Abstract

In current scenario, the integration of renewable energy resources (RESs) especially, wind and PV generation, has been tremendously increasing due to the three key factors, namely environmental concerns, technological innovation and government new policies. However, the planning, operation and control of distribution systems are significantly becoming a challenge to accommodate the large number of installation and penetration of intermittent RESs. Typically, the intermittent RESs have impact on voltage constraints, network efficiency, voltage stability, and congestion. However, flexible sources (e.g. battery energy storage, dispatchable generation and flexible demands) alleviate the impacts of the intermittent and variable production of RESs. Recently, the updated IEEE 1547 − 2018 standard stated that all inverter-interfaced distributed energy resources (DER) to be equipped with smart inverter functions (e.g. volt−var mode, volt−watt mode, voltage ride through, etc.). Thereby, smart inverter can provide effective solutions to alleviate the *operational challenges* of connecting the large number of intermittent RESs. However, the abnormal proliferation of RESs in terms of installations number, types, locations, capacity and connection time can impose the *planning challenges* to the utilities. Typically, utilities have maintained the network performance (e.g., voltage profile, network losses, maximum voltage rise and voltage drop limits, system reliability) over the use of utility-owned voltage control devices, such as on-load tap changing transformers (OLTC), voltage regulators (VRs), reactive power compensators (RPCs), remoted controlled switches (RCSs) and capacitor banks (CBs). However, abnormal and high proliferation of RESs in the network can impact the effectiveness of the existing devices. Thus, the conventional planning and operation decisions are needed to updated with advanced devices such that they are flexibly adaptable to any diverse proliferation of RESs in the distribution networks. Although, active network management schemes such as distribution network reconfiguration (DNR) and volt-VAR control (VVC) techniques have been employed for improving network per-

formance and enhance the system reliability. Nevertheless, these techniques have been implemented separately. Moreover, conventional VVC operation has been performed by traditional voltage control devices, which could not handle the sharp voltage violations caused by the intermittent nature of RESs. Further, frequent operation of these devices deteriorates their lifetime. Hence, there is a need of fast acting voltage regulation devices (e.g. smart inverter) along with traditional VVC devices to encounter these issues. However, without proper coordination of these devices may cause a detrimental impact on distribution operations and network assets. Therefore, the proper planning and operation of DERs in conjunction with advanced distribution management schemes are required for improving the distribution network performance and accommodation of high RESs penetration.

In this thesis, an integrated approach has been proposed for performance enhancement of distribution network and accommodation of high RESs penetration. Under this approach the following five aspects have been accomplished: 1) developed a new methodology for combined operation of distribution network reconfiguration (DNR) and volt-var control (VVC) devices in the presence of DERs. 2) developed a time series model of coordinated VVC scheme considering DNR and soft open point operations. 3) developed a hierarchical coordinated volt-VAR optimization (VVO) methodology for conflict objectives. 4) developed the real time hierarchical coordinated voltage control of smart inverters for active distribution network with high PV penetration. 5) developed two-layer coordinated optimization framework for planning and operation of DERs.

The first part presents an efficient and optimal approach for combined operation of DNR and VVC techniques. To achieve the optimal solution, modified binary grey wolf optimization (MBGWO) algorithm has been proposed. In the proposed approach, a centralised as well as local control schemes have been employed for optimal operation of distribution network such that no system constraints are violated. Centralized control scheme provides the optimal set points for field devices in regular intervals based on measurements fed back through advanced metering infrastructure (AMI) and control sensors through communication infrastructures. However, local control scheme action executed based on local measurements or the criterion adopted by the local operator. Besides, proposed method has been employed for service restoration considering voltage regulation and peak demand reduction under faulty condition. For validation, the performance of the proposed algorithm has been tested on balanced as well as unbalanced distribution systems.

The second part presents a time series model of coordinated VVC scheme to minimize the energy demand including operating cost in distribution system considering DNR. Besides, soft open point (SOP) a flexible power electronic device has been introduced in the VVC scheme. Instead of simply opening/closing normally-open points, SOP devices are capable to control load transfer and optimize network voltage profile by providing fast, dynamic and continuous real/ reactive power flow control between feeders. Furthermore, technical-economical-environmental benefits of proposed coordinated scheme has been presented. Validation of proposed coordinated scheme has been carried out on well-known 69 bus distribution system.

The third part introduces a hierarchical coordinated multi objective optimization model for the effective operation of ADN in presence of high penetrated photovoltaic based DER. The proposed model determines the optimal network configuration that achieves two objectives: 1) Minimizing the total operating cost and 2) Minimizing the total voltage deviation. In this methodology, the $\varepsilon-$constraint method has been employed to obtain set of non-inferior solutions and fuzzy decision-making method to determine the best compromise solution among the set of non-inferior solutions. Besides, the significance of battery energy storage (BES) on total operating cost and voltage deviation has also been presented.

The fourth part introduces real-time validation of hierarchical coordinated voltage control for active distribution network with high PV penetration. Besides, the impact of advanced flexible power electronic devices such as PV smart inverter and soft open point (SOP) on energy consumption and losses have been presented. The proposed methodology has been implemented on modied 33 bus distribution system. The test results demonstrate the signicant impact of the proposed integrated operation on voltage violation, energy losses and energy consumption. Furthermore, real-time co-simulation platform for operation and control of DER in the distribution system using MATLAB and Real Time Digital Simulator (RTDS) have been developed and tested.

The fifth part presents a new two-layer coordinated optimization framework for planning and operation of DERs and soft open point (SOP) in active distribution network (ADN). It consists of outer and inner layer optimization model, where the outer and inner layer corresponding to the decision-making in the planning and operation levels respectively. The outer-layer performs the planning of DER and SOP devices. In outer layer, decision variables are the locations and capacities of DER and SOP to be installed. For coordination purpose, all the candidate planning proposals will then be transferred to the inner layer, where optimal scheduling of DER, SOP and VVC devices over a day have been performed considering uncertainties of solar irradiance, wind speed and loads. Meanwhile, the feasibility of outer layer decisions has also been checked in these simulations, where the technically infeasible solutions are recognized and discarded. After this step, the posted scheduling of DERs, SOPs and VVC devices have been fed back to revise previous planning scheme in the upper layer. With on-going simulations, these procedures would finally arrive at the optimal solution. In order to solve the planning and operation of DERs in distribution system, a co-simulation platform has been developed using MATLAB and General Algebraic Modeling System (GAMS) tools. Besides, an integrated long-term planning model for DER has been presented that addresses the economic, operational, and environmental issues of DER. Furthermore, combined impact of DNR and VVC techniques in conjunction with smart inverter and SOPs on DERs planning has been presented.