



**INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS**

Name of the Student : Upasana Sarma

Roll Number : 166102003

Programme of Study : Ph.D.

Thesis Title: Design and control of PEM fuel cell-battery-hybrid energy system for locomotive applications.

Name of Thesis Supervisor(s) : Dr. Sanjib Ganguly

Thesis Submitted to the Department/ Center : Department of Electronics and Electrical Engineering

Date of completion of Thesis Viva-Voce Exam : 18/08/2021

Key words for description of Thesis Work : PEM fuel cell, locomotive, hybrid energy system, design optimization, energy management, PWM controlled DC/DC converter, infrastructure planning of hydrogen refueling station.

SHORT ABSTRACT

The development of economically feasible renewable energy technologies to replace the fossil fuel run machineries is one of the significant areas of research in this century. Over the years, the proton exchange membrane fuel cell (PEMFC) based hybrid energy system (HES) has emerged as a promising source of electrical power for use in transportation. This is because the PEMFC has the advantages of being clean energy, low operating temperature, high efficiency, etc. In this thesis, the PEMFC-battery-HES is proposed to retrofit the diesel locomotives which are currently used to haul the passenger trains operating in North Eastern Frontier Railway (NEFR), Assam, India. However, the investment and operational costs are the important factors associated with a HES. Thus, it is important to optimise the sizes of the HES components and to design an energy management strategy (EMS) for optimum distribution of load in the HES.

In this thesis, the optimal component sizing of the PEMFC and battery that constitute the HES is carried out to provide the similar driving force as the WDM-3D class of diesel locomotives to pull the intercity passenger trains in Assam, India. To do this, single-objective and multi-objective design optimization approaches are formulated. The objective function of single-objective optimization is the minimization of the total cost of HES. The objective functions of multi-objective optimization are the simultaneous minimization of the total cost of HES and the PEMFC fuel consumption. In both the approaches, the optimization is carried out under the operational constraints of the battery state-of-charge limit, the PEMFC capacity constraint, and the instantaneous power balance between the source and load. Two EMSs are designed and are suitably incorporated into the particle swarm optimization (PSO) based solution algorithm to solve the design optimization problems.

The application of PEMFC-battery-HES in locomotives requires the maintenance of a constant DC-bus voltage across the load against the wide variation in the PEMFC output voltage with changing operating and loading conditions. This can be achieved through the use of DC/DC converters. In view of this, the design and control of a multi-input single-output (MISO)-DC/DC boost converter are carried out in this thesis. The feedback controllers regulate the pulse width modulation of the converter switches to implement the EMS and to maintain the DC-bus voltage. The performances of the designed MISO converter and the controllers are validated on MATLAB/SIMULINK and on developing an experimental set-up. Both the simulation and hardware results show that the PWM controlled MISO converter provides the desired performances.

Another vital aspect of a HES is the design of an efficient EMS to regulate the power flow in the HES based on the operational characteristics of the energy sources. Hence, two energy management optimization (EMO) approaches are devised that aim to generate the PEMFC power references at each loading point with the objective function of the minimization of the total fuel consumption of the PEMFC. The constraints of the first EMO approach include the limits on battery state-of-charge variation, the dynamic change in the PEMFC output power and the instantaneous power balance between the source and load. However, in the second EMO model, the durability limits of the energy sources are also considered in addition to the aforementioned operational constraints. The EMO approaches are executed using General Algebraic Modeling System. The performance comparison of the proposed approaches with some of the already available approaches confirms its proficiency in the reduction of fuel consumption with optimum utilization of the capacities of the energy sources.

All the above studies are carried out using the data of the dynamically varying locomotive power demand for practical drive cycle scenarios of NEFR, Assam, India.

The viable deployment of the hydrogen powered passenger trains requires a proper refueling infrastructure. In view of this, the optimal allocation planning of the hydrogen refueling stations (HRS) for the rollout of hydrogen powered passenger trains in NEFR, Assam, India is presented in this thesis. The problem of optimal allocation planning is firstly addressed as a single-objective optimization approach with the objective function of the minimization of the total cost ownership (TCO) of the HRS for a specified planning period. A multi-objective optimization approach is then designed with the objective functions of simultaneous minimization of the TCO and the average cost of refueling of the HRS. The optimization problems are solved using binary PSO based solution algorithms with the real-time data of the intercity railway traffic of NEFR, Assam, India as the input. Besides this, the total investments incurred in the HRS infrastructure development under the different scenarios of installed HRS capacity are also investigated