LIGHTNING SEARCH ALGORITHM FOR OPTIMAL ECONOMIC AND EMISSION DISPATCH OF PHOTOVOLTAIC INTEGRATED WITH THERMAL POWER SYSTEM

MURAD YAHYA NASSER NASSAR

A thesis submitted in
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

MAY 2021

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged

Student :  .....

MURAD YAHYA NASSER NASSAR

Date : 30 / 05 /2021 .....

Supervisor :  .....

DR. MOHD NOOR BIN ABDULLAH

To my beloved parents,

Yahya Nasser Nassar & Hasna Hasan Al-abdi

My beloved wife and son,

Suaad Mohammed Abudunya & Abdulqader Murad Nassar

My uncle and all my siblings,

Dr. Hamoud Nassar, Najeeb, Ibrahim, Redwan, Mohammed, Fawaz & Ayman

To my helpful friends,

Dr. Waddah Waheeb, Dr. Wafi Adam, Dr. Naif Al-duais & Dr. Asif Ahmed

Thank you for your prayers, support, guidance and love

ACKNOWLEDGEMENT

Foremost, I would like to acknowledge the Almighty God for His benevolence and for granting me strength, patience and perseverance not only in the time of research and writing of this thesis, but indeed, throughout my life.

I express, with heartfelt appreciation, my gratitude to my supervisor, Dr. Mohd Noor bin Abdullah for his support, motivation, and invaluable intellectual guidance extended to me throughout my master research completion. My sincere appreciation goes to the Ministry of Education Malaysia and Universiti Tun Hussein Onn Malaysia for providing me with financial support. I extend my appreciation to all my friends for their unwavering support and who have stood by me through so many tough times.

Last but not least, special thanks to my beloved parents, to my brothers and sisters, to my wife and son for their prayers, blessings, unconditional supports and unflinching insistence, who have always encouraged me to never stop achieving my goals in life.

ABSTRACT

Power dispatch plays an essential role in the planning process and control of modern power systems. Therefore, the optimization of the power dispatch problem is fundamental in the power system in order to achieve the optimal power output for minimizing generation cost and emission while satisfying operational system constraints. Many types of research have solved the power dispatch problem based on thermal power generation. However, it became more complex when integrating renewable energy (RE) such as photovoltaic (PV) in the system. Thus, both cost and emission level must be minimized to operate the power system economically and environmentally friendly. Solving this problem requires a good, fast, and robust algorithm. Therefore, this research proposed a lightning search algorithm (LSA) to solve the power dispatch problem for thermal and PV power generation for cost and emission minimization. The results obtained by LSA have been compared with other methods reported in the literature review. The LSA algorithm has been applied to determine the optimal power dispatch in six different conditions in this research. The first three conditions are minimizing economic dispatch (ED), emission dispatch (EmD), and combined economic and emission dispatch (CEED) on thermal power generation. Furthermore, the other three conditions are minimizing the ED, EmD, and CEED on thermal generation integrated with PV plants. The power balance and generator limits constraints have been considered in all test systems in this research. There are four-test systems, including 3, 6, 13, and 40 thermal units, to minimize operating costs. One test system consists of 6 thermal units that optimize EED and CEED problems on thermal generation. Then, the test system consists of 6 thermal incorporated with thirteen PV units to minimize EED and CEED problems for 24 hours. It can be concluded that LSA was able to solve the power dispatch rightly whether it used to optimize the multi-objective or single objective. Furthermore, it is found that the LSA technique outperformed the compared algorithms that existed in the literature of this research in obtaining better solution quality.

ABSTRAK

Penghantaran kuasa memainkan peranan penting dalam proses perancangan dan kawalan sistem kuasa moden. Oleh itu, pengoptimuman masalah penghantaran kuasa adalah asas dalam sistem kuasa untuk mencapai output kuasa yang optimum untuk meminimumkan kos penjanaan dan pelepasan sambil memenuhi kekangan sistem operasi. Banyak jenis penyelidikan telah menyelesaikan masalah penghantaran kuasa berdasarkan penjanaan tenaga terma. Namun, ia menjadi lebih kompleks ketika mengintegrasikan tenaga boleh diperbaharui seperti fotovoltaik (PV) dalam sistem. Oleh itu, kedua-dua tahap kos dan pelepasan mesti diminimumkan untuk mengendalikan sistem kuasa yang mesra ekonomi dan persekitaran. Untuk menyelesaikan masalah ini diperlukan algoritma yang baik, cepat, dan mantap. Oleh itu, penyelidikan ini mencadangkan algoritma carian kilat (LSA) untuk menyelesaikan masalah penghantaran tenaga untuk penjanaan tenaga terma dan PV untuk kos dan pengurangan emisi. Hasil yang diperoleh oleh LSA telah dibandingkan dengan hasil kaedah lain yang dilaporkan dalam tinjauan literatur. Algoritma LSA telah digunakan untuk menentukan penghantaran kuasa yang optimum dalam tiga keadaan yang berbeza; meminimumkan penghantaran ekonomi (ED), meminimumkan gabungan pengeluaran ekonomi dan pelepasan (CEED), dan masalah CEED yang disatukan dengan PV. Kekangan had keseimbangan kuasa dan penjana telah dipertimbangkan untuk semua sistem ujian dalam penyelidikan ini. Terdapat empat sistem ujian termasuk tiga, enam, tiga belas, empat puluh unit termal digunakan untuk meminimumkan kos operasi sahaja. Satu sistem ujian terdiri daripada enam unit termal yang dianggap dapat mengoptimumkan pengeluaran dan pengeluaran pelepasan. Kemudian, sistem ujian terdiri daripada enam unit termal dan tiga belas PV dipertimbangkan untuk mengurangkan masalah CEED. Dapat disimpulkan bahawa LSA dapat menyelesaikan pengiriman daya dengan betul sama ada digunakan untuk mengoptimumkan objektif pelbagai atau objektif tunggal. Selanjutnya, didapati bahawa teknik LSA mengatasi algoritma perbandingan yang ada dalam literatur dalam penyelidikan ini untuk mendapatkan kualiti penyelesaian yang lebih baik.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

P_{min}	–	Minimum Power Limits
P_{max}	–	Maximum Power Limits
P_L	–	Transmission Loss
B_{ij}, B_{oi}, B_{00}		Loss Coefficient Matrix
P_D	–	Power Demand
ai, bi, ci, e_i, f_i	–	Cost Coefficients of the i^{th} Generating Unit
α_i, β_i, γ_i, ε_i, λ_i	–	Emission Coefficients of the i^{th} Generating Unit
n	–	Number of Thermal Units
$F_i(P_i)$	–	Cost Function
$E_i(P_i)$	–	Emission Function
G	–	CEED Objective Function
w	–	Weighted Sum Method
h	–	Price Penalty Factor
P_{rated}	–	Rated Power
T_{amb}	–	Ambient Temperature
T_{ref}	–	Reference Temperature
S_i	–	Incident Solar Radiation
ED	–	Economic Dispatch
EmD	–	Emission Dispatch
EED	–	Economic and Emission Dispatch
CEED	–	Combined Economic and Emission Dispatch
REs	–	Renewable Energy Resources
LSA	–	Lightning Search Algorithm
PSO	–	Particle Swarm Optimization
FA	–	Firefly Algorithm
PV	–	Photovoltaic
VPE	–	Valve Point Effect

GA	Genetic Algorithm
ACO	Ant Colony Optimization
VSC	Variable Structure Control
eFPA	Euclidean Affine Flower Pollination
NSGA	Non-Dominated Sorting Genetic Algorithm
MHS	Modified Harmony Search
WOA	Whale Optimization Algorithm
CMOPEO	Constrained Multi-Objective Population Extremal Optimization
RBFNN	Radial Basis Function based on Neural Network
ACO	Ant Colony Optimization
CIHSA	Chaotic Improved Search Algorithm
SA	Simulated Annealing
BA	Bat Algorithm
PS	Pattern Search
FAPSO	Fuzzy Adaptive Particle Swarm Optimization
NM	Nelder-Mead
V2G	Vehicle-to-Grid
BSA	Backtracking Search Algorithm
DEC-SQP	Chaotic Differential Evolution And Sequential Quadratic Programming
ICA-PSO	Improved Coordinated Aggregation-Based PSO
ABC	Artificial Bee Colony

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

In the present civilization, electric power systems are considered one of the most complex industrial systems that play an important function in modern societies. Therefore, produce and distribute electric power must be accomplished cost-effectively, reliably, and in a responsible approach to the environment. The main aim of the planning and operation mission in power generation is to fulfil the power demand with the least possible cost. Furthermore, electric energy is primarily generated by conventional sources that use fossil fuels such as coal, natural gas, and oil, etc. These fossil fuels are expensive, and they produce harmful gases that cause environmental pollution. Due to the increment of power plant numbers, minimizing the pollutants of power generation is becoming very significant [1].

Power dispatch problem is to allocate the power schedule of the generation units to supply a determined power demand. This problem has two objectives that need to be minimized. The economic dispatch (ED) problem is concerned about optimal scheduling of the generators in the power system to reduce total operating cost with satisfying the operating constraints and power demand [2]. ED problem plays an essential role in the planning process and control of modern power systems. However, the emission dispatch (EmD) aims to control the generation schedule to obtain minimum emission. Because of the rising concern to the environment and the clean air act amendments of 1990, the utilities of power generation have been forced to adjust their strategies to minimize cost and reduce the emission [3]. Several types of research

have confirmed the concern of widespread pollution in power systems such as sulphur dioxide, carbon dioxide, and nitrogen oxides [4].

Optimal economic and emission dispatch (EED) is vital planning in the power system to schedule the power output of the generator at a minimum cost and emission level. The efficient optimal solution of the EED problem can ensure the power generation operates at a lower cost and emission level to support the national greenhouse gases reduction up to 45% by 2030, as stated in Green Technology Master Plan Malaysia 2017 [5]. Optimal EED does not require substantial additional implementation cost and can be performed on an existent system. Thus, this method is appropriate for decreasing harmful gases. When giving more attention to the emission level in electric power dispatch, it can offer a considerable advantage to gain lower operating cost and minimize the environmental pollution resulting from thermal generators. In this regard, the power dispatch becomes multi-objective where both ED and EmD problems can be combined to form the CEED problem. Consequently, the operating cost and emission level need to be minimized simultaneously. In the present era, the rising environmental apprehension and fuel expenditure reduction request have led to more investment in RE sources. Therefore, incorporate RE with the conventional power generation is getting high consideration to acquired sustainable energy [6].

Previously, many algorithms such as particle swarm optimization (PSO), firefly algorithm (FA), genetic algorithm (GA), and ant colony optimization (ACO) have been proposed to solve the power dispatch problem successfully. However, most of them are focused on thermal generators. One of the latest optimization algorithms called lightning search algorithm (LSA) that inspired by the natural aspect of lightning [7]. The LSA algorithm has been applied to solve several applications problems. For instance, the LSA algorithm is used to improve the system performance in a new design in the power system for variable structure control (VSC), enhance power quality of the electrical system, etc. Therefore, the LSA was found as an effective, flexible, and competitive technique and provided better outcomes than other methods. Thus, the LSA algorithm is proposed in this research to solve power dispatch problem based on PV energy.

1.2 Problem statement

The optimization of the power dispatch problem is fundamental in the power system in order to achieve the optimal power output for generation cost-minimizing while satisfying operational system constraints. The ED problem became complex when considering valve point effect (VPE) along with transmission losses. Similarly, the EmD problem increased the complexity of the power dispatch problem linked with different affected environmental assessment parameters. For that reason, the power generation must minimize the cost and the emission level to operate the system economically and environment-friendly at the same time. Many researchers have solved the power dispatch problem on thermal power generation for minimizing both single objective and multi-objective problems. The increment of fuel cost, depletion of fossil fuel reserves and the environmental considerations have compelled the researchers to incorporate RE in the power system. The integration of RE such as PV power plant in the power system has changed the research direction to reduce environmental issues of conventional power dispatch. However, the intermittence behavior of solar irradiation increased the complication of the problem. Minimizing the operating cost without considering the emission level in power dispatch has produced harmful gases to the environment, such as carbon dioxide. Hence, it was necessary to ensure the power generation has considered both cost and emission level in operation and planning. Therefore, this research has formulated the power dispatch problem based on RE since solving this problem requires a good, fast, and robust algorithm. This research focused on the power dispatch problem incorporated with PV for cost and emission minimization. A new metaheuristic algorithm called LSA algorithm was used for solving this problem. It is an efficient technique capable of dealing with multi-objective optimization. The performance of the proposed algorithm is compared with other algorithms from the existing literature, such as firefly algorithm (FA).

1.3 Objectives

This research work embarks on the following objectives:

a) To develop the LSA algorithm for minimizing total operating cost and emission level of power dispatch problem for thermal generation power plant.

b) To formulate the power dispatch problem with the incorporation of the solar power plant using the LSA algorithm.

c) To compare the LSA results with other methods from the existing literature in terms of cost and emission minimization, convergence characteristic, and robustness.

1.4 Scopes of study

The research is carried out within the scopes as follow:

a) The CEED problem was formulated to minimize the operational cost and the emission of harmful gases.

b) Optimal economic emission dispatch problem focused on the thermal generation and PV energy.

c) Lightning search algorithm used to find an optimal solution for this research.

d) MATLAB R2020a software used for simulation and identify the result of CEED.

e) Four standard test systems comprising of three, six, thirteen and forty units have been considered to solve the ED problem as the single objective function.

f) IEEE 30 bus test system consisting of six thermal units incorporated with thirteen PV units have been investigated for 24 hours.

g) The result of the CEED problem, based on PV energy obtained by the LSA algorithm was compared with the FA algorithm in terms of convergences and optimal solution for cost and emission.

1.5 Significance of study

The significances of this research are as follow:

a) The optimal ED and EmD obtained in this research can reduce the operating cost and emission level of thermal power generation respectively.

b) The proposed LSA algorithm has successfully solved different test systems to minimizing both operating cost and emission level as single objective and multi-objective of power dispatch problem respectively.

c) The proposed test system based on the thermal and PV power plants can reduce fossil fuel usage and emission level to operate the system economically and environment-friendly.

d) The proposed LSA algorithm can provide better optimal solutions compared to reported results in the literature for the considered case studies.

1.6 Outline of the thesis

In this thesis, the work carried out has been organized into five chapters in this research.

Chapter 2 presents the literature review on economic and emission dispatch and provides an overview of the research work. All types of optimization methods, including the proposed LSA, are discussed.

Chapter 3 discusses this research methodology, including problem formulation, objective function, constraints, and implementation on the LSA algorithm to solve the CEED problem.

Chapter 4 includes the result of the simulation, analysis, and discussion to solve optimal economic and emission dispatch with thermal generation and solar energy.

Chapter 5 presents the conclusion and recommendations for the upcoming work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presented a comprehensive survey of the research area that conducted on this thesis. Based on that, it provided the needed background of the power dispatch problem in the power system. It also covered the latest published research related to optimal power dispatch. The problems of economic dispatch, emission dispatch, and combined economic emission dispatch have been covered in this literature review. Previous papers have reviewed power dispatch with renewable energy such as PV energy. The types of optimization methods for solving power dispatch problem were described. It can be divided into three categories that are classical methods, metaheuristic methods, and hybrid methods. Furthermore, it discussed the lightning search algorithm that is proposed for solving the power dispatch problem.

2.2 Overview of power dispatch

Power dispatch is a technique used to obtain optimal operation by modifying some control variables and allocating the system's power. Therefore, to plan and operate the power system reliably and efficiently, power dispatch is considered critical because it schedules the power plant and achieves an optimal power output. The power dispatch problem that needs to be optimized can be classified into three categories, namely ED, EmD, and CEED.

2.2.1 Economic dispatch

The ED is one of the basic optimizing problems in the power system operations that allocate the shared power demand between the generating units. Due to the rising cost of power generation along with the demand for electrical energy, optimal power system operation is important in electrical networks for operating the designed flow with minimal energy cost. Therefore, the ED aims to minimize the total cost of generation with satisfying the operating constraints [8].

A power plant that operates using the produced steam from water called the thermal power plant, and the working fluid here is water. Generally, the thermal unit system consists of a boiler, a steam turbine, and a generator. The fuel is boiler input, and the steam volume is the output. By heating, the water in the boiler is converted to steam at constant pressure, and then the steam turns the turbine giving mechanical work to the rotor shaft of the generator. After that, the steam passes out of the turbine is condensed and used repeatedly in the plant. Thermal plants can be modelled shown as the transfer function of energy conversion from fossil fuel into electricity in Figure 2.1.

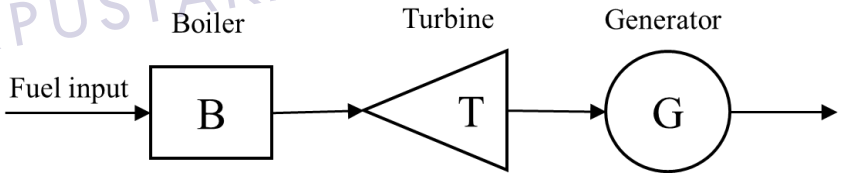

Figure 2.1: Simple model of thermal plant [2]

There are many types of fossil fuels have been used in the thermal plant, such as oil, natural gas, and coal, to generate power. For the last years, the fossil fuel is rapidly depleted, and the power demand is doubled as well [54]. Thus, the depletion of fossil fuel's main effect will be the price. Figure 2.2 shows that the curve of operating cost is increasing convex with the power generated. P_{min} and P_{max} are the minimum and maximum limits on the real power generation of the committed units [9].

REFERENCES

[1] Hemamalini S and Simon S 2010 Economic/emission load dispatch using artificial bee colony algorithm *ACEEE Proc. Int. Conf. Control. Commun. Power Eng.* 338–43

[2] Chen M-R, Zeng G-Q and Lu K-D 2019 Constrained multi-objective population extremal optimization based economic-emission dispatch incorporating renewable energy resources *Renew. Energy* 143 277–94

[3] Sita H and Reddy P U 2016 A Comprehensive Study On Combined Economic and Emission Dispatch Optimization Problem 1–9

[4] Chiang C-L 2007 Optimal economic emission dispatch of hydrothermal power systems *Int. J. Electr. Power Energy Syst.* 29 462–9

[5] Ministry of Energy G T and W (KeTTHA) 2017 *Ministry of Energy , Green Technology and Water (KeTTHA), Block E4 / 5 , Complex E , Federal Government Administrative Centre , Tel Fax Email Website*

[6] Joshi P M and Verma H K 2019 An improved TLBO based economic dispatch of power generation through distributed energy resources considering environmental constraints *Sustain. Energy, Grids Networks* 18 100207

[7] Shareef H, Ibrahim A A and Mutlag A H 2015 Lightning search algorithm *Appl. Soft Comput.* 36 315–33

[8] Barisal A K and Prusty R C 2015 Large scale economic dispatch of power systems using oppositional invasive weed optimization *Appl. Soft Comput.* 29 122–37

[9] Reddy A S and Vaisakh K 2013 A GA-API Solution for the Economic Dispatch of Generation in Power System Operation *IEEE Trans. Power Syst.* 28 570–570

[10] Mihaljan J M 2012 The exact solution of the Rossby adjustment problem *Tellus* 15 150–4

[11] Vaishnavi V J and Reddy A S 2014 Multi-Objective Economic Emission Dispatch using Backtracking Search Optimization Algorithm 39–46

[12] Chaturvedi K T, Pandit M and Srivastava L 2006 On-line Solution to Combined Economic and Emission Dispatch Problem *2006 IEEE International Conference on Industrial Technology* (IEEE) pp 1553–8

[13] Ziane I, Benhamida F, Graa A and Salhi Y 2016 Combined economic emission dispatch with new price penalty factors *2015 4th Int. Conf. Electr. Eng. ICEE 2015*

[14] Liang H, Liu Y, Shen Y and Li F 2017 A multiobjective chaotic bat algorithm for economic and emission dispatch *2017 Chinese Automation Congress (CAC)* (IEEE) pp 4684–9

[15] Kim I Y and de Weck O 2004 Adaptive Weighted Sum Method for Multiobjective Optimization *10th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference* vol 1 (Reston, Virigina: American Institute of Aeronautics and Astronautics) pp 236–48

[16] Liang H, Liu Y, Li F and Shen Y 2018 Electrical Power and Energy Systems A multiobjective hybrid bat algorithm for combined economic / emission dispatch *Electr. Power Energy Syst.* 101 103–15

[17] Dey B, Roy S K and Bhattacharyya B 2019 Solving multi-objective economic emission dispatch of a renewable integrated microgrid using latest bio-inspired algorithms *Eng. Sci. Technol. an Int. J.* 22 55–66

[18] Gandhi O, Rodriguez-Gallegos C D and Srinivasan D 2016 Review of optimization of power dispatch in renewable energy system *2016 IEEE Innovative Smart Grid Technologies - Asia (ISGT-Asia)* (IEEE) pp 250–7

[19] Khan N A, Awan A B, Mahmood A, Razzaq S, Zafar A and Sidhu G A S 2015 Combined emission economic dispatch of power system including solar photo voltaic generation *Energy Convers. Manag.* 92 82–91

[20] Gupta A and Anand H Analysis of scheduling of solar sharing for economic / environmental dispatch using PSO *2015 Annu. IEEE India Conf.* 1–5

[21] Wadhawan A, Verma P, Grover S and Anand H 2017 Economic environmental dispatch with PV generation including transmission losses using PSO *2016 IEEE 7th Power India Int. Conf. PIICON 2016* 1–6

[22] Wibowo R S, Firmansyah K R, Aryani N K and Soeprijanto A 2017 Dynamic economic dispatch of hybrid microgrid with energy storage using quadratic programming *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON* 667–70

[23] Shilaja C and Ravi K 2017 Optimization of emission/economic dispatch using

euclidean affine flower pollination algorithm (eFPA) and binary FPA (BFPA) in solar photo voltaic generation *Renew. Energy* 107 550–66

[24] Sarfi V, Livani H and Yliniemi L 2017 A new multi-objective economic-emission dispatch in microgrids *2017 IEEE Power & Energy Society General Meeting* (IEEE) pp 1–5

[25] Xiaoyan Y, Chunlin G, Xuan X, Dequan H and Zhou M 2018 Research on large scale electric vehicles participating in the economic dispatch of wind and thermal power system *CIEEC 2017 - Proc. 2017 China Int. Electr. Energy Conf.* 223–8

[26] Ran L, Zhengyu L and Zhen C 2018 Economic Dispatch of Off-Grid Photovoltaic Generation System with Hybrid Energy Storage *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2)* (IEEE) pp 1–6

[27] Elattar E E 2018 Modified harmony search algorithm for combined economic emission dispatch of microgrid incorporating renewable sources *Energy* 159 496–507

[28] Santillán-Lemus F D, Minor-Popocatl H, Aguilar-Mejía O and Tapia-Olvera R 2019 Optimal Economic Dispatch in Microgrids with Renewable Energy Sources *Energies* 12 181

[29] Moosavian S M, Modiri-Delshad M, Selvaraj J and Abd Rahim N 2016 Solution techniques for optimal power dispatch problems - A review *4th IET Clean Energy and Technology Conference (CEAT 2016)* (Institution of Engineering and Technology) pp 17 (7 .)-17 (7 .)

[30] Gherbi F Z and Lakdja F 2011 Environmentally constrained economic dispatch via quadratic programming *2011 International Conference on Communications, Computing and Control Applications (CCCA)* (IEEE) pp 1–5

[31] Irisarri G, Kimball L M, Clements K A, Bagchi A and Davis P W 1998 Economic dispatch with network and ramping constraints via interior point methods *IEEE Trans. Power Syst.* 13 236–42

[32] Zhan J P, Wu Q H, Guo C X and Zhou X X 2014 Fast λ-Iteration Method for Economic Dispatch With Prohibited Operating Zones *IEEE Trans. Power Syst.* 29 990–1

[33] Damodaran S K and Kumar T K S 2016 Combined Economic and Emission Dispatch Using a Classical Technique *IFAC Proc. Vol.* 47 1049–53

[34] Momoh J A and Reddy S S 2014 Combined Economic and Emission Dispatch using Radial Basis Function *IEEE Power Energy Soc. Gen. Meet.* 2014-Octob

[35] Lin C and Viviani G 1984 Hierarchical Economic Dispatch for Piecewise Quadratic Cost Functions *IEEE Trans. Power Appar. Syst.* PAS-103 1170–5

[36] Ramanathan R 1985 Fast Economic Dispatch Based on the Penalty Factors From Newton's Method *IEEE Trans. Power Appar. Syst.* PAS-104 1624–9

[37] Pothiya S, Ngamroo I and Kongprawechnon W 2010 Ant colony optimisation for economic dispatch problem with non-smooth cost functions *Int. J. Electr. Power Energy Syst.* 32 478–87

[38] Abido M A 2003 A novel multiobjective evolutionary algorithm for environmental/economic power dispatch *Electr. Power Syst. Res.* 65 71–81

[39] Jong-Bae Park, Yun-Won Jeong, Joong-Rin Shin and Lee K Y 2010 Closure to discussion of "An improved particle swarm optimization for nonconvex economic dispatch problems" *IEEE Trans. Power Syst.* 25 2010–1

[40] Rezaie H, Kazemi-Rahbar M H, Vahidi B and Rastegar H 2018 Solution of combined economic and emission dispatch problem using a novel chaotic improved harmony search algorithm *J. Comput. Des. Eng.*

[41] Kumar A I S, Dhanushkodi K, Kumar J J and Paul C K C 2004 Particle swarm optimization solution to emission and economic dispatch problem *TENCON 2003. Conference on Convergent Technologies for Asia-Pacific Region* (Allied Publishers Pvt. Ltd) pp 435–9

[42] Liang H, Liu Y, Li F and Shen Y 2018 A multiobjective hybrid bat algorithm for combined economic/emission dispatch *Int. J. Electr. Power Energy Syst.* 101 103–15

[43] Ravi Kumar G, Rohith A, Priyanka G and Vamsipriya G 2018 Multi-objective optimal economic emission power dispatch using Bat algorithm *2017 Innov. Power Adv. Comput. Technol. i-PACT 2017* 2017-Janua 1–5

[44] Sayah S and Hamouda A 2013 A hybrid differential evolution algorithm based on particle swarm optimization for nonconvex economic dispatch problems *Appl. Soft Comput.* 13 1608–19

[45] Niknam T 2010 A new fuzzy adaptive hybrid particle swarm optimization algorithm for non-linear, non-smooth and non-convex economic dispatch problem *Appl. Energy* 87 327–39

[46] Abbas G, Gu J, Farooq U, Raza A, Asad M U and El-Hawary M E 2017

Solution of an Economic Dispatch Problem Through Particle Swarm Optimization: A Detailed Survey – Part II *IEEE Access* 5 24426–45

[47] Afandi A N, Fadlika I, Sendari S, Miyauchi H, Fujita G and Tutkun N 2018 Comparison of ABC and Genetic Algorithms on Economic Power Dispatch *2018 10th International Conference on Information Technology and Electrical Engineering (ICITEE)* (IEEE) pp 40–5

[48] Farag A, Al-Baiyat S and Cheng T C 1995 Economic load dispatch multiobjective optimization procedures using linear programming techniques *IEEE Trans. Power Syst.* 10 731–8

[49] Mohan M R, Kuppusamy K and Khan M A 1992 Optimal short-term hydrothermal scheduling using decomposition approach and linear programming method *Int. J. Electr. Power Energy Syst.* 14 39–44

[50] Basu M 2005 A simulated annealing-based goal-attainment method for economic emission load dispatch of fixed head hydrothermal power systems *Int. J. Electr. Power Energy Syst.* 27 147–53

[51] Schlünz E B and Van Vuuren J H 2013 An investigation into the effectiveness of simulated annealing as a solution approach for the generator maintenance scheduling problem *Int. J. Electr. Power Energy Syst.* 53 166–74

[52] Naderi E, Azizivahed A, Narimani H, Fathi M and Narimani M R 2017 A comprehensive study of practical economic dispatch problems by a new hybrid evolutionary algorithm *Appl. Soft Comput.* 61 1186–206

[53] Sen T and Mathur H D 2016 A new approach to solve Economic Dispatch problem using a Hybrid ACO–ABC–HS optimization algorithm *Int. J. Electr. Power Energy Syst.* 78 735–44

[54] Younes M, Khodja F and Kherfane R L 2014 Multi-objective economic emission dispatch solution using hybrid FFA (firefly algorithm) and considering wind power penetration *Energy* 67 595–606

[55] El Majdouli M A and El Imrani A A 2015 Lightning Inspired Search Algorithm introduction & application to the traveling salesman problem *2015 10th Int. Conf. Intell. Syst. Theor. Appl. SITA 2015*

[56] Sirjani R and Okonkwo E C 2016 A new wind power model using the lightning search algorithm *13th HONET-ICT Int. Symp. Smart MicroGrids Sustain. Energy Sources Enabled by Photonics IoT Sensors, HONET-ICT 2016* 93–7

[57] Sarker M R, Mohamed R, Saad M H M and Mohamed A 2019 dSPACE

Controller-Based Enhanced Piezoelectric Energy Harvesting System Using PI-Lightning Search Algorithm *IEEE Access* 7 3610–26

[58] Thangaraj Y and Kuppan R 2017 Multi-objective simultaneous placement of DG and DSTATCOM using novel lightning search algorithm *J. Appl. Res. Technol.* 15 477–91

[59] Shareef H, Mutlag A H and Mohamed A 2015 A novel approach for fuzzy logic PV inverter controller optimization using lightning search algorithm *Neurocomputing* 168 435–53

[60] Elsisi M and Abdelfattah H 2019 New design of variable structure control based on lightning search algorithm for nuclear reactor power system considering load-following operation *Nucl. Eng. Technol.*

[61] Kabalci Y and Kabalci E 2019 Noise insensitive optimal harmonic estimator design with lightning search algorithm *Swarm Evol. Comput.* 46 219–34

[62] Aljanad A, Mohamed A, Shareef H and Khatib T 2018 A novel method for optimal placement of vehicle-to-grid charging stations in distribution power system using a quantum binary lightning search algorithm *Sustain. Cities Soc.* 38 174–83

[63] Abdullah M N, Abu Bakar A H, Abd Rahim N And Mokhlis H 2015 Modified particle swarm optimization for economic-emission load dispatch of power system operation *TURKISH J. Electr. Eng. Comput. Sci.* 23 2304–18

[64] D.V. Kiran N M G K and S M S 2018 A Comprehensive Review on Optimization Strategies for Combined Economic Emission Dispatch Problem *Renew. Sustain. Energy Rev.* 81 3006–20

[65] Sonmez Y 2011 Multi-Objective Environmental/Economic Dispatch Solution with Penalty Factor Using Artificial Bee Colony Algorithm *Sci. Res. Essays* 6 2824–31

[66] Kulkarni P S, Kothari A G and Kothari D P 2000 Combined economic and emission dispatch using improved backpropagation neural network *Electr. Power Components Syst.* 28 31–44

[67] Abdelaziz A Y, Ali E S and Abd Elazim S M 2016 Flower pollination algorithm to solve combined economic and emission dispatch problems *Eng. Sci. Technol. an Int. J.* 19 980–90

[68] Rajan A and Malakar T 2016 Optimum economic and emission dispatch using exchange market algorithm *Int. J. Electr. Power Energy Syst.* 82 545–60

[69] Modiri-Delshad M and Rahim N A 2016 Multi-objective backtracking search algorithm for economic emission dispatch problem *Appl. Soft Comput. J.* 40 479–94

[70] Aydin D, Özyön S, Yaşar C and Liao T 2014 Artificial bee colony algorithm with dynamic population size to combined economic and emission dispatch problem *Int. J. Electr. Power Energy Syst.* 54 144–53

[71] Modiri-Delshad M and Rahim N A 2014 Solving non-convex economic dispatch problem via backtracking search algorithm *Energy* 77 372–81

[72] Al-Sumait J S, AL-Othman A K and Sykulski J K 2007 Application of pattern search method to power system valve-point economic load dispatch *Int. J. Electr. Power Energy Syst.* 29 720–30

[73] Yaşar C and Özyön S 2011 A new hybrid approach for nonconvex economic dispatch problem with valve-point effect *Energy* 36 5838–45

[74] Nadeem Malik T, ul Asar A, Wyne M F and Akhtar S 2010 A new hybrid approach for the solution of nonconvex economic dispatch problem with valve-point effects *Electr. Power Syst. Res.* 80 1128–36

[75] Vitthaladevuni P K and Alouini M-S 2003 Discussion of "Economic Load Dispatch - A Comparative Study on Heuristic Optimization Techniques With an Improved Coordinated Aggregation-Based PSO" *IEEE Trans. Broadcast.* 49 408–408

[76] Ke Meng, Hong Gang Wang, ZhaoYang Dong and Kit Po Wong 2010 Quantum-Inspired Particle Swarm Optimization for Valve-Point Economic Load Dispatch *IEEE Trans. Power Syst.* 25 215–22

[77] Dos Santos Coelho L and Mariani V C 2006 Combining of Chaotic Differential Evolution and Quadratic Programming for Economic Dispatch Optimization with Valve-Point Effect *IEEE Trans. Power Syst.* 21 1465–1465

[78] Srinivasa Reddy A and Vaisakh K 2013 Shuffled differential evolution for large scale economic dispatch *Electr. Power Syst. Res.* 96 237–45

[79] Bhattacharjee K, Bhattacharya A and Dey S H N 2014 Oppositional Real Coded Chemical Reaction Optimization for different economic dispatch problems *Int. J. Electr. Power Energy Syst.* 55 378–91

[80] Bulbul S M A, Pradhan M, Roy P K and Pal T 2018 Opposition-based krill herd algorithm applied to economic load dispatch problem *Ain Shams Eng. J.* 9 423–40

[81] Hemamalini S and Simon S P 2010 Artificial Bee Colony Algorithm for Economic Load Dispatch Problem with Non-smooth Cost Functions *Electr. Power Components Syst.* 38 786–803

[82] Kumar R, Sharma D and Sadu A 2011 A hybrid multi-agent based particle swarm optimization algorithm for economic power dispatch *Int. J. Electr. Power Energy Syst.* 33 115–23