Electrical Power and Energy Systems 63 (2014) 645–656

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A multiobjective hybrid evolutionary algorithm for robust design of distribution networks

Eduardo G. Carrano [a,*], Cristiane G. Tarôco [b], Oriane M. Neto [c,1], Ricardo H.C. Takahashi [d]

[a] Department of Electrical Engineering, Universidade Federal de Minas Gerais, Av. Antônio Carlos, 6627, Belo Horizonte, MG 31270-901, Brazil
[b] Programa de Pós Graduação em Engenharia Elétrica, Universidade Federal de Minas Gerais, Brazil
[c] Department of Electrical Engineering, Universidade Federal de Minas Gerais, Brazil
[d] Department of Mathematics, Universidade Federal de Minas Gerais, Brazil

ARTICLE INFO

Article history:
Received 7 September 2013
Received in revised form 9 June 2014
Accepted 10 June 2014
Available online 12 July 2014

Keywords:
Distribution network design
Robust optimization
Multiobjective optimization
Hybrid algorithms
Local search operator

ABSTRACT

In this paper, an evolutionary multiobjective algorithm (NSGA-II) and some local search methods are employed to solve the power distribution network design problem. The design procedure takes into account three relevant aspects: monetary cost, fault cost (reliability) and robustness (ability to deal with different scenarios of load growth). The final objective is to identify topologies (conductor configuration and capacity) that are efficient with regard to cost and reliability at the same time they are robust enough for dealing with uncertainties on load prediction. Uncertainties in the load growth, energy price and interest rate are considered. Four local search methods are proposed in order to improve solution robustness and reliability, taking into account a given set of possible scenarios. The proposed algorithm achieves high-quality solutions with low computational cost, outperforming the results achieved by former works that dealt with similar problem formulations. Results for 21, 100 and 300 bus systems are presented in order to illustrate the efficiency of the proposed method.

© 2014 Elsevier Ltd. All rights reserved.

Introduction

Power distribution networks must be constantly redesigned and expanded to comply with load changes [1–3]. Although the load forecast techniques have evolved considerably, the problem of obtaining a reliable estimation of long term demand is endowed with intrinsic uncertainties that are structural. This means that the network design techniques should be able to accommodate a random component of the load growth. It becomes necessary to model the future loads as random variables, whose uncertainty (variance) grows within time [4,5]. Therefore, the uncertainties intrinsic to the prediction process give rise to a multiple set of possible demand scenarios. The consideration of all possible scenarios in the design procedure is not feasible, since the number of design problems to be solved would be extremely large even for distribution systems of moderate size. In order to surpass such a limitation, most of the current design approaches take into account a single scenario for design, usually the "mean" or the "most likely" scenario [2,3]. However, if the design scenario is wrongly chosen, two undesirable situations may arise: (i) *under-estimated scenario:* if the system is designed considering an under-estimated load scenario (i.e. the value estimated for some loads is considerably lower than the load that will be installed at a given time), it will become unable to supply the loads properly within the design time. In this case, it will be necessary to perform an early redesign of the system, what increases the installation costs estimated previously. (ii) *Over-estimated scenario:* on the other hand, if the system is planned considering an over-estimated load scenario, it will be over-sized. Although the network is expected to work properly in those cases, such a network will be more costly than necessary.

In order to try to achieve a good allocation of resources, the problem of distribution network design has been addressed in the last two decades using optimization methodologies. Power distribution network design can be classified as a high cost combinatorial problem with nonlinear objective functions and constraints [6,7]. Given a set of clients (loads) and a set of feeders (usually substations), the problem can be stated as to identify the best solution (places in which the conductors are to be installed and their capacities) that is able to comply with technical constraints (voltage level, current and power capacity, etc.) and load demands. Finding the optimal solution is a hard computational task even in the scenario in which the loads are well known [8,9]. This complexity,

* Corresponding author. Tel.: +55 31 34093413; fax: +55 31 34094810.
E-mail addresses: egcarrano@ufmg.br (E.G. Carrano), cristiane@cpdee.ufmg.br (C.G. Tarôco), oriane@cpdee.ufmg.br (O.M. Neto), taka@mat.ufmg.br (R.H.C. Takahashi).
[1] In memoriam.

http://dx.doi.org/10.1016/j.ijepes.2014.06.032
0142-0615/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

$\mathcal{G}(\mathcal{V},\mathcal{E},\mathcal{T})$	graph in which the decision variables are defined
$\mathcal{V}$	set of vertices
$\mathcal{E}$	set of edges
$\mathcal{T}$	set of conductor types available for design
$N \subseteq \mathcal{G}$	subgraph of $\mathcal{G}$ that represents a candidate solution
$n(i,j,k) \in N$	binary decision variable that assumes 1 if the vertices i and j (edge (i,j)) are connected using a conductor of type k, or 0 otherwise
$f_{mc}(N)$	monetary cost of the distribution network N (in \$)
$f_{fc}(N)$	fault cost of the distribution network N (in \$)
$f_{inf}(N)$	infeasibility ratio of the distribution network N
f_{inf}^{max}	maximum acceptable infeasibility ratio for a robust distribution network
$\mathcal{L}(i,j)$	length of edge (i,j) (in km)
$\mathcal{C}_I(k)$	installation (or replacement) cost of a conductor of type k (in \$/km)
$\mathcal{C}_M(k)$	maintenance cost of a conductor of type k (in \$/km/year)
$\mathcal{C}_L(i,j,k,\mathfrak{L}_E,\mathfrak{E}_E) = 8760 \cdot lf \cdot \mathfrak{E}_E(i,j) \cdot \mathcal{O}(i,j,k,\mathfrak{L}_E)$	cost related with losses on edge (i,j), which is connected with a conductor of type k (in \$/year)
$\mathfrak{E}_E(i,j) \in \mathfrak{E}_E$	energy tax for the edge (i,j) (in \$/kWh)
$\mathcal{O}(i,j,k,\mathfrak{L}_E)$	loss on edge (i,j), which is connected with a conductor of type k, for a load scenario $\mathfrak{L}_E$ (in kW). It is calculated through load flow
lf	loss factor
dt	time horizon considered in design (in years)
ir	annual interest rate (in %)
$V(N,i,\mathfrak{L}_E)$	voltage at bus i of distribution network N for the load scenario $\mathfrak{L}_E$
v_{min}	minimum acceptable voltage for a load bus
v_{max}	maximum acceptable voltage for a load bus
$\mathcal{I}(N,i,j,k,\mathfrak{L}_E)$	current on edge (i,j) of distribution network N, which is connected with a conductor of type k, for a load scenario $\mathfrak{L}_E$ (in A)
$i_{max}(k)$	maximum admissible current for a conductor of type k
$\lambda(k)$	expected number of faults per year of a conductor of type k (in #faults/km/year)
cf	mean cost per fault occurrence (in \$/fault)
$\zeta(k)$	mean duration per fault of a conductor of type k (in hours/fault)
$\mathcal{P}_{NL}(i,j,k,\mathfrak{L}_E)$	active power on edge (i,j) (discounting all losses), which is connected with a conductor of type k, for a load scenario $\mathfrak{L}_E$ (in kW)
f^q	value that corresponds to the quantile q% among the ones observed for function f
$N(\mu,\sigma)$	Gaussian random variable with mean μ and standard deviation σ.

associated to the high time required for evaluating solutions, probably explains why most works handle with a single load growth scenario during network design [9–11]. The "most likely" scenario is often adopted in those cases. This means that, if the uncertainty about the load growth is high, there is a considerable chance for the network designed in that way to become under-estimated, causing the need of an expensive early re-design.

This work proposes a new hybrid multiobjective evolutionary algorithm for performing robust multicriteria design of power distribution networks, employing a Monte Carlo simulation approach in order to consider uncertainty in the load growth. This algorithm combines the Non-dominated Sorting Genetic Algorithm II (NSGA-II) [12], that is employed to find the network structure, and four deterministic local search procedures, which are used to adjust conductor capacities. Monetary cost and reliability (resilience against faults) are handled simultaneously, in a multiobjective framework, in order to identify a good approximation of the set of the solutions which represent good trade-offs between those objectives. The robustness, stated as the capacity of the network to accommodate future load growth scenarios, is treated as a constraint, avoiding the generation of solutions which become infeasible for small perturbations in the predicted loads. The proposed algorithm delivers as outcome a set of solutions that are, at the same time, feasible, robust and efficient with regard to cost and reliability. The proposed local search algorithms are the key elements that provide the computational efficiency which is necessary for dealing with the problem using a reasonable computational effort. The resulting algorithm becomes computationally efficient, presenting a stable performance (reaching the same solutions in most runs), and achieving solutions that outperform, by far, the results found by the few references that have dealt with uncertainty in the load growth [13–15]. The proposed algorithm was shown to work in large problem instances (100 and 300 bus systems), being suitable for handling typical real problems.

This paper is structured as follows: a literature review is presented in Section 'Evolutionary algorithms in power system design'; the problem formulation is shown in Section 'The problem'; the genetic algorithm and local search operators proposed are described in Section 'Genetic algorithm and local search operators'; finally, results on three instances are discussed in Section 'Results'.

Evolutionary algorithms in power system design

Recently, evolutionary algorithms have been widely employed for solving problems related with power system design and operation. This trend is due to the flexibility of these algorithms, which can be easily adapted to deal with a large range of problems without major adaptations. Some examples of the application of evolutionary algorithms to power distribution networks are presented in the next paragraphs:

In [16], the authors employ the NSGA-II to adjust Proportional Integral (PI) and Proportional Integral Derivative (PID) controllers for the automatic control of generation. Several controller assessment metrics are considered during optimization and the decision is supported by a fuzzy approach. A multiobjective clonal selection algorithm is employed in [17] for performing optimal dispatch taking into account load uncertainties. In [18], the Artificial Bee Colony (ABC) algorithm is employed for the same application.

The authors in [2] propose a genetic algorithm to solve a multi-stage planning of distribution network problem. The planning period is divided into stages and a peak load is considered for each stage. The design is performed for each stage at a time and the algorithm provides a set of time ordered investment decisions.

The expansion planning of electric distribution systems is modeled as an integer-variable dynamic problem in [19]. In this paper, the system expansion is performed by incremental discrete steps in time. A genetic algorithm, so-called Dynamic Programming Genetic Algorithm (DP-GA), is proposed to solve the problem using problem-dedicated mutation and crossover operators. The algorithm also delivers, as output, a set of installation decisions within time.

متن کامل مقاله ← دریافت فوری

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات