Candidate: Muhammad Ahmed Qureshi, 36th PhD Cycle
Doctorate in Electrical, Electronics and Communications Engineering
Politecnico di Torino, Italy

Thesis Title: A Novel Adaptive Algorithm for the Modeling and Regulation of Power Converters for Grid Applications

Abstract:

While coal, oil, and natural gas contribute more than 60% to global electricity generation, they also bring hazardous issues due to the depletion of fossil fuels and global warming. Fortunately, renewable energy sources (RES) are promising to replace those fossil fuel based energy sources for electricity generation. After intensive research in the past two decades, microgrids composed of RES systems such as Photovoltaic (PV) arrays or wind turbines have emerged as a feasible and attractive alternative to traditional power system structure.

In modern microgrids, power converters are absolutely essential for converting renewable energy into electricity by connecting the converters to the grid. These converters enable bidirectional power flow, which is the defining feature of modern power grid and is essential for integrating distributed energy resources. Power converters also help maintain power quality, stability, and frequency regulation within the grid.

As the penetration of RES increases, the grid-connected converters supplied by RES are expected to establish and maintain voltage and frequency independently in grid-forming mode or to operate within the grid in grid-following mode. To enable the converter to fulfill the tasks mentioned above, as well to dynamically respond to changes in load and generation, the control strategy of power converters has become of utmost importance. This thesis is therefore motivated to develop a novel adaptive control strategy for power converters to cope with fast transients and dynamic operating conditions.

This thesis proposes a new control strategy based on an adaptive control approach for regulating different DC-DC power converters as well as DC-AC power inverters. The proposed methodology is based on the Torelli Control Box (TCB) principles originally applied to power converters. The TCB approach is derived using the Lyapunov stability theory and can ensure asymptotic stability of the system. The application of the TCB approach overcomes the disadvantage of the traditional non-linear control approach, that is, the requirement for the derivation of an appropriate energy function, which can be cumbersome and requires trial and error. The adaptive control approach presented in this thesis derives the control law for the system based on the Lyapunov approach without the need for Lyapunov function derivation while using only information of local measurements and parameters.

In addition to controlling dynamical systems, the TCB approach can also provide an alternative method for modeling systems whose dynamics are constrained by differential-algebraic equations. This is shown by the application of TCB approach for the modeling of Non-Isolated single input Multiple-Output DC-DC converters.

The TCB approach was then used to derive the control law for the regulation of Buck and Boost power converters in both ideal and non-ideal cases. The simulations highlight the

effective response of the converter as compared to other nonlinear control techniques. The results were further verified by building hardware prototypes of both converters and testing the control performance in real time.

Similarly, the TCB approach was used for the Maximum Power Point Tracking application using a non-inverted buck-boost converter. The results show robust response and low steady-state errors even under extreme conditions of temperature and irradiance variation. The approach was further tested on single-phase DC-AC inverter for a bidirectional Vehicle to Grid system. Comprehensive tests were conducted to show the response of the controller under different modes and different operating conditions.

The effective performance of the controller in relation to others was highlighted. Finally, the novel approach was tested for the regulation of three-phase inverters for UPS applications and Grid-Forming operations. The controller performance was tested initially in the Matlab/Simulink environment and further verified on a small-scale inverter prototype in the laboratory. The testing carried out by changing the load showed excellent performance in tracking the targeted output voltage.

Due to the difficulty and safety concerns of building a full-scale GFM inverter, the verification of its controller design was done through the use of a real-time simulator OP 5700 using RT-Lab software. The inverter was simulated using the latest FPGA based solver (eHS) from OPAL-RT. The results matched the ones that were concluded from Matlab/Simulink simulations.