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A Three-Phase Microgenerator Based Solution for Power Harvesting Applications

M. Alves[1], J. M. Fonseca[2], J.M. Dias Pereira[1,3]

[1] ESTSetúbal-LabIM/IPS
R. Vale de Chaves, Estefanilha, 2910-761 Setúbal (Portugal)
Phone: +351 265 790 000
e-mail: **mario.alves@estsetubal.ips.pt**; **dias.pereira@estsetubal.ips.pt**

[2] Universidade Nova de Lisboa
Faculdade de Ciências e Tecnologia, 2829-516 Caparica
Phone: +351 212 948 380
e-mail: **jmrf@fct.unl.pt**

[3] Instituto de Telecomunicações, Instituto Superior Técnico
Av. Rovisco Pais 1, 1049-001 Lisboa (Portugal)
Phone: +351 218 418 454, Fax: +351 218 418 472

Abstract. With the fast growth of wireless communications between nodes/sensor units, devices installed in remote places require continuously energy supply for their functionality or communication requirements. For these applications energy harvesting takes place as a good solution to increase the availability of energy, in opposition to the conventional systems of energy supply. Regenerative energy sources like thermoelectric, magnetic, piezoelectric, and/or renewable sources such as photovoltaic and wind, among others, allowed the development of different powering solutions for sensor units. The purpose of this work is to characterize a three-phase micro generator that is used to convert the energy extracted from wind or water flow, among others mechanical energy sources, to electrical energy. The study is carried out taking into account the velocity of axis versus power provided to a load.

Keywords

Regenerative energy sources; energy harvesting; mechanical energy; autonomous systems; sensor applications.

1. Introduction

Nowadays, with electronics becoming smaller and requiring less power, the energy harvesting has began to be a topic of great importance with objective of self-powered systems. The energy available in the surrounding environment of an application can be a viable option to allow the development of energy autonomous systems or a great increase of their autonomy.
Different sources that capture the energy of environment, like solar, wind, vibration and temperature gradients, have been target of recent developments to improve their performances and efficiency.

The same type of environmental source as a global solution for supply a wide range of applications is not recommended, since the requisites of power can be completely different in amplitude or time.

Many energy harvesting systems are oversized, either because there is no controller to manage and optimize the energy flow or because they are designed for worst-case scenarios [1]. The problem of autonomous devices self-powered over a full lifetime by harvesting energy of the environment is how to storage it. The energy that is not consumed by the system is request when the source can not deliver the amount of energy that guarantees the consumption needs.
Two main storage components can be used: batteries and supercapacitors. The use of supercapacitors has the following advantages: life cycle, which is at least two orders of higher magnitude than the corresponding one of lead acid batteries; long operation time in a temperature range of -40ºC to +60ºC; higher power capability; able to deliver for short time electrical energy at significantly higher power than batteries [2].
Energy harvesting is an area of rapid development, and the day approaches when component life rather than battery charge will limit low-duty-cycle sensor systems.[3]

The goal of this work is to characterize a three-phase microgenerator to convert mechanical rotational energy to an electrical voltage. In instrumentation it is possible to use this principle for energy harvesting in some type of anemometers. At the same time that they perform wind speed measurement, it is possible to use the range of voltage generated for supplying the integrated application.

An alternative way to capture the wind energy can be used associated with a vertical or horizontal axis of a turbine, to extract the energy of a fluid in movement. Energy harvesting originated from the windmill and water wheel is widely being considered as a low maintenance solution for a wide variety of applications. [4]
Horizontal axis turbines are common in tidal energy converters and are very similar to modern day wind turbines from concept and design point of view. [5]
Actually, the water hydrokinetic systems can be defined as wind turbines partially or completely submerged under water. [6]

The scaled generator purposed has the objective of supply enough energy for monitorization of physic variables in applications like air or water quality assessment nodes. This energy must also be sufficient to assure the data wireless communication.

2. Mechanical harvesting energy

This work focuses technological solutions of power harvesting, to increase the autonomy of low-power consumption applications. A three-phase generator is tested as a solution to increase the energy sustainability and performance of instrumentation systems with wireless communication capabilities. Particularly, when installed in places where the viability of conventional energy supply is very expensive or technically difficult being crucial to minimize maintenance requirements. Figure 1 represents the block diagram of a sensing node with power harvesting and wireless communication capabilities.

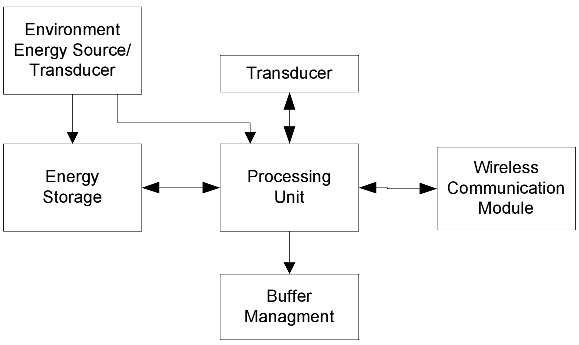
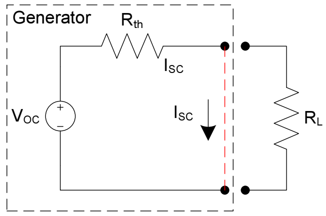


Fig. 1. Sensing node with power harvesting

A. Available Power Management

The power lost in power harvesting circuit must be negligible, since the energy harvested is very small. Embedded devices that scavenge enough energy for their operations and not depends of life cycle of batteries is the main objective. Nowadays devices researchers are following the objective of using electronic that use less power consumption in order to increase the performance of power management techniques.

By a simple method like the equivalent Thevenin circuit (Figure 2), it is possible to determine the Maximum Power Point (MPP) as function of the relation between open circuit voltage (V_{OC}) and the short circuit current (I_{SC}). The V_{OC} and I_{SC} are the two main parameters that allow to start characterization of this system.



$$R_{th} = \frac{V_{OC}}{I_{SC}} \quad (1)$$

Fig. 2. Equivalent Thevenin circuit.

Other approaches are being investigated to optimize the MPP of power harvesting sources. However, they have power consumption and are no longer a low price solution. The knowledge of all factors and the limitation of the solution for a very specific application can maximize the efficiency and avoid the use of these circuits.
It is difficult to generalize about which parts of the node consume the most power. In case of actuators present, they are responsible for consume a large amount of the total power. In most of the applications it is possible that measuring nodes utilizes sleep mode for a significant proportion of time and wake up either at fixed time intervals or in response to some external event. A typical value of 70 mW of power harvested is sufficient to power a wireless sensor network node, even in continuous receive mode. [4]

However, not only the method of physical environment variable conversion for electrical power, electronics consumption and storage elements, limits the power/energy supplied to an specific application. A well knowledge of the variation of environment conditions, physical location of primary capture element and well projected primary element, have a great influence in the final result. The set of all these considerations, associated with the design simplicity and low costs, are factors that may determine the success of a developed solution.

B. Mechanical Energy

Sources of mechanical energy may usefully be grouped as those dependent on motion which is essentially constant over extended periods of time, such as fluid and air flow used in a turbine, those dependent on intermittent motion and those where the motion is cyclic. [7]

In this work we are particularly interested in the first group, where this type of sources of energy are widespread and used on the macro scale for electrical power generation as in wind turbines and hydroelectric plants but have also been considered for smaller scale harvesting applications. In reference [8], a mechanical (rotational) energy source, originating by a hydraulic door closer and a fitness exercise bicycle, are tested and the conversion and storage circuits build for low-power electronic applications.

The first results obtained are very promising and allowed to verify the good levels of power extracted from this system when compared with other solutions. As an example the use of piezoelectric materials where the high voltage level generated is not followed by good levels of available power.

3. Experimental Results

Experimental tests were performed using a small three-phases generator (dynamo), whose geometric dimensions are represent in table 1. Figure 3 depicts the three-phases generator that was used for testing purposes.

Table 1. three-phases generator dimensions

Diameter	Thickness	Tick. + axis
24mm	8,2mm	16,5mm

To increase the amount of electrical power extracted from the generator, two pulleys coupling were used. Using this method it is possible to optimize the power transfer between the mechanical rotational movements capture from environment and the rotational speed of dynamo.

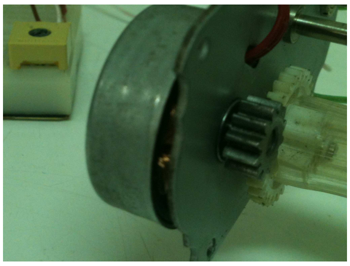


Fig. 3. Three-phases generator

The AC voltage at terminals of generator is unsuitable for supply embedded and remote system applications. In a first stage the AC voltage is converted to DC by a Three-Phase Diode Bridge Rectifier (Graetz Bridge) as represented in circuit of figure 4. The simplicity of the proposed solution intends to represent an advantage in terms of internal power consumption.

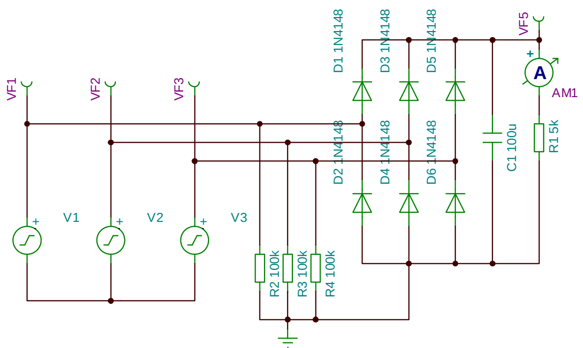


Fig. 4. Three-phases AC-DC converter based on a Graetz Bridge rectifier circuit

The rectified DC Voltage connected to a load (R_1) permits to define the capability of generating power for instantaneous consumption, or energy storage when connected to a battery or supercapacitor. Since it does not have access to a common point of 3 phases of generator, the R_2, R_3 and R_4 permits create a virtual ground. The capacitor connected in parallel with load works as a filter to smooth the DC voltage. The simulation results of the circuit are represented in figure 5. It was considered a 4V maximum voltage generated in each phase, connected to a resistive load of 5KΩ.

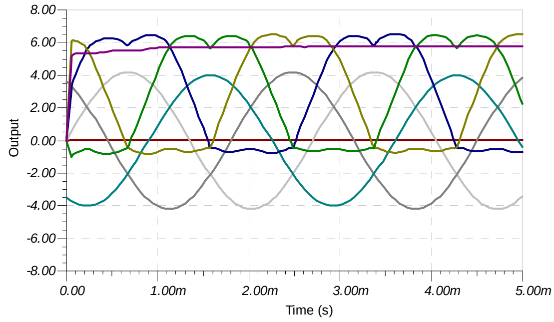


Fig. 5. Circuit simulation results

The experimental results obtained with circuit of figure 4, with the same conditions of simulation are showed in next two oscilloscope image. Figure 6 represents the AC voltage at three phases of generator, and figure 7 the rectified DC voltage at terminals of resistive load.

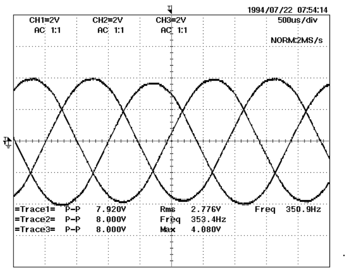


Fig. 6. Waveforms of the three-phases input voltage

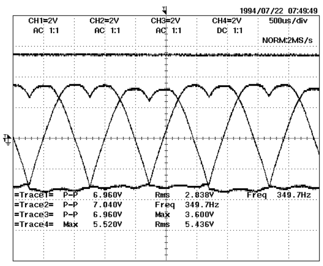


Fig. 7. Rectifier DC voltage Vout

The DC Vout show in figure 7 corresponds approximately to,

$$Vout \approx \sqrt{3} \times Vin \quad (2)$$

where Vin is the maximum amplitude value. However the voltage drop in each diode (0,7V) is responsible for a lower value that expected by equation (2). This value is according with simulation results in figure 5. Since low power consumption is involved, it's possible the use of Schottky diodes. With voltage drops of 0,32V at 1A according with datasheet, a increasing in voltage Vout becomes possible to approach equation (2).

Maintaining the previous value of resistive load and capacitive filter of 100µF, it was started the dynamo characterization for different velocities of rotational movement applied to the axis. The experiments results that were obtained are represented in figure 8.

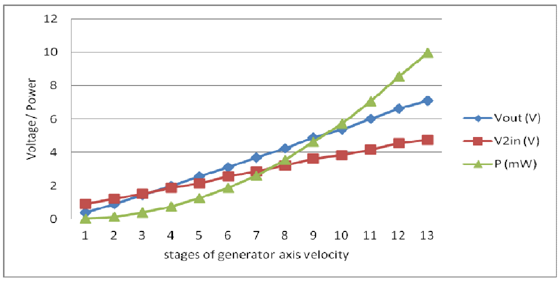


Fig. 8. Voltage and power behavior for different velocities

These results show a linear relation between the velocity of generator axis and amplitude of AC voltage in the terminals of each generator phase and consequently the DC voltage supplied to the load. Also the frequency of AC voltage varies in a linear form with velocity. For the tested velocities the range of frequency are between 76Hz and 436Hz. However the variation velocity/current has a nonlinear behavior, as it can be confirmed by the curve of power delivered to load. The load current varies in the range between 0,08mA, for the lower speed, and 1,40mA for maximum speed. The power has the same behavior with a variation between 0,03mW and 9,97mW. The cross point of DC voltage (Vout) with delivered power corresponds to a level of voltage important for supplies circuits with low power consumption microchips. The voltage at these point is around 5V and the power value of 6mW is perfectly adequate for these type of circuit.
A number of chip producers are offering low cost, low power processors for sensor networks.

Another possible approach is to observe the behavior of the generator at a constant axis velocity supplying different load values (figure 9). The voltage/current relation is completely exponential, with the voltage remains constant and current drops for values very close 500µA. This characteristic is important particularly when connected to a storage element. The batteries which have a higher energy density (ideal for long time application voltage supply) and supercapacitors with higher power density to handle short power requirement, as needed in wireless systems to transmit or receive small bit/rates of data (sensors information), periodic in time.
Energy storage elements, have different voltage-current characteristics, which must be matched to each other as well as the energy requirements of the system to maximize harvesting efficiency [9].

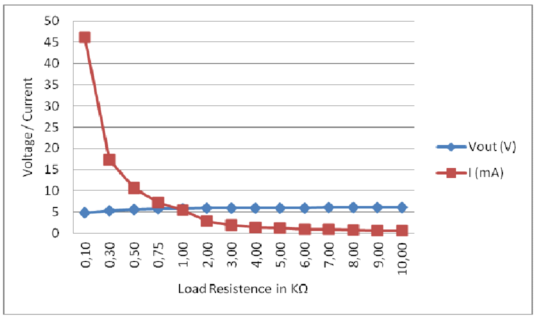


Fig. 9. Voltage and current generated with different loads

To conditions applied in figure 9, the obtained VOC=6,56V and ISC=800mA indicates a very low value of resistive load where is obtained the MPP.

Figure 10 represents the power delivered to different loads at different velocities. The values of current and voltage various drastically around the value of RL=Rth, corresponding to the MPP extracted from the generator. The MPP occurs very close to RL, as expected by the theoretical results. However, the direct supply of the application near MPP can be difficult, taking into account the very low values of load. Also we can confirm that the level of power output have an important relationship with the axis velocity, but not in a linear way has it can be confirmed by the curves represented in figure 8.

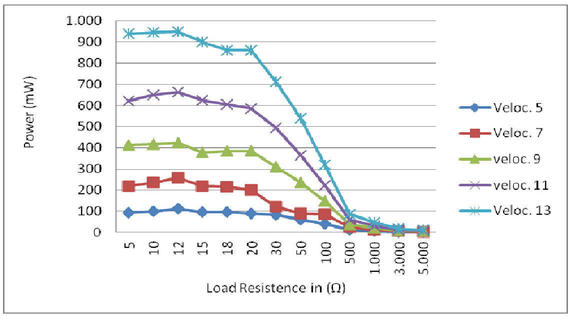


Fig. 10. Power harvesting in function of load and velocity

Achieving the MPP in function of load for different velocity of rotational axis it is important to optimize the application of this type of energy harvesting. Not in a significant form, but it is possible to observe in figure 10 that MPP it is going to move along the variation of velocity axis, the value or type of the load or storage system connected.

4. Conclusions and Future Work

As a way of converting rotational movement from environment to electric energy, we show that this three-phases microgenerator is perfectly feasible as a power harvesting source for most of the small application requirements. However, the design of an efficient harvesting system involves a full understanding of several factors. The correct characterization of environmental conditions, load impedance, power/energy supply needs and storage elements are very important to optimize the efficiency of a specific application.

Future work will be dedicated to study other generators of the same type for different power requirements. Power consumption will be optimized and the capability of different storage elements will be analyzed.

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