DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

PhD Public Defence

Title:	Lifetime Models for Lithium-ion Batteries used in Virtual Power Plant Applications
Location:	Pontoppidanstræde 101, Room 23
Time:	Monday 17 November 2014 at 13.00
PhD defendant:	Daniel Ioan Stroe
Supervisor:	Professor Remus Teodorescu
Moderator:	Associate Professor Tamas Kerekes
Opponents:	Associate Professor Erik Schaltz, Dept. of Energy Technology, AAU (chairman) Senior researcher Søren H. Jensen, DTU, Roskilde Professor Torbjørn Thiringer, Chalmers Tekniska Högskola, Göteborg

All are welcome. The defence will be in English.

After the public defence there will be an informal reception in Pontoppidanstræde 101 room 25/27.

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Abstract:

The penetration of wind power into the power system has been increasing in recent years. However, despite its environmental friendliness, the wind power grid integration at a large scale faces several limitations, mainly caused by the characteristics of the wind (i.e. intermittent, variable, and not 100% predictable), which can lead to power system instability, reliability issues, and power quality issues. Consequently, a lot of concerns related to the reliable and stable operation of the power system have been recently addressed. Several solutions were identified and proposed in the literature, in order to mitigate the aforementioned issues.

An attractive solution is represented by the use of energy storage systems (ESSs) together with wind power plants (WPPs). The inherent characteristics of the ESSs will allow the new system, often referred as virtual power plant (VPP) to behave similar to today's conventional generating units seen from the TSO's perspective, by complying with future harsher grid codes and by providing a diversity of grid support services (e.g. frequency regulation, forecast error balancing).

A wide variety of energy storage technologies are available on the market; however, because of their advantages, which include fast response, high efficiency, long lifetime and environmental friendliness, Lithium-ion (Li-ion) batteries represent suitable candidates for integration within VPPs, especially when they are required to provide short- and medium-time services. The family of Li-ion batteries is broad with many different chemistries available at present on the market. Nonetheless, the Li-ion battery based on the lithium iron phosphate/graphite (further referred LFP/C) chemistry is investigated in this thesis.

The lifetime of the Li-ion battery ESS represents a key parameter in the analysis of the economic feasibility of integrating such systems in WPPs. Even though their price is decreasing due to the research carried out mainly in the automotive sector, Li-ion batteries are still expensive energy storage devices. Therefore, accurate information about Li-ion batteries' lifetime is mandatory in the project planning stage in order to assess its economic feasibility. Moreover, the performance of the Li-ion batteries is lifetime-dependent and thus accurate information about their state-of-health, in each operating point during their life, will allow the selection of the best energy management strategy; this would further result in the successful delivery of the application (service).

The main objective of this thesis was to develop accurate lifetime models for LFP/C battery cells, which are used in VPP applications. Several approaches to model the lifetime of Li-ion batteries are presented in the literature. In this thesis an equivalent-electrical circuit performance-degradation modelling approach was followed to develop the lifetime models for the selected LFP/C battery cells. In order to develop the desired lifetime model, laboratory ageing tests are mandatory. However, ageing the Li-ion batteries in the laboratory under real operating conditions, which are characteristic to VPP applications are extremely time consuming and cost demanding. Thus, the Li-ion battery cells were aged in laboratory following an accelerated lifetime testing methodology, which considers both the cycling and the calendar lifetime dimensions.

The developed lifetime models are able to predict with good accuracy the capacity fade, the internal resistance increase, and the pulse power capability decrease of the tested LFP/C battery cells for both calendar and cycling ageing conditions. Moreover, in this thesis, the use of the electrochemical impedance spectroscopy (EIS) technique was proposed as a method to estimate the pulse power capability decrease, which is caused by ageing, of the tested LFP/C battery cells.

The developed lifetime models were used to analyse the degradation behaviour, in terms of capacity fade and power capability decrease, of LFP/C battery cells while providing primary frequency regulation on

the Danish ancillary services market. For this study case, a realistic mission profile, measured on field during one year, was considered.