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VOLTAGE CONTROL ISSUES IN SMART GRID-A RECENT PERSPECTIVE

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ABSTRACT

With the growing power demand and increasing use of renewable energy sources, the traditional power grid network also is evolving into an interactive and intelligent grid network and leading to the emergence of the concept of Smart Grid. Conceptually, a Smart Grid network can be considered to be consisting of smart infrastructure, smart monitoring and protection system and smart control and management system to meet the power demand as well as reduce the energy consumption and costs. However, there are many associated issues like Voltage Control, Frequency control, Harmonic distortion control, Power quality control, Reactive power compensation control, Synchronization control, System stability and reliability control, Energy storage, Seamless transfer between grid connected mode and islanded model, Balance between supply and demand, Micro source issues, Communication among microgrid components with the smart grids out of which voltage control is the significant control issue. This paper reviews various methodologies and strategies for voltage control in Smart Grids and presents their classifications into different categories based on the literature survey. In this review, many strategies for voltage control in smart grids have been explored such as Based on Intelligent Control, Energy Storage, Control Strategy, Droop Control Methods, Communication Techniques, Decentralized Schemes, and Algorithm/Architecture. The novelty of this survey is in the classification, volume of information provided, and outlining of *future* research for voltage control in smart grids.

INTRODUCTION

Traditionally, the electric grid is an electrical system comprising electricity generation, transmission, distribution, consumption and control. The conventional power grids have been in existence since decades and are generally used to carry power from a few central generators to the customer premises. But due to environmental concern and depleting conventional resources of energy, there is lot of focus on the use of renewable energy sources (RES) for the electricity generation and utilization. The conventional power grid is not always amenable to incorporate these changes and therefore, the concept of Smart Grid has emerged [1]. It is expected that in near future, a large number of distributed generation (DG) units consisting primarily of the RES will be connected directly at the local distribution networks, in the framework of Smart Grid to reduce the transmission cost and to best exploit renewable energy sources The term "Smart Grid" can conceptually be considered to represent the integration of all generation, grid, and demand side connected to a digital information infrastructure which can provide two-way communications to offer numerous advantages for both the power producers and consumers. The Smart Grid utilizes intelligent devices and a digital communication upgraded power system to enhance the performance of transmission and distribution grids. It has a large monitoring capacity with data integration, advanced analysis to support system control, enhanced power security and effective communication to meet the power demand as well as reduce energy consumption and costs [2]. There are many challenges, however, associated with Smart Grid. Voltage control is one of the significant control issues, which has drawn the attention of the researchers in the recent years and lot of work has been reported in literature and is being pursued as an active research area. The focus of this paper is to present a comprehensive literature review on the voltage control issue in Smart Grid based on the work reported in literature so far. The review is presented under different categories, probably not presented so far. This review paper systematically classifies the works for the voltage control and provides volume of information on the available literature. This review is structured under seven categories based on the control concepts used, energy storage devices used, communication, decentralized schemes, and algorithms and architectures.

CONCEPT OF SMART GRID

The conventional power system grid has been in existence and use for decades, whereas, the concept of Smart Grid is a recent phenomenon which can be considered as a power network comprising electric power supply, grid, and demand side elements integrated with intelligent devices and two-way communications infrastructure to enhance the performance of grids. Smart Grid offers the flexibility of real time continuous assessment of its condition and provides the capability of self healing in the event of a fault, adapts to the system changes, controls distributed generation integration

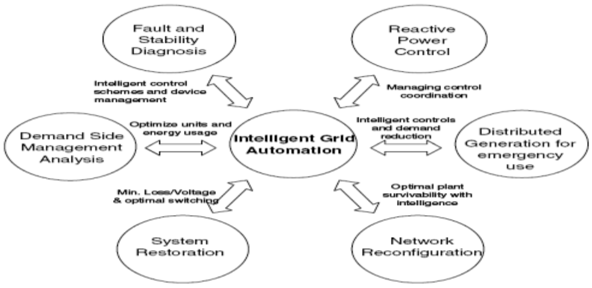

Fig.1. Function of Smart Grid

and exercises demand side management through optimizing the performance of smart appliances of end users. The important intelligent functions of Smart Grid are as shown in Fig. 1 [3].

OVERVIEW OF VOLTAGE CONTROL SCHEMES

Voltage control in Smart Grid is one of the most important considerations for both the power producers and end users to maintain stability, security and reliability of the system. In order to perform voltage control efficiently and smartly in the Smart Grid, a large number of various types of Power Electronics devices and methodologies have been used utilizing different control concepts [4]. Due to the complexity involved and bidirectional power flows, there is the need of improved control strategies in Smart Grids. Lot of information flowing from within the system is required to effectively support the voltage control thereby, making the use of Smart meters mandatory which have got the capability to provide real-time voltage measurement and communication between the consumers and grid network controllers. The real time grid network condition is monitored, measured, reported and analyzed and accordingly control signals are sent to various voltage control devices to exercise voltage control across the entire network. Therefore, a more flexible and well coordinated voltage control is performed in a Smart Grid with an aim to provide good quality power to the consumers.

Various control schemes have been proposed by the researchers in the recent past for voltage control in Smart Grids. These schemes can be differentiated based on control concept, energy storage devices, communication methods, architecture and algorithms etc. This paper presents in the following subsections the comprehensive review of these schemes for voltage control in Smart Grids under different categories.

A. Based on Intelligent Control

Due to lot of ill conditioning and convergence difficulties associated with mathematical optimization techniques, artificial intelligent systems are used as alternatives to improve the power system capability [5]. For enhancement of grid voltage profile and to reduce the power losses, bus variables and main variables are amalgamated with the help of Timed Automata Based Fuzzy Controller to identify proper control action for voltage regulation [6]. Fuzzy Logic Controllers are designed for improvement in voltage profile of distribution network which depends on the network parameters and load characteristics [7]. A Fuzzy based Multi-Agent Control Scheme is proposed to convert (on-load tap changer) LTC agent, (distributed generation) DG agent and Load agent into fuzzy system and find out voltage regulation directly related with load variations [8]. A decentralized and non-hierarchal fuzzy-based solution algorithm is processed for improvement in the bus voltage magnitude with the proper control action identification [9]. A new intelligent control scheme based on the learning control in which power system stability and controlled performances are improved at same time is proposed in [10]. In [11], a fuzzy logic based generalized droop control (GDC) is proposed for simultaneous frequency and voltage regulation in an islanded microgrid (MG). Here, the fuzzy approach is used to improve the coefficients of the PI controllers.

B. Based on Energy Storage

A control strategy proposed in [12] makes a connection of hybrid DG system to main grid under voltage disturbance conditions and also shows DG helping extent that depends on DG capacity and Grid capacity for voltage regulation of main grid. With the help of MPPT algorithm and dc-dc boost converter, photovoltaic systems voltage level is maintained within technical limits and system efficiency is reduced as illustrated in [13]. Both Electrical energy storage (EES) systems and demand side response (DSR) operated in collaboration to overcome the voltage drop problem in the distribution networks [14]. A photovoltaic (PV) based optimized operating scheme is proposed to effectively control the active and reactive power of system, and feeder size, battery size, market economics and geographical conditions play an important role in voltage regulation as reported in [15]. Pricing and constraints of (plug-in electric vehicles) PEV's further divides into day-ahead command-based and day-ahead price based, and also its limited amount of active and reactive power is used for voltage and frequency regulation [16]. For effective sizing of distributed battery energy storage system (BESS) in the distribution networks under high photovoltaic (PV) penetration level a strategy is proposed in [17] when the distributed BESS is applied for voltage regulation and peak load shaving. This paper has proposed a new method to discover a cost-benefit BESS size when distributed BESS is integrated into the distribution system under high PV penetration. In [18] an approach is proposed for coordinated and integrated control of solar PV generators with the maximum power point tracking (MPPT) control and battery storage control to provide voltage and frequency (V-f) support to an islanded microgrid. In the present methods, the control parameters are dependent upon the PV, battery, and external grid conditions and must be re-tuned with the changing conditions. Two coordinated voltage control algorithms suitable for usage in distribution networks including several distributed energy resources are proposed and studied [19]. The first algorithm uses control rules to determine its control actions and the second algorithm utilizes optimization.

C. Based on Control Strategy

A microgrid system consisting of PV, wind turbine, fuel cell and battery is established and a control scheme to regulate frequency and voltage of microgrid system operating in islanded mode is proposed. The control strategy introducing the voltage and current feed forward of load reduces the influences on the voltage and frequency disturbed by load and develops the regulating speed of battery [20]. An improved voltage automatic coordination control strategy (VACCS) based on double-layer coordination control is proposed in [21] to overcome voltage disturbance and significantly improve the sensitivity to voltage fluctuation and extends the battery life. As illustrated in the paper, the AC voltage deviations can be controlled within [-5%, 5%] of the rated voltage and the life expectancy of battery is extended by reducing the charge/discharge depth. In [22], a control scheme is proposed for voltage balancing in an islanded microgrid system, in which negative-sequence component of the voltage is controlled at zero using a time-domain based0 controller. Whereas, in [23] a novel and effective approach has been proposed for selective compensation of PCC voltage main harmonics in a grid-connected microgrid system. Harmonic compensation is achieved through proper control of DGs interface converters. Authors in [24] suggested that the EES integrated coordinated voltage control scheme is capable to provide cost-optimized voltage control solutions for the distribution networks with highly clustered distributions of load and generation LCTs and can solve steady-state voltage excursions and %VUF excursions, which are occurring concurrently at two MV nodes and a LV node in the case study network. In [25], a controller is developed for controlling appliances based on local measurements of voltage that contributes to stabilizing voltage levels and, in LV distribution systems increases the load factor. The so designed controller seems to be effective at reducing the extremes of voltage and increasing the load factor while respecting end-use temperature constraints. The authors in [26] introduce several local voltage control strategies using PV storage systems. These strategies focus on adding a voltage control capability to self-consumption strategies through a combination of voltage dependent battery charging, automatic reactive power provision as well as PV power curtailment. In [27], a novel device for the implementation of dynamic load response, which is known as the electric springs (ES), has been developed for mitigating both active and reactive power imbalances at the microgrid level. The proposed control strategy can realize the active power and reactive power control of ES by adjusting the shift angle and the amplitude of the modulation signal. In [28], a voltage-based droop control is presented for controlling the loads and distributed generation (DG) units in an islanded microgrid and the storage elements in islanded microgrids. This paper demonstrates that by using the terminal voltage for the primary control a proper cooperation of the different grid assets in the microgrid control with a similar control strategy and without inter-unit communication is possible. In [29], an adaptive sliding-mode controller (ASMC) is presented to enhance disturbance-rejection performance of control system of islanded parallel inverters and presents a nonlinear voltage controller for parallel inverters operating in islanded microgrid. This scheme is capable in eliminating the reaching phase of motion state of control system of inverter and makes the control system attain global robustness by designing adaptive algorithm to observe filter parameters. In [30], a new coordinated voltage control (CVC) method is presented with reactive power management scheme (RPMS) for a hybrid micro-grid (MG). As per the authors, the CVC associated with RPMS demonstrates superior performance to regulate MG voltage by controlling the reactive power among DERs, OLTC, and Cap banks for grid connected and islanded mode of operation.

D. Based on Droop Control

In a microgrid consisting of multiple DGs, the power sharing among different DGs is made properly with the help of a control strategy called droop control [31]. The droop control regulates the real power on the basis of frequency droop control and it controls the reactive power on the basis of voltage control [32]. A hierarchical control scheme is described for microgrid operating in islanding mode with the architecture consisting of DG's local controllers (primary level), three-phase voltages, PCC terminal, and a central secondary controller [33]. In [34], a hierarchical control scheme is proposed for enhancement of sensitive load bus (SLB) voltage quality in microgrids. The control structure consists of primary and secondary levels. A Droop Control Method is presented in [35] to compensate the DG's from power excursions and protect the DGs from overload. A quadratic design paradigm to examine reactive power demand among distributed generated units is proposed in [36]. Whereas, in [37], a unified compensation framework is proposed using the common load condition in local controller to compensate the voltage Drop and load sharing errors in which voltage deviation is compensated with a P controller while the load sharing is compensated through a PI controller. A three-phase damping VBD (voltage based droop) control method presented in [38]mitigates unbalance, allows the DG units to share the unbalanced currents, and is able to operate both in grid-connected and islanded modes of operation of the systems.

E.Based on Communication

A Distributed scheduling algorithm is proposed in [39] based on wireless communication for scheduling of the sensors where wireless communication is used for information transmission to voltage sensors. Scheduling of these sensors can significantly reduce the cost due to voltage deviation. The sample-contention scheme to provide communication resource efficient service for voltage state reporting in smart grid using WiMAX is reported in [40]. In this paper, optimal power flow (OPF) model is also formulated to find out the tap position of the OLTC and minimize the distribution losses by coordinating the on load-tap changer (OLTC) and the capacitor banks. or banks. The proposed method in [41] is the extension of a demand-response control mechanism based on low bit-rate broadcast signals and is able to compensate voltage sags associated to the inrush of large loads.

F. Based on Decentralized Schemes

In this methodology Grid frequency and voltage fluctuations are suppressed by controllable loads and power fluctuations are also suppressed by active and reactive power control of controllable loads that also allow wind turbine generator and photovoltaic generation operate to the maximum power point as reported in [42]. Decentralized voltage control algorithm is proposed in [43] based on cost function which works efficiently without knowledge of operating conditions and grid structure. The authors in [44] proposed a decentralized non-hierarchal Intelligent and co-operative voltage regulation architecture in which smart controller is used to detect voltage value at the monitored buses and also shows that grid performance depends upon computed information from nearby node. A methodology is presented to achieve suppression of frequency deviation and voltage fluctuation by using distributed controllable loads such as heat pump and electric vehicles in [45]. As reported in [46], a hierarchical distributed voltage control structure can be applied to facilitate the autonomous integrated Volt-Var control in distribution networks with DG integration, in which Local controllable zones LCZ) are used to determine the voltage control boundaries and also LCZs can be adapted to handle the changes of network conditions. A decentralized control scheme is presented in [47] wherein the voltage and frequency control is exercised at a very fast rate on timescale and in such cases renewable sources (commonly equipped with storage devices) can be modeled as constant voltage generators. Whereas, in [48], a distributed AVS (average voltage sharing) scheme is presented to maintain the terminal voltage at the nominal value and secure the uniform current sharing irrespective of the variations in the loading conditions.

G. Based on Algorithm/Architecture

A PSO based algorithm is proposed to stabilize the voltage of a hybrid ac/dc microgrid from stability point view [49]. In [50], a voltage sensitivity approach is used for improvement of voltage profile in Smart grid to find out effective locations for reactive power injection by VAR compensation. Another voltage regulation method based on sensitivity theory to control the node voltage, regulating the reactive power injected by the generators with the help sensitivity table is proposed in [51] which is capable of overcoming voltage unbalance condition. In [52], an optimal power control strategy has been proposed for an inverter based DG unit with an aim to improve the quality of the power supply by using PSO algorithm incorporated into the Vf control mode to implement a real-time self-tuning method in order to regulate the microgrid voltage and frequency, especially when the microgrid transits to the islanding operation mode.

CONCLUSION

This paper presents a recent perspective on the voltage control issues in Smart Grids. Due attention has been paid to recent developments such as use of intelligent control schemes based on the concept of Fuzzy logic and other evolutionary algorithms. Emphasis has been given to categorizing various voltage control schemes reported in the literature for smart grids that highlights their salient features. Although the authors have sincerely attempted to present the most recent set of references on voltage control issues, however, since the literature on smart grid is voluminous, it might have been possible that some papers are not included in this review paper, Authors would like to apologize for exclusion of many valuable papers on voltage control issues of smart grids. It is envisaged that this paper will serve as a valuable resource to any further worker in this emerging area of research.

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