HARVESTING ELECTRICAL ENERGY FROM MULTI-DIRECTIONAL VIBRATIONS

By

ENG. Ehab Khattab Mohammed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements of the Degree of
MASTER OF SCIENCE
in

Electrical Power and Machines Engineering

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Key Words: Harvesting Energy, Vibration, Directional, Generation ,Green Energy

Summary:

For this work, a summary of different energy harvester with a comprehensive literature survey with their different types is presented with traditional classification.

Anew classification approach must be taken in consideration by a novel harvester presented here, where all previous harvester harvest energy in one – dimensional and the presented novel design provide facility to harvest in two-dimension.

A survey of potential power sources is performed; general steady state analysis of MPG is performed with general model presentation to estimate the output power, voltage and resonance frequency. Summary of key of Design with needed parameter is given. A novel VBMPG model is proposed with detailed design parameter based on both load requirements and available input mechanical vibrations. Validation of analytical model represented with simulation analysis by finite element analysis by ANSYS and confirmed by fabricated model tested.

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This work is dedicated to my family:
DAD, MOM, Brother, and my wife
Thank you for your love and support through the years!

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Abstract

NOWADAYS, the concept of harvesting energy from the surrounding environment has picked up a wide focused view in the scientific society due to the need of reliable source of energy in inaccessible locations within numerous applications such as military and medical applications in addition to a huge reduction in size and power consumption of Micro Electro-mechanical System –MEMS‖ device like transducers and sensors. These devices are usually designed to run on rechargeable batteries. The replacement of batteries is not practical in many applications.

The limited lifespan of batteries may induce costly maintenance, in the case of density networks. Moreover, batteries dying without warning cause serious problems in safety monitoring applications. That led to a surge of research in the area of energy harvesting.

Sustainable power generation may be achieved in converting ambient energy into electrical energy. Some possible ambient energy sources are, for instance, thermal energy, light energy and mechanical energy. After an extensive survey of potential energy harvesting methods, the conversion of ambient vibrations to electricity was chosen as a method for further research. Since mechanical vibrations exist in most systems, many works focused on vibration-driven generators. In this field, the electromagnetic induction is well suited for the mechanical to electrical energy conversion. The design of the mechanical system that transmits the surrounding vibration energy to the electromagnetic generator is of critical importance.

According to load requirements and power needed a single micro power generator or a group of micro power generators can be used to feed load requirements and/or extends battery life time where energy generated is relatively limited with operating time, which imposes excessive constraints on their usability.

The main feature of all Vibration Based Micro Power Generators "VBMPGs" is that they are application based where it is designed and optimized to collect or harvest maximum vibration energy at fundamental frequency within small bandwidth of surrounding environmental natural frequency regardless their various operating mechanism.

Outside desired bandwidth, the output generated power decreases to non-useful value to be used. This constrains is increased also by designing VBMPG with higher quality factor to reduce damping which decrease losses for system, and so random and widest of most vibration in environmental imposes constrains on usage of dedicated MPG in to other applications.

Most of the previously reported VBMPG are classified according to their moving element part, coil and magnet shapes, input vibration and /or the device volume. From point of view in this research a novel consideration must be taken in classifying VBMPG depending on direction of harvesting energy from surrounding environmental.

A new architecture for VBMPG is introduced in this thesis by collecting energy from Omni directional vibration in the environment, which increases its usage with different application regardless mounting, constrains.

The Simulation results performed by means of finite elements method using ANSYS software to determine the optimum parameters for new model, such as static deflection, spring constant and resonant frequency. Finite element method is also used for the analysis, evaluation and optimization of the magnetic field design of the electromagnetic micro generator. The objectives behind this analysis are to characterize the permanent magnet and to investigate the optimum position of the coil relative to the magnet.

Experimental result show good agreement of design concept introduced and simulation results by using shaker system.

Chapter 1: Introduction

1.1 Preamble

Over the past few years, there has been a growing interest in the field of micro-systems and their applications across wide range of area, including Wireless sensor networks (WSN), which are receiving increasing interest, lead to higher efficiency and lower energy consumption in order of μW level [**1**]. These new WSN are useful in built environment control; emergency response; and the structural health monitoring of airframes, ships, and automobiles. This exposed new and attractive research areas; supplying power to micro systems as an alternative to batteries, which have limited life time, large size and weight.

1.2 Research Motivation

WSN offer greater flexibility, increased reliability and reduced costs compared with a wired infrastructure. In addition, transmitting the data wirelessly presents the possibility of embedding the sensors in previously inaccessible locations.

WSN are usually designed to run on batteries which need replacement and recharging; the replacement of batteries is not practical and the problem of wiring a large number of nodes in a dense network has become critical with respect to the prohibitive cost of wiring power to them or replacing them. Furthermore; batteries dying with wasted stored energy without warning cause serious problems in safety monitoring applications with environmental impact due to harmful content.

Energy harvesting seems to be a promising and effective solution for delivering power to WSN as alternative power sources that can overcome all challenges of batteries drawbacks.

Energy harvesting refers the use of energy present in the environment of an application that enables it to perform its own task or function through a convenient energy converter or transducer, called a micro-power transducers or micro-power generators (MPG). The advantage of using the energy present in the immediate environment is that it minimizes or eliminates the need for external sources of energy and the need to transport this energy from another location.

A system or device can become self-powered through the attachment of a convenient energy harvester to the sensor. A self-powered sensor with wireless communication greatly minimizes the complexity and cost of monitoring and control, while enhancing reliability and flexibility. The lifetime of the whole system then becomes equal to the life of the powering transducer itself.

Even if a system uses a battery, harvesting energy can decrease the energy demand on the battery and prolong its life and excess energy present at any particular moment can even be used to recharge the battery.

Vibration-driven generators were very attractive due to the availability of the vibration energy in the environment. This thesis is focused on using the principle of electromagnetic induction for the generation of electrical power from different vibration frequencies in the environment (like vibration from bridges). Enhanced with new design provide harvesting energy from two direction regardless mounting depending on cantilever used as a moving element get a linear movement.

The electromagnetic generator was classified as a moving coil, moving magnet, micro machined or macro sized assembled generators. To the best of the author‘s knowledge there was no focus on the direction of harvesting energy regardless mounting constrain on all previous designed MPG. Therefore, the motivation in this thesis is to design an efficient power source harvesting energy from surrounding vibration in environment to be the first multi-directional VBMPG.

1.3 Objective of the thesis

The aim of this research is to investigate the methodology for designing and fabricating a novel electromagnetic micro power generating devices at micro level which scavenging multi directional vibration. Such micro generating device can be used to power wireless sensors network in remote, hazard areas and inaccessible applications.

The research consists of:

- Reviewing the literature of power generation at micro level with different available techniques compared to traditional techniques emphases advantages and drawbacks.
- Analysis and modeling of vibration based micro power generator (VB-MPG).
- Provide a numerical analyses investigation for the multi directional micro power generator (MD-MPG) design parameters by developing an analytical model.
- Develop an analytical finite element models for mechanical and magnetic characterization to optimize the proposed electromagnetic micro generator.
- Validate the models by comparison to available literature data and analyses.
- Develop an experimental setup and test a novel VBMPG to verify the developed models through direct comparison of the simulation results.