Abstract

Generation sources near the customer location in an active distribution network, known as distributed generation, help to reduce transmission losses and costs. Increasing greenhouse gas emissions and environmental degradation due to fossil-based sources have paved the way for renewable sources like solar photovoltaic and wind power. Also, plug-in hybrid vehicles are replacing conventional internal combustion engine vehicles. The change of the original power flow pattern due to the penetration of distributed generation and plug-in hybrid vehicles, as well as the variability of renewable sources, makes operation and planning challenging. Further, the DC-microgrid architecture is becoming popular for serving remote rural households and facilities, community buildings, data centres, etc. Since the capacity of controllable power generation facilities is limited in a DC-microgrid, a high proportion of renewable energy sources, like solar and wind, introduces volatility and uncertainty in maintaining the generation-demand balance. This thesis deals with the energy management scheme for a DC microgrid from different perspectives.

The second chapter of this thesis addresses the challenges of modelling the correlation between input random variables while formulating the energy management scheme of a DC-microgrid. Correlation between input random variables is modelled using an Inverse Nataf transformation-based approach. Previous studies used an empirical formula to map the correlation between the normal and arbitrary marginal distributions, limiting the approach's applicability to those marginal distributions for which empirical formulae existed. By contrast, Newton's Interpolation-based technique is used instead of empirical formulae for correlation mapping between normal space and arbitrary marginal distributions in this work. Newton's interpolation-based technique allows the Inverse Nataf transformation-based approach to be applied to any marginal distribution describing the behaviour of the correlated input random variables, which obviates the limitations of previous studies. Also, a multi-objective energy management scheme is formulated for a DC-microgrid by modelling and incorporating uncertainties of renewable energy sources, load demand, plug-in hybrid vehicles load, and grid power price. The energy management scheme strategy envisages coordination between power procurement from various sources (renewable energy sources, grid, dispatchable unit), demand response implementation, battery energy storage system, and soft open point scheduling.

In the third chapter, a privacy-preserving energy management scheme with a retail-

power price-based decentralized demand response program is proposed for a DC-microgrid with sectoral coupling between electricity and hydrogen, aiming to maximize the profit of the DC-microgrid operator and reduce consumer energy costs. The retail power price is established on a theoretical foundation using the concept of competitive equilibrium, considering the DC-microgrid network model and constraints. Operational flexibilities of plug-in hybrid vehicles and battery energy storage system, building thermal inertia, and the demand-shifting potential of hydrogen storage system are coordinated into an "integrated demand response scheme" to enhance the techno-economic performance of the coupled electricity-hydrogen DC-microgrid. Additionally, uncertainties, including correlations among input random variables, are modelled using probabilistic Copula models and integrated into the energy management scheme to mitigate risks in dispatch strategies under uncertainty.

In chapter four, a bi-level probabilistic Stackelberg game-based energy management scheme is proposed for a grid-connected electricity-hydrogen DC-microgrid with a hybrid energy storage system incorporating islanding constraints and with coordination between the operation of the DC-microgrid and demand response participators. The uncertain input random variables are modelled in the probabilistic domain using a copula-embedded Monte Carlo dynamic averaging approach and incorporated into the energy management scheme module. The objective of the DC-microgrid operator is to maximize the day-ahead profit for grid-connected operations using available generation sources and grid power, a hybrid energy storage system (battery energy storage system and hydrogen storage system), and controllable loads subject to equipment and network operating constraints. On the other hand, the objective of flexible consumers is to minimize the cost of day-ahead electricity usage. The demand response participation is coordinated with the DC-microgrid operation using a bi-level Stackelberg game.

In the fifth chapter, a resilience-oriented economic model predictive control-based energy management scheme is proposed for a DC-microgrid, enabling the co-optimization of hydrogen and electrical systems to ensure economical operation with automatic frequency restoration reserve market participation during normal periods, proactive preparation before extreme events, and reliable critical load supply with minimal non-critical load curtailment during emergencies. Designed with the DC-microgrid network model and incorporating equipment and network-level constraints, the resilience-oriented economic model predictive control-based energy management scheme ensures operational feasibility. Additional constraints are integrated to support automatic frequency restoration reserve market participation during grid-connected operation without violating system limits. Probabilistic Copula models address uncertainties in renewable energy sources generation and load demand and their correlations, mitigating the risks of dispatching under uncertainty.

Finally, the sixth chapter concludes the thesis by summarizing key findings and suggesting directions for future research.