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Review

A review of power distribution planning in the modern power systems era: Models, methods and future research

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ABSTRACT

In recent years, significant research efforts have been devoted to the optimal design of modern power distribution systems. The aim of power distribution planning (PDP) is to design the distribution system such as to timely meet the demand growth in the most economical, reliable, and safe manner possible. The gradual transformation of the distribution grid from passive to active imposes the need to also consider the effect of distributed generation and active demand during planning and the increased advantages of their control. Several models and methods have been proposed recently for the solution of the modern PDP problem. This paper presents an overview of the state of the art models and methods applied to the modern PDP problem, analyzing and classifying current and future research trends in this field.

Contents

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1. Introduction

The designer of the power distribution system, in the context of power distribution planning (PDP), has as a primary goal to design the distribution system such as to timely meet the demand growth in the most economical, reliable, and safe way. This is not straightforward, because of the very large extension of the power distribution system, as well as the fact that this system is responsible for most of the electrical energy losses and most of the interruptions due to faults. In general, the traditional PDP consists of finding the most economical solution (single objective function) with the optimal location and size (capacity) of future substations and/or feeders to meet the future demand. The objective of the traditional PDP is the minimization of an economic cost function (the investment cost to add, reinforce or replace substations and/or feeders, plus the energy loss cost), subject to a set of technical and operational constraints.

In the last years the distribution planning function is further complicated by the high penetration of distributed generation (DG) technologies, including storage, and the participation of the consumers in the form of active demand, encouraged by national and regional policies worldwide. This is the basic notion of the active distribution network (ADN) that incorporates DG, distributed storage, active demand, automation, communication, and advanced metering in its operational planning. It is now widely recognized that by exploiting the capacity and control capabilities of the distributed energy resources (DER) at distribution level instead of just connecting them to the network (the so-called "fit and forget" approach) can provide optimal planning solutions with significant cost savings. For example, the optimal placement of DG into *existing* power distribution systems has already attracted the interest of significant research efforts [1] in the last twenty years, with the first work published in 1994. An exhaustive review of PDP works has been provided in [2–4], published in 1997, 2000, and 2002, respectively. As will be shown later in Table 2, with respect to modern PDP of active distribution networks, the consideration of automatic switching actions appears in 2005; consideration of DER integration and control appears in 2007; and consideration of multiple controls (active and reactive power control of DG units, on-line network reconfiguration, demand side response, and generation curtailment) appears in 2008. This paper provides an overview of selected PDP works published after 2005 (when the first modern PDP appears) [5–81]. It should be noted that in [1], 83 state of the art publications on the optimal placement of DG into *existing* power distribution systems were reviewed, while in this paper, 77 completely different state of the art publications on modern PDP are reviewed. More specifically, this paper reviews 77 selected PDP articles, published after 2004, which optimize at least the feeders and/or the substations of the distribution network. As will be shown in this paper, the modern PDP models and methods are more integrated (e.g., simultaneously optimize the substations and feeders), more often multiobjective, more often consider the installation of DG simultaneously to the expansion of substations and feeders, and more often consider DG control, load control and automatic switching actions, in comparison to the traditional PDP models of the past [2–4].

This paper introduces a taxonomy of the state of the art PDP models and methods, offering a unifying description of a relatively large number of works devoted to the subject [5–81]. Moreover, this work analyzes and classifies current and future research trends in PDP. This review aims to serve as a guide to power system engineers and researchers on the available PDP models and methods in the modern power systems era.

The paper is organized as follows. Section 2 focuses on PDP models, defines the general problem statement, outlines and classifies the published models and presents the objectives, constraints, design variables, types of application, problem types, categories of planning period, characteristics of load models, and types of distributed generation studied in PDP. Section 3 outlines and classifies the published PDP methods. Section 4 discusses the contribution of the reviewed works. Section 5 suggests future research ideas and Section 6 concludes.

2. PDP models

2.1. General problem statement

The typical PDP consists of finding the most economical solution with the optimal location and size of future substations and/or feeders to meet the future demand. The objective of the typical PDP is the minimization of an economic cost function (e.g., the investment cost to add, reinforce or replace substations and/or feeders, plus the energy loss cost), subject to a set of technical and operational constraints. The PDP is a complex mixed integer nonlinear optimization problem.

2.2. Objective

This section is focused on the main objective functions of the PDP problem. The PDP can be formulated as a single-objective problem or a multiobjective problem. The main single-objective functions minimize the net present value of the following costs: