Summary

Piezoelectric materials are capable of converting mechanical deformation to electric voltage and vice versa. Due to these features, they have been widely used in many engineering applications such as vibration energy harvesting, sensing and actuation technology. This dissertation is divided into two parts. Following the introduction, Part 1 consists of Chapters 2 and 3 dealing with analytical and numerical electromechanical modelling and analysis of different piezoelectric smart structures proposed for vibration energy harvesting. Part 2 consists of Chapters 4 to 7 covering analytical modeling of dynamic and static problems for piezoelectrics bimorph/unimorph structural elements such as beams, plates, and shells with substrates made of functionally graded materials (FGMs) and porous materials.

Piezoelectric vibration energy harvesting has been investigated by many researchers from different disciplines throughout the last two decades. The ultimate goal of this line of research is to power small electronic components by harvesting the ambient vibration available in their environment. Taking into account the issues and shortcomings of available studies, the former part of this present work is focused on developments of reliable piezoelectric energy harvesting models for a unimorph cantilevered beam, a novel multi-beam smart structure, and a bimorph plate harvester with porous substrate, by means of both analytical and numerical techniques. First of all, analytical modeling of the unimorph piezoelectric harvester is presented based on the thin-beam theory, followed by its numerical model simulated in the commercial software of COMSOL Multiphysics®. Using several of this unimorph harvester, as well as two identical proof masses, a novel multi-beam piezoelectric structure is then proposed for harvesting vibration from low frequency applications (below 100 Hz). Moreover, regarding the bimorph plate harvesters with substrate containing porosities, an exact electromechanical model based on shear deformation theories is presented, which can be used for analyzing moderately thick and thick plate-like energy harvester configurations. For each of such piezoelectric scavengers, the respective electromechanical response to external harmonic excitation is extracted, reliability of the models is verified, and finally detailed parametric studies are presented to demonstrate the performance of the scavengers.

On the other hand, developing computationally efficient but accurate electromechanical models is of great importance to the research community of the rapidly growing and multi-disciplinary area of piezoelectric smart structures. Therefore, the focus in the latter part of this thesis is placed on proposing comprehensive analytical solutions for the particular problems of free vibration, wave propagation and buckling analysis of beam-, plate-, and shell-like smart sandwich structures consisting of functionally graded or porous substrates, and integrated piezoelectric layer(s). Analytical methods, as long as they are available, are usually much faster than the numerical solution techniques such as the finite element modeling and other energy-based discretization techniques. To study the above-mentioned problems analytically, the governing equations of each system are first derived based on higher-order shear deformation theories, and through the use of Hamilton's principle and Maxwell's equation. Depending on the type of boundary conditions, the obtained governing equations, that are highly coupled, are solved using Navier's approach, state space approach and Galerkin method. As the systems response, closed-form expressions have been extracted for the wave characteristics, free vibration, and buckling problems of the systems of interest, providing the opportunity to study the effects of the systems parameters explicitly, and understand the physics of the problem clearly. Finally, the effects of variety of the systems parameters such as characteristics of selected materials, mechanical and electrical boundary conditions, as well as geometrical properties are studied in detail. The analytical models presented in this part of the thesis not only furnish benchmark solutions of shear deformation theories for the piezoelectric coupled structures but also provide insight into the significance of shear deformation on the response. The exact results obtained from those analytical models can also be used for verification of the numerical approaches.

Keywords: Smart Structures; Piezoelectricity; Energy Harvesting; Electromechanical Modeling; Structural Analysis; Vibration Analysis; Analytical Solutions; FGMs; Porosity.