Technical University of Cluj-Napoca

Faculty of Electrical Engineering

HABILITATION THESIS

-Abstract-

Development approaches for electromechanical systems applied to transport electrification

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The present thesis entitled ***Development approaches for electromechanical systems applied to transport electrification*** written by Dr. Mircea RUBA emphasizes a general image about his research and academic career started in 2008 until today. The motivation of this work is to obtain the habilitation to coordinate PhD. thesis projects in the field of electrical engineering within the Technical University of Cluj-Napoca, Romania. His career started with his PhD. Thesis defense in 2010, followed by an 11 months postdoctoral period within Universite Libre de Bruxelles, Belgium. After this period he returned to the Technical University of Cluj Napoca and became assistant with the Department of Electrical Machines and Drives, where he is evolved, becoming associate professor in 2022. His general efforts research and academia wise were focused on electrical machines, power electronics, control of those systems, real-time simulations, and hardware in the loop testing. Continuously combining his research interests with the academic activity, he was teaching electrical machines, electronics, system integration and modelling and testing of electromechanical systems to the students from bachelor and master lines of study. In doing so he was able to publish many research papers, books and book chapters and patents. He membered as researcher a lot of national and international research project, he was the project manager of two of them, coordinator of several others, some being related directly to industry cooperations.

The present thesis is composed of 7 chapters including the introduction and his future perspectives. The references attached to the study reflect briefly the amount of research studies he digested through his career till now.

The first chapter introduces the reader in the general concept of the thesis highlighting the topics that will be debated in each of the following chapters.

The second chapter entitled *Electromechanical systems analysis methods* presents the method for electrical machines study via finite element analysis (FEA) with an example based on a permanent magnet synchronous machine. From this point, a step is performed to the system level analysis where it is proven that using hybrid models, that contain analytical expression and FEA based data can reach high accuracy and reduced computation time and power. The example focuses on the development of a simulation model for a switched reluctance machine. Part of this model is designed with analytical models that compute voltages and currents while the torque development and magnetic flux variations are fetched from the machine's FEA model. Using the loop-up-table concept, fuzzing the two different approaches into one is a simple and lucrative solution. The chapter continues with a modelling formalism, called Energetic Macroscopic Representation (EMR), developed by the University of Lille in the L2EP lab. The EMR is actually an organization standard for any simulation model based on the action and reaction concepts in physics. In using EMR, designers are able to exchange models, or modify existing ones with minimum effort. Another strong feature of EMR is for any model designed in this philosophy, creating its control loop requires only the mathematical inversion of the action path. In doing so, the possibility of creating wrong control loops is avoided. Also the control designer does not have to use schematics that are difficult to understand, but he can create his own ones that are reflected from the system's model. EMR was introduced in both academic and research activities of Mircea RUBA and now it reaches the students, helping those to understand and have a clear image about designing control loops for simulation systems.

The third chapter entitled *Multilevel modelling and analysis of electromechanical systems* mixes the concepts from the previous chapter exemplifying the philosophy of multilevel model design. The latter refers to building models for the same system but with increasing complexity and accuracy. Lower accuracy and simpler models are to be used for concept validation while those with increased complexity and accuracy are used for more precise and detailed analysis. Using EMR organization a permanent magnet synchronous machine model is exemplified with 3 different levels of complexity. These go from the classical constant inductances model to phase magnetic flux variation based fetched from FEA. The latter ones are included in the model in look up tables, mixed with the analytical equations of the machine. Another such example is presented for models of the Li-Ion battery cells and for the supercapacitors. For both the complexity is based on the type of model approach and parameters identification processes. The conclusions of this study underline the benefits and the difficulties in creating complex and highly accurate system models.

The fourth chapter entitled *Fault tolerance applied to electromechanical systems* debates the features that need to be added to different systems in order to ensure their continuous operation despite faults occurrence. Some examples are presented showing the modifications that need to be performed both for machine and electronic converter structures to reach fault tolerant abilities. The chapter ends with a patented method for current sensors fault detection and compensation. This is a procedure that can be embedded into the main processor of any multiphase converter. Using an experimental setup, the behavior of this method was proven, operating in detecting and compensating the faults without any disturbance in the global system.

The fifth chapter entitled *Control of electromechanical systems* debates the control methods applied to different types of systems. Initially torque linearization method for the switched reluctance machine are presented proving that despite its natural torque ripple, this machine, with proper control, can deliver linear torque to its load. This, combined with the simplicity of the machine and its power electronics makes the SRM a good candidate for any electromechanical system. The chapter presents the methodology of control and regulators design for 3-phase synchronous machines as well. In doing so, the reader can adept the method to its own needs using also the EMR concept to design the correct control loop. All these details are to be found in this chapter. The study ends with presentation of complex system's control exemplified by the complete traction unit of an urban electrical vehicle supplied form supercapacitors. The model also includes the required charging station supplied from the 230Vac grid. Again, using EMR the control loops are designed as reversed action paths for each of the considered assemblies of the system.

Chapter six, entitled *Testing of electromechanical systems* focuses on X-in the Loop testing methods applied both in industry and academia research activities. The chapter starts with an example of building a Digital-Twin (DT) for an actual test bench using two interconnected Filed Programable Gate Arrays (FPGA). Their link replicates the actual communication between a test bench and its control unit, as the DT is divided into the two FPGAs. One replicates the test bench and the second the electronic control unit. The chapter continues with the X-in the Loop concept, presenting examples for hardware testing in different configuration. X stands for hardware (H), software (S), model (M) and processor (P) in the loop. A particular example (BIL) battery in the loop is presented where a real battery is tested while the entire electric vehicle supplied by it is simulated in a complex approach. The same test is then performed by emulating the battery with a hybrid power supply. Finally, the Hardware in the Loop (HIL) testing is performed. The comparative analysis carried out proves the benefits of using any of the above mentioned approaches in the condition of precise and accurately built simulation models. Another modern approach is presented in the same chapter, a real-time cloud based computation and testing. This divides the simulation (or testing) into slow dynamics, such as mechanics of a vehicle, running on a cloud computation and the fast dynamics, such as control of electrical models, running on a real-time target in the laboratory. The link between the two entities is carried out via internet protocols. Despite long distances between the cloud computer and the laboratory, it was proven that this approach is a lucrative tool that may help researchers for different laboratories all over the world to use the same analysis tools.

The last chapter of the thesis emphasizes an image of the candidate about his future envisions for both academic and research activities. In this chapter, the author briefly presents his results and achievements both in the research and academic career, linking those to future developments. Fuzzing knowhow from research to teaching mitigates the bridge between classical teaching methods and modern ones. This will put at the student's disposal information that will promote their engineering skills in up-to-date methods and activities linked to electrical engineering research and development.

The thesis falls into the field of Electrical Engineering dealing with modern and trending concepts for system's development, analysis and testing. The content proves the skills of the author to conduct future research with PhD. students in the filed of Electrical Engineering