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Optimum allocation of distributed generation in multi-feeder systems using long term evaluation and assuming voltage-dependent loads

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ABSTRACT

The analysis of actual distribution systems with penetration of distributed generation requires powerful tools with capabilities that until very recently were not available in distribution software tools; for instance, probabilistic and time mode simulations. This paper presents the work made by the authors to expand some procedures previously implemented for using OpenDSS, a freely available software tool for distribution system studies, when it is driven as a COM DLL from MATLAB using a parallel computing environment. The paper details the application of parallel computing to the allocation of distributed generation for optimum reduction of energy losses in a multi-feeder distribution system when the system is evaluated during a long period (e.g., the target is to minimize energy losses for periods longer than one year) and voltage-dependent load models are used. The long term evaluation is carried out by assuming that the connection of the generation units is sequential, and using a divide and conquer approach to speed up calculations. The main goals are to check the viability of a Monte Carlo method in some studies for which parallel computing can be advantageously applied and propose a procedure for quasi-optimum allocation of photovoltaic generation in a multi-feeder distribution system.

1. Introduction

Distributed generation can support voltage, reduce losses, provide backup power, improve local power quality and reliability, provide ancillary services, and defer distribution system upgrade [1–3]. Modeling of renewable generation raises several challenges to distribution load flow calculations since capabilities for representing intermittent generators, voltage-control equipment, or multi-phase unbalanced systems are required. In addition, the study of systems with intermittent non-dispatchable resources will usually require a probabilistic approach and calculations performed over an arbitrary time period that may range from minutes to years. Load representation is another important issue since voltage-dependent loads with random variation must also be accounted for. These issues complicate the study since software tools have to combine new analysis capabilities with a high number of models for representing various generation technologies, besides the conventional distribution system components, and include capabilities for time mode calculations [4].

The optimum allocation of distributed generation can be seen from two different perspectives:

- From the independent producer's point of view the goal is to optimize the benefit. Although the utility will usually impose some constraints to the generation units to be connected to its system (e.g. a maximum rated power), it can be assumed by default that the units can be connected to any system node. Therefore, the optimization approach will be in general a feasibility study whose main goal is to check the viability of the installation and select the most economical size (irrespective of the location) and, in case of dispatchable units, the control strategy that will maximize the benefit; see for instance [5,6].
- From the utility's point of view the goal is to maximize the positive impact of distributed generation (e.g., voltage support, energy losses, investment deferring) and minimize or avoid those aspects that can negatively affect the system performance (e.g. miscoordination of protective devices, overvoltages during low load periods); see for instance [7].

Several surveys of the methods proposed for optimum allocation of distributed generation have been presented in the literature; see [8,9]. This work is related to the second perspective; namely, the optimum allocation of photovoltaic (PV) generation aimed at minimizing distribution system energy losses taking into account

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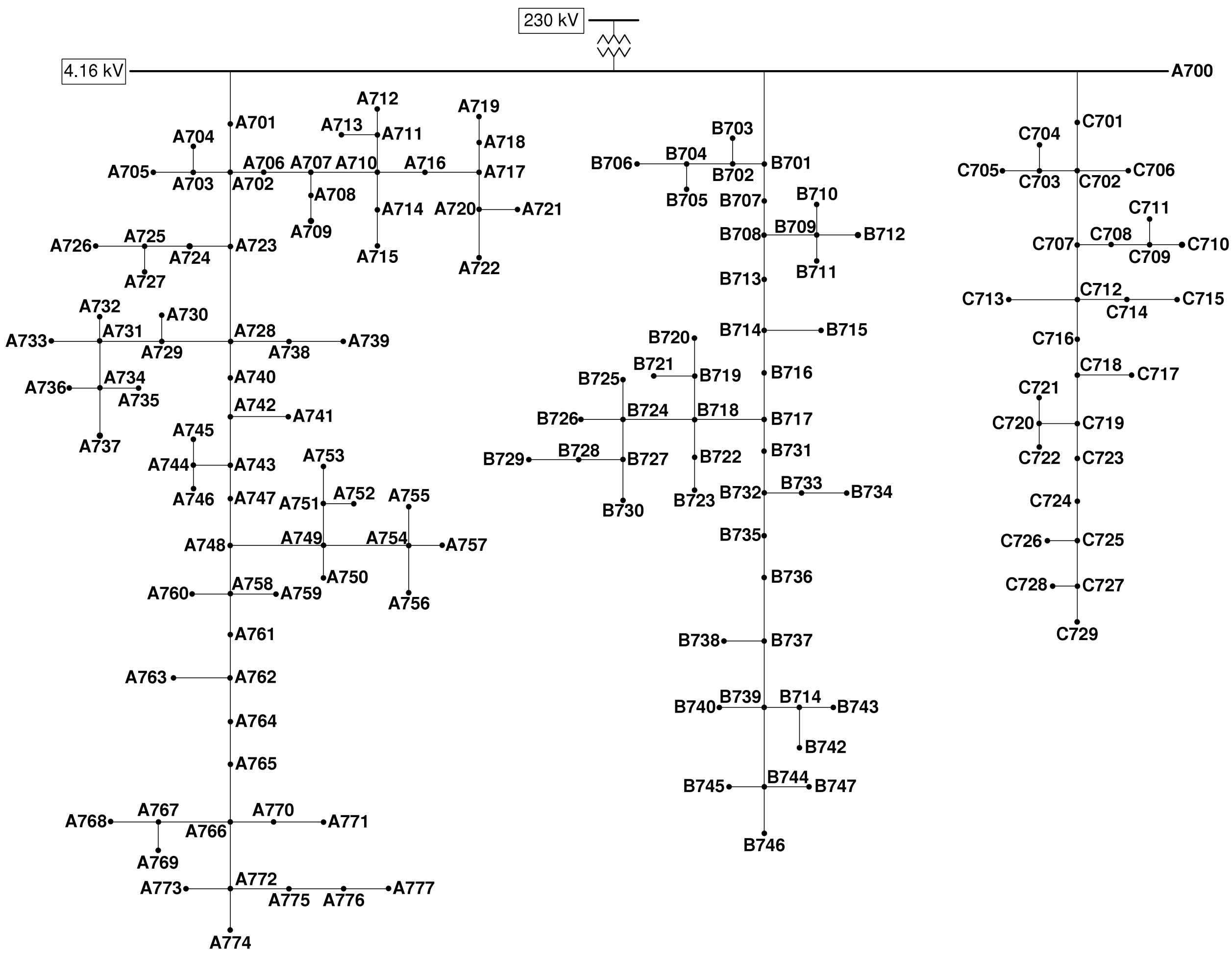

Fig. 1. Test system configuration.

some constraints (e.g., there is a maximum voltage that should not be exceeded; there is a thermal limit for each system line section).

A previous paper by the authors presented a procedure for optimum allocation of PV generation units aimed at minimizing the yearly energy losses of a distribution system; the procedure was based on the Monte Carlo method and the utilization of a multicore computing environment (e.g., multicore installation) [10]. The work used OpenDSS as a COM DLL driven from MATLAB [11].

The present study is aimed at estimating the optimum allocation of PV generation using again a distributed computing environment but considering a long term evaluation (i.e., 10 or more years). That is, the goal is to estimate the rated power and location of PV generators whose connection will minimize distribution system energy losses for a certain time period. In addition, it is assumed that the connection of PV generation units will be sequential and the loads can be voltage-dependent.

Some information is required when considering time-varying load and intermittent generation; namely, the variation of load and photovoltaic generation over the evaluation period. Different algorithms were previously implemented by the authors in MATLAB to obtain node load and PV generation yearly curves for their application with OpenDSS, see references [12,13].

Some studies (e.g. feasibility studies) rely on evaluation periods as long as 20 years or more; in such cases time-varying curves must be yearly updated taking into account randomness (for both load and generation shapes) and the forecasted load variation. For this purpose the algorithms previously developed by the authors and presented in [12,13] have been modified in order to create system curves adequate for long term evaluation. By default, it is assumed that PV generation units will inject only active power.

The paper has been organized as follows. The main characteristics of the system tested in this work are presented in Section 2, while Section 3 introduces the Monte Carlo approaches applied in this study. Section 4 explores the application of the approaches based on the conventional Monte Carlo method and the refined method proposed by the authors in [10] to the simultaneous connection of one or more units considering that the target is to minimize the energy losses of the test system during one year. The conclusions of that study are used in Section 5, which presents the application of the Monte Carlo method to the optimum allocation of PV generation units using a long term evaluation and assuming a sequential (i.e. non-simultaneous) connection of the generators. Section 6 proposes an alternative methodology for optimum allocation of distributed PV generators based on a “divide and conquer” approach [14], assuming again a sequential connection of PV generation units. The main results and some consequences of the study presented in this paper are discussed in Section 7. The main conclusions of the paper are summarized in Section 8.

2. Test system

Fig. 1 shows the diagram of the test system. It is a three-phase overhead system serving three feeders with different topologies and load characteristics. The system is based on IEEE test feeders [15], and has been created on purpose for this study. The model includes a simplified representation of the high-voltage system.