Optimal Power Management for Grid connected Piezoelectric Energy Harvesting System with Battery ⋆

Lumbumba Taty-Etienne Nyamayoka, Lijun Zhang, Xiaohua Xia

Department of Electrical, Electronic and Computer Engineering, University of Pretoria, South Africa (e-mail: xxia@postino.up.ac.za).

Abstract

This paper attempts to propose an optimal power flow management for grid connected to a piezoelectric energy harvester conversion with a storage system to power streetlights and traffic signals. The system includes piezoelectric energy harvesting conversion, battery, grid and the loads, which are composed of streetlights and traffic signals. The aim is to help intensive penetration of piezoelectric energy harvesting generated into the grid by reducing the electrical power consumption during periods of maximum demand (peak demand hours) on the power utility at the lowest cost (peak shaving service). The battery plays two roles. Firstly, it stores electrical energy that is generated by the piezoelectric energy harvesting conversion; and secondly; it ensures the continuity supply of power when needed during down time of the piezoelectric energy harvesting. This paper presents different model operations based on load orientation. The optimization system is done using a simple rule based management.

Keywords: Energy management system, Vibration, Piezoelectric effect, Energy Storage, Peak Shaving, Street Lights and Traffic Signals.

1. INTRODUCTION

Global energy demand is met in most countries in the world by an exhaustible resource of fossil fuels. This is also the case of South Africa, where electricity is mainly produced from coal. The burning of coal increases the emission of greenhouse gasses in the atmosphere, which has a major impact on global warming and climate change (Dabrowski et al. 2008). In this regard, all research that aims to produce electricity from clean and renewable energy sources is encouraged. Energy harvesting from vibrations has become a research and topical focus (Armontrong, 2009). Vibration energy represents the most abundant energy source after solar energy and the exploitation of this ambient vibration appears to be an excellent way of converting vibration to electricity (Yildiz, 2009). Piezoelectric energy harvesting is one of the promising technologies using the piezoelectric material or piezoelectric effect. Piezoelectric energy harvesting is used to supply streetlights as well as traffic signals. Instead of considering traffic on the road as a problem, we can take it as an opportunity (vibration energy generated by the vehicle movement on the road) to produce electrical energy by using the piezoelectric effect. In addition, the generated electrical energy from the traffic is utilized to supply streetlights and traffic signals. The use of batteries (Tazvinga et al. 2015; Shevtsov and Flek 2016) is essential, as the street lights only operate during the evening and night. The electrical energy stored is dispersed if necessary at these periods for streetlights and traffic signals. This depends on the impact of the peak demand where the time-of-use (TOU) tariff-based demand side management (DSM) has on changing the load shape to reduce peak load (Wu et al. 2015). In this paper, a power flow management for a grid connected to a piezoelectric energy harvester conversion with a battery system to supply streetlights and traffic signals is proposed. The configuration system includes piezoelectric energy harvesting, battery, grid and the loads, which are streetlights and traffic signals. Piezoelectric energy harvesting generated must be enough to supply the load and if there is not much power, the battery can automatically supply during peak demand hours at a low cost.

2. OVERVIEW OF PIEZOELECTRICITY

The word piezoelectricity, from Greek “piézein” or “piezo” meaning “to press” or “to squeeze” and “electric” or “electron”, means electricity resulting from user pressure. By definition, piezoelectricity is the electrical load that builds up in certain solid materials under the action of mechanical stress or in response to applied mechanical stress. Conversely or inversely, these materials are deformed under the action of an electrical field (Skoog et al. 2007).

In general, two effects manifest piezoelectricity; namely, the direct as well as the converse piezoelectric effect. In the piezoelectric effect, the materials have the ability to convert mechanical strain into electrical charge while in the converse piezoelectric effect; the materials have the ability to convert an applied electrical potential charge into mechanical strain energy. These two domains are illustrated in Figure 1 (Nyamayoka and Inambao, 2015).

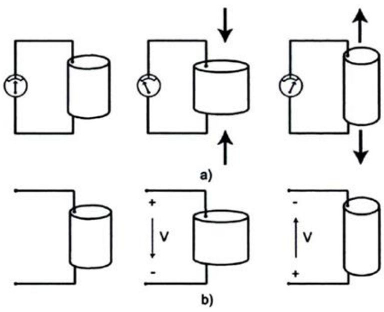

Figure 1: (a) Direct piezoelectric effect and (b) Converse piezoelectric effect.

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The direct and converse piezoelectric effects can be expressed mathematically by two linearized equations. These mathematical models have four variables (two mechanical and two electrical variables), which can be converted by a set of nine equations, and are called the piezoelectric constitutive law. The IEEE standard on piezoelectricity gives various series of constants used in conjunction with the axes notation (IEEE Standard on Piezoelectricity, 1987). According to this standard, Equations 1 and 2 give the Electric displacement D and Strain S.

$$D = d\sigma + \varepsilon^{\sigma} E \qquad (1)$$

$$S = s^{E} + dE \qquad (2)$$

Where:

D is the polarization [C/m2]; d is the piezoelectric charge coefficient [m/V or C/N]; S is the strain [m/m]; σ is the stress [N/m2]; E is the electric field [N/C or V/m]; ε^{σ} is the dielectric constant (permittivity) under constant stress [F/m]; s^{E} is the compliance when the electric field is constant [m2/N] (the superscript E denotes that the electric field is constant).

3. PRINCIPLE OF WORKING

The basic principle used to generate electricity is the piezoelectric effect. The piezoelectric materials are incorporated into the asphalt layer to harvest the energy generated by the movement of the vehicles. The wheels exert pressure over the asphalt layer into deformation of the piezoelectric materials. The excess deformation induced by these vehicles are captured and converted into electrical energy. According to Abramovich and Edery-Azury, (2010), the electrical energy generated can be up to 400 kW from 1 km and this can be enough to feed the power grid of the streetlights and traffic signals. Since the streetlights only operate during the evening and at night, the light dependent resistor (LDR) is automatically controlled to switch on during the night-time and to switch off during the daytime. However, the traffic signals operate for 24 hours every day, and it is automatically controlled by the infrared (IR) transceivers placed on the road. The battery mainly stores the electrical energy from the piezoelectric materials. However, it is used as an alternative source of electrical energy to supply streetlights and traffic signals when the energy from the piezoelectric energy harvesting conversion is not available. Figure 1. shows the schematic grid connected piezoelectric energy harvesting system with battery. It comprises of PZT and battery both connected to the grid and then to power the loads.

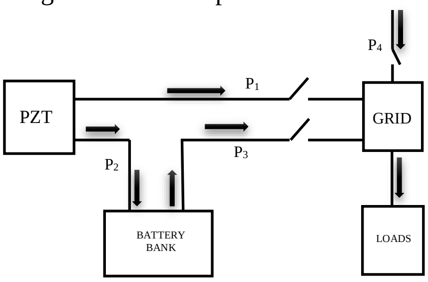

Fig. 1. Grid connected piezoelectric material and battery to supply loads

There are three sources of electrical energy to supply the loads; these include the power for the grid itself, the piezoelectric materials as well as the battery. The microcontroller is used to control the whole system to switch to different sources of power available. Table 1 describes different models of power available to supply loads of the grid connected piezoelectric energy harvesting system and battery.

Table 1. Different model of operation

Model Nº	State of the switching device				Power available
	P1	P2	P3	P4	
Model I	On	On	Off	Off	PZT Mode
Model II	Off	Off	On	Off	Battery Mode
Model III	Off	Off	Off	On	Grid Mode
Model IV	On	On	On	Off	PZT/Battery Mode

4. CONCLUSION

The piezoelectric energy harvesting system is the main source of generating electricity to supply streetlights and traffic signals. Different models of operation, according to the sources available and the power demand was elaborated upon. It is suggested that the switching device could help us to save electricity costs, especially during peak demand. It is proposed that future work be done by determining the optimal model for both energy and cost savings.

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