THERMOELECTRIC POWERED HIGH TEMPERATURE USING BOOST CONVERTER WITH SUPERCAPACITOR

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This thesis submitted to the senate of UTeM and has been accepted as fulfillment of the requirement for the Bachelor of Electronic Engineering (Industrial Electronic).

Signature	: …………………………………………………
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Date	: June 12th 2013

DEDICATION

To my beloved parents *for the love that arose for me until today*

My supporting brother and sisters *that never stopped praying for me*

And

My entire friends and lecturers *for the encouragement and ideas*

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ABSTRACT

Substation is one of the most important parts of power system. The manual inspection is still used in many substations in Malaysia. Obviously, it is significant to establish an aid inspection monitoring and positioning system in substations, which is useful to the inspectors and manager. Thus, this project focused on Thermoelectric Powered High Temperature using Boost Converter with Supercapacitor to help user in monitoring temperature. This project aims to detect the high temperature using Thermoelectric generator (TEG) where is connected to a DC to DC boost converter circuit and power up the microcontroller circuit to send the data to user. The main objective of this project is to design DC-DC Boost Converter that is able to harvest energy using TEG with super capacitor. Meanwhile, the supercapacitor stores energy to supply the current to the microcontroller circuit if the main power source was not available. In this project, the energy harvesting and boost converter were introduced for mankind in the future and the performance of the system was analysed.

ABSTRAK

Pencawang elektrik adalah salah satu bahagian yang paling penting dalam sistem penjanaan kuasa. Pemeriksaan manual masih digunakan dalam banyak pencawang di seluruh Malaysia. Jelas sekali, ia adalah penting untuk mewujudkan pemantauan pemeriksaan dan sistem kedudukan dalam pencawang yang berguna kepada pemeriksa dan pengurus. Oleh itu, projek ini mengenai "Thermoelectric Powered High Temperature using Boost Converter with Supercapacitor" ini dicadangkan untuk membantu pengguna memantau suhu. Projek ini bertujuan untuk mengesan suhu tinggi menggunakan penjana termoelektrik (TEG) yang telah disambungkan kepada penukar rangsangan litar DC ke DC dan menjana kuasa ke litar pengawal mikro untuk menghantar data kepada pengguna. Objektif utama projek ini adalah untuk mereka bentuk litar penukar rangsangan litar DC ke DC yang mampu menuai tenaga menggunakan TEG dengan superkapasitor. Sementara itu, Superkapasitor menyimpan tenaga untuk membekalkan arus kepada litar kawalan mikro jika sumber kuasa utama tidak ada. Dalam projek ini, penuaian tenaga dan litar penukar rangsangan telah diperkenalkan kepada pengguna untuk kegunaan di masa hadepan dan prestasi sistem ini telah dianalisis.

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Chapter 1

Introduction

1.1 Background

The demand on energy conservation increasing lately and there is fast growing interest in the development of clean energy technologies. Energy conservation is the process of converting available ambient energy into usable electrical energy such as heat, sound, light, vibration or movement, through the use of a particular material or transduction mechanism [1].

Power transformers are the largest and probably the most expensive items of equipment in power systems. The main issue that need to be considered is health condition of power transformer. Obviously appropriate care and health monitoring of these assets are necessary in order to estimate and predict their live spans. The monitoring should be done over regular time intervals. Failure of power transformers may lead to excessive costs.

Historically, the way to monitor power transformer has started to evolve from typical monitoring technique to the use of sensor. In line with the green technology, the new development of using energy harvesting technology to power up sensors network for the monitoring purpose is proposed. The ambient heat energy from power transformer will be harvested from thermoelectric generator (TEG) to power up power electronic compensator and driven sensors.

In this project, Thermoelectric Power Generator (TEG) is used to convert the heat energy into the electrical energy in order to generate power to electronic devices. Thermoelectric Power Generator (TEG) produces small electrical energy such as 0.7V, so the boost converter is needed in order to increase and stabilize the electrical energy that will channel to electric device. For this project, the voltage should be increase to 3.3V to 5.0V.

The super capacitor in this project is used to store energy from the DC-to-DC Boost Converter that was harvested from the TEG to replace the usage of battery that can save the maintenance cost to change the battery as the battery known to have short life time. This research project improves the lifetime of the sensor system and eliminates the needs of battery.

1.2 Objectives

1.2.1 To design DC-DC Boost Converter that is able to harvest energy using TEG with super capacitor.

1.2.2 To demonstrate experimentally the designed DC-DC Boost Converter using TEG with super capacitor.

1.2.3 To analyse and evaluate the performance of TEG and DC-DC Boost Converter with super capacitor.

1.3 Problem Statement

Power transformers are the largest and probably the most expensive items of equipment in power systems. Obviously appropriate care and health monitoring of these assets are necessary in order to estimate and predict their live spans. Practically the monitoring should be done over regular time intervals. This will assist in predicting any future maintenance requirements. Failure to do so may lead to catastrophic failure and may incur excessive costs. An international survey by CIGRE on large power transformers, revealed a failure rate of 1% to 2% per year (CIGRE Working Group 05, 1983). This may look a relatively small quantity; however a single failure of a large power transformer causes significant disruption to utilities and is unacceptable. Since many manufacturers are merging or shutting down, repair costs are considerable. Therefore appropriate to plan for predictive maintenance where the use of appropriate monitoring and assessment is essential.

The needs of alternative power supply to power the sensor system for long operational task to grant the effectiveness of the sensor system.

The maintenance cost to change the battery is a big issue as batteries is known to have short lifetime.

1.4 Scope of Work

This project will primarily focus on all the three main parts, which are:

1.4.1 Thermoelectric Power Generator (TEG)

- Convert energy from thermal energy to electrical energy.

1.4.2 DC- to- DC Boost Converter

- Step-up and stabilize the power in circuit.

1.4.3 Super Capacitor

- Power management.

All the parts above function in one system in order to convert energy from thermal energy to electrical energy and to stabilize the power using boost converter. This project only focused on design the boost converter and the technique to stabilize the power produced from boost converter.

1.5 Project Significant

1.5.1 This system can be operating in an autonomous and self-powered manner.

1.5.2 This system can increase the very low voltage in order to power up the macro scale devices.

1.5.3 This system using energy harvesting technology to power up sensors network, and environmental friendly.

1.6 Report Structure

There are 5 chapters in the thesis, such as Introduction, Literature Review, Project Methodology, Result and Discussion and lastly Conclusion and Recommendation.

Introduction: This first chapter is more on the general overview of the project. In this chapter, the background of the problem and the emergence of the project are stated first. Besides, the project objectives, scope of project and the methods used are also included.

Literature Review: This second chapter discusses the background of study related to the project. This chapter consists of the evidence with the broad (e.g. books, internet, lecture notes etc) and focus (previous PSM, thesis, journal papers etc) areas of the study. In this chapter, the trend, direction and research issues are also identified. This chapter is more on the evidence of not repeating what others have done.

Project Methodology: In project methodology, the materials, subjects, and equipment or apparatus used are identified. Besides, the methods or procedures during the project implementation are also stated. Insufficient, the justification for choosing the method or approach is also stated.

Results and Discussion: In this chapter, the observation and result obtained from the data analysis are presented. Then, the project discovery is arranged tidily using the aid of figures and tables. Besides, the result or discovery is explained and compared with previous studies. Then, the result from the comparison is discussed.

Conclusion and Recommendation: The conclusion part is about the summarization of main findings of the projects. A brief recommendation for future study is stated at the recommendation part.

Chapter 2

Literature Review

2.1 Fundamental of Thermoelectric Generator (TEG)

Thermoelectric generator (TEG) is a device that converts thermal energy directly into electrical energy. A typical TEG structure is shown in Figure 2.1. Early TEG devices utilize metallic TE material, whereas more recently manufactured TEGs use alternating n-type and p-type semiconductor materials. The TEG structure is consisting of thermoelectric materials which are sandwiched by two heat exchanger plates at its two ends respectively. One of the two exchangers has high temperature, and is called the hot side of the TEG. The other has low temperature and is called the cold side of the TEG. There are electrical-insulate-thermal-conductive layers between the metal heat exchangers and the TE material. The two ends of n- and p-type legs are electrically connected by metal.

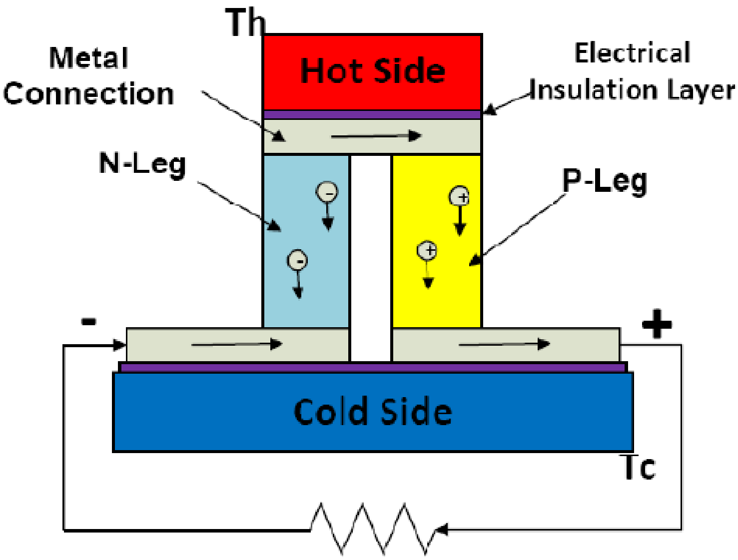

Figure 2.1: Simplified illustration of TEG

The theory of thermal energy for energy harvesting begins with Seebeck effect in 1822. The effect was that a voltage, the thermoelectric EMF (electromotive force), is created in the presence of a temperature difference between two different metals or semiconductors. This causes a continuous current in the conductors if they form a complete loop. Figure 2.2 shows the Seebeck effect in a complete loop circuit. TEGs are solid-state device, which means that they have no moving parts during their operations. Together with features that they produce no noise and involve no harmful agents, they are the most widely adopted devices for waste heat recovery.

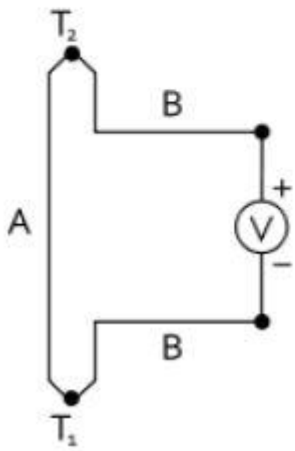

Figure 2.2: The Seeback effect due to temperature gradient

The voltage or EMF across the temperature T1 and T2 from the Figure may be calculated from the famous temperature gradient conduction as follows:

$$V = \int_{T_1}^{T_2} \left(S_B(T) - S_A(T)\right)\, dT. \tag{2.1}$$

The design of thermoelectric system for energy harvesting to power up sensors network, may consist of semiconductor or metals element with simple junction connection as shown in Figure 2.3.

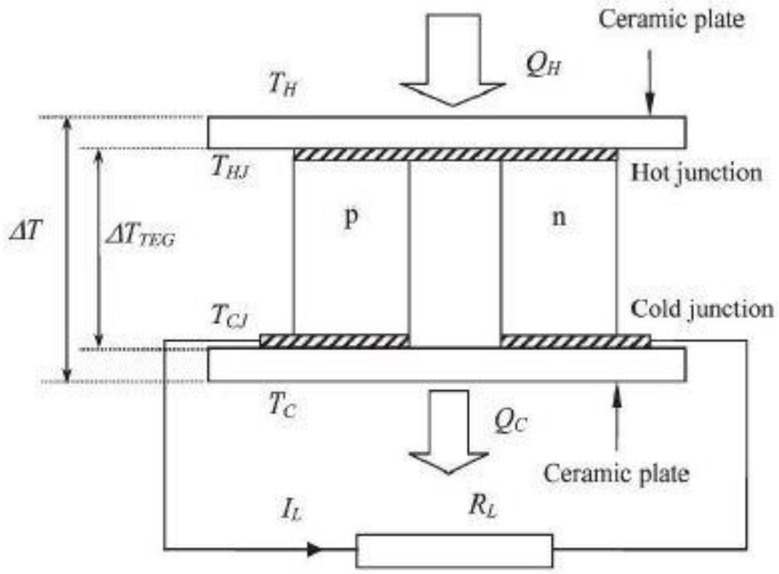

Figure 2.3: Basic structure of thermoelectric couple. [2]

The basic thermoelectric circuit is made of two different temperatures TCJ and THJ. Assuming that the loop is opened at the cold junction at temperature TCJ, an open-circuit voltage VG = ΔVab is present between conductors **a** and **b** due to the Seebeck effect. The voltage VG is proportional to the temperature difference according to the following equation where **αab = αa – αb** is the Seebeck coefficient between materials **a** and **b**:

$$V_G = \Delta V_{ab} = \alpha_{ab}(T_{HJ} - T_{CJ}) \tag{2.2}$$

Materials **a** and **b** are now substituted with the p- and n-type semiconductors, respectively. The p-type semiconductor has a positive Seebeck coefficient **αp**, whereas for the n-type semiconductor, the Seebeck coefficient **αn** is negative. The overall Seebeck coefficient **αp – αn = αpn** is, therefore, positive. The thermocouple is sandwiched between two electrically insulating and thermally conducting ceramic plates with finite thermal conductance K.

Figure 2.4 shows an equivalent electrical model of a thermocouple, where thermal variables Q, T, and K are, respectively, represented by electrical analog quantities given by currents, voltages, and conductance.

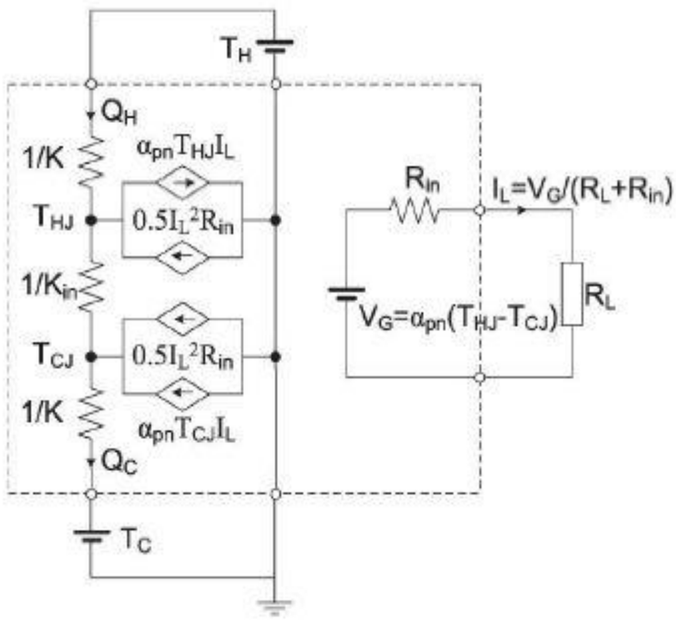

Figure 2.4: Equivalent thermoelectric model. [2]

The lower thermal port represents the cold side of the thermocouple at environment temperature TC, whereas the upper thermal port is the heat source at temperature TH. The current sources describe the contribution of the Joule effect and the Peltier effect to the heat rate at the hot/cold junctions. The right port represents the electrical output port of the couple that is used as a power generator, where VG is the open-circuit output voltage, as described by Equation 2.3, and Rin is the internal electrical resistance of the device.

The output power PL delivered by a single thermoelectric couple to the load RL is the difference between QH and QC or, equivalently, the product of the voltage on the load and the current flow, i.e.

$$P_L = I_L V_L = I_L[\alpha_{pn}\Delta T_{\text{TEG}} - I_L R_{in}] \tag{2.3}$$

When the load resistance RL is equal to the internal electrical resistance Rin, the thermocouple is on matched-load conditions generating the maximum output power given by:

$$P_{L\,\max} = \frac{\alpha_{pn}^2 \Delta T_{\text{TEG}}^2}{4R_{in}} = \frac{\alpha_{pn}^2 \beta^2 \Delta T^2}{4R_{in}} \tag{2.4}$$

The term thermopower or Seebeck coefficient of a material is a measure of the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material. The Seebeck coefficient has units of V/K, though is more practical to use mV/K. The Seebeck coefficient of a material is represented by S and is non-linear as a function of temperature, and dependent on the conductor’s absolute temperature, material and molecular structure.

Table 2.1 Seebeck coefficients for some common elements [3].

Material	Seebeck Coeff.	Material	Seebeck Coeff.	Material	Seebeck Coeff.
Aluminum	3.5	Gold	6.5	Rhodium	6.0
Antimony	47	Iron	19	Selenium	900
Bismuth	-72	Lead	4.0	Silicon	440
Cadmium	7.5	Mercury	0.60	Silver	6.5
Carbon	3.0	Nichrome	25	Sodium	-2.0
Constantan	-35	Nickel	-15	Tantalum	4.5
Copper	6.5	Platinum	0	Tellurium	500
Germanium	300	Potassium	-9.0	Tungsten	7.5

*Units are μV/°C; all data provided at a temperature of 0 °C