PREFACE

The faster depletion of fossil fuels and their detrimental effect on the environment, such as greenhouse gas emissions, has led to several nations to adopt the carbon emission reduction program and curtailed the electricity generation through fuel-based power plants. Though, the power generation through non- conventional sources focusing on distributed renewable energy sources has emerged as a potential solution globally but needs a lot of investment with a defined time period to achieve the goal. Another cost-effective way to achieve this goal is to enhance the energy efficiency and distribute electricity more efficiently by optimal utilization of the network assets and control devices with the help of smart technologies. In this context, energy-saving through conservation voltage reduction (CVR) has gained momentum because of its positive correlation between voltage and power demand. Moreover, the large-scale integration of distributed energy resources (DER) in the distribution network has emerged as a solution and issues for grid operation and control. Hence, there is a need for efficient, optimal, and coordinated control methodology to measure the performance of the CVR scheme, unlock the opportunity of further energy savings and to manage the voltage profiles to remain closer to the minimum limit.

The present research work focuses on the development of smart such voltage and VAR control (VVC) algorithms in the purview of CVR implementation for energy conservation in active distribution network (ADN). A closed-loop smart grid-enabled CVR method assisted through ADMS has been introduced in order to enhance the observability and energy efficiency of the system. A case study on effect of different types of load models on CVR has been performed, and simulation results validate the positive correlation between voltage-dependent loads and CVR.

Further, advanced control algorithms have been developed for optimal coordination among network devices and assets. Moreover, the proposed CVR methodology has been implemented via VVO based methods in the presence of active devices such as solar photovoltaic (PV), wind power and energy storage systems and developing controls that leverage these distributed energy resources (DERs). Besides, both the deterministic and stochastic optimization methods have been utilized to solve the centralized VVO problems. In order to maximize the benefits of CVR and distributed energy storage (DES), a coordinated, centralized deterministic VVO methodology has been proposed, and the optimal solution has been obtained using the heuristic discrete gravitation search algorithm and particle swarm optimization.

Though the centralized approach works well for a fixed time horizon interval, but it might be inflexible for fast-response events such as PV intermittency. To resolve these issues, a time horizon-based model predictive VVO methodology along with a local controller has been introduced in the smart grid framework. Moreover, increasing penetration of flexible loads such as electrical vehicle (EV) in ADN is also one of the major concerns for DNO. Therefore, in this thesis, the impact of EV charging loads with different profiles have also been considered in stochastic VVO formulation under CVR scenarios. The noteworthy application of vehicle to grid (V2G) reactive power dispatch from EV charging station for voltage regulation has also been demonstrated.

Validation of the developed methods and models has been carried out in a real-time environment. To accomplish this, a real-time event-driven predictive framework has been proposed to validate the developed VVO methods. The proposed methodology adopts the aggregated and autonomous approach for the functioning of VVO devices actively in multi time scale operation. A communication free, autonomous droop control scheme for real-time local VVC has been developed.

To check the effectiveness of the developed control algorithms and framework, a real-time co-simulation platform using the real-time digital simulator (RTDS) in distribution mode through co-simulation with models based on Python and OpenDSS (Open Distribution System Simulator) has been built. Real-time validation demonstrates that the proposed VVO methodology works well in centralized as well as local domain and also capable of controlling the voltage fluctuations during a sudden change in network behaviour and occurrence of unpredictive events.

Further, case studies carried out reveal that the proposed VVO formulation fruitfully utilized the benefits of both CVR and DER technology. Besides, higher penetration of EV charging loads having the constant power characteristics behaviour influences the CVR operation. The reduced load demand through CVR algorithms directly reduces the power generation requirement from fossil fuel-based power plants. Hence, reductions in carbon emission could be achieved as value addition in terms of cost and carbon footprint reduction.