# ABSTRACT

***Title:*** Design and Integration of Battery Energy Storage System in More Electric Aircraft.

***Details of the work done:***

In the presented work a detail study on the battery technologies used in aircrafts in the last five decades is done. A general background of the battery system is studied and the performance of the batteries based on energy densities and low temperature capabilities is evaluated for the deployment in the more electric aircraft (MEA). Evolution of MEA with its power system architecture and load profile is analysed to understand the requirements of the battery system. An effective battery energy storage system (BESS) is designed considering the weight saving and cost analysis factors. Based on the analysis, Li-ion battery with Lithium ferrous phosphate (LFP) chemistry is designed and proposed for the MEA.

After the design, the proposed Li-ion battery system is successfully integrated with the power distribution 270V DC bus architecture of the MEA and tested under different dynamic conditions using three different control techniques. Firstly, a direct estimation based technique is proposed for determining the phase shift of the phase shifted high power bidirectional dc-dc "PSHPBD" converter (A charger for the batteries). Secondly, a current mode control for the single phase shift control technique for the PSHPBD converter is also proposed. The proposed control technique has an inherent capability of current limit. The design of coupling inductor and duty cycle, keeping in view the requirement of maximum power transfer in the MEA environment as well as ZVS operation in wide range is done for the PSHPBD converter for MEA operating parameters. An optimal harmonic number based harmonic modeling of the PSHPBD converter is done so as to reduce the complexity involved in operating with the switch model. Thirdly, a peak current controller is also proposed which provides a limit on the peak current as well as it gives fast transient response. The advantages of using the proposed peak current control in avoiding the saturation of the transformer core is also reported in the work.

Furthermore, a control method which can improve the life of the BESS and a multi-functional battery charger for an efficient operation of the BESS is also proposed. The proposed control method is activated during the light load conditions and reduces the RMS current of the charger circuit thereby reducing the losses and temperature rise in the system. The functionality of the proposed multi-functional battery charger is also discussed in detail in the work.

# ***Publication List:***

## Patents*:

[1] **M. Tariq**, A. I. Maswood and C. J. Gajanayake, "Multi-functional Battery Charger", (in process).

[2] **M. Tariq**, A. I. Maswood and C. J. Gajanayake, "Control Method to Improve the Life of Battery Energy Storage System", (in process).

## Journals:

[3] **M. Tariq**, A. I. Maswood, C. J. Gajanayake and A. K. Gupta, "Aircraft Batteries: Current Trend towards More Electric Aircraft", *in IET Electrical Systems in Transportation*, vol. 7, no. 2, pp. 93-103, 6 2017.

[4] **M. Tariq**, A. I. Maswood, A. C. Moreddy, C. J. Gajanayake, M. Y. Lee and A. K. Gupta, "Reliability, Dead-Time and Feasibility Analysis of a Novel Modular Tank-less ZCS Inverter for More Electric Aircraft", in *IEEE Transactions on Transportation Electrification*, vol. 3, no. 4, pp. 843-854, Dec. 2017.

[5] **M. Tariq**, A. I. Maswood and C. J. Gajanayake, "Modeling of a Lithium-ion Battery Energy Storage System and its Integration with the More Electric Aircraft 270 V DC Power Distribution Network using a Predictive Peak Current Control Technique", in *IEEE Access special issue on Battery Energy Storage and Management Systems*, [in review].

## Conferences:

[6] **M. Tariq**, A. I. Maswood, C. J. Gajanayake, A. K. Gupta and F. Sasongko, "Battery energy storage system integration to the more electric aircraft 270 V DC power distribution bus using peak current controlled dual active bridge converter," *2017 IEEE Energy Conversion Congress and Exposition (ECCE)*, Cincinnati, OH, 2017, pp. 2068-2073.

[7] **M. Tariq**, A. I. Maswood, C. J. Gajanayake and A. K. Gupta, "Modeling of a Li-ion battery energy storage system using an optimal harmonic number based model of DC-DC converter for more electric aircraft," *IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society, Florence*, 2016, pp. 4429-4434.

[8] **M. Tariq**, A. I. Maswood, C. J. Gajanayake and A. K. Gupta, "A Lithium-ion battery energy storage system using a bidirectional isolated DC-DC converter with current mode control for More Electric Aircraft," *2016 IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, Penang, 2016, pp. 149-154.

[9] **M. Tariq**, A. I. Maswood, et al., "Battery integration with more electric aircraft DC distribution network using phase shifted high power bidirectional DC-DC converter," *2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Brisbane, QLD, 2015, pp. 1-5.

Note: * Both the patents are in review stage by Rolls-Royce global panel and have been approved by the ECG, Singapore local patent committee and the global subject matter expert (SME) for ECG, Rolls-Royce for possible publication of Patent.