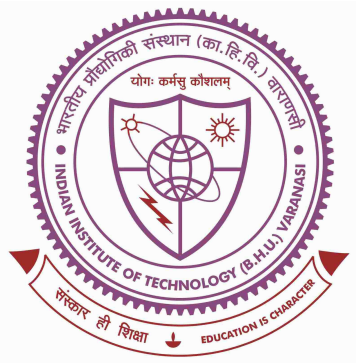
Energy Management of DC Microgrid considering Correlated Input Uncertainties



Thesis submitted in partial fulfillment
for the award of degree

Doctor of Philosophy

by

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Chapter 6

Conclusions and Future Scope

6.1 Conclusion

This thesis deals with EMS strategies for DCμG, incorporating economic, probabilistic, and resilient frameworks to address uncertainties and RES integration challenges. The chapters propose EMS frameworks that are robust, scalable, and applicable to diverse operating conditions, validated through extensive simulations. The following are the conclusions that can be drawn from each chapter:

- *Chapter-2:* An optimal EMS for a grid-connected DCμG is developed, modelling correlated uncertainties through inverse NT and Newton's interpolation for arbitrary marginal distributions. The EMS optimises power procurement, BESS, MT, and DR scheduling, minimising costs and losses using a convex MO framework. Simulations on a ten-bus DCμG network demonstrate the effectiveness of the proposed EMS.

- *Chapter-3:* A decentralised EMS for an electricty-H_2 DCμG and RPP-based DR is discussed in this chapter. A theoretical framework for determining the appropriate incentive price for DR participation for the flexible consumers in an electricity-H_2 DCμG is developed. The DCμGO coordinates flexible resources such as MT, HSS, electrolysers, and thermostatically controlled loads using ADMM. Correlated uncertainties are modelled with Copula theory, and simulations validate the proposed framework's ability to balance operator profits and consumer costs.

- *Chapter-4:* This chapter introduces a bi-level Stackelberg game-based EMS for grid-connected electricity-H_2 DCμG, integrating $24-1$ islanding constraints and hier-

archical DR. Correlated input uncertainties are modelled using Copula theory and Monte Carlo dynamic averaging. The EMS balances DCμGO profits and consumer cost reductions through iterative optimisation of dynamic RPP and flexible resource scheduling. The problem is solved using MILP and validated through simulations.

- *Chapter-5:* In Chapter 4, a $24-1$ islanding criterion is used, in which 24 denotes the scheduling horizon (i.e., 24 hours) and 1 denotes the consecutive hours for which the DCμG can operate in island mode. However, it is crucial to supply critical loads longer (to meet critical criterion) without grid and WPG during an emergency. Therefore, to address this shortcoming, in this chapter, a resilient EMS for electricity-H_2 coupled DCμG is developed considering normal, proactive, and emergency operations (due to extreme events). The framework maximises profit during normal operations, prepares resources proactively, and ensures critical load supply during emergencies. The EMS incorporates aFRR market participation, input uncertainty modelling via Copula theory, and MPC-based optimisation strategy validated on a six-bus DCμG network.

6.2 Future scope

The research presented in this thesis deals with various aspects of EMS for a DCμG considering correlated input RVs. However, the following aspects can be explored in the future:

1. The optimisation model presented in this thesis does not account for the behavioural aspects of flexible consumers participating in the DR program, highlighting the need for their inclusion in future research.

2. In this thesis, electrolyser efficiency is assumed to be constant. Accounting for the variation of electrolyser efficiency with loading levels and incorporating it into a convex optimisation framework remains challenging for future research.

3. The duration of the proactive preparation period is crucial for optimal economic and resilient performance. Therefore, future research can focus on developing a scheme for optimising the duration of proactive preparation to strike a balance

between minimising operational costs during normal operation and reducing load curtailment during emergencies for improved system resilience.

4. Peer-to-peer energy transactions among DCμGs with resilient considerations of individual DCμG can be an interesting research area.

5. In this thesis, a probabilistic approach is used for modelling the uncertainties. However, other approaches, such as range arithmetic, will be explored in future research.

6. In this thesis, we have used the Copula approach and the Nataf transformation for modelling the correlation. Other approaches, such as the maximum entropy principle and the polynomial chaos expansion approaches, will be explored in the future.

7. In this thesis, we have assumed perfect rationality while formulating the Stackelberg game. We have also assumed that the leader and followers have complete information, and the Stackelberg game is well-defined. In the future, the above limitations will be addressed by incorporating robustness approaches in the Stackelberg framework to account for a range of follower behaviour. Further, anchoring theory will be explored to model how followers might interpret the leader's actions when they do not have full visibility into the strategy space. In scenarios where uncertainty around the follower's preferences or capabilities is higher, a Bayesian Stackelberg formulation will also be explored.

8. In the future, other convex relaxation methods, such as semidefinite programming (SDP) or second-order cone programming (SOCP), will be explored for convexifying non-convex power flow equations.