ABSTRACT

Energy security and the quality of power supply are the key issues being faced with rising demand for electricity. Remote locations which are not connected to the electric grid or the locations with high levels of power shedding increases the concern over energy security. Efforts to improve the power situation in remote locations include the integration of distributed generation sources. The scarcity of fossil fuels and adverse impact on the environment by fossil fuel based power generation has supervened the focus on renewable energy. Intermittent and variable nature of renewable energy creates an energy security issue. This can be mitigated using energy storage or controlled power source. In India, diesel generator (DG-set) has a major footprint as a controlled power source. However, DG-set is one of the key CO2 emitters at the distributed level. An alternative prominent controlled source of power in India is biomass based power generation.

A biomass power plant in general runs round the clock, however interruption in continuous operation is due to constraints of availability of biomass and other challenges related to the supply chain. Due to such issues, plant availability reduces and thus reduces plant load factor. For sustainability and to increase the availability to maximum, hybridization is one of the key options available. This thesis proposes an optimal hybridization of solar thermal with a biomass plant for continuous power generation. The detailed analysis of different types of integration and capacity optimization has been carried out based on the techno-economic analysis and operational strategies for solar-biomass thermal hybrid power plant (SBTHPP). Another option of RDF based fuel supplement is elaborated for sustainability evaluation of such hybridization.

Energy storage plays a vital role in multi-generation systems (MGS) by smoothening the variations. A comparative techno-economic analysis of battery and thermal storage has been presented in this thesis. Thermal storage is suitable for microgrids having a thermal load and an economical solution varies from case to case based on application. However, an approach for obtaining optimal asset configuration of MGS for mitigating DG-set along with operating strategy for a battery energy storage system (BESS) is the real challenge. A generic adaptable model for techno-economic optimization has been developed and presented. This thesis attempts to find the optimal sizes of a distributed energy resources (DERs) along with battery bank integrated with a distribution system in a microgrid configuration.

The developed model is solved using mixed integer linear programming (MILP) for six different real case studies including health-care, educational, industrial and residential facilities. The proposed optimal model has been rigorously tested for all cases to evaluate the robustness of the self-sustained asset configuration. Another important aspect addressed in this optimization is generation expansion planning (GEP). Based on the projected load, new asset configuration after a certain planning period is optimized with the developed model. The techno-economic analysis result (LCOE and NPV) shows that the obtained optimal asset configuration with renewable energy (RE) combination gives a cost effective optimal solution with a minimal carbon footprint.

Since thermal loads form a significant portion of the total energy consumption, the remote power systems may be developed as multi-energy systems with parallel heat and power networks. To effectively implement such systems, this thesis focuses on optimal system sizing and multi-energy dispatch model for combined heat and power (CHP) systems.

This thesis proposes a comprehensive framework for developing a multi-energy off-grid microgrid with a decoupled flow of thermal and electrical energies in a rural setting. A carbon-neutral microgrid with a hybrid generation system constituting a photovoltaic (PV) unit and biofuel generator is proposed. In order to enhance the fuel utilization efficiency, the biofuel generator is operated in combined cooling heating and power (CCHP) mode, and the recovered thermal energy forms the heat distribution network in the microgrid. The flexibility of system operation is improved by suitable multi-energy (electrical and thermal) storage. Firstly, an optimal sizing framework has been developed for the system as a mixed integer linear programming (MILP) model. Secondly, a coordinated multi-energy management system (MEMS) has been developed for combined optimal dispatch of multiple generation and storage resources. The MEMS has been developed as a mixed-integer non-linear programming (MINLP) model, which minimizes system operational cost while considering minimum battery degradation to prolong its lifetime. Finally, a detailed economic analysis of the proposed system has been presented, highlighting the levelized cost of energy (LCOE) and net present value (NPV). Extensive case studies and simulation results depict the effectiveness and suitability of the proposed MEMS for the rural off-grid microgrid.