

Studies in Computational Intelligence

Volume 822

Series editor

Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland
e-mail: kacprzyk@ibspan.waw.pl

The series “Studies in Computational Intelligence” (SCI) publishes new developments and advances in the various areas of computational intelligence—quickly and with a high quality. The intent is to cover the theory, applications, and design methods of computational intelligence, as embedded in the fields of engineering, computer science, physics and life sciences, as well as the methodologies behind them. The series contains monographs, lecture notes and edited volumes in computational intelligence spanning the areas of neural networks, connectionist systems, genetic algorithms, evolutionary computation, artificial intelligence, cellular automata, self-organizing systems, soft computing, fuzzy systems, and hybrid intelligent systems. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution, which enable both wide and rapid dissemination of research output.

The books of this series are submitted to indexing to Web of Science, EI-Compendex, DBLP, SCOPUS, Google Scholar and Springerlink.

More information about this series at <http://www.springer.com/series/7092>

Erik Cuevas · Emilio Barocio Espejo ·
Arturo Conde Enríquez

Metaheuristics Algorithms in Power Systems

Erik Cuevas
Departamento de Electrónica, CUCEI
Universidad de Guadalajara
Guadalajara, Mexico

Emilio Barocio Espejo
CUCEI
Universidad de Guadalajara
Guadalajara, Mexico

Arturo Conde Enríquez
Universidad Autónoma de Nuevo León
San Nicolás de los Garza, Nuevo León, Mexico

ISSN 1860-949X ISSN 1860-9503 (electronic)
Studies in Computational Intelligence
ISBN 978-3-030-11592-0 ISBN 978-3-030-11593-7 (eBook)
<https://doi.org/10.1007/978-3-030-11593-7>

Library of Congress Control Number: 2018967415

© Springer Nature Switzerland AG 2019

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Power systems represent one of the main technologies in this electricity-driven modern civilization. In this context, there exist a great variety of problems in which power systems can be applied. Such problems are generally nonlinear and complex, demanding other complementary methods to solve them. Recently, power systems have been conceived as a multidisciplinary field regarding the multiple approaches used for their design and analysis. Therefore, each new scheme that is developed by other scientific community is quickly identified, understood, and assimilated in order to be applied to power system problems. This multidisciplinary covers from signal processing, electronics to computational intelligence including the current trend of using metaheuristic computation.

In the last years, researchers, engineers, and practitioners in power systems have faced problems of increasing complexity. These problems can be stated as optimization formulations. Under these circumstances, an objective function is defined to evaluate the quality of each candidate solution composed of the problem parameters. Then, an optimization method is used to find the best solution that minimizes/maximizes the objective function.

Metaheuristic methods use as inspiration our scientific understanding of biological, natural, or social systems, which at some level of abstraction can be conceived as optimization processes. They are considered as general-purpose easy-to-use optimization techniques capable of reaching globally optimal or at least nearly optimal solutions. In their operation, searcher agents emulate a group of biological or social entities which interact with each other based on specialized operators that model a determined biological or social behavior. These operators are applied to a population of candidate solutions (individuals) that are evaluated with respect to an objective function. Thus, in the optimization process individual positions are successively attracted to the optimal solution of the system to be solved.

The aim of this book is to provide an overview of the different aspects of metaheuristic methods in order to enable the reader in reaching a global understanding of the field and in conducting studies on specific metaheuristic techniques that are related to applications in power systems. Our goal is to bridge the gap

between recent metaheuristic optimization techniques and power system applications. To do this, in each chapter we endeavor to explain basic ideas of the proposed applications in ways that can be understood by readers who may not possess the necessary backgrounds on either of the fields. Therefore, power system practitioners who are not metaheuristic computation researchers will appreciate that the techniques discussed are beyond simple theoretical tools since they have been adapted to solve significant problems that commonly arise in such areas. On the other hand, members of the metaheuristic community can learn the way in which power system problems can be translated into optimization tasks.

Metaheuristic algorithms are vast and have many variants. There exist a rich amount of literature on the subject, including textbooks, tutorials, and journal papers that cover in detail practically every aspect of the field. The great amount of information available makes it difficult for no specialist to explore the literature and to find the right optimization technique for a specific power system application. Therefore, any attempt to present the whole area of metaheuristic computation in detail would be a daunting task, probably doomed to failure. This task would be even more difficult if the goal is to understand the applications of metaheuristic methods in the context of power systems. For this reason, the best practice is to consider only a representative set of metaheuristic approaches, just as it has been done in this book.

This book has been structured so that each chapter can be read independently from the others. Chapter 1 describes the main concepts of metaheuristic computation. This chapter concentrates on elementary concepts of metaheuristics. Readers that are familiar with these concepts may wish to skip this chapter.

In Chap. 2, an algorithm for the optimal parameter identification of induction motors is presented. To determine the parameters, the presented method uses a recent evolutionary method called the gravitational search algorithm (GSA). Different to the most of existent evolutionary algorithms, GSA presents a better performance in multi-modal problems, avoiding critical flaws such as the premature convergence to sub-optimal solutions. Numerical simulations have been conducted on several models to show the effectiveness of the presented scheme.

Chapter 3 considers the problem of overcurrent relay coordination under an optimization perspective. Protective relaying comprehends several procedures and techniques focused on maintaining the power system working safely. Overcurrent relay is one of the oldest protective relays, and its operation principle is straightforward: When the measured current is greater than a specified magnitude, the protection trips. However, its main disadvantages consist in increased tripping times and difficulties in finding faults (since faults could be located far from the relay location). In order to solve this problem, a scheme of coordination among relays is proposed. In the approach, the invasive weed optimization (IWO) algorithm is applied for getting the best configuration.

In Chap. 4, the problem of the coordination in overcurrent relays is analyzed. In the approach, both sensitivity and security requirements of relay operation are considered. The scheme has as a basis a metaheuristic algorithm. In order to compare the results, several metaheuristic methods have been employed such as the

ant colony optimizer (ACO), the differential evolution (DE) algorithm, and the gray wolf optimization (GWO).

In Chap. 5, a method to solve an optimal power flow problem with one single function and with multiple and competing objective functions is presented. As a first approach, the modified flower pollination algorithm (MFPA) is employed to show its potential application to solve the OPF problem. Then, the normal boundary intersection (NBI) method is considered as a complementary technique to determine the Pareto front solution of the multi-objective OPF problem. To help in the decision-making process, several strategies are compared to select the best compromise solution from the Pareto frontier. To demonstrate the capabilities of the proposed method, different objective functions are combined to calculate the Pareto front solution on the IEEE 30 bus test system. Finally, a visual tool is developed to display the OPF solution. This tool would help the user to intuitively visualize potential damage on the power system.

In Chap. 6, an improved version of the crow search algorithm (CSA) is presented to solve complex optimization problems typical in power systems. In the new algorithm, two features of the original CSA are modified: (I) the awareness probability (AP) and (II) the random perturbation. With such adaptations, the new approach preserves solution diversity and improves the convergence to difficult high multi-modal optima. In order to evaluate its performance, the proposed algorithm has been tested in a set of four optimization problems which involve induction motors and distribution networks. The results demonstrate the high performance of the proposed method when it is compared with other popular approaches.

Chapter 7 presents a method for obtaining the optimal configuration of a set of fault current limiters on a distribution network. The approach considers several popular metaheuristic methods as search strategies to find the best architecture of limiters considering different objective functions. The algorithms involve genetics algorithm (GA), particle swarm optimization (PSO), and differential evolution (DE).

Finally, Chap. 8 presents a method that combines dimensionality reduction (DR) technique with particle swarm optimization (PSO) algorithm for clustering load profile electricity data. The DR techniques allow to obtain a low-dimensional data model that can be used to project representative electricity load (REL) data onto an easily interpretable 3D space. On the other hand, the PSO algorithm and a validation index algorithm are also applied to obtain an optimal number of clusters.

Guadalajara, Mexico
Guadalajara, Mexico
San Nicolás de los Garza, Mexico
2015

Erik Cuevas
Emilio Barocio Espejo
Arturo Conde Enríquez

Contents

1	Introduction to Metaheuristics Methods	1
1.1	Definition of an Optimization Problem	1
1.2	Classical Optimization	2
1.3	Metaheuristic Algorithms	5
1.3.1	Structure of a Metaheuristic Scheme	6
	References	7
2	Metaheuristic Schemes for Parameter Estimation in Induction Motors	9
2.1	Introduction	9
2.2	Problem Statement	11
2.2.1	Approximate Circuit Model	11
2.2.2	Exact Circuit Model	12
2.3	Gravitational Search Algorithm	13
2.4	Experimental Results	14
2.4.1	Induction Motor Parameter Identification	15
2.4.2	Statistical Analysis	20
2.5	Conclusions	21
	References	21
3	Non-conventional Overcurrent Relays Coordination	23
3.1	Genetic Algorithms Implementation	24
3.2	Invasive-Weed Optimization	27
3.3	Coordination like Optimization Problem	30
3.3.1	Overcurrent Relays	31
3.3.2	Sensitivity of Relays	33
3.3.3	Directional Overcurrent Relay (DOCRs)	35
3.3.4	Directional Overcurrent Relay Coordination (DOCRs)	36
3.3.5	Objective Function of the Optimization Algorithms	39
3.3.6	General Model for Non-conventional Time Curves	41

3.4	Coordination with Genetic Algorithms	44
3.5	Coordination with Invasive-Weed Optimization	47
3.5.1	Sequential Quadratic Programming	49
3.5.2	Implementation	50
3.6	Results	51
3.7	Summary	56
	References	57
4	Overcurrent Relay Coordination, Robustness and Fast Solutions . . .	61
4.1	Overcurrent Relay like Optimization Problem.	61
4.2	Ant-Colony Optimization	62
4.2.1	Steps of Protection Coordination Using Ant-Colony Algorithm	64
4.3	Differential Evolution	70
4.3.1	Steps of Protection Coordination Using Differential Evolution Algorithm	71
4.3.2	Evaluation of DE Family for Overcurrent Relay Coordination Problem	75
4.4	Grey Wolf Algorithm	77
4.4.1	Motivation and Social Hierarchy	77
4.4.2	Hunting (Searching of Prey)	79
4.4.3	Encircling of Prey	80
4.4.4	Attacking of Prey	81
4.4.5	DOCRs Coordination Using GWO	83
4.4.6	DOCRs Coordination Using MOGWO	88
4.5	Evaluation	91
4.5.1	Evaluation Among ACO and DE	93
4.5.2	Evaluation of GWO and MOGWO Algorithms	96
4.6	On-Line Coordination	107
4.7	Summary	109
	References	110
5	Bio-inspired Optimization Algorithms for Solving the Optimal Power Flow Problem in Power Systems	111
5.1	Introduction	111
5.2	General Formulation of OPF Problem	113
5.2.1	Objective Functions $f_i(x, u)$	113
5.2.2	Inequality Constrains $g_i(x, u)$	115
5.2.3	Penalty Functions	116
5.3	Flower Pollination Algorithm	116
5.3.1	Description of the Flower Pollination Algorithm	117
5.4	Modified Flower Pollination Algorithm	118
5.4.1	Improving the Initial Conditions Process	118
5.4.2	Switching the Local to Global Pollination Process	119

5.5	Multi Objective Modified Flower Pollination Algorithm	120
5.5.1	Normal Boundary Intersection Method for Generation of Pareto Frontier	120
5.6	General Description of the Bio-inspired Multi-objective Optimization Procedure	121
5.7	Best Compromise Solution Criteria	122
5.7.1	Fuzzy Membership Function Method	123
5.7.2	Entropy Weight Method	123
5.8	Numerical Results	124
5.8.1	Benchmark Test Function	124
5.8.2	Optimal Power Flow Solution for a Single Function	125
5.8.3	Optimal Power Flow Solution a Multi-objective Functions	129
5.9	Conclusions	134
	References	134
6	A Modified Crow Search Algorithm with Applications to Power System Problems	137
6.1	Introduction	137
6.2	Crow Search Algorithm (CSA)	139
6.3	The Proposed Improved Crow Search Algorithm (ICSA)	141
6.3.1	Dynamic Awareness Probability (DAP)	141
6.3.2	Random Movement—Lévy Flight	141
6.4	Motor Parameter Estimation Formulation	144
6.4.1	Approximate Circuit Model	144
6.4.2	Exact Circuit Model	145
6.5	Capacitor Allocation Problem Formulation	146
6.5.1	Load Flow Analysis	146
6.5.2	Mathematical Approach	147
6.5.3	Sensitivity Analysis and Loss Sensitivity Factor	148
6.6	Experiments	150
6.6.1	Motor Parameter Estimation Test	150
6.6.2	Capacitor Allocation Test	152
6.6.3	Statistical Analysis	159
6.7	Conclusions	159
	Appendix: Systems Data	160
	References	163
7	Optimal Location of FCL	167
7.1	Fault Current Limiters	168
7.2	Optimal Location of FCL	168
7.2.1	Formulation of Optimal FCL Sizing and Allocation Problem	169
7.2.2	Optimal Function	169

7.3	Fault Current Limiters	170
7.3.1	Resonant Fault Current Limiters (R-FCLs)	170
7.3.2	Solid-State Fault Current Limiters (SS-FCL)	172
7.4	Sizing of FCLs	173
7.4.1	R-FCLs	173
7.4.2	Sizing <i>SS-FCLs</i>	174
7.4.3	Evaluation of FCLs	175
7.5	Performance Analysis	177
7.6	Optimal Location Results	180
7.7	Summary	183
	References	184
8	Clustering Representative Electricity Load Data Using a Particle Swarm Optimization Algorithm	187
8.1	Introduction	187
8.2	Dimensional Reduction Techniques	188
8.2.1	Dimensional Reduction Concept	189
8.2.2	Principal Component Analysis	190
8.2.3	Isometric Feature Mapping (Isomap)	191
8.2.4	Stochastic Neighbour Embedding (SNE)	191
8.3	Clustering Tendency of Low-Dimensional Data	192
8.3.1	Visual Assessment of Cluster Tendency Algorithm	192
8.4	Particle Swarm Optimization (PSO) Algorithm	194
8.4.1	Clustering Data Problem	194
8.4.2	Codification of PSO Based on Centroids	194
8.4.3	Objective Function of the Optimization Scheme	196
8.4.4	Design Criteria Function for Clustering Data	197
8.5	Validation Index	198
8.6	General Description of Clustering Procedure	199
8.7	Results	200
8.7.1	Clustering of Low Dimensional Synthetic Data	200
8.7.2	Clustering REL Data of ERCOT System	203
8.8	Conclusions	208
	References	209
	Appendix A	211