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Review of control strategies for voltage regulation of the smart distribution network with high penetration of renewable distributed generation

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ABSTRACT

Integration of renewable energy sources (RES) into traditional power system is one of the most viable technologies to meet the ever increasing energy demand efficiently. But, this technology arises a lot of challenges which are necessary to be taken care of for smooth operation of the network. Voltage regulation is the most significant technical challenge that tends to limit the amount of penetration of renewable distribution generators (DGs) into the distribution network. This paper attempts to present a detailed review of the control strategies that are being utilized to mitigate voltage regulation challenges when increased amount of renewable DGs are connected within the distribution network. This study analyses the direct impacts of increased accommodation of renewable DGs on the distribution network operation and evaluates current research status of voltage control strategies. Then qualitative analysis is performed for all kinds of voltage control approaches involving their pros and cons for the first time. The objective of this contribution is to present the latest research status of distribution system voltage control strategies with highly penetrated renewable DGs and a brief review of different control methodologies.

Contents

1. Introduction

The incorporation of RES in electric power system is being popular day by day. Previously, it was mostly off grid connection. But nowadays, grid connected RES are coming into trend. Integration of

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Nomenclature

RES	Renewable energy sources
DG	Distribution generators
PV	Photovoltaic
DNO	Distribution network operators
PSS/E	Power System Simulator for Engineering
DN	Distribution network
OLTC	On-load tap changer
DSSE	Distribution system state estimation
SC	Switched capacitor
SVR	Step voltage regulator
ANM	Active network management
SCADA	Supervisory control and data acquisition
STATCOM	Static synchronous compensator
FACTs	Flexible AC Transmission System
CBA	Cost benefit analysis

RES into power distribution system was not any serious issue a few years ago as the amount of penetration wasn't that much significant. But currently, a large amount of renewable energy sources are being connected which are posing a lot of impacts on the operation and protection of the distribution network [1–3].

The characteristics of the power distribution network are different from power transmission network in several ways. They are as follows [4]:

- It works in radial topology.
- There can be significant unbalance.
- The R/X ratio of the distribution network is relatively higher than the transmission network.

For the planning and stable operation of smart distribution infrastructure, it is necessary to analyse the relation between the integration of renewable DGs and the distribution network's behavior [5]. As DGs are connected very near to customers, connecting them has significant effects on distribution network's technology, environment and economy as well as customers [6–8]. Integration of DGs in the distribution networks is not yet problem free. The traditional grids were designed to supply the electric power from generation side to customer's loads. According to this design, the electric power flow was supposed to be unidirectional (from higher to lower voltage level) through the whole system. But, when we integrate DGs in the distribution network, the excess power generated by DGs after meeting the customer's demand, flow back to the generation side. So, the power flow remains no longer unidirectional. It is rather bi-directional which has significant adverse effect on the operation, voltage regulation and protection of the power distribution network [6,9,10].

Several efforts have been made to review the stability issues, operations and control technologies of the power system when large-scale DGs are interconnected [11–15]. Refs. [11,12] have discussed about different control strategies and stability issues in a systematic structure but they mainly focused on micro grids. Refs. [13,14] have done extensive reviews on the power quality issues, reactive power management and voltage management where several control devices and methods have been discussed and relative comparisons of their performances have been presented. But, systematic classifications of voltage control structures according to respective functionalities have not been discussed. Ref. [15] investigates some low-voltage ride-through enhancement methods during voltage dips and inter-area oscillation damping techniques for wind and photovoltaic power plants. But, control schemes for real time voltage regulation during system operation was not widely discussed.

This paper mainly focuses on the voltage regulation challenges raised from increased renewable DG interconnection with low-voltage distribution networks and detailed review of voltage control strategies to mitigate its adverse impacts on voltage profile. Existing control methodologies have been classified into centralized, decentralized autonomous and decentralized coordinated control structures according to their respective functionalities. Then qualitative analysis is performed among these classes involving their advantages and disadvantages. This paper is organized as follows. Section 2 describes the challenges that arise due to increased DG accommodation. Section 3 details the impacts of large-scale DG connection on the voltage profile of the network. Section 4 analyses several traditional and advanced voltage control methods and different control structures depending on their functionalities. Section 5 establishes the conclusion derived from the work.

2. Challenges of increased penetration of DGs in distribution network

The challenges that occur due to increased penetration of DGs in distribution networks can be classified into three categories [3].

1) Technical challenges.
2) Commercial challenges.
3) Regulatory challenges.

These challenges are going to be discussed in brief.

2.1. Technical challenges

2.1.1. Power quality

Depending on the particular circumstance, connecting DGs within the distribution network can either deteriorate or improve power quality [16–18]. DGs are connected closer to the loads and most of the loads are supplied by DGs in case of higher penetration. As a result, lesser amount of power is drawn from the distribution substation. So, the amount of current flow from the distribution substation to the consumer's loads through the feeder and its laterals is reduced. So does the power loss through the feeder [16]. But, there are other two important aspects of power quality. They are:

- Transient voltage variation.
- Harmonic distortion of the network voltage.

Single large DGs may cause power quality problems in a weak distribution network particularly during starting and stopping.

2.1.2. Protection

The protection of the distribution network due to integration of DGs is affected in several ways [19].

- Changes in the traditional distribution network short circuit power.
- Changes in fault current level.
- Changes in the characteristics of the fault current, such as amplitude, direction and distribution.