

# Modeling and Control for a Class of Non-linear Systems With Non-affine Polynomial Control Input

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**Abstract**—In this work we deal with the control of a non-affine nonlinear system in the control input. Said system is a thermoelectric module (TEM) powered by a buck-type DC/DC converter. The mathematical model of the module is polynomial in the control input. The proposed control technique is the LQR control plus an integral action. Said controller is designed on the basis of an approximate linearization of the combined reducer-TEM dynamic model. The effectiveness of the proposed technique is verified through experimental results obtained with an experimental platform designed for this purpose.

**Index Terms**—Thermoelectric module, Linear Quadratic Regulator, Non-affine systems.

## I. INTRODUCTION

The thermoelectric effect is the interaction between electrical and thermal phenomena. It consists of the conversion of a temperature difference to voltage and vice versa. Thermoelectricity, known since the 19th century, has been defined as the science and technology associated with thermoelectric generation and refrigeration [1], the effects that produce it were discovered and studied by physicists: Thomas J. Seebeck, Jean C. Peltier, William Thomson, James P. Joule and Joseph Fourier. Due to its characteristics, the TEM (Thermoelectric Module) can be classified within the area of thermoelectricity. TEMs are solid-state heat pumps that require a heat sink to dissipate heat by using the Peltier effect (discovered in 1834). Because they are solid-state devices, TEMs have no mechanical parts, resulting in high reliability. [2]. TEMs are normally made up of semiconductor materials (p and n type), which are thermally bonded in parallel and electrically in series by means of copper plates; they can also feature heat sinks bonded to the alumina ceramic on both sides of the TEM.

A TEM has the ability to function as a thermoelectric cooler/heater. As a cooler, it generates a certain temperature on the cold side that depends on the supplied voltage, the ambient temperature and the intrinsic characteristics of the TEM. Typically the current demand of a TEM is high, which is

reflected in energy efficiency and cooling/heating capacity [3]. TEMs have a high efficiency when the volume to be cooled is small when compared to traditional cooling systems. When the volume to be cooled increases, the TEM shows poor efficiency. Some applications of thermoelectric modules include cooling of power sources [4], cooling jackets [5], thermal reactors [6], cooling processors [7], power electronics [8], tests on printed circuits [9], physiotherapy [10], solar panel cooling [11] among others.

In order to control the temperature of the cold face of a TEM, a mathematical model of it is required. Different versions of this model can be found in the existing literature, but all of them share a common feature: they are distributed parameter models. This leads to dynamic models in partial differential equations, which generally makes model-based controller design difficult. In [2], [12] the TEM is modeled using an equivalent electrical circuit (lumped parameter model) for which, as will be seen in this work, based on such a circuit, a dynamic model can be established in state variables, which is highly non-linear and non-affine in the control input [13].

The nature of the control input (non-affine and non-linear) makes control of the thermoelectric system challenging, since the non-linear input is a crucial part of the election of a control strategy, which has to be designed accordingly. In [14] the TEM is controlled by feedback linearization that makes the system stable and overcomes the non-affine input by linearization. A sliding modes controller is implemented in [15] with similar results and in [16] where an input-output linearization is made with good results that show a simple yet effective solution. All these control laws are designed to be directly applied to the TEM, but do not take into account the dynamic of the electronic circuit that drives the TEM, thus the control law is not designed for the entire electronic system comprising the driving elements and the TEM. Not using a complete model implies losing the ability to enhance the performance of the system, while reducing energy

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