Ain Shams University
Faculty of Engineering
Electrical Power & Machines Department

Voltage Regulation of Active Distribution Networks

By

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A Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science in Electrical Engineering

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STATEMENT

This Thesis is submitted to Ain Shams University in partial fulfillment of the requirements for M.Sc. degree in Electrical Engineering.

The included work in this thesis has been carried out by the author at the department of electrical power and machines, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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ABSTRACT

The amount of non-centralized generation connected to distribution networks nowadays is still increasing. The structure and control methods of existing distribution networks are planned and operated assuming unidirectional power flows. Distributed generation (DG) affects power flows in the distribution networks and its effect on their operation can be positive or negative depending on the size, location and time variation of the generator. Anyways, DGs force the operational and planning principles of distribution networks to be changed radically. The voltage rise is usually the factor that limits the hosting capacity of the networks for DG. At the meantime, this rise is often handled by passive means such as increasing the conductor size or connecting the generator to a specially constructed feeder. These passive means keep the traditional principles of the operation of networks but leads to high connection costs of DGs and do not sufficiently increase their hosting capacity.

Modern means referred as active voltage control methods change the network operational principles radically but leads to significantly smaller total costs of the distribution network and higher hosting capacity for DG than the passive approach. These methods can utilize active resources such as DGs in their control in addition to the existing voltage control equipment such as the main transformer tap changer. However, the implementations of active control approach in real distribution networks are still very low and the distribution network operators (DNOs) do not consider that approach as a real option in planning. Hence, much work is still required to enable the widespread utilization of active voltage control.

This thesis aims at overcoming some of the existing challenges of applying active voltage control strategies in real distribution networks. In this thesis, a previously published active voltage control algorithm is developed in order to

achieve economically optimized results. Moreover, the developed algorithm is tested using real time simulations through Hardware-In-The-Loop (HIL) technique of simulation tests to verify the reliability of its dynamics. The software utilized is MATLAB Simulink while the hardware component is an ATmega2560 microcontroller included as a built-in component in an Arduino Mega 2560 board.

This thesis addresses an unhandled problem resulted from the failure of communication with the DGs in case of coordinated active voltage control methods. An alternative algorithm is proposed to be applied in these emergent cases to avoid the full disconnection of the generator. This achievement makes the implementation of coordinated active control methods more reliable and applicable for the real world.

The target of this thesis is to provide additional support to the DNOs for the implementation of active voltage control methods and make this issue as easy as possible. All the developed and proposed algorithms in this thesis can be implemented as a part of the existing distribution management systems (DMS) and utilize the already existing data transfer infrastructure of SCADA.

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LIST OF ABBREVIATIONS

AMR	Automatic meter reading
AVC	Automatic voltage control
AVR	Automatic voltage regulator
DB	Dead band
DC	Direct current
DG	Distributed generation
DER	Distributed energy resource
DMS	Distribution management system
DNO	Distribution network operator
EU	European Union
HIL	Hardware-in-the-loop
HV	High voltage
I/O	Input/output
IT	Information technology
LV	Low voltage
MPPT	Maximum power point tracking
MV	Medium voltage
NIS	Network information system
OLTC	On-load tap changer
p.u	Per unit
PV	Photovoltaic
RMS	Root mean square
RTD	Real-time data
SCADA	Supervisory Control and Data Acquisition
THD	Total harmonic distortion
TSO	Transmission system operator
UART	Universal Asynchronous Receiver/Transmitter

1 INTRODUCTION

Over the last century, many large centralized power plants are used to produce electricity. The locations and capacities of these plants are planned in coordination with the whole traditional power system. The electricity is then transferred to the loads locations through the transmission network and several distribution networks. The transmission network is used to connect the whole country including the locations of generation of electricity and those of loads. The transmission and distribution networks are planned in previous and operated by means of many studies such as power flow studies, geographical studies, etc. The traditional concept of planning and operation of the medium and low voltages distribution networks is based on the assumption that the flow of power is unidirectional in a downstream way from the substation to the nearby loads and that all components connected at various buses of the distribution networks are passive. The passive control of components means that their operation of supplying or consuming power is not determined based on the network state.

One of the tremendous and effective trends nowadays in modern power systems is the transition from centralized power plants towards the high penetration of non-centralized distributed generation (DG), mostly connected at the terminals of the medium and low voltages distribution networks. There are substantially increasing investments put in the field of DGs, especially the renewable sources because of environmental and political aspects and the need of security of supply. Most countries incentivize these investments. For example, the governments of the European Union (EU) were working their best to meet a resounding target declared by EU that the renewable resources share by 20 % of the total energy produced in EU by 2020 [1]. Many other countries have applied feed-in tariffs for the purpose of production of renewable energy too resulting in a continuous increase of DG. In addition, other distributed energy resources