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Energy harvesting technologies in roadway and bridge for different applications – A comprehensive review

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HIGHLIGHTS

- Comprehensive review of energy harvesting in roadway and bridges.
- Summarized previous work on material and system using experiments and modeling.
- Compare levelized cost of energy, TRL, advantages, disadvantages, and support.

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ABSTRACT

Energy harvesting is a promising technique that can help produce renewable and clean energy and improve sustainability of infrastructure. The objective of this paper is to review available energy harvesting techniques that are used for roadway and bridge for different applications, including photovoltaic cell, solar collector, geothermal, thermoelectric, electromagnetic, and piezoelectric systems. The energy harvested can produce electric energy, provide heating or cooling, ice melting, power wireless sensors, and monitor structure conditions. Each energy harvesting technology is examined in depth including working principles, application examples, prototype developments, and major findings reported in the literature. The review summarized previous study efforts on energy harvesting system in the areas of material design, system optimization, theoretical analysis, laboratory testing, field experiment, and numerical modeling. Different energy-harvesting technologies were compared in terms of power output, cost-effectiveness, technology readiness level, advantages and disadvantages, support from government and industry. Finally, future research recommendations of energy harvesting in roadway and bridge were proposed.

1. Introduction

The discovery of green energy resources that are renewable is one of the critical challenges facing the world for sustainable development. Petroleum, coal, hydraulic, natural gas, and nuclear energy are currently most common energy resources that are used for generation of power. Energy harvesting is a promising technique that can produce renewable and clean energy and improve sustainability of infrastructure. Energy harvesting technologies capture unused and wasted energy and convert it into a more usable form. Solar [1], wind [2], hydro [3], thermo [4], and kinetic [5] energy are the common energy sources that can be used for energy harvesting in general. In recent years, researchers have begun to harvest electrical energy from the ambient environment using different techniques, such as piezoelectric, thermoelectric, electromagnetic, and photovoltaic energy harvesting [6].

Roadways are one of the major civil infrastructures that play an important role in connecting communities, and moving people. Traditionally, roadway is regarded as the structure platform to carry traffic loading. Roadway surfaces and bridge decks are continuously exposed to vehicle loading and solar radiation, which induces mechanical vibration and thermal gradients in pavement layers [7,8]. Mechanical energy can be converted into electricity via magnetic field for electromagnetic material or strain field for piezoelectric material. Solar energy can be harvested through photovoltaic cell, heat flux, or thermoelectric field. Therefore, the wasted energy in the roadway can be harvested and converted into usable energy that has different applications. Fig. 1 illustrates all available energy harvesting technologies that can be applied in roadways.

The energy harvesting system is usually composed of three main

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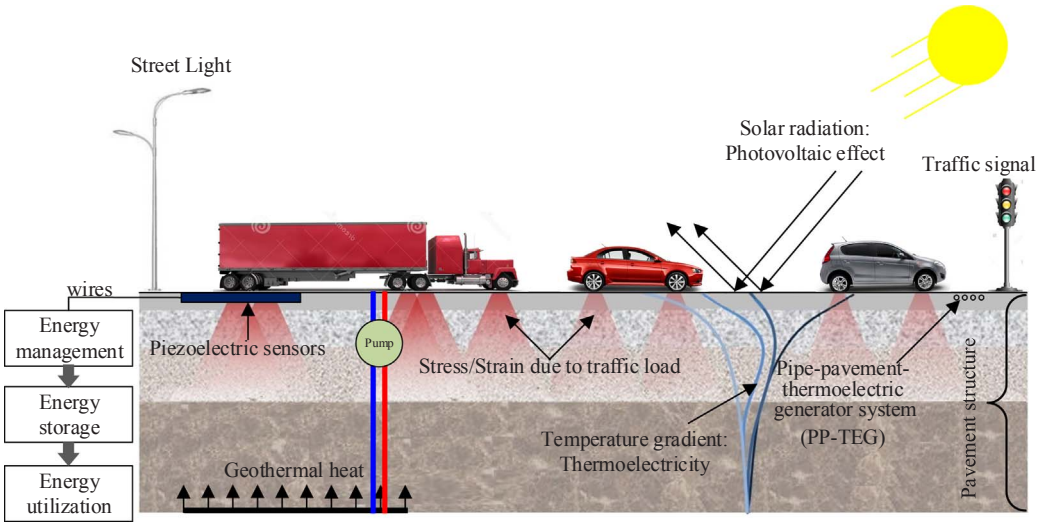

Fig. 1. Available sources of energy harvesting in roadways.

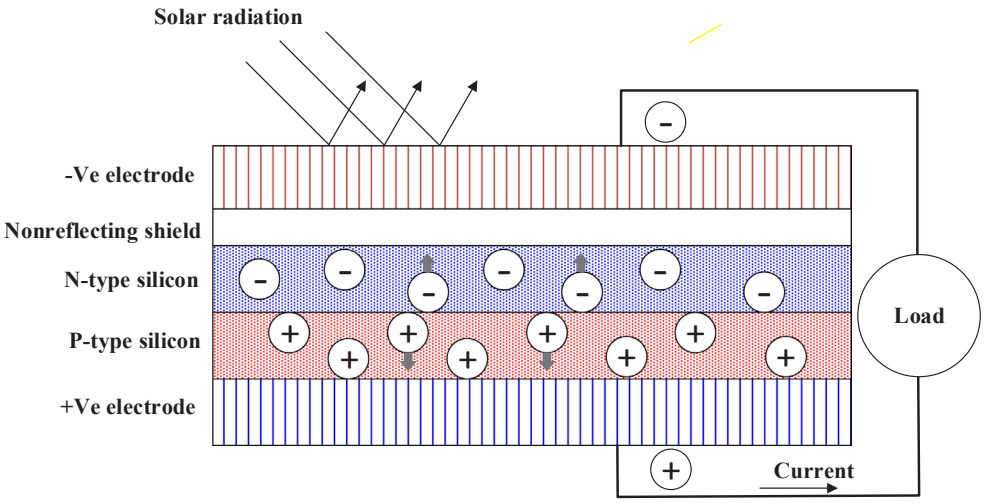

Fig. 2. Working principle of photovoltaic solar cell.

components energy generator, electrical circuit, and storage device. After electrical energy is converted from other energies in the ambient environment, electrical circuit is used to raise and regulate the generated voltage. The harvested energy can be stored in rechargeable battery or super-capacitor. Depending on the principle of each harvesting technology, the amount of energy output varies significantly. The large amount of energy can be directly used for electrical power and grid [9]. On the other hand, the relatively small amount of energy can be used for heating road surface or bridge deck for anti-icing, lighting, or powering traffic devices [10–12].

On the other hand, energy harvesting could provide continuous power support for in-situ monitoring sensors placed on roadways and bridge decks. Traditional sensors used for monitoring in-situ condition of civil structures include accelerometer, displacement sensor, force sensor, resistance strain gauge, and optical fiber. Recently, wireless sensor network has been widely used for structural health monitoring (SHM). However, one of main limitations of wireless sensor is power supply for long-term application. Piezoelectric sensor with proper design of packaging can behave as smart materials for SHM. For example, highway bridges vibrate continuously due to moving vehicles and winds. The dynamic response of bridges causes strains in the electromagnetic or piezoelectric sensors attached to bridge members, which can be used to provide power supply for sensors [13].

The objective of this study is to review different energy-harvesting technologies (solar, geothermal, thermoelectric, electromagnetic, and piezoelectric) used in roadways and bridges for different applications. Each technology is examined in depth including working principles and the main findings from previous studies in the literature. The literature review focused on several important aspects of energy harvesting system including material design, laboratory study, field experiment, and numerical modeling. Different energy-harvesting technologies were compared in terms of power output, cost, technology readiness level, advantages, and disadvantages. The advantages and limitations of each technology were identified and the future research recommendations were discussed.

2. Energy harvesting for roadway applications

2.1. Solar energy harvesting

2.1.1. Basic principles of photovoltaic (PV) cell energy

Photovoltaic (PV) cell is used to convert solar radiation into electric power. The solar cell consists of a P-type semiconductor and an N-type semiconductor. When sunlight reaches the semiconductor materials of PV cell, free electrons are forced to flow in a certain direction. The negatively charged electrons move toward the N-type semiconductor; while the positively charged electrons move toward the P-type semiconductor. The working principle of PV cell is shown in Fig. 2. The flow of moving electrons creates an electrical current when connected to electrical load [14].