator output has to be processed by a suitable power converter before providing to the electronic loads.

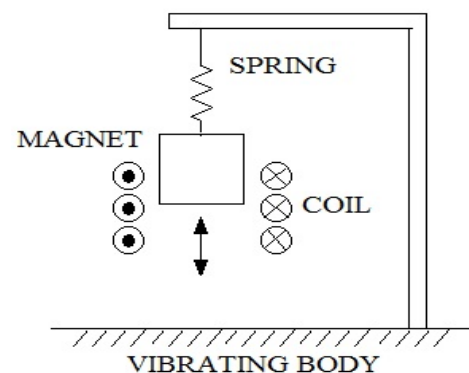


Fig. 1 Schematic diagram of electromagnetic micro generator

The block diagram for the low voltage energy harvesting is shown in Fig. 2. The ambient vibration in the form of mechanical energy is converted to electrical energy by the MEMS transducer. The output of the transducer is an AC voltage with a low magnitude which is to be converted to a DC volt-

- Vrinda Vijayan is currently pursuing masters degree program in power Electronics & Power Systems in Adi Shankara Institute of Engineering & Technology, Kalady. E-mail: vrindavijn90@gmail.com
- Vinida.K is currently pursuing PhD degree in Electrical & Electronics engineering in CUSAT, Cochin. E-mail: vinidaranjan@yahoo.in

age and needs to be stepped up to the adequate value to supply the low power electronics load [7], [8], [9]. In energy harvesting systems, power electronic circuit forms the key interface between transducer and electronic loads. The power electronic circuits are employed to (a) regulate the power delivered to the load and, (b) actively manage the electrical damping of the transducers so that maximum power could be transferred to the load

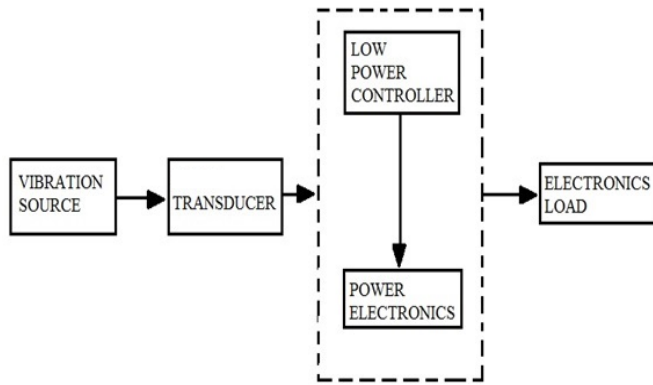


Fig. 2 Block diagram for low voltage energy harvesting

Since the voltage generated by the electromagnetic micro generator is an AC voltage which is of the order of few millivolts and the load is an electronic device which needs a dc supply of the order of a few volts, there are two stages involved in this conversion process. They are rectification and boosting processes. So the conventional power converters reported for energy harvesting circuits consist of a diode bridge rectifier and a dc/dc converter for stepping up the voltage as shown in Fig. 3.

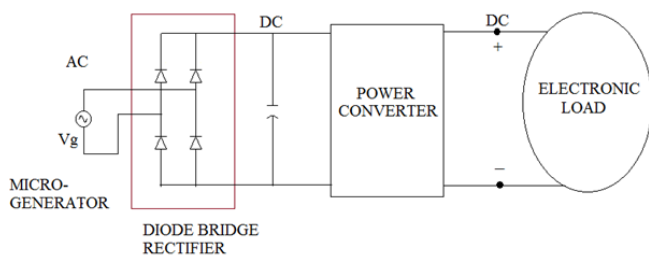


Fig. 3 Block diagram for conventional power converters

The main disadvantage in this two stage topology is that since the output voltage of micro generator is very low, rectification is not possible with the use of conventional diodes. Moreover, the forward voltage drop in the diodes causes losses as input current is much higher than the output current, thereby the power conversion efficiency is decreased. This leads to the development of direct AC/DC step up converter which converts the AC voltage with low magnitude generated by the electromagnetic micro generator into a dc voltage with

a higher magnitude thereby avoiding diode bridge rectifier.

The paper presents a new bridgeless boost rectifier as shown in Fig.4, which is a unique integration of boost and buck-boost converters to condition the positive and negative half portions of the input AC voltage, respectively. During the positive half cycle of the input AC voltage, S1 is turned ON and D1 is reverse biased and hence, the circuitry operates in the boost mode. During the negative half cycle, the buck-boost mode starts by turning ON S2 and reverse biasing D2.

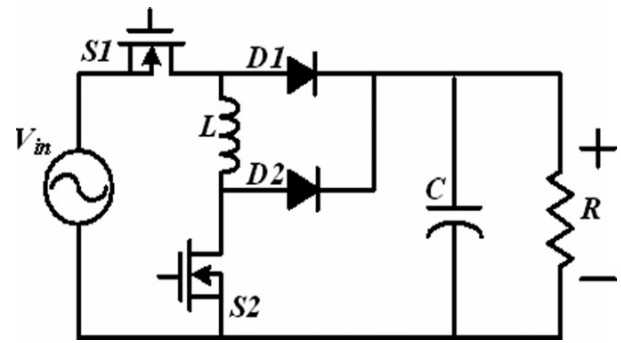


Fig. 4 Bridgeless boost rectifier for energy harvesting

The section 2 describes the various operating modes of the converter and section 3 discuss on design procedures and guidelines. Section 4 addresses the simulation results and result analysis. The conclusion is given in section 5.

2 DIRECT AC-DC CONVERTER

2.1 Basic Principle of the Proposed Direct AC – DC Converter

The bridgeless boost converter topology is a unique integration of boost and buck-boost converter. The boost converter is the common power conditioning interface due to its simple structure, voltage step-up capability, and high efficiency. The buck-boost converter has ability to step up the input voltage with a reverse polarity; hence, it is an appropriate candidate to condition the negative voltage cycle. Besides, the boost and buck-boost converter topologies could share the same inductor and capacitor to meet the miniature size and weight requirements. In this paper, a 0.8V peak to peak, 108-Hz sinusoidal AC voltage source is adopted to emulate the output of the electromagnetic energy harvester.

2.2 Control Scheme

The control scheme for the proposed converter is shown in Fig. 5. Here, the actual voltage is being compared with the reference voltage, and the error signal is then given to another comparator which compares the control voltage with a saw-tooth voltage waveform. The gate pulses are then given to the boost and buck-boost converter switches by the detection of positive and negative peaks, respectively.

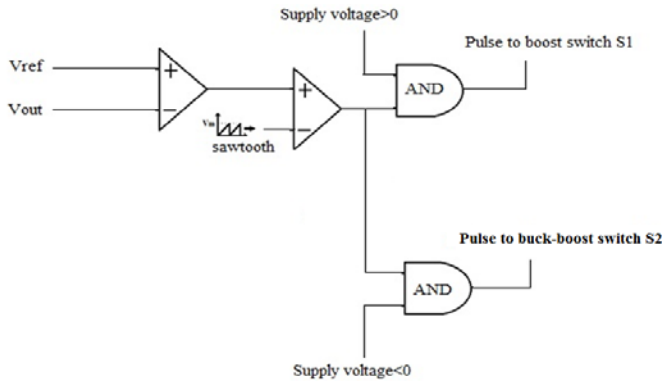


Fig. 5. Closed-loop control Scheme for the proposed Converter

2.3 Modes of Operation

There are six operation modes for the bridgeless boost converter as shown in Fig. 6. Modes I-III is for the circuit operation in the positive half cycle, whereas, modes III-VI are for the circuit operation during the negative half cycle. During the positive half cycle, S1 is turned ON and D1 is reverse biased while S2 is turned ON and D2 is reverse biased during the negative half cycle. The topology is operated in the boost and buck-boost mode during positive and negative half portions of the input AC voltage, respectively.

MODE I: During this mode, buck-boost switch S2 is turned ON at t_0 through zero current switching (ZCS) to reduce the switching losses. Here, the inductor current is zero. Since both S1 and S2 are conducting, the inductor is energized by the input AC voltage. Both the diodes are reverse biased and load is powered by the energy stored in the output filter capacitor, C.

MODE II: S2 is turned OFF here, and the energy stored in the inductor during Mode I is transferred to the load side.

MODE III: As soon as inductor current drops to zero, D2 is automatically turned OFF. This avoids the reverse recovery losses of the diode and load is again powered by the energy stored in the capacitor. The converter would return to Mode I as soon as S2 is turned ON, if the input voltage is still in positive cycle.

MODE IV: The negative cycle begins in this mode that is when the buck-boost switch is being given the gate pulse. This mode starts as soon as S1 is turned ON. The energy is transferred to the inductor L again, while the output filter capacitor feeds the load.

MODE V: Here, S1 is turned OFF and hence, the energy stored in the inductor during MODE IV is transferred to the load. The inductor current decreases linearly. During this mode, switching loss occurs during the turn on of the diode D1.

MODE VI: As soon as the inductor current drops to zero, D1 is turned OFF at zero current. The load is continuously powered by the charge stored in the output filter capacitor. The converter would return to Mode IV as soon as S1 is turned ON, if the input voltage is still negative.

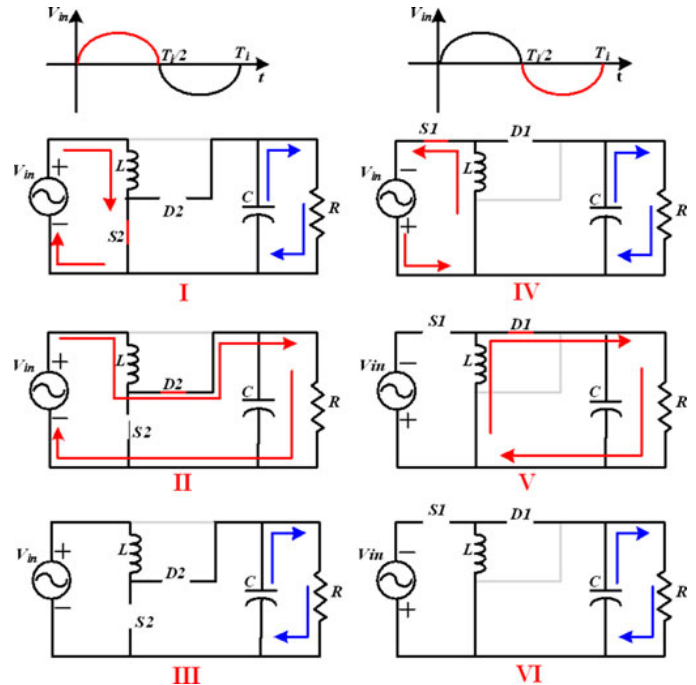


Fig. 6 Operation modes of the proposed boost rectifier

The Fig. 7 shows the waveforms of the proposed boost rectifier in the boost and buck-boost operation modes.

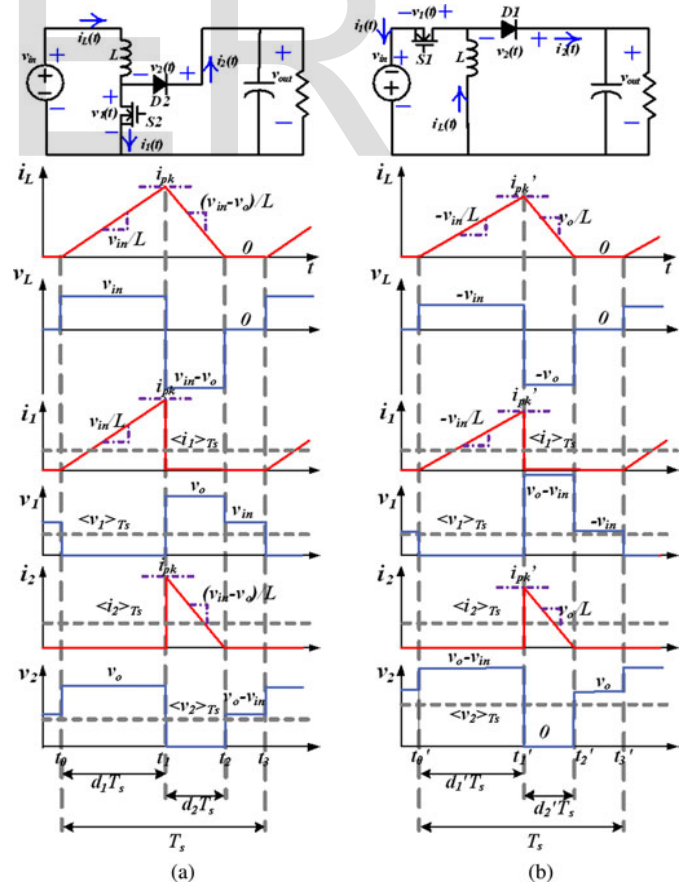


Fig. 7 Waveforms of the proposed boost/buck-boost rectifier. (a) Boost operation (b) Buck-boost operation

According to the analyses of operation modes, the switches are turned ON with ZCS and the diodes are turned OFF with ZCS. Due to the DCM operation, the input current sensor can be eliminated and switching loss can be reduced. Moreover, the control scheme of DCM operation is relatively simpler. Since the circuit size can be reduced and the efficiency can be enhanced, DCM operation is more suitable than the continuous conduction mode (CCM) operation.

3 PSIM SIMULATION MODEL

The proposed direct AC to DC converter circuit with boost and buck-boost converter is simulated using PSIM. A closed loop operation of the circuit is modeled and simulated. Here, the actual voltage is compared with the reference voltage (3.3V) and the error signal is given to a PI controller. Then, a hysteresis control is given by using a saturation block which limits the PI controller output (control voltage) to remain within certain limits. The control voltage is again compared with a saw tooth waveform from the signal generator so that gate pulses are being given to the boost and buck-boost converter switches according to the detection of positive and negative peaks, respectively. The simulation is done for obtaining a dc output voltage, $V_o=3.3V$ from the electromagnetic micro generator which is modeled as a sinusoidal voltage source with the specification, $V_{in}=400mV$ and frequency 100Hz. For closed loop operation the PSIM model of boost- buck-boost converters created as in Fig. 8. Circuit parameters used for the simulation are $L=4.7\mu H$, $C=500\mu F$, $R=100\Omega$, switching frequency=10 kHz.

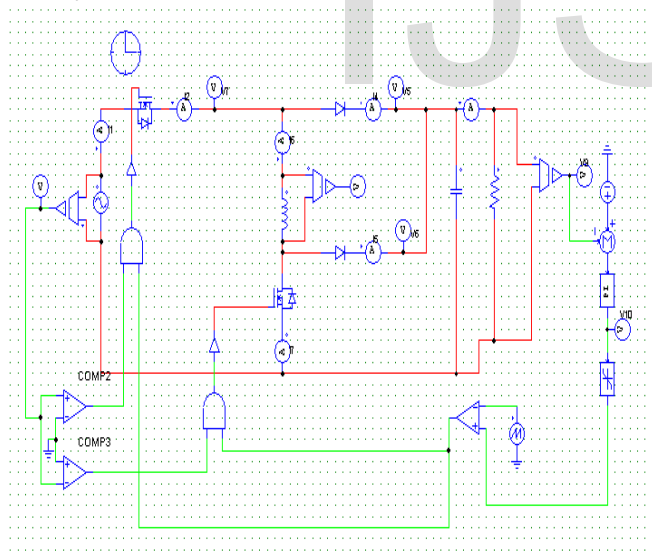


Fig. 8 Simulation of the proposed boost rectifier

4 RESULT ANALYSIS

The Fig .9 shows the gate pulses for the boost switch and buck-boost switch during the positive half and negative half

cycle, respectively.

Fig .10 shows the inductor voltage and inductor current waveforms. It can be seen that the inductor is operated during the entire half cycle, which is during both positive and negative half cycle of the input voltage.

Fig. 9 Pulses for boost and buck-boost switches

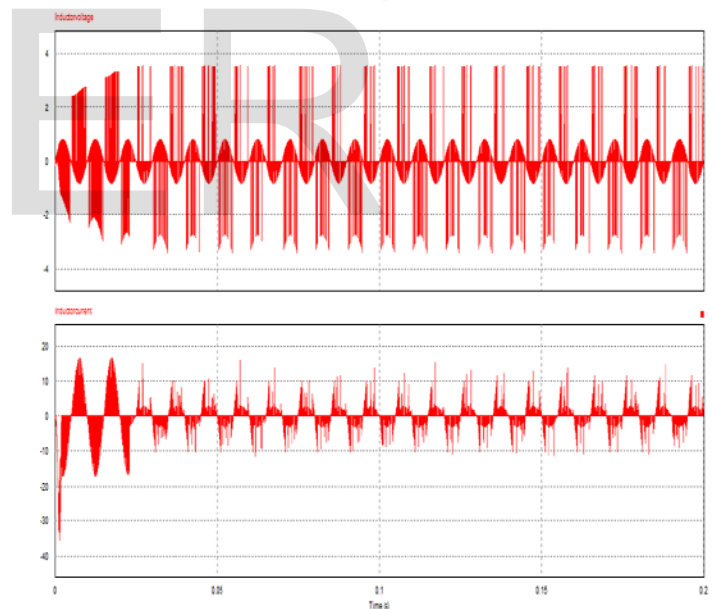
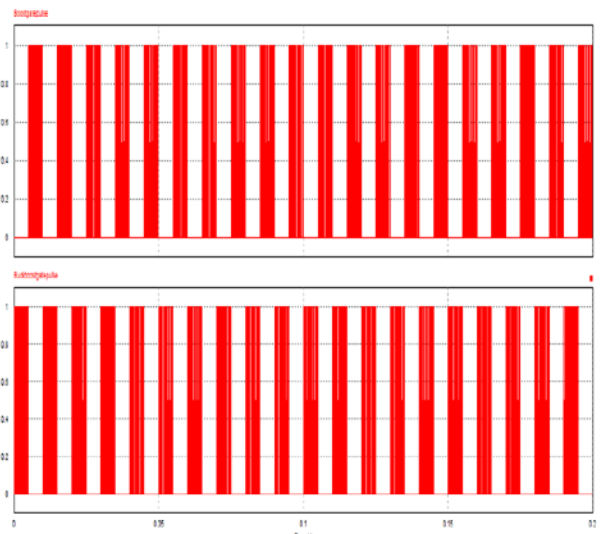


Fig. 10. Inductor voltage and current waveform

The Fig. 10 shows the output voltage and output current waveform. The AC voltage of the micro generator is being given to the proposed AC-DC step up converter which rectifies and boosts the AC voltage to a DC voltage of constant magnitude which is found to settle at 3.23V, whereas the output current settles at 0.0646A.

The Fig .11 shows the control voltage waveforms. Fig .11 (a) shows the saw tooth voltage and (b) shows the PI controller voltage. When the saw tooth voltage is cut by the PI controller voltage, gate pulses are obtained which is given to the two

switches. These pulses are given to the switches according to input voltage polarity. During the positive half cycle, pulses are given to the boost converter topology, whereas during the negative half cycle, pulses are given to the buck-boost converter topology.

linear Effects", IEEE Transactions On Power Electronics' Vol.25, No. 8, August 2010

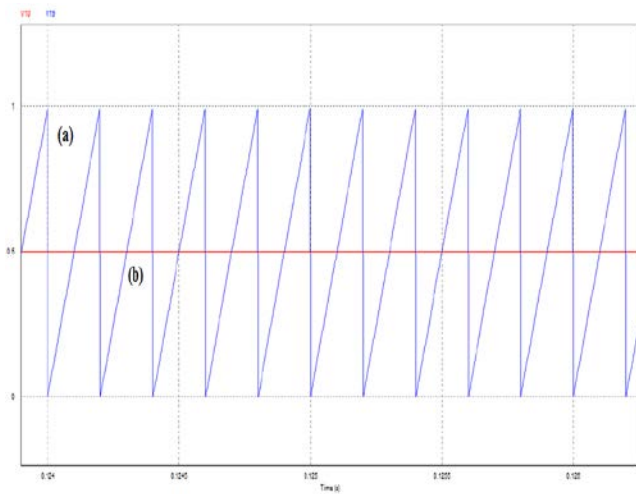


Fig. 11 (a) Sawtooth voltage (b) PI controller voltage

REFERENCES

- [1] Suman Dwari, and Leila Parsa, "An efficient AC to DC step-up converter for low-voltage energy harvesting," IEEE Trans. Power Electron., Vol. 25, no. 8, AUG 2010
- [2] S. Meninger, J. O. Mur-Miranda, R. Amirtharajah, A. P. Chandrakasan, and J. H. Lang, "Vibration-to-electric energy conversion," IEEE Trans. Very Large Scale Integr. Syst., vol. 9, no. 1, pp. 64-76, Feb. 2001
- [3] M. El-Hami, P. Glynne-Jones, N. M. White, M. Hill, S. Beeby, E. James, A. D. Brown, and J. N. Ross, "Design and fabrication of a new vibration based electromechanical power generator," Sens. Actuators A: Phys., vol. 92, pp. 335-342, 2001.
- [4] T. M. Thul, S. Dwari, R. D. Lorenz, and L. Parsa, "Energy harvesting and efficient power generation from human activities," in Proc. Center Power Electron. Syst. (CPES) Semin., Apr. 2007, pp. 452-456
- [5] N. G. Stephen, "On energy harvesting from ambient vibration," J. Sound Vibrations, vol. 293, pp. 409-425, 2006.
- [6] B. H. Stark, P. D. Michelson, M. Peng, T. C. Green, E. Yeatman, and A. S. Holmes, "Converter circuit design, semiconductor device selection and analysis of parasitics for Micropower electrostatic generators," IEEE Trans. Power Electron., vol. 21, no. 1, pp. 27-37, Jan. 2006.
- [7] C. B. Williams and R. B. Yates, "Analysis of a micro-electric generator for microsystems," in Proc. Int. Conf. Solid-state Sens. Actuators, 1995, pp. 369-372.
- [8] P. D. Michelson, T. C. Green, E. M. Yeatman, and A. S. Holmes, "Architecture for vibration-driven Micropower generators," Microelectromech. Syst., vol. 13, no. 3, pp. 429-440, Jun. 2004
- [9] Rohan Dayal, Suman Dwari, Leila Parsa, "A New Design for Vibration-Based Electromagnetic Energy Harvesting Systems Using Coil Inductance of Microgenerator", IEEE Transactions on Industry Applications. Vol.47, No.2, March/April 2011.
- [10] Enrico Dallago, Marco Marchesi, and Giuseppe Venchi, "Analytical Model of a Vibrating Electromagnetic Harvester Considering Non-