Abstract

Design optimization is an area of immense importance in renewable energy systems. Based on power generation from solar photovoltaics (PV), design optimization focuses predominantly on scenarios that resolve the issues of maximizing PV power availability. A prime example of such and optimization problem is the design of a maximum power point tracking (MPPT) system which is able to enhance the power generation capability of the PV system, ensuring its optimal operation based on changes in the external sources, namely the solar irradiance and temperature profiles. A fundamental component of any such MPPT system is the power converter interface, the DC-DC converter. While numerous algorithms have been successfully implemented to enhance power production capacity of the PV systems, there is a need to study the role of the individual converter in meeting the optimal system operation by changing the operating duty ratio. The design optimization of a DC-DC converter interface goes a long way in enhancing the power transfer capability of the PV based MPPT system. One aspect of this thesis focuses on an optimally designed converter to be used as power converter interface in MPPT for standalone PV systems.

Furthermore, the demand based power generation using PV based hybrid renewable energy sources (HRES), PV with complementary hydro generation offers a viable solution. Such a system, when optimally designed will allow the users to make the most out of the available power generation capability. In addition to being environment friendly, such systems are modular in nature and are able to serve the requirements of energy demand to isolated hamlets, where grid integration is otherwise not available or is not cost effective.

The thesis aims to bridge some crucial research gaps to generate clean power from standalone PV as well as PV-hydro based hybrid renewable energy systems (HRES). To start with, the design optimization problem based on the minimized power loss in a boost DC-DC power converters is addressed. Secondly, the application of MPPT based algorithms plus optimally designed DC-DC power

converters as the MPPT interface are applied to standalone PV systems. The evolutionary and metaheuristic algorithms are found to be the most effective for MPPT. This information supports the idea that combining a well-designed converter with a suitable algorithm will outperform other technique for extracting the maximum power from PV. The performance evaluation of optimally designed DC-DC converter topology with a proper tracking algorithm in MPPT application for PV standalone systems is examined in the thesis. Additionally, the design optimization of the HRES considering minimized levelized cost of energy (LCOE) for demand based energy supply in a rural hamlet in North East India having both solar and hydro power potential is also addressed.

A total of 23 algorithms are selected and a comprehensive examination of their performance is conducted using statistical performance indicators, algorithm computational time and convergence characteristics to find the global optima in the design of DC-DC boost converter and for size optimization of PV based HRES. These algorithms are known for their effectiveness and robustness. Moreover, a novel hybrid GWOSCAPSO algorithm is developed inspired from three algorithms namely Grey Wolf Optimizer (GWO), Sine Cosine Algorithm (SCA)and Particle Swarm Optimization (PSO). The primary aim of this hybridized algorithm is to focus on optimizing renewable energy systems, particularly the specific design optimization problem being investigated in the current research, as well as addressing engineering optimization problems in a broader sense. Comparing the hybrid GWOSCAPSO method to known algorithms reveals its advantages in terms of high reliability, robustness, quick convergence characteristics and low computational cost.

The optimal fitness value attained for the boost converter for all the 23 algorithms is within the range of 1.7538 -1.7565 W, with the highest design efficiency of 91.93%. Taking into account all performance parameters, including the mean values, best value and highest value, iteration time, design constraints values for filter inductor and capacitor, switching frequency, computational time, best optimized result for minimized power loss, and convergence curve,the Whale Optimization Algorithm (WOA) in the swarm intelligence category outperforms the 22 other algorithms.

Incorporating this approach an optimum boost converter is used for MPPT tracking in a 120 Wp reference PV module. The designed converter with the combination of the Particle Swarm Optimization (PSO) algorithm gives the best tracking performance with highest tracking efficiency of 98.99%, when compared with four other popular tracking algorithms. This combination also gives the best

performance in terms of high relative power gain (RPG) and minimal relative power loss (RPL) when compared to the combination of optimal boost converter and Perturb & Observe (P&O) technique. The Boost-PSO combination gives best RPG equal to 19%, while the lowest RPL is recorded to be 1 W.

The total capacity of the optimized hybrid system was determined to be 31.86 kW, with the photovoltaic (PV) system contributing 16.12 kW and the hydro system contributing 15.74 kW to meet the varying load demand ranging from 11.1 kW to 24.61 kW during the different seasons of the year. The PV system covered an area of 95.58 m^2, while the hydro system had an effective head of 9.0 meters and flow rate of 0.21 m^3/sec. The most favorable value of LCOE was determined to be 6.408 INR/kWh. The comparison of all deployed algorithms reveals that the GWO, belonging to the category of swarm intelligence approaches, surpasses other algorithms in terms of attaining optimal values of the objective function, statistically significant outcomes, and rapid convergence properties.

Keywords: Renewable Energy, DC-DC Converters, Solar Photovoltaic (PV), Hybrid PV-Hydro based Renewable Energy Systems, Metaheuristic Algorithms, Design Optimization.