DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

PhD Public Defence

Title: Topologies and Control in Photovoltaic Systems with and without Storage

Location: Pontoppidanstræde 111, auditorium

Time: Wednesday 11 December at 13.00

PhD defendant: Abderezak Lashab

Supervisor: Associate Professor Dezso Sera

Moderator: Associate Professor Daniel Ioan Stroe

Opponents: Associate Professor Erik Schaltz, Dept. of Energy Technology, Aalborg University (Chairman)
Professor Pavol Bauer, Delft University of Technology, the Netherlands
Research Professor Dmitri Vinnikov, Tallinn University of Technology, Estonia

All are welcome. The defence will be in English.

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Abstract:

Photovoltaic (PV) systems have a great potential in many countries to be the top source of new power capacity due to their advantageous features, such as free energy source, and sustainable. Furthermore, they are clean and noiseless, which is promoting them to be installed almost anywhere. Due to some challenging issues related to resorting to such systems on both the technical and economic aspects, considerable efforts by the research community are being carried out. Owing the fact to the partial and complete solar unavailability during, respectively, cloudy and night times, a good combination would be by integrating energy storage systems (ESS). However, the latter comes with more technical and economic challenges as well. By taking into account that a power electronics system consists of mainly two parts—hardware part and software/control part, this thesis is structured accordingly, where these two parts are first looked into considering PV systems, then these two parts are looked into considering PV with built in ESS.

PV system topologies side is explored in the first part of this thesis as the following. An overview of converter topologies in PV systems is presented, where the last generation developments and industrial technologies are outlined. By the end of this overview, the issue of multilevel converters (MLCs) for PV systems suffering from distorted output signals (voltage and current) during unbalance power cells' irradiance (UPCI) is mathematically analyzed. Based on the outcome of this analysis, a cascaded MLC topology has been proposed, and its performance has been compared to some of the existing solutions considering different aspects. Finally, it is proposed to add an extra PV array to quasi Z-source inverters (qZSIs), where the aim is to extract more PV power while using the same parameters of the conventional ones. This proposed topology has been also compared to the conventional ones by taking into account the topology cost, as well as efficiency.

The control part of PV systems differs from the control of other power electronics-based systems in an additional algorithm, called the maximum power point tracking (MPPT) algorithm. As its name denotes, this algorithm works on driving the power converter to the peak of the P(v) curve for a maximized PV power harvesting. The main two challenging issues in MPPTs, regardless of their nature, is their steady-state accuracy, as well as their ability of tracking the MPP during rapidly changing meteorological conditions. The second part of this Ph.D. project aims at providing a critical analysis of advanced control strategies in PV systems, namely, MPPT algorithms and make further contributions to this field by designing more advanced techniques. Contributions to the MPPTs field are as follows. First, a comprehensive overview of recent advances in developing MPPTs by using model predictive control (MPC) is conducted. This overview is of interest to both researchers and engineers as it highlights the advantages and disadvantages of different MPC-based MPPTs. Second, based on the performed overview, an advanced MPC-based MPPT has been designed, where the main shortcomings of the previously introduced MPC-based MPPTs are coped with in it. The addition of a PV array to qZSIs, which is proposed in the PV converters part, comes with the challenge that, the added PV array affects the original one and vice-versa, which makes two MPPTs for these two PV arrays do not work properly. Therefore, a two MPPs tracker (MPPsT), which is an algorithm for tracking the MPPs of two PV arrays in one converter has been developed.

The third part of this thesis is devoted to converter topologies for PV systems with integrated ESS. One of the main disadvantages of MLCs is their high semiconductors count. This disadvantage becomes prominent when integrating ESS beside the PV one as the switches count get doubled. A cost-effective, lighter, and less sizable converter topology has been proposed, where the switches count has been greatly reduced. The saved switches could reach nearly 50% in the high voltage levels cases. Finally, the proposed topology has been compared to one of its counterparts, namely, the conventional cascaded H-bridge (CHB), where it is shown that the proposed topology still

conserves the advantages of the CHB. It has been also compared to the CHB in terms of switching and conduction loss, where it is shown the proposal reaches a higher efficiency.

The last part of this thesis is dedicated to analyzing the control strategies in PV systems with integrated ESS and based on this analysis, new designs are established. It is known that linear controllers applied to qZSIs with integrated ESS suffer from a low-frequency ripple in the battery current as well as in the second qZ-network inductor current, which limits the battery life span and constraints the design requirements of the qZ-network passive elements. Hence, a control strategy based on MPC has been designed in this thesis for two-level three-phase qZSIs, where the battery current is directly controlled. Since MPC is computationally expensive, another control strategy has been designed for two-level single-phase qZSIs, where the computational effort has been significantly reduced. The latter strategy has been further extended for cascaded multilevel qZSIs.