UNIVERSITI PUTRA MALAYSIA

OPTIMAL POWER FLOW OF POWER SYSTEMS USING HARRIS HAWKS OPTIMIZATION AND SALP SWARM ALGORITHM

ISLAM MOHAMMAD ZOHRUL

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By

ISLAM MOHAMMAD ZOHRUL

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

This thesis is gratefully dedicated to my beloved Parents for their support, patience and inspiration and my beloved sister.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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Chairman : Associate Professor Ir. Noor Izzri bin Abdul Wahab, PhD
Faculty : Engineering

Optimal Power Flow (OPF) is one of the most significant tools used over a decade to till date in energy management system for reliable operation and planning of modern power system. The main objective is to adjust all the controlling parameters by satisfying equality and inequality constraints in order to optimize several objective functions.

The recent deregulation of power industry, growing energy demand, limitations of extension of existing transmission and distribution line have intensified the acute implementation of optimization techniques. Moreover, the deploying available natural resources and ever-increasing concern of the environmental pollutant gases, such as CO_2, emission during power generations and its serious impact on environment has gained more attention.

This thesis has proposed recently developed Harris Hawks Optimization (HHO) and Salp Swarm Algorithm (SSA) to solve single- and multi-objective OPF problems considering fuel cost, power loss and environment emission. Additionally, the proposed methods solved multi-objective OPF problem with the help of no preference weighted sum method.

Standard IEEE-30-bus and 57-bus test system data have been studied to justify the effectiveness of the proposed methods for single- and multi-objective OPF problems considering fuel cost, power loss and environment emissions. Additionally, no preference weighted sum method has been employed to solve multi-objective OPF problems simultaneously. The obtained results showed the decent improvement comparing to other swarm-based techniques like Whale Optimization Algorithm (WOA), Math Flame (MF), and Glowworm Optimization Algorithm (GOA) in terms of convergence performance and quality. As per the results, the proposed HHO technique outperforms to give the fuel cost of 801.829$/h improving by 0.01% indicating the best

optimal solution for single-objective solution among the various methods presented. Likewise, power loss and environment emission improved predominantly by 0.37 % and 3.72% respectively. Multi-objective OPF results recorded at 0.02% to 0.55% for different cases. Lastly, three objectives were scrutinized together where the performance increased by 0.45% comparing to benchmark method.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SISTEM ALIRAN KUASA OPTIMAL MENGGUNAKAN TEKNIK PENGOPTIMUMAN HARRIS HAWKS DAN ALGORITMA SALP SWARM

Oleh

ISLAM MOHAMMAD ZOHRUL

Februari 2021

Pengerusi : Professor Madya Ir. Noor Izzri bin Abdul Wahab, PhD
Fakulti : Kejuruteraan

Aliran Kuasa Optimum (OPF) adalah salah satu alat paling penting yang digunakan selama satu dekad hingga kini dalam sistem pengurusan tenaga untuk operasi dan perancangan sistem kuasa moden yang boleh dipercayai. Objektif utama adalah untuk menyesuaikan semua parameter pengendalian dengan memenuhi kekangan kesamaan dan ketaksamaan untuk mengoptimumkan beberapa fungsi objektif.

Dewasa ini, deregulasi industri tenaga, permintaan tenaga yang semakin meningkat, batasan penyambungan saluran transmisi dan pengedaran yang ada telah memperhebat pelaksanaan teknik pengoptimuman secara akut. Lebih-lebih lagi, penggunaan sumber daya alam yang ada dan keprihatinan gas pencemaran alam sekitar yang semakin meningkat, seperti pelepasan CO2 semasa penjanaan kuasa dan kesannya yang serius terhadap alam sekitar telah mendapat perhatian yang lebih.

Tesis ini mengemukakan Pengoptimuman Helang Harris (HHO) dan Algoritma Kawanan Salpa (SSA) yang dikembangkan baru-baru ini untuk menyelesaikan masalah OPF tunggal dan pelbagai objektif yang mempertimbangkan kos bahan bakar, kehilangan kuasa dan pelepasan persekitaran. Selain itu, kaedah yang dicadangkan menyelesaikan masalah OPF pelbagai objektif dengan bantuan kaedah jumlah wajaran tanpa pilihan.

Data sistem ujian standard IEEE 30-bas dan 57-bas telah dikaji untuk mewajarkan keberkesanan kaedah yang dicadangkan untuk masalah OPF tunggal dan pelbagai objektif yang mempertimbangkan kos bahan bakar, kehilangan kuasa dan pelepasan persekitaran. Selain itu, tidak ada kaedah jumlah wajaran pilihan yang digunakan untuk menyelesaikan masalah OPF pelbagai objektif secara serentak. Hasil yang diperoleh menunjukkan peningkatan yang baik dibandingkan dengan teknik berasaskan kawanan lain seperti Pengoptimuman Algoritma Paus (WOA), Nyalaan Kupu-kupu (MF), dan

Pengoptimuman Algoritma Cacing Cahaya (GOA) dari segi prestasi dan kualiti penumpuan. Keputusan yang didapati menunjukkan teknik HHO yang dicadangkan mengatasi teknik-teknik lain dengan memberikan biaya bahan bakar sebanyak 801.829 $/jam yang membaiki sebanyak 0.01% menunjukkan solusi optimum terbaik untuk penyelesaian objektif tunggal di antara berbagai kaedah yang dikemukakan. Begitu juga, kehilangan kuasa dan pelepasan persekitaran masing-masing diperbaiki sebanyak 0.37% dan 3.72%. Hasil OPF pelbagai objektif dicatatkan pada 0.02% hingga 0.55% untuk kes yang berbeza. Terakhir, tiga objektif diteliti bersama di mana prestasi meningkat sebanyak 0.45% jika dibandingkan dengan kaedah penanda aras.

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Islam Mohammad Zohrul

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Noor Izzri bin Abdul Wahab, PhD
Associate Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Hashim bin Hizam, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Nashiren Farzilah binti Mailah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 10 June 2021

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Signature:	
Name of Member of Supervisory Committee:	Associate Professor Dr. Hashim bin Hizam

Signature:	
Name of Member of Supervisory Committee:	Associate Professor Dr. Nashiren Farzilah binti Mailah

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LIST OF ABBREVIATIONS

AAM	Affine Arithmetic Method
ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
ACOPF	AC Optimal Power Flow
AI	Artificial Intelligence
APL	Active Power Loss Minimization
BBBC	Big-Bang Big Crunch Algorithm
BBO	Biogeography Based Optimization
BSA	Backtracking Search Algorithm
CCS	Carbon Capture and Sequestration Technology
CFO	Central Force Optimization
CKH	Chaotic Krill Heard
CSS	Charged System Search
DA	Dragonfly Algorithm
DA-PSO	Dragonfly-Particle Swarm Optimization
DC-OPF	Direct Current Optimal Power Flow
DE	Differential Evolution
DE	Differential Evolution Algorithm
DG	Distributed Generation
DSA	Differential Evolution Algorithm
EA	Evolutionary Algorithm
ED	Economic Dispatch
EED	Environmental/Economic Dispatch
EGA	Enhanced Genetic Algorithm

EP	Evolutionary Programming
ES	Evolution Strategy
EV	Electrical Vehicles
FA	Firefly Algorithm
FEA	Faster Evolutionary Algorithm
GA	Genetic Algorithm
GB	Galaxy Based
GM	Gradient Method
GOA	Glowworm Optimization Algorithm
GP	Genetic Programming
GR	Gradient Reduced Method
GS	Group Search Algorithm
GSA	Gravitational Search Algorithm
GSO	Group Search Optimizer
GWO	Grey Wolf Optimization Algorithm
HBMO	Honey Bee Mating Optimization
HHO	Harris Hawks Optimization
HLM	Human Learning Method
HS	Harmony Search
IEP	Improved Evolutionary Programming
IMFO	Improved Moth-Flame Optimization Algorithm
IPM	Interior Point Method
KBF	Knowledge Based Framework
LCM	Linear Compression Methods
LF	Levy Flight
LP	Linear Programming

MBFA	Multi-hive Bee Foraging Algorithm
MDE	Modified Differential Evolution Algorithm
MF	Moth Flame
MHBMO	Modified Honey Bee Mating Optimization
MIP	Mixed Integer Programming
MM	Newton Method
MO	Magnetic Optimization
MOO	Multi-objective Optimization
MOOPF	Multi-objective Optimal Power Flow
MTLBO	Modified Teaching Learning Based Optimization
NLP	Non-Linear Programming
NM	Newton-based Methods
NP	Linear Programming
OPF	Optimal Power Flow
ORPD	Optimal Reactive Power Dispatch
PSO	Particle Swarm Optimization
QP	Quadratic Programming
SCED	Security Constraint Economic Dispatch
SCOPF	Security Constraint Optimal Power Flow
SI	Swarm Intelligence
SOOPF	Single-objective Optimal Power Flow
SSA	Salp Swarm Algorithm
TEC	Total Emission Cost
TFC	Total Fuel Cost
TLBO	Teaching Learning Based Optimization
TS	Tabu Search

WOA	Whale Optimization Algorithm

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Over the decades, the optimal power flow (OPF) tool is an inevitable part of energy management system for reliable operation and proper planning of modern power system. The significant importance of optimization of generation dispatch to meet the load demand has taken a giant leap with the advent of advanced computer technologies. In recent years, the optimization techniques were tremendously used in solving power system problems. Owing to the continuous growth of power demand, also the concern of uninterrupted and quality power supply, environmental emissions, and restructuring of power system due to the introduction of renewable energy sources because of limited natural resources. These motivated the researchers to employ heuristic-based several optimization techniques in reducing the losses of the system and also supplying quality power to the end consumer with optimal operating cost of power generation.

The restructuring in power sector has been observed in many countries like the UK, Sweden, Finland, and USA to make the monopoly system of power supply to open market systems (Sumit Verma et al., 2016). The electric power system is a complex interconnected network comprises of power generation, transmission lines, and distribution facilities, whose main goal is to deliver the electricity from power grid to a wide range of consumers (Mohd Herwan Sulaiman et al.,2015). To meet the increased demand of electricity, the power system has been very intricate than ever before which requires effective optimization of existing networks while the dramatically fluctuating consumer's load. In these circumstances, to ensure the system reliability and security intensive numerical analysis and its study is an indispensable part of power system (Ruey-Hsun Liang et al., 2015). Additionally, due to the technical and environmental restrictions, the expansion of conventional power plants is well-nigh impossible (Mahmoud Pesaran H.A et al., 2017).Therefore, utility industries are repeatedly trying to find the best economic manner to run the generating units for supplying the increased load demand (Diljinder Singh et al., 2019). Because of the intriguing multi-faceted challenges in operation and planning strategy, the increase in role of decision-makers plays another significant importance over the operational management and simultaneous optimization priorities. As most of the real-life problems have several solutions but optimization of one parameter affects the other. So, there is a need to sacrifice some possible set of solutions which is not comprisable of all parameters in the system to be optimized. The concept of Optimal Power Flow (OPF) was first proposed by the French scholar Carpentier in 1960 since then the research on the optimal operation of power systems have reached a new dimension. OPF was regarded as an extension of the class of power flow (Xuanhu He et al., 2015). OPF seeks to determine the optimal setting of control variables by minimizing the selected objective function considering equality and inequality constraints of power system (A.E. Chaib et al., 2016).

In deregulated power market, the OPF problem is a highly non-linear, non-convex, non-differentiable, and multi-dimensional complex problem with a mixture of discrete and continuous variables (Khaled ben oualid Medani et al., 2018). In this context, the main goal of OPF is to optimize several objective functions of the system for example fuel cost, real and reactive power loss, voltage stability, environmental emissions by satisfying the equality and inequality constraints. The control variables include the generator real powers except the slack bus, the generator bus voltage, the tap ratio of transformer, and the reactive power generation of VAR sources, and the state variables include the generator reactive power output, the load bus voltage and network line flow. These variables are to be adjusted optimally by optimizing the predefined objective function in order to operate the system efficiently and economically over the continuous change in the load demand (K. Pandiarajan et al., 2016).

More recently, environmental emission has become the biggest concern as a consequence of rising global warming and climate change. As a result, minimization of the fuel cost of generation is no longer the only focus for power system operator (Ehab E. Elattar et al., 2019). Because, these pollutant gases such as oxides of sulfur (SOx), oxides of nitrogen (NOx), Carbon monoxide (CO), carbon dioxide (CO2) and also small amounts of toxic metals released by the thermal power plants during the power generation process into the atmosphere and pollute the environment (Carlos Alberto Oliveira De Freitas et al.,2018, Narges Daryani et al., 2016). On the other hand, with the advanced development of modern science and technology, the standard of living in our society has immensely increased which has led to dramatic growth of the per capita energy consumption. To meet this ever-increasing load demand, electricity generation must be increased in proportion to the power consumption with minimum environmental emission (Govind D. Sen et al., 2017). In fact, most of the power plants all around the world generate electricity with natural gas, coal or oil as the basic fuel to run the electrical generators. As a result, the greenhouse gas elements, in particular, CO2 is produced more and more resulting in global warming (Ranjit Roy et al., 2015). The US clean air act amendments of 1990, directed the utility companies to generate energy in keeping the pollution at the minimum level in association with other power system constraints (Elnaz Davoodi et al., 2018).

At present, due to the increasing of energy crisis, most of the researchers emphasize the fuel cost minimization and operational efficiency in power systems. As a consequence, this bulk power generation increases the amount of pollutant gasses in the environment which causes serious global warming. Therefore, ignoring the acute environmental issues, only considering the fuel cost minimization in the OPF is far enough from the economic, and reliable operation of the power system. Whereas, the emission reduction must be taken into the problem for clean, economic and reliable operation (Xiaohui Yuan et al., 2017). All these points have given a number of choices to decision-makers to optimize the objective function optimally as most of the power system OPF problems are conflicting and multi-objective. In fact, no optimal solution is paramount but a group of a possible solutions can be obtained in solving the multi-objective optimization (Warid et al., 2018).

1.2 Problem Statement

Conventional methods have been successfully implemented to solve the OPF problems. These optimization techniques have more than one local optimum and only one global optima. Further, these methods trapped at local minima, if the primary guess is not assumed close to the solution. Another drawback, the complexity of the problem increases because of the number of non-linear constraints and large-scale size of the system.

On the other hand, to overcome these shortcomings of conventional techniques, researchers for the last few decades have been focusing on meta-heuristic-based techniques to attain the solution of OPF problem without trapping into the local minima due to the immense development in computer technologies. However, these approaches also trapped in local minima due to poor exploration capability and become inefficient. Besides, sometimes these methods show infeasible solution by violating operational constraints and poor convergence property. Thus, none of these optimization techniques can assure the consistency of an optimal solution for solving all real-world problems or the OPF with many objectives as specified earlier. Therefore, still there is need for advanced powerful optimization technique to overcome the existing short comings in solving OPF problem effectively by enforcing the security constraints within their limits. HHO and SSA are the two recently developed nature-inspired optimization techniques which demonstrate promising exploration and exploitation capabilities in attaining global optima.

1.3 Research Aims and Objectives

The main objective of this thesis is to propose a novel nature-inspired heuristic-based optimization techniques to solve the selective OPF problem considering fuel cost, power loss and environment emission while satisfying the power system equality and inequality constraints. The prime objectives can be described as,

1. To propose Harris Hawks Optimization (HHO) and Salp Swarm Algorithm (SSA) to solve single-objective OPF considering total fuel cost, active power loss and environment emission individually.

2. To apply the proposed HHO and SSA with no preference weighted sum method for solving multi-objective optimization problems.

3. To validate the proposed HHO and SSA methods by comparing with other techniques mentioned in the literature.

1.4 Scope and Limitation of this Study

This study has proposed a recently developed optimization techniques for solving the non-linear OPF problems in power system network. In this study, only conventional generator is using to test the effectiveness of the proposed methods by formulating three selective objective functions namely fuel cost, power loss and environment emission. However, the main limitations of this study as follows:

1. This study did not consider the effect of placement of Distributed Generation (DG) to reduce the cost and improve the voltage profile.

2. The application of the proposed methods for solving multi-objective OPF in large-scale test system were not studied.

The further research of the proposed methods can be extended as follows:

1. The concept of OPF problem can be considered for the optimal placement and sizing of DG and economic dispatching of renewable integrated power system.

2. The proposed methods also can be employed to solve multi-objective OPF using Pareto font in real-time large-scale system including other objectives, such as, voltage stability.

1.5 Thesis Layout

The remaining part of this thesis is structured as follows.

Chapter 2 deals with the literature review on optimal power flow in the power system network. A number of conventional and heuristic based optimization techniques have been described in terms of single and multi-objective OPF problems. This section also mentioned the comparison among all optimization methods.

Chapter 3 presented the mathematical formulation of the single and multi-objective OPF problems including network constraints to solve by the proposed method. Likewise, the inspiration, problem solving behavior of the proposed heuristic method was illustrated. Furthermore, this section showed the application of swarm-based technique in solving optimization problem in power system in a flow chart.

Chapter 4 discussed the numerical results achieved by the proffered method and the comparison among other selected well-known nature-inspired methods of optimization in power system. The results were portrayed in the separate sections as single and multi-objective segment. It also discusses the comparative analysis with literature work for case 1.

Chapter 5 reiterates the objective of the work and justification of the proposed method. It also highlights the findings and the future scope of the work.

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