Cairo University

# VOLTAGE STABILITY ENHANCEMENT OF RADIAL DISTRIBUTION NETWORKS

**By**

**Galal Fathy Abdelaal Ahmed**

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Electrical Power and Machines Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
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Under the supervision of


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FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis : **Voltage Stability Enhancement of Radial Distribution Networks**

Key Words : Voltage stability enhancement, radial distribution networks, distributed generator, voltage dependent load models, daily load curves.

Summary :

Voltage instability problem arises due to the ever increasing load demand which pushing the networks to their stability boundaries and increases the risk of partial blackouts. Therefore, there is a need to assess the voltage stability of the system in order to know of how close the operating point is from the voltage stability limit. When the system is close to voltage instability, actions are required to relieve the situation and mitigate the problem. Distributed generation (DG) and capacitor placement are introduced as vital solutions to maintain the voltage stability in the distribution networks.

The main core of this thesis to obtain the optimal allocation of DG and capacitor which enhance the voltage stability of the network also to capture the real performance of loads in the network the realistic behavior of load demand and how the optimal allocation of DG is affected by that behavior has also investigated.

# AUTHOR'S DECLARATION

This thesis is submitted to Cairo University in partial fulfillment of the requirement for the Master of Science degree in Electrical Engineering. No Part of this thesis has been submitted for a degree or a qualification at other university or institute. Finally, I understand that my thesis may be made electronically available to the public.

| | |
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# List of Abbreviation

| | |
|---|---|
| ABC | Artificial Bee Colony |
| BIBC | Bus Injection to Branch Current |
| BCBV | Branch Current to Bus Voltage |
| CP | Constant Power |
| CZ | Constant Impedance |
| CI | Constant Current |
| CS | Cuckoo Search |
| CPF | Continues Power Flow |
| DG | Distributed Generation |
| FA | Firefly Algorithm |
| GSS | Golden Section Search |
| GA | Genetic Algorithm |
| IEEE | Institute of Electrical and Electronics Engineers |
| KCL | Kirchhoff's Current Law |
| MCDGC | Multiple Combined DG-Capacitor |
| PSO | Particle Swarm Optimization |
| P-VSI | Active Power Voltage Stability Index |
| PLR | Power Losses Reduction |
| Q-VSI | Reactive Power Voltage Stability Index |
| VSI | Voltage Stability Index |
| VSM | Voltage Stability Margin |

# ABSTRACT

Voltage instability problem arises due to the ever increasing load demand which pushes the power systems to their stability boundaries and increases the risk of wide spread of partial blackouts. Therefore, there is a need to assess the voltage stability of the system in order to know how close the actual system's operating point is from the voltage stability limit. When the system is close to voltage instability, actions are required to relieve the situation and mitigate the problem.

The main core of this thesis is based initially on finding a method to define voltage stability boundaries of the network. Accordingly, presents the solutions to improve voltage stability in distribution networks based on different objective functions.

The target of this thesis is to investigate, analyze and enhance the voltage stability of radial distribution systems based on the following main tasks; load flow analysis for computing the bus voltage and line loss, voltage stability analysis to evaluate the voltage stability index ($VSI$) for each bus of the system, and voltage stability enhancement to mitigate voltage instability problem by applying the proposed solutions.

In this research to overcoming the aforementioned problem, distributed generation (DG) and capacitor placement are introduced as vital solutions in order to maintain the voltage stability in the distribution systems. However, installation of DG or capacitor non-optimally may result in an increasing in system losses, voltage instability problems, etc., so DG or capacitor size and location are selected optimally.

Voltage stability enhancement in this thesis is formulated via objective function of either total active losses minimization or maximization of stability indicator. In order to check the validity of the optimal allocation results, different optimization techniques have been proposed to solve the optimization problem.

Since constant power load models are not accurate enough for capturing the real performance of load in the network. Therefore the realistic behavior of load demand and how the optimal location and size of DG and other optimized results are affected by that behavior has also investigated. The proposed strategy utilizes the voltage dependent load models combined with the daily load curves of different load pattern to identify accurate realistic results about the DG planning and performance of the network after integration of DG unit. According to that, effect of the realistic behavior of load on the DG optimal allocation and other subsequent results has been found. Then this new strategy is compared with a DG allocation obtained from the conventional study.

To demonstrate the validity of the proposed solutions and techniques, computer simulations are carried out on *IEEE* 33 bus radial distribution network and the simulation results are presented and discussed. All the required software is developed using MATLAB script-files as a platform.

# Chapter 1: Introduction

*The introduction chapter is dedicated to introduce the research topic in a generic way. This chapter gives an overview about the problem that have been dealt with, the purposes from the research, highlights of the thesis work, and -finally- the thesis outline.*

## 1.1 Overview

Distribution network is the last segment of the overall power system that links the bulk power system to the consumer service points. It is usually designed as a radial structure where a single source of power is supplying a network of downstream feeders. Figure 1.1 shows a simplified example of a small radial feeder.

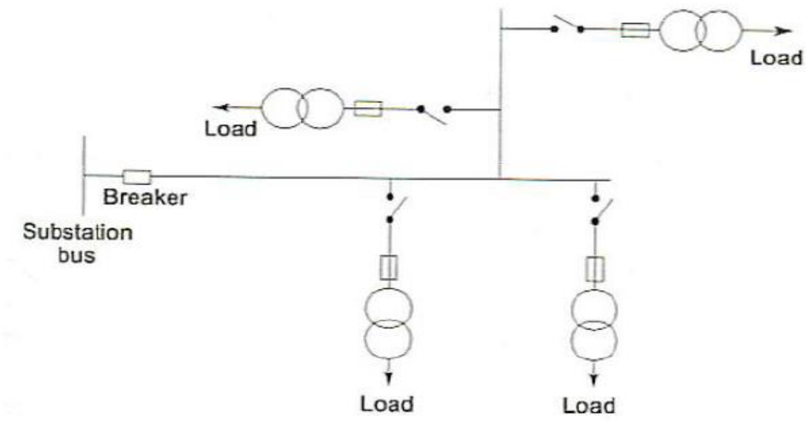


**Figure 1.1: A simplified radial distribution system**

Distribution system is clearly different from transmission system in its operation and characteristics. The distribution system is usually characterized by being radial in nature with high resistance to reactance $(r/x)$ ratio of distribution cables, extremely large number of branches and buses and unbalanced distributed load.

As the distribution networks become more complex and due to progressive increase in load demands, voltage stability problems also become more severe. Not only the sharp and continuous increase in load demand, but also the aging of the existing distribution networks is a factor which increases the risk of voltage instability scenarios. This in turn increases the possibility of contingencies that stress even more an already congested networks. Consequently, always electric distribution networks need to be upgraded in order to maintain the system operation of the network in safe and secure manner.

Basically, voltage stability is defined as the ability of a power system to maintain steady-state voltage at all buses in the system after being subjected to a disturbance from a given initial operating condition [1]. Operating the system to the point where voltage stability problems are a concern requires to carefully monitor the operating conditions in order to evaluate how far the system is from the voltage stability limits, how it will react in case of a contingency, and how much more load can be supplied without going to unsafe conditions. Thus, the distribution networks need to be developed to avoid compromising the quality of life of people and cause operation disruptions.

## 1.2 Problem Statement

By increasing the load demand, the drawn current by the load increases and as a result of that the line losses increase, which causes greater voltage drop at these lines and consequently low voltage profile at all buses of distribution network. This sequence of events leading to declining voltages and blackout and this catastrophic result called voltage collapse. The system becomes prone to voltage instability, when a disturbance causes a progressive and uncontrollable decline in voltage.

## 1.3 Research Objectives

The main trend in this thesis is directed to present the following points:

- Discuss the voltage stability problem in distribution networks and present a literature survey about the available solutions techniques.
- Study and construct an overall view of voltage stability in radial distribution network.
- Presents the proposed solutions to mitigate voltage instability problem based on different objective functions.
- Show the effects of voltage stability enhancement on the system performance.
- Study the effect of realistic load behavior on voltage stability analysis and DG optimal size and location.

## 1.4 Scope of Work

Prepare a comprehensive study about the voltage stability analysis in radial distribution networks to identify the most sensitive bus to voltage collapse and how far away from the instability area.

Suggest a solution techniques to improve voltage stability of the network based on different objective functions. With the help of proposed techniques for mitigate voltage instability the optimal size and location of distributed generation (DG) or capacitor are obtained.

Studying the effect of voltage dependency load modeling combined with daily load curves of different load pattern on the optimal allocation of DG unit and other following