Modelling and Signature Analysis of Vibration Energy Harvesting System using Electromagnetic Energy Conversion

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***Abstract* - The electromagnetic energy harvester works on the principle of electromagnetism. It harvests the vibration energy from acceleration of people during different activities such as walking, running, jumping and cycling and converts it into electrical energy using electromagnetic principles of conversion. The harvested electrical power is then converted to DC by using AC-DC converter. The energy harvesting input ac voltage boosts up the dc output by using ac-dc boost converter. Energy storage devices are used to store the converted power.**

Keywords - Electromagnetic energy harvest, ac-dc converter, electrical power, magnetic material.

I. INTRODUCTION:

Energy harvest strategy is recycled to convert the environmental energy keen on electrical energy. The translation of electrical energy beginning a vibrate resource to a renewable storage space, such at the equivalent time as chargeable batteries or super capacitors. The electrical power stored in the storage space knows how to be recycled for little power integrated circuit. Vibration power producer using laser micromachining which be capable of generate the upper limit power of 830W. The interface circuit introduces a comment control into a feed forward dc-dc (PWM) boost converter as an energy produce circuit and shows high power conversion effectiveness.

Energy can be harvest from wasted source such as solar thermal energy, vibration force and pressure force, which can be there converted into working electricity. Electromagnetic harvest systems have lesser production charge, longer period, and higher power effectiveness. Electromagnetic methods comprise linear generator and rotating generator [1]. Harvesting energy generator from shaking, as alternative energy source, has grown to be increasingly extensive since vibrations are general. Harvesting generator is calculated to work at small frequencies, close to ambient shaking, but it can be alive modified to work at towering value of occurrence [2]. Increasing the energy-conversion good organization and keeping it tall at a fairly large vibration amplitude have been not easy, and no minute energy harvester has exposed more than tens of mill watt power stage from sub millimetre pulsation amplitude. Electromagnetic force conversion, on the other hand, is beneficial owing to its potential to drive a low impedance weight and generate a high output current [3].

Vibration-based electromagnetic energy combines by a mechanical frequency up-conversion process for harvest energy starting peripheral low-frequency vibrations within range of 1–10 Hz. In the folder of electromagnetic energy harvesters, increase the generated power compactness is accomplished by using more than degrees of choice [5]. The regulator contain the power electronics subsystem which is accountable for stimulating the transducer in the course of its energy translation sequence, and have been optimized to condense losses, and a digital control centre which generate the timing pulse which force the gates of power FETS in the power electronics subsystem[6]. Energy harvest from thermal source such as body heat and mechanical source such as human motion have been planned. There are moreover antenna network systems that harvest energy on or after the observable part of the electromagnetic field. Energy be harvest from the electromagnetic force glowing from AC power outline and use it to control a wireless antenna network by means of a low duty-cycle [7].

An electromagnetic energy harvester produces power owing to the relative association of a coil and a magnet, which induce voltage across the coil terminal. Electromagnetic harvest system contains lower construction cost, longer life, and upper power effectiveness. Electromagnetic method contains linear generator and rotating generator. In a rotary-type generator, linear vibration action is converted into rotating action using screws, chains, or gears [9]. Vibration based energy harvesting machine through a linear spring-mass method can generate utmost power output at a exact resonant occurrence, but typically with a relatively narrow

bandwidth connotation that power output decrease considerably, when the occurrence of the vibration source shifts from the resounding frequency. This restriction the convenient use of energy harvesting machine because the ambient vibrations such as human being and wind flow usually reveals a random occurrence spectrum [10].

Vibration is solitary of the promising sources in this case to power sensors. Nevertheless, to harvest energy form such source is not easy for the reason that of its irregularity in term of characteristic frequency and amplitude [12]. An electromagnetic energy reaper utilizes the modify magnetic flux connecting the coils to bring on electric current. Electromagnetic energy harvest is an attractive applicant for vibration energy harvesters owing to a slightly straightforward mechanism of convert relative motion connecting magnet and coil into electric energy and aptitude to provide moderately high output power [15]. The translation of electrical energy from a vibrating resource to a renewable storage space such as rechargeable batteries or super capacitors. The very low duty cycle of such system push power wishes of a supply into the W range Self-powered system based on harvesting ambient energy happen to feasible alternatives, eliminating the batteries and low-maintenance, autonomous system [19].

The main contribution of this work given by,

- To design a vibration energy harvest system by electromagnetic energy conversion method.
- To obtain an output voltage by exciting the magnetic material using vibration energy.

II. METHODOLOGY

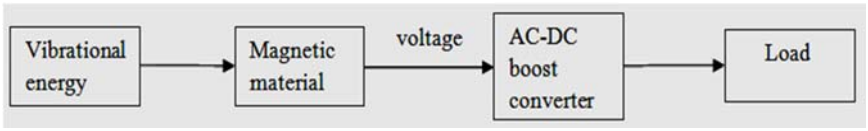

Fig.1 Block diagram of proposed system

A 60 kg person produces vibration energy during different activities. It is given to the magnetic material as an input. The output of the magnetic material is ac voltage, which is transformed to dc voltage by ac-dc converter.

The electromagnetic micro generators are mass-spring limitation based on arrangement in which the ambient mechanical energy is transformed to electrical energy by electromagnetic combination. The output voltage of this micro generator is of AC type, while the electronic loads have need of DC voltage. Therefore, the micro generator production has to be process by a proper power converter previous to providing the electronic loads.

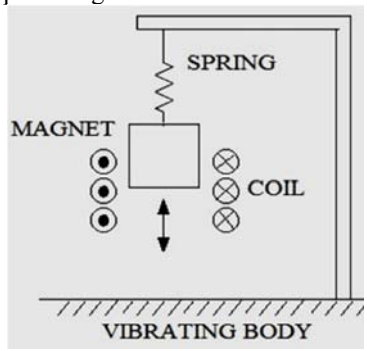

Fig.2 Diagram of electromagnetic micro generator

This paper present a new bridgeless boost rectifier as shown in Fig.2, which is a restricted combination of boost and buck-boost converters to situation the positive and negative half portion of the input AC voltage, correspondingly. During the positive half cycle of the input AC voltage, S1 is turned ON and D1 is reverse biased and consequently, the circuitry activate in the boost mode. During the negative half cycle, the buck-boost mode starts by turning ON S2 and reverse biasing D2.

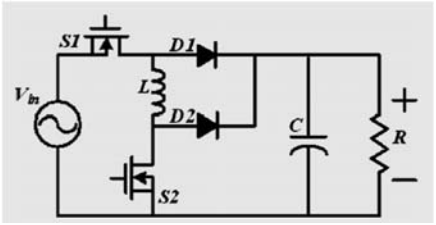

Fig.3 Bridgeless boost rectifier for energy harvest

The section 2 describes the variety of functional modes of the converter and section 3 talks about on propose events and guidelines. Section 4 addresses the simulation results and result analysis. The termination is given in section 5.

III. ELECTROMAGNETIC ENERGY

Electromagnetic energy can be changed to previous form of energy. For instance, a solar panel convert light energy to electrical energy. In the similar method, other form of energy can be converted to electromagnetic energy. Electromagnetic energy translation into kinetic energy and heat with the purpose of operate in the solar corona, astrophysical accumulation disks, dynamic galactic nuclei, and earthly magnetospheres. Energy conversion connecting electrical and mechanical forms, electromechanical procedure is residential. The slow

growth of battery machinery and expansion of stumpy power semiconductor technology has situated energy harvest as a reasonable option for low power applications. EM energy harvester Voltages and currents are used to explain the state of the electrical subsystem and they are governing by the basic circuital law: Ohm's law, KCL and KVL.

Electric and magnetic field as combination of intermediate, but why generally of the Electromechanical Energy Conversion devices use magnetic field. An electromagnetic energy harvester utilize the modify of magnetic flux connecting the coils to encourage electric current. Electromagnetic energy harvest is an attractive applicant for vibration energy harvesters due to a rather straightforward mechanism of converting virtual motion linking magnet and coil into electric energy and aptitude to present comparatively high output power. Energy harvesting from human being or environmental source has established to be a useful alternative otherwise complement. As the electronics' scale decreases, so does the energy consumption.

The initial acceleration generated voltage of the energy harvester is alternating, an AC/DC converter is essential to make the induced voltage usable by a load. The utilized interface electronics must have high conversion good organization in order to transfer the maximum amount of power from the harvester to the load. The integrated interface electronics for vibration-based energy harvesters generally contain a rectifier and a step-up converter stage.

The PM is emotionally involved to the coil through the spring. The system works in such a manner that when there is a vibration input, the coil cuts during the magnetic flux fashioned by the PM due to the relative displacement connecting the PM and the coil. A sinusoidal electromotive strength in the coil can be generated and in consequence transfer mechanical energy into electrical energy. While the output power of the power generator is quite small, an energy harvesting interface circuit with high power transfer efficiency needs to be residential to renew and store the electrical power into the energy storage elements. Furthermore, while the voltage of the renewable power supply should be high sufficient, the voltage should be better to an adequate level. A mini electromagnetic power generator was fabricating at the Hong Kong University of Science and Technology, which is considered to generate power from the vibration of an automobile and other vehicles. Thus, the power generator tightly fixed on the shaker can include controlled perpendicular vibration. The maximum power that this device can generate is given by:

$$P_{max} = m\,\zeta_t\,\omega_n^3\,Z^2_{max} \quad (1)$$

$$\zeta_t = \frac{c}{2m\omega_m} \quad (2)$$

Where m is the mass of the PM is, ζ_t is the damping ratio; c is the damping coefficient; ω_n and is the resonant frequency of the entire vibration power generator system. Typical boost converter. The vibration power generator. Zmax is the maximum relative displacement involving the coil and the PM. Here, the resonant frequency of the intended power generator is 40 Hz.

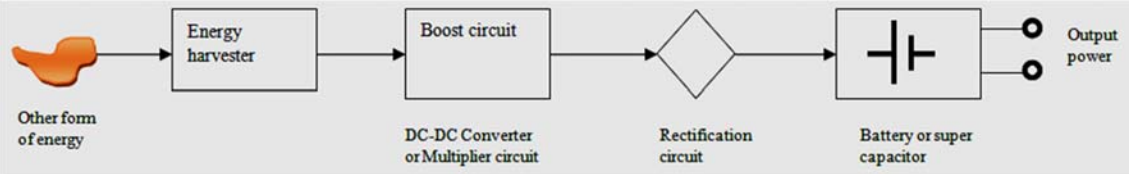

Fig 4. Basic design of Energy Harvesting System.

Methods and designs that enable the realization of energy harvesters capable of harvesting low-frequency vibrations prevalent in built and naval environments. Towards this goal, two energy harvester designs are introduced in the thesis. First, we model, analyze, and characterize the spring less electromagnetic energy harvester introduced by Mahmud et. al. We find the system reaction under various configurations and investigate the nonlinearities appearing in that response. Second, we establish a novel electromagnetic energy harvester dubbed the "field disruption energy harvester". The electromagnetic transduction method used here disrupts the magnetic field crossing the coil while the coil and magnets remain stationary. We model, analyze, and characterize this new harvester.

IV. PROPOSED NEW CONVERTER

A. Basic Principle of the Proposed AC – DC Converter

The bridgeless boost converter topology is an exclusive combination of boost and buck-boost converter. The boost converters are the general power conditioning boundary owing to its simple configuration, voltage step-up potential and higher efficiency. The buck-boost converter has capability to step up the input voltage with a reverse divergence; thus, it is suitable applicant to condition the negative voltage sequence. Moreover, the boost and buck-boost converter topologies could share the equal inductor and capacitor to get together the little size and weight requirements. In this paper, a 0.8V peak to

peak, 108-Hz sinusoidal AC voltage foundation is adopted to imitate the output of the electromagnetic energy harvester. The control technique for the proposed converter. At this time, the authentic voltage is individual compare with the suggestion voltage, and the error signal is next given to an additional comparator which compare with the control voltage with a saw-tooth voltage waveform. The gate pulses are then settled to the boost and buck-boost converter switches by the exposure of the positive and negative peaks, correspondingly.

An ac to dc convertor is a device which converts the alternating current (ac) from the mains to direct current (dc). In many electrical appliances we need often dc supply, hence the device convertor is used that converts regulated ac supply in to dc. The dc outputs are mainly used in diversity of application such as washing machines, refrigerators, industrial machines etc. Ac to dc converters in general comprise a rectifier bridge to put right the ac current of the input line and a regulating apparatus supplying on output of one or more regulated dc voltages.

The receive power as of ac power mains often rectify the sine wave (ac) mains voltage and cache energy in a capacitor. The capacitor generally charges to the peak mains voltage such that current simply flow into the power supply just about the peaks of the input voltage. A lot of ac-dc power converters make use of power factor correction. This is often skilful with two stages in series, a boost converter input stage and a buck converter second stage.

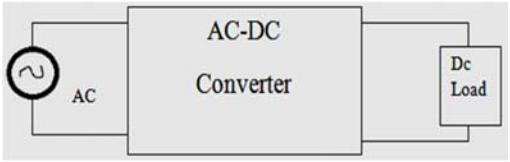

Fig 5. AC-DC Converter Block Diagram

B. Modes of Operation

There are six operation modes for the bridgeless boost converter as shown in Fig. 6. Mode I-III is for the circuit function in the positive half cycle, while, mode III-VI is for the circuit function intended for the duration of the negative half cycle. During the positive half cycle, S1is turned ON and D1 is overturn biased though S2 is turned ON and D2 is reverse biased for the duration of the negative half cycle. The topology is activating in the boost and buck-boost mode for the length of positive and negative half portions of the input AC voltage, correspondingly.

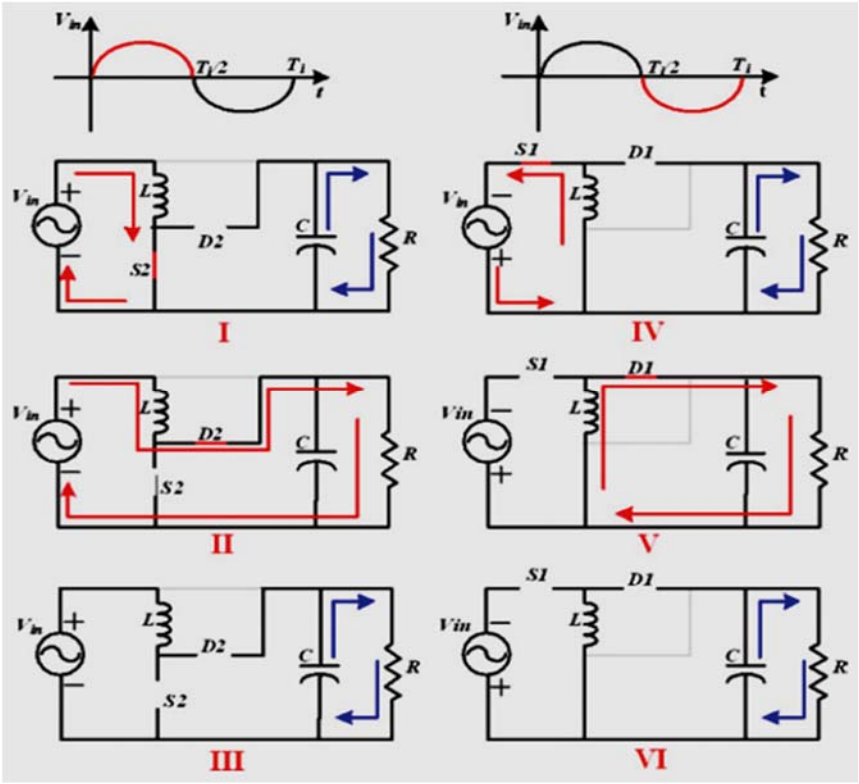

Fig.6 Operation modes of the proposed AC-DC converter

Mode I: For the duration of this mode, buck-boost switch S2 is turned ON at near throughout zero current switching (ZCS) to decrease the switching losses. At this time, the inductor current is zero. Because both switches S1 and S2 are conduct, the inductor is energized by the input AC voltage. Mutually the diodes are reverse biased and load is powered by the energy store in the output filter capacitor, C.

Mode II: S2 is turned OFF now, and the energy stored in the inductor through Mode I is transfer to the load side.

Mode III: As soon as inductor current drop to zero, D2 is automatically turned OFF. These avoid the reverse recovery losses of the diode and load is once more powered by the energy stored in the capacitor. The converter would come back to Mode I as soon as S2 is turned ON, if he input voltage is at rest in positive cycle.

Mode IV: The negative cycle begin in this mode that is when the buck-boost switch is organism specified the gate pulse. This mode starts as almost immediately S1 is turned ON. The energy is transfer to the inductor L once more, though the output filter capacitor feed the load.

Mode V: Now, S1is turned OFF and for this reason, the energy stored in the inductor for the duration of MODE IV is transfer to the load. The inductor current decrease linearly. In this mode, switching loss occur for the duration of turn on the diode D1.

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

V. SIMULATION AND RESULTS:

The Energy harvesting through using electrostatic energy harvester on or after vibration energy sources is modeled using MATLAB/SIMULINK and a coupled model (i.e. includes both mechanical and electrical properties) of the variable capacitor is used. Mechanical vibrations are specified to the variable capacitance which separates the plates and mechanical energy is transformed to the electrical energy with an electromechanical converter. The obtained output voltage is improved by means of a boost converter for future applications.

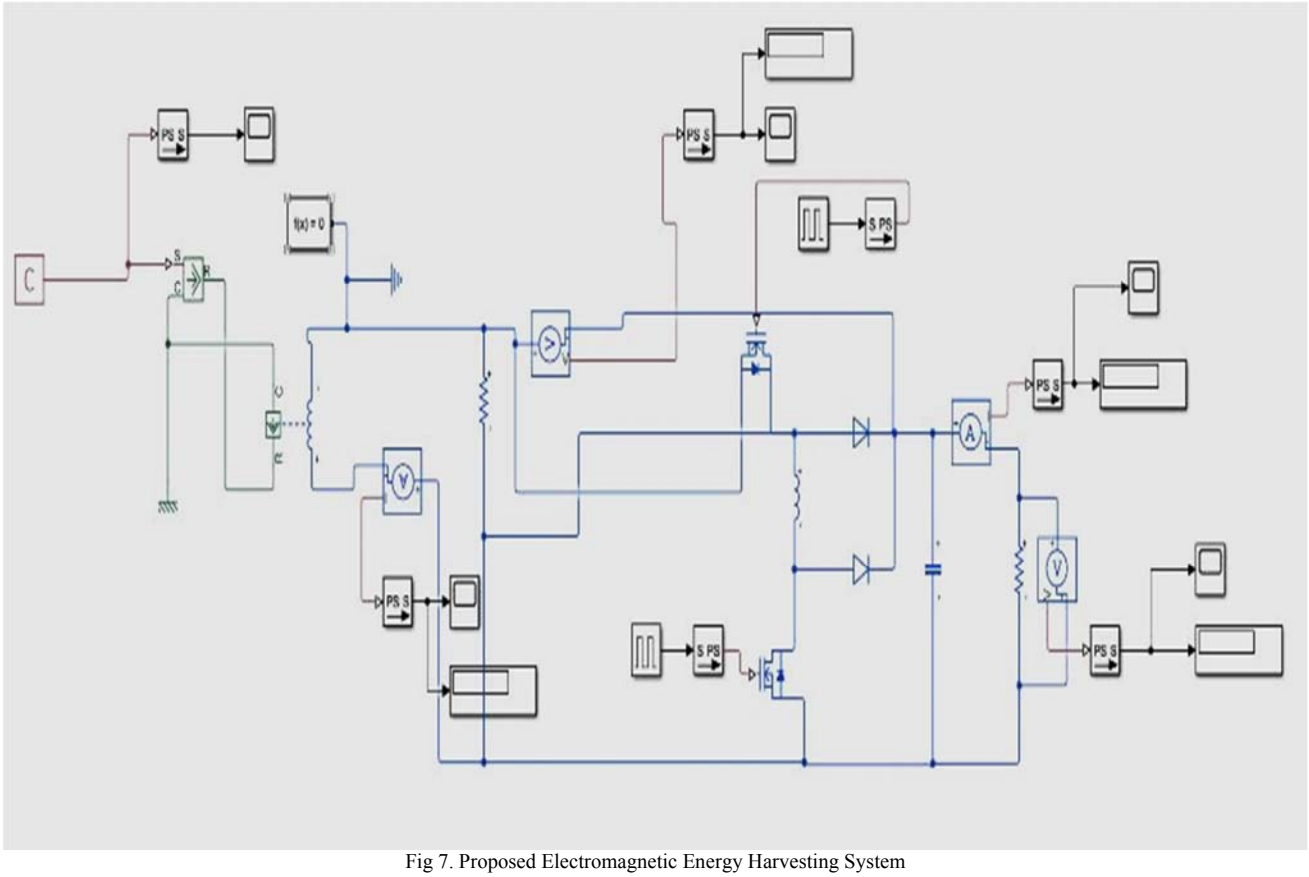

Fig 7. Proposed Electromagnetic Energy Harvesting System

Consider a person have weight x and gravity y the weight and gravity are multiplied and produced force F. Then the force f is functional to the electromagnetic material and the electrical signal is obtained. In order to amplify to the ac signal the charge amplifier is used. The charge amplifier output is given to the AC-DC boost converter to boost the voltage. Finally the result obtained is DC signal which is agreed to the load. Figure 4 shows the simulation diagram of electromagnetic energy harvesting. The acceleration of people during different activities such as walking; running; jumping and cycling convert it into electrical energy with electromagnetic method of energy conversion. The simulations are done in the MATLAB version 2016a. The various cases and its waveforms are described in below.

Case1:

Assume a person having weight with 60 kg and this weight is multiplied with the gravity and the resultant power is agreed to the electromagnetic material, which produces the AC signal value which is lies above 8V-10V. If the electromagnetic material produces the AC signal value lies 8V- 10V is represented as he is under walking condition. The obtained results from the electromagnetic material and AC to DC boost converter are shown in fig 8.

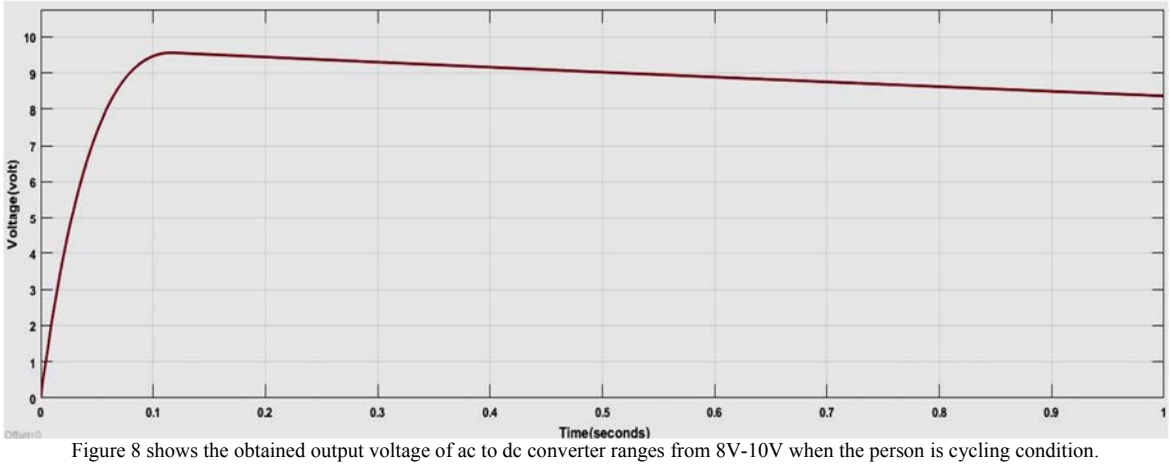

Figure 8 shows the obtained output voltage of ac to dc converter ranges from 8V-10V when the person is cycling condition.

Case 2:

A 60 kg person gives a force which is useful to the electromagnetic energy harvesting circuit which produces the dc voltage. In order to improve the obtained voltage, the boost converter is used. Boost converter boost the dc output voltage. If the obtained voltage ranges between 0.8V-1.5V, then the person is under cycling.

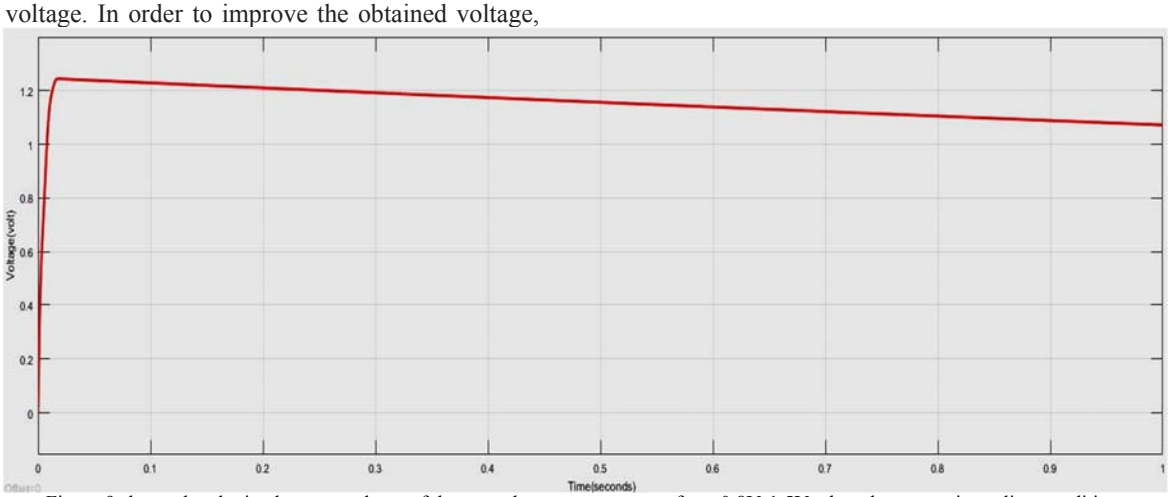

Figure 9 shows the obtained output voltage of the ac to dc converter ranges from 0.8V-1.5V when the person is cycling condition.

Case 3:

Assume a person having weight with 60 kg and this weight is multiplied with the gravity and the resultant force is given to the electromagnetic material, which produces the AC signal values which is lies between 9V to 12V. If the electromagnetic material produces the AC signal values lies between 9V to 12V is represented as he is under running condition. The obtained results as of the electromagnetic material and the AC to DC boost converter are shown in figure 10.

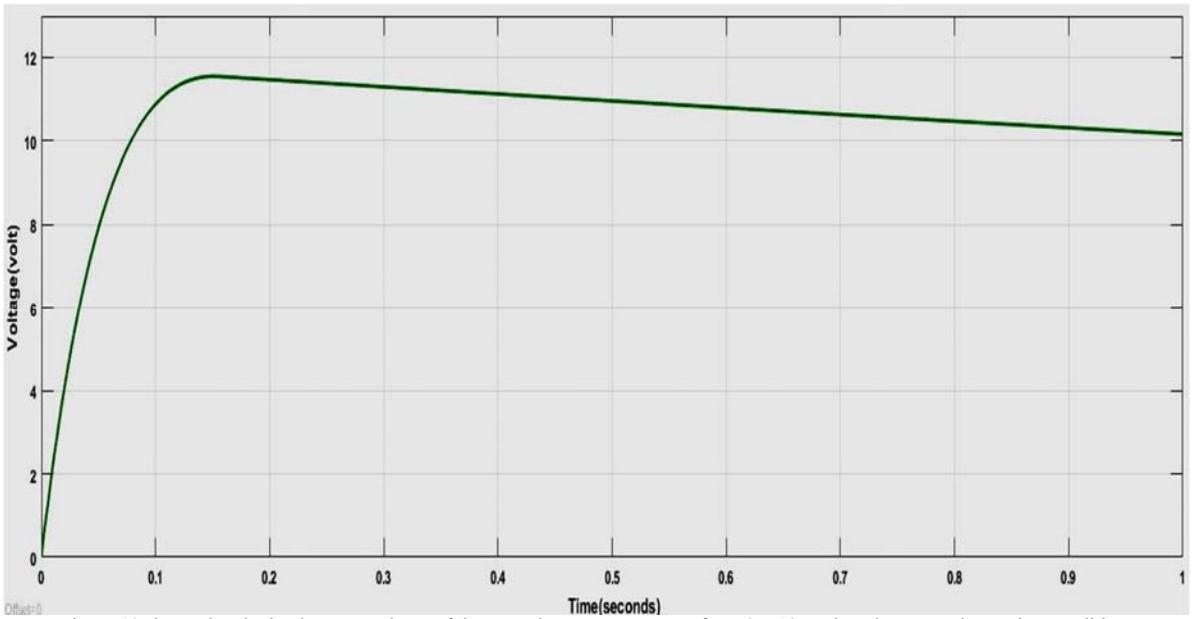

Figure 10 shows the obtained output voltage of the ac to dc converter ranges from 9V-12V when the person is running condition.

Case 4:

Assume a person having weight with 60 kg and this weight is multiplied with the gravity and the resultant force is agreed to the electromagnetic material, which produces the AC signal values which is lies above 2V to 12V. If the electromagnetic material produces the AC signal values lies above 2Vto 12V is represented as he is under jumping condition. The obtained results from the electromagnetic material and the AC to DC boost converter are shown in figure 11.

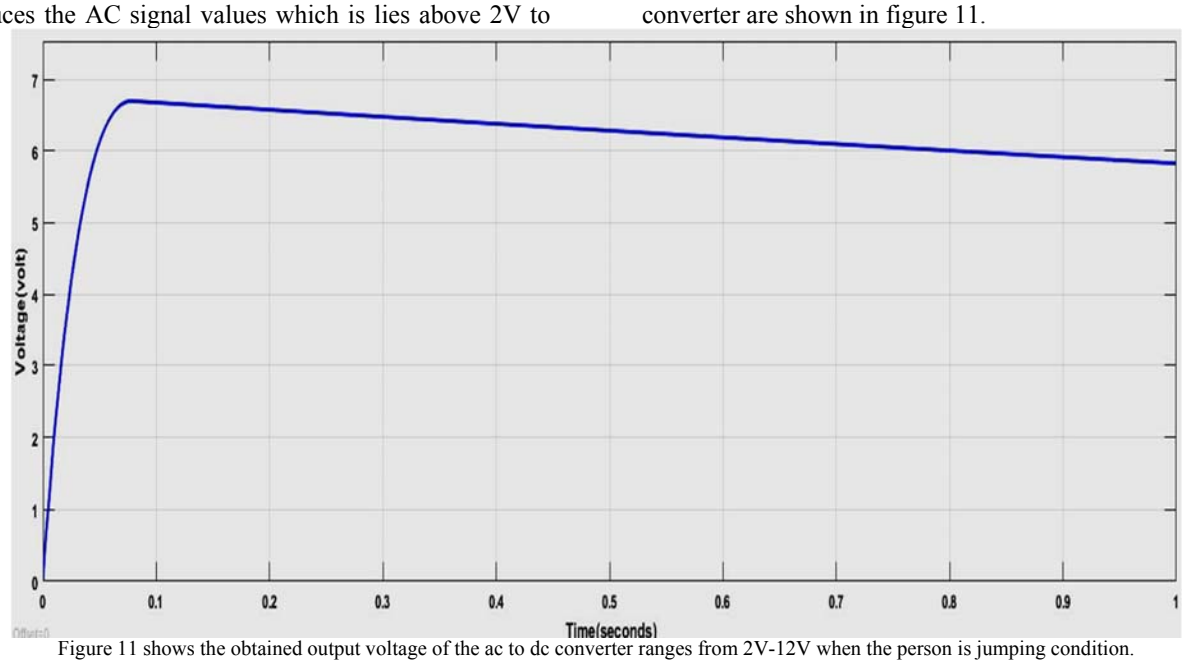

Figure 11 shows the obtained output voltage of the ac to dc converter ranges from 2V-12V when the person is jumping condition.

TABLE I. VOLTAGE RANGES UNDER DIFFERENT CONDITIONS

Case	Force(N)	Voltage(v)	Conditions
1	82	0.8-1.5	Cycling
2	455	2-12	Jumping
3	882	8-10	Walking
4	1764	9-12	Running

Table I shows the voltage ranges during different conditions. When the voltage lies between 0.8v to1.5v, the person under cycling condition. If the voltage lies between 2V to 12V, the person under jumping condition. If the voltage lies between 8V to 10V, the person under walking condition. If the voltage lies between 9V to 12V, the person under running condition.

VI. CONCLUSION

The acceleration of people during different activities such as walking, running, jumping cycling was measured and converted into electrical energy by means of Electromagnetic energy method of energy conversion. Then the harvested electrical power is transformed to AC using AC-DC converter .The converted power is stored in the Energy storage devices. The simulation result show the various values of AC and DC outputs while during different activities. This method is mainly applicable in small power purposes such as source for sensor, actuators etc.

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