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Some contributions to Lagrangian modelling of power converters

Mosaib Ul Munieeb [a,b,1], Shakir Showkat Sofi [a,c,*,1], Fazil Bashir [a,1], Muneeb Ul Hassan [a,1], Shahkar Ahmad Nahvi [a,1]

[a] Department of Electrical Engineering, IUST, Awantipora, J&K, 192122, India
[b] Department of Electrical Engineering, NTUST, Taipei, 10607, Taiwan
[c] Department of Electrical Engineering (ESAT), KU Leuven, Leuven, 3000, Belgium

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ABSTRACT

Lagrangian modelling can be used to derive mathematical models for complex power electronic converters. This approach uses scalar quantities (kinetic and potential energy) to derive models, which is simpler than using (vector-based) force balance equations. It employs generalized coordinates, making it easier to deal with complex systems with constraints. This systematic approach results in equations that can be expressed in state-space form, which allows for the simplification of the simulation and design process and the use of many standard software packages for system analysis and simulation. In this work, contributions are made regarding the procedure to be followed for the Lagrangian modelling of power converters and the incorporation of constraints within the Lagrangian framework. Furthermore, for the first time, Lagrangian modelling is extended to non-ideal, high-fidelity descriptions of standard power electronic circuits.

1. Introduction

Power electronic converters find increasing applications in devices and systems like computers, cell phones, domestic appliances, cars, aeroplanes, industrial processes, medical applications, communication systems, transportation systems and high-power electrical transmission systems. Modelling and simulation of power electronic converters are required for verification, testing and optimization of their design. It is required to conceptualize and fabricate power electronic converters in stages [1], starting with an ideal circuit and gradually incorporating complex phenomena like parasitics. Accurately simulating power electronic converters is required in many applications, e.g., ones which require their dynamic characterization or evaluation of phenomena like electromagnetic interference. This is especially true for power electronic converters that process power in the range of megawatts, wherein the requirement for accurate simulation is more stringent and includes accounting for distributed stray parameters to obtain the energy balance of various transient topological models [2].

Energy and its conversion is a basic, underlying phenomenon within all physical systems. Energy is a scalar quantity, and obtaining important system information from it is easier and more systematic in general, for example, in complex mechanical systems, using Energy-based methods for deriving models is easier than using force balance equations. Modelling of mechanical systems based on energy was introduced by Euler and Lagrange in the 1750s. Analogies between mechanical and electrical systems are ubiquitous [3] and are used to derive equations of motion for mechanical systems using electrical models. Representing physical properties in terms of energy and power for power electronic converters helps in obtaining a deeper insight into the workings of the converters. Examples of such methods include models based on Brayton–Moser equations [4], port-Hamiltonian [5] and Euler–Lagrangian (EL) models [6–10]. One advantage of representing the physical properties of power electronic converters in terms of energy and power is that these properties can be used for controller design. For example, the EL modelling framework causes the dynamical equations to clearly reflect energy storage, which is required in the design of passivity-based controllers [11].

In this paper, we make three distinct contributions. First, we revisit the step-by-step procedure for EL modelling of switching circuits discussed in detail in [7,9,12,13] and point out cases where it is not directly applicable or gives erroneous results. We also suggest modifications to the procedure in order to improve it. Secondly, we discuss in detail the issue of incorporation of constraints in EL modelling. We deliberate on the contention [7] that the choice of canonical coordinates charge and current, and the corresponding Lagrangian mean that Kirchoff current law is not included in the framework and point out the fact that proper labelling of system variables (in this case, in terms of the currents flowing through the dynamic circuit elements) lead to automatic incorporation of constraints in the framework and EL

* Corresponding author at: Department of Electrical Engineering (ESAT), KU Leuven, Leuven, 3000, Belgium.
E-mail address: shakir.sofi@skoltech.ru (S.S. Sofi).
[1] The authors share the first authorship. At the time of the research, all the authors were affiliated to the Department of Electrical Engineering, IUST, J&K, 192122, India.

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