ABSTRACT

This thesis primarily focuses on the following areas within the field of hybrid solid oxide fuel cell (SOFC) power technology:

- Proposing a new configuration of solid oxide fuel cell (SOFC)–gas turbine (GT) –steam turbine (ST) integrated combined cycle (CC) power plant system with a single pressure bottoming ST cycle and a provision for fuel and air preheating utilizing the GT exhaust heat; additional fuel burning in the combustor and steam extraction from the ST for fuel reforming in the pre–reformer (PR).
- Development of a thermodynamic model and conduction of energy and exergy based parametric analysis of the proposed SOFC integrated combined GT–ST power cycle.
- Estimation of operating parameters of the proposed SOFC–GT–ST (single pressure ST cycle) power cycle via inverse analysis.
- Development of a thermodynamic model for simulation of a novel SOFC–GT–ST configuration with dual and triple pressure reheat bottoming ST cycle to predict its energy and exergy based system performance.
- Conduction of a comparative performance analysis, with regard to both energy and exergy, for the SOFC integrated combined power cycles with three different bottoming ST cycles viz. the triple pressure reheat, dual pressure reheat and single pressure ST cycle.

The study presented in this thesis provides the energy and exergy based performance analysis of the proposed SOFC–GT–ST combined power cycle. The system utilizes the GT exhaust heat for fuel and air preheating subsequently in a fuel recuperator (FR) and an air recuperator (AR) before finally producing steam in a heat recovery steam generator (HRSG) coupled with the ST cycle. The system considers 30% external reforming in a PR using the steam extracted from the bottoming ST plant. This study considers the effect of additional fuel burning in the combustion chamber as a means for increasing the net GT and ST power output. A detailed parametric analysis based on the variation of compressor pressure ratio (CPR), fuel flow rate (FFR), air flow rate (AFR), current density, single level boiler pressure and ST inlet temperature (STIT) is

conducted. The results indicate improved system performance at comparatively high CPR. The optimum single level boiler pressure is observed to be 40 bar with 50% additional fuel burning. The burning of additional fuel improves the GT and ST power output; however it reduces the overall plant efficiency. Further performance comparison with a similar other system where the AR is placed ahead of the FR indicates a slightly better performance of the proposed system with respect to the one where FR is placed ahead of AR (FRAOAR).

Subsequently, this thesis presents the inverse analysis of the proposed SOFC–GT–ST CC power plant that uses a single pressure for the bottoming ST cycle. The net power, efficiencies (energy and exergy) and the total system irreversibility of the SOFC–GT–ST CC at compressor pressure ratios (CPR) of 6 and 14 are considered as objective functions for the inverse analysis. A differential evolution (DE) based inverse algorithm is used to simultaneously estimate the six operating parameters of the proposed plant, viz. CPR, FFR, AFR, current density, single level boiler pressure and STIT. It is observed that the DE based inverse method has been exceedingly effective in estimating the operating parameters of the hybrid SOFC–GT–ST power plant properly within the prescribed lower and upper boundaries of the parameters. Moreover, the results provide multiple combinations of the parameters that satisfy a given objective function which is only possible through the inverse analysis and it is a significant advantage over the forward simulation method. Any objective function value can be set and subsequently corresponding operating parameters can be determined using the proposed DE based inverse method. This method also provides extensive scope for the selection of suitable operating parameters satisfying a given objective function.

The thesis further presents the parametric analysis of the proposed SOFC–GT system with triple pressure reheat cycle in the bottoming steam turbine (ST) plant. The steady state performance of the power cycle is analysed with respect to the net power output, energy efficiency, exergy efficiency and total system irreversibility. A parametric analysis is conducted to investigate the effect of the CPR on the performance of the SOFC integrated CC. The results indicate improved performance at comparatively high CPR. The net power and efficiencies (energy and exergy) increase while the total system irreversibility decreases at higher CPR. Additionally, performance comparison is conducted amongst (i) triple pressure reheat (ii) dual pressure reheat and (iii) single pressure ST cycles. This study reveals that the system with single pressure ST cycle performs better compared to the others; the highest power is obtained from this system with minimum total irreversibility. It is recommended that the system with single pressure ST cycle would be the most appropriate as it is simple with less number of components and minimum total cost.