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A Comprehensive Review of Optimal Power Flow Based on Artificial Intelligence Methods

E.A. Nyiekaa¹, C.O. Onah², F.T. Ikule³

Department of Electrical and Electronics Engineering, Federal University of Agriculture Makurdi,
Benue State, Nigeria^{1,2,3}

ABSTRACT: The optimal Power Flow (OPF) has been one of the most important and extensively considered nonlinear optimization problems for over five decades. OPF in general refers to the optimization of the operation of electric power system comprising of power generation, transmission and network distribution while satisfying various system constraints and control limits. There has been a wide variety of OPF formulations and solution techniques due to its rapid evolution as a result of dynamic electricity markets and the integration of renewable energy sources. OPF methods are classified into conventional and intelligent methods. However, this survey is focused on artificial intelligence methods to provide a comprehensive literature review for the state of the art in OPF formulations and solution methods. This survey captures the general OPF formulation, review of 30 heuristic or artificial intelligence methods and their various optimized objective functions. This paper is useful to power system operators as well as researchers for efficient planning, monitoring, control, operation and management of electric power systems.

KEYWORDS: Optimal Power Flow, Artificial Intelligence (AI), System Constraints, Economic Load Dispatch, Flexible Alternating Current Transmission System (FACTS), Metaheuristic Algorithm.

I. INTRODUCTION

Optimal Power Flow (OPF) has gained much attention in recent times due to its relevance in the power sector. It is considered to be an important tool for efficient planning, management and operation of power systems operations. The major task of Optimal Power Flow is to ascertain the best or the safest operating point (control variables) for certain objective functions while satisfying the system equality and inequality constraints [1]. There are several objective functions related to electric power systems that can be optimized such as fuel cost of generation, transmission losses, cost of Flexible Alternating Current Transmission System (FACTS), voltage stability, economic generation scheduling, load forecasting, voltage deviations, power transfer capability, generation emission, system security, etc. The adjustable system control variables include the active power generation, size of FACTS devices, transformer tap settings and generation voltage buses.

II. PROBLEM FORMULATION

The solution of Optimal Power Flow (OPF) problem is aimed to optimize an objective function by means of adjustment of power control variables optimally while satisfying numerous equality and inequality constraints. According to Ebeed et al [1], the optimization problem can be represented mathematically as presented in equations (1) – (33)

$$\left. \begin{array}{l} \text{Min } F(x, u) \\ \text{subjected to} \\ g_j(x, u) = 0 \quad j = 1, 2, \dots, m \\ h_j(x, u) \leq 0 \quad j = 1, 2, \dots, p \end{array} \right\} \quad (1)$$

where F is the objective function, x is a vector quantity representing the dependent variables (state variables), u is the vector quantity representing the independent variables (control), g_j and h represent the equality and inequality constraints respectively, m and p represent the number of equality and inequality constraints respectively. The dependent variables (x) in power system can be represented as equation (2).



$$[x = P_{G1}, V_{L1} \dots V_{L, NPQ}, Q_{G,1} \dots Q_{G, NG}, S_{TL,1} \dots S_{TL, NTL}] \tag{2}$$

where slack bus power is P_{G1} , voltage of load bus is V_L , the generator reactive power output is Q_G , the apparent power flow in the transmission line as S_{TL} , number of load buses is NPQ , number of generator buses as NG , and number of transmission lines as NTL .

The independent variables u of power system are as indicated in equation (3).

$$u = [P_{G,2} \dots P_{G, NG}, V_{G,1} \dots V_{G, NG}, Q_{C,1} \dots Q_{C, NC}, T_{1 \dots L, 1} \dots T_{NT}] \tag{3}$$

where the output active power of the generator is denoted as P_G , voltage of generator bus is V_G , the injected reactive power of shunt compensator as Q_C , transformer tap settings as T , number of shunt compensator units as NC , and the number of transformers as NT .

II-1-Objective Function

II-1-1- Single Objective

The most common objective functions used for optimal power flow solution considering optimization techniques include:

(a) *Quadratic Fuel Cost*

The objective function here refers to the quadratic equation of total fuel cost of generation which can be formulated as equation (4).

$$F_1 = \sum_{i=1}^{NG} F_1(P_{Gi}) = \sum_{n=1}^{NPV} (a_i + b_i P_{Gi} + c_i P_{Gi}^2) \tag{4}$$

where, the fuel cost of the i th generator is F_i , and the cost coefficients of the i th generator are a_i , b_i and c_i .

(b) *Quadratic Function with Valve-Point Effect*

In an ideal sense, the quadratic fuel costs of some generating plants are non-smooth as a result of the influence of steam admission from their control valves which is known as valve-point loading effect. Steam admission will amount to the occurrence of ripples in fuel cost. Addition of sine term to the fuel cost signifies the effects of valve-point loading effects as shown in equation (5).

$$F(x, u) = \sum_{i=1}^{NG} F_1(P_{Gi}) = \sum_{i=1}^{NG} (a_i + b_i P_{Gi} + c_i P_{Gi}^2) + |d_i \sin(e_i (P_{Gi}^{min} - P_{Gi}))| \tag{5}$$

where the fuel cost coefficients of the i th unit with valve-point effects are represented as d_i and e_i .

(c) *Piecewise Quadratic Cost Function*

Thermal generating plant can have numerous fuel sources such as natural gas, oil and coal. Therefore, the fuel cost functions of such plants will be non-convex and can be split as piecewise quadratic cost functions for different fuel types as presented in equation (6).

$$F(P_{Gi}) = \begin{cases} a_{i1} + b_{i1} P_{Gi} + c_{i1} P_{Gi}^2 & P_{Gi}^{min} \leq P_{Gi} \leq P_{G1} \\ a_{i2} + b_{i2} P_{Gi} + c_{i2} P_{Gi}^2 & P_{G1} \leq P_{Gi} \leq P_{G2} \\ \dots \\ a_{ik} + b_{ik} P_{Gi} + c_{ik} P_{Gi}^2 & P_{G(k-1)} \leq P_{Gi} \leq P_{Gi}^{max} \end{cases} \tag{6}$$

(d) *Voltage Profile Improvement*

The objective function for the minimization of voltage deviations of load buses from the specified voltage limits can be expressed as equation (7)

$$F_3 = VD = \sum_{i=1}^{NPQ} |(V_i - 1)| \tag{7}$$

(e) *Voltage Stability Enhancement*

Voltage stability index (L) proposed by Kessel and Glavitsch has been known to be an important value used in determining system stability. Voltage stability index is calculated for all load buses and it varies from 0 (no-load situation) to a maximum of 1 loading point (voltage collapse situation), which confirm the fact that minimization of this value saves the power system from voltage collapse scenario. The objective function can be developed using equation (8).

$$F_4 = \min(L_{max}) = \min(\max(L_n)) \quad n = 1, 2, \dots, NPQ \tag{8}$$

where the voltage stability index L_n of the bus n th, which can be calculated with the help of equation (9)

$$L_n = \left| 1 - \sum_{i=1}^{NPV} F_{ij} \frac{V_i}{V_j} \right| \tag{9}$$

where the voltage of the i th generator bus is given as V_i and the voltage of the load bus as V_j . Therefore, the F_{ij} can be obtained from the Y_{bus} matrix as shown in equation (10)

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \tag{10}$$

where the complex currents are given as I_G, I_L and the complex voltage vectors at the generator and load buses as V_G and V_L respectively. The submatrices of system Y_{bus} are given as Y_{GG}, Y_{LL}, Y_{GL} and Y_{LG} . Manipulations of equation (10) results in equation (11)

$$\begin{bmatrix} V_G \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} V_G \\ I_G \end{bmatrix} \tag{11}$$

where $F_{ij} = |F_{LG}| = -|Y_{LL}|^{-1}|Y_{LG}|$.

(f) *Real Power Losses Minimization*

Minimization of the active power loss as the objective function can be formulated as equation (12)

$$P_{loss} = \sum_{i=1}^{NLT} G_{ij} (V_i^2 + V_j^2 - 2V_i V_j \cos \delta_{ij}) \tag{12}$$

The conductance of the transmission is given as G_{ij} , the number of transmission lines is NLT and the phase voltage difference as δ_{ij} .

(g) *Emission minimization*

Reduction in environmental pollution can be achieved through minimization of gaseous emission from thermal power plants. The objective function of these emission can be expressed by equation (13)

$$E_m = \sum_{i=1}^{NG} \gamma_i P_{Gi}^2 + \beta_i P_{Gi} + \alpha_i + \zeta_i \exp(\lambda_i P_{Gi}) \tag{13}$$

where the emission coefficients of the i th generator are given as $\gamma_i, \beta_i, \alpha_i, \zeta_i$ and λ_i .

II-1-2- *Multi-objective Functions*

The key purpose of solving multi-objective problems is to simultaneously optimize numerous objective functions. The multi-objective problem can be formulated as equation (14)

$$\text{Min } F(x, u) = [F_1(x, u), F_2(x, u), \dots, F_i(x, u)] \tag{14}$$

The number of objective functions is represented as 'i'. Pareto optimization method or weight factors is used to achieve solution of multi-objective functions as given in equations (15) – (18).

$$F(x, u) = \omega_1 \left(\sum_{i=1}^{NG} (\alpha_i + b_i P_{Gi} + c_i P_{Gi}^2) \right) + \left(\sum_{i=1}^{NPQ} |(V_i - 1)| \right) \tag{15}$$

$$F(x, u) = \omega_1 \left(\sum_{i=1}^{NG} (\alpha_i + b_i P_{Gi} + c_i P_{Gi}^2) \right) + \omega_2 \left(\sum_{i=1}^{NTL} G_{ij} (V_i^2 + V_j^2 - 2V_i V_j \cos \delta_{ij}) \right) \tag{16}$$

$$F(x, u) = \omega_1 \left(\sum_{i=1}^{NG} (\alpha_i + b_i P_{Gi} + c_i P_{Gi}^2) \right) + \omega_2 (\max(L_n)) \tag{17}$$

$$F(x, u) = \omega_1 \left(\sum_{i=1}^{NPQ} |(V_i - 1)| \right) + \omega_2 \left(\sum_{i=1}^{NTL} G_{ij} (V_i^2 + V_j^2 - 2V_i V_j \cos \delta_{ij}) \right) + \omega_3 (\max(L_n)) \tag{18}$$

The weight factors which are selected in accordance with relative importance of one objective to others are given as ω_1 , ω_2 and ω_3 . The values of weight factors are usually selected as given by equation (19)

$$\sum_{i=1}^n \omega_n = 0 \tag{19}$$

II-1-3- Constraints

Several constraints found in the transmission system can be characterized as follows:

(a) Equality Constraints

The balance load flow equations representing the equality constraints can be formulated as presented in equation (20) and (21).

$$P_{Gi} - P_{Di} = |V_i| \sum_{j=1}^{NB} |V_j| (G_{ij} \cos \delta_{ij} + B_{ij} V_j \sin \delta_{ij}) \tag{20}$$

$$Q_{Gi} - Q_{Di} = |V_i| \sum_{j=1}^{NB} |V_j| (G_{ij} \sin \delta_{ij} - B_{ij} V_j \cos \delta_{ij}) \tag{21}$$

The generated active and reactive power at bus i is given as P_{Gi} and Q_{Gi} respectively.

The active and reactive load demand at bus i as P_{Di} and Q_{Di} respectively.

The conductance and susceptance between bus i and j as G_{ij} and B_{ij} respectively.

(b) Inequality Constraints

The inequality constraints can be categorized as presented in equations (22) – (28).

(i) The generators active power output $P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad i = 1, 2, \dots, NG$ (22)

(ii) Generators bus voltages $V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max} \quad i = 1, 2, \dots, NG$ (23)

(iii) Generators reactive power output $Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \quad i = 1, 2, \dots, NG$ (24)

(iv) Transformer tap settings $T_{Gi}^{min} \leq T_i \leq T_{Gi}^{max} \quad i = 1, 2, \dots, NT$ (25)

(v) Shunt VAR compensator $Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max} \quad i = 1, 2, \dots, NC$ (26)

(vi) Apparent power flow in transmission lines $S_{Li} \leq S_{Li}^{min} \quad i = 1, 2, \dots, NTL$ (27)

(vii) Voltage magnitude of load buses $V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max} \quad i = 1, 2, \dots, NPQ$ (28)

(viii) The quadratic penalty formulation of objective function can be used to easily consider the dependent control variables in the optimization solution, which can be expressed as equation (29).

$$F_g(x, u) = F_i(x, u) + K_G (\Delta P_{G1})^2 + K_Q \sum_{i=1}^{NPV} (\Delta Q_{Gi})^2 + K_V \sum_{i=1}^{NPQ} (\Delta V_{Li})^2 + K_S \sum_{i=1}^{NTL} (\Delta S_{Li})^2 \tag{29}$$

where the penalty factors are given as K_G , K_Q , K_V and K_S . The high positive values in terms of penalty ΔP_{G1} , ΔQ_{Gi} , ΔV_{Li} , and ΔS_{Li} are defined as equation (30), (31), (32) and (33) respectively.



$$\Delta P_{G1} = \begin{cases} (P_{G1} - P_{G1}^{max})P_{G1} > P_{G1}^{max} \\ (P_{G1} - P_{G1}^{min})P_{G1} < P_{G1}^{min} \\ 0 & P_{G1}^{min} < P_{G1} < P_{G1}^{max} \end{cases} \quad (30)$$

$$\Delta Q_{Gi} = \begin{cases} (Q_{Gi} - Q_{Gi}^{max})Q_{Gi} > Q_{Gi}^{max} \\ (Q_{Gi} - Q_{Gi}^{min})Q_{Gi} < Q_{Gi}^{min} \\ 0 & Q_{Gi}^{min} < Q_{Gi} < Q_{Gi}^{max} \end{cases} \quad (31)$$

$$\Delta V_{Li} = \begin{cases} (V_{Li} - V_{Li}^{max})V_{Li} > V_{Li}^{max} \\ (V_{Li} - V_{Li}^{min})V_{Li} < V_{Li}^{min} \\ 0 & V_{Li}^{min} < V_{Li} < V_{Li}^{max} \end{cases} \quad (32)$$

$$\Delta S_{Li} = \begin{cases} (S_{Li} - S_{Li}^{max})S_{Li} > S_{Li}^{max} \\ (S_{Li} - S_{Li}^{min})S_{Li} < S_{Li}^{min} \\ 0 & S_{Li}^{min} < S_{Li} < S_{Li}^{max} \end{cases} \quad (33)$$

III. OPTIMAL POWER FLOW METHODS

Numerous deterministic (classical) and non-deterministic (recent) heuristic optimization techniques have been used in finding the solution to Optimal Power Flow problems. Sensitivity analysis and gradient-based methods have been the commonest classical techniques used. However, it is important to note that the deterministic/conventional methods used may be trapped in local optimum as a result of non-linearity of the Optimal Power Flow problems, which makes the metaheuristic or artificial intelligence optimization techniques more suitable in solving Optimal Power Flow problems.

III-1-Bee Colony Optimization (BCO)

Artificial Bee Colony (ABC) mimics the intelligent scavenging behaviour of a honeybee swarm. ABC concept is simple with fewer control parameters which makes it easy to implement.

The Harvest Season Artificial Bee Colony Algorithm was presented to improve search mechanism performance and convergence speed [2]. An improved Artificial Bee Colony (IABC) for Optimal Power Flow (OPF) problem in electric power system based on orthogonal learning meant to handle ABC issues has also been presented [3]. W. Bai presented an ABC algorithm that can handle different objectives [4], and a swarm intelligent-based approach in solving OPF problem based on modified artificial bee colony algorithm with global and local neighborhoods (ABCGLN) for optimal settings of OPF control variables [5].

III-2- Optimal Power Flow with FACTS Devices

Several algorithms have been reported in the literature on how to solve OPF and Power flow problems for power system equipment using different FACTS devices. A paper presentation on the use of Genetic algorithm (GA) for the placement of TCSC in improving power system security and availability on the Nigerian grid network made of 35-buses was modelled and simulated using PSAT software [6]. Komolafe and Lawal [7] presented an OPF analysis of Nigerian 330kV power system whereby the Static Synchronous Compensator (STATCOM) and Unified Power Flow Controller (UPFC) data were concurrently incorporated into an existing Newton-based OPF algorithm for improved performance. [8] proposed an Artificial Immune System (AIS) for minimization of OPF control with TCSC and TCPS based on the clonal selection principle, hyper-mutation, ageing operator and tournament selection.

III-3- Grey Wolf Optimizer (GWO)

Grey Wolf Optimizer is a population-based heuristic algorithm that mimics the leadership ladder and hunting mechanism of grey wolves in nature.

A unique Hybrid Imperialist Competitive and Grey Wolf Algorithm (HIC-GWA) used to solve twelve different cases of simple and multi-objective OPF problems for modern power systems involving wind and photovoltaic power generators have been presented [9]. whereas a novel Single/Multi-Objective Optimization based on Grey Wolves (S/MOGWO) to enhance fast convergence, minimize emission grades of pollutants and at the same time reduce the individual cost of production [10]. A Multi-Objective Grey Wolf Optimizer (MOGWO) for evaluation of OPF problems was proposed by [11] for minimization of emission, fuel cost and active power loss. The transmission line capacity enhancement with optimal placement and sizing of Unified Power Flow Controller (UPFC) on the IEEE 14-

bus network was presented by [12] to provide adequate network capacity for the transmission lines to accommodate daily load demand.

III-4- Shuffled Frog-Leaping Algorithm (SFLA)

Shuffled Frog Leaping Algorithm is a memetic heuristic method designed to achieve a globally optimal solution through heuristic search performance based on evolution, carried by the individual and global exchange of information among the population. It's a combination benefit of local search tool of PSO and mixture of information from the parallel local search for the purpose of moving towards a global solution. A modified shuffle frog-leaping algorithm (MSFLA) for multi-objective optimal power flow with the target of handling emission issue was presented by Taher Niknam [13]. K. Lenin et al [14] presented an algorithm based on Modified Shuffled Frog-Leaping Algorithm (MSFLA) Optimization to solve multi-objective reactive power dispatch problem taking into cognizance numerous generator constraints in a power system and formulations. A modified shuffled frog leaping algorithm for multi-objective optimal power flow with FACTS devices was employed [15]. A. K. Khamees et al proposed an efficient and reliable hybrid evolutionary-method based on Shuffled Frog Leaping Algorithm (SFLA) and Grey Wolf Optimizer (GWO) to solve Optimal Power Flow (OPF) problem to minimize the total cost of production [16].

III-5- Harmony Search Algorithm (HSA)

The Harmony Search Algorithm is an optimization algorithm developed by Geem, Kim and Loganathan in 2001. The algorithm is based on musical improvisation analogy of jazz, where musicians try to have repeated iterations, the aesthetically pleasant harmony which can be termed optimum solution to a problem. The key advantages of the HSA are its clarity of execution, a record of success and its ability to handle numerous complex problems.

HSA has produced outstanding results across various kind of complex problems such as optimal power flow using a fuzzy logic system with harmony search algorithm (FHSA) to minimize total fuel cost of the generation having quadratic cost characteristic and severity index [17], congestion management [18], renewable energy [19], neural networks [20] and many other applications. A non-linear formulated multi-objective optimal control problem based on harmony search algorithm (HSA) to minimize generation fuel cost and power loss has been presented and tested on IEEE 30-bus system to determine its efficiency and feasibility [21].

III-6- Chicken Swarm Optimization (CSO) Algorithm

Chicken Swarm Optimization Algorithm is associated with birds that live in clusters [22]. Chicken Swarm Optimization (CSO) algorithm stirred out of the social performance of chickens. Every chicken has its laws of motion and chickens are identified by their values of fitness as roosters, hens and chicks. The groups are categorized according to identities. The fittest, weakest and intermediate chickens are simulated as roosters, chicks and hens respectively.

[23] presented an academic paper to investigate the appropriate chicken swarm optimization in solving extreme challenges of non-convex economic load dispatch problem with valve point loading effect, banned operating zones, ramp-rate limits and transmission losses involving disparities of consumer load patterns.

III-7- Bat Algorithm

Bat Algorithm is simple, flexible and very efficient in handling nonlinear and multi-objective problems. Bats have high special level of echolocation which is used to locate prey, obstacles, roosting crevices detection and differentiate various kinds of insects. The BA efficiency depends on automatic zooming and frequency tuning. An improved BA to solve multi-objective power flow (MOPF) problem based on weighted method has been proposed by [24] whose formulation is based on non-linear constrained optimization problem where the reduction in the fuel cost and emission as the objective functions were considered. [25] presented a hybrid method based on ant colony optimization (ACO) and Bat algorithms (BA) for the Optimal Reactive Power Dispatch (ORPF) to improve voltage stability used for determination of the optimal settings of On-load Tap changing Transformer (OLTC), generator excitation and static var compensation. A paper presentation on minimization of real power losses in power system based on Bat algorithm (BA) with and without the presence of UPFC was tested on 5-bus and a modified IEEE 30-bus system [26].

III-8- Firefly Algorithm (FA)

The present population of firefly species is over 2000 [27]. The process of generating the flash light is called the Bioluminescence. The model of warning signals is produced using the light. Each objective function of optimization problem is represented by different light intensity. There are some similarities between firefly algorithm (FA) and bacterial foraging algorithm (BFA). Their respective attraction is based on objective function, fitness and distance. FA is capable of solving discrete and continuous optimization problems. [28] presented a Firefly Optimization Technique (FFOT) for solving convex economic load dispatch problem, formulated to minimize the total generation cost of fuel

without violation of system constraints using quadratic fuel cost model of four different Nigerian power stations which include: Sapele, Delta, Afam and Egbin power station. [29] presented an OPF problem based on firefly algorithm (FA) using Unified Power Flow Controller (UPFC) for optimal placement of UPFC to minimize the real power losses and enhanced the loadability of the system. [30] developed a firefly algorithm in MATLAB environment to solve OPF problems in power system in which a quadratic cost function was applied in the minimization of the fuel cost objective. An effective meta-heuristic, population-based Hybrid Firefly Particle Swarm Optimization (HFPSO) algorithm for solving various non-linear and convex OPF problems has been proposed in [31] to enhance exploration, exploitation strategies and rapid convergence rate.

III-9- Ant Lion Optimization (ALO) Algorithm

Ant Lion Optimizer is equally known as Antlion Optimizer. It's a novel meta-heuristic algorithm whose mathematical formulations mimic the interactions of ants and antlions. The random movements of ants, traps building and entrapment of ants in traps, grasping of prey, and traps re-building formed the basis for formulation and implementation of Ant lion algorithm [32]. Ant lion lives under the pit and waits for the prey to be trapped. Ant lions consumed the trapped prey, pushed out the remnants and amend the pit for the next hunt. [33] developed an algorithm based on hunting mechanism of antlions known as Ant Lion Optimizer (ALO) to solve optimal reactive power dispatch (ORPD) problem involving large scale systems. [34] proposed an interactive partitioning structure-based Ant Lion Optimization method to improve the quality and accuracy of the OPF using Multi-Static VAR Compensator (SVC) and Thyristor Controlled Series Controller (TCSC). [35] presented a novel meta-heuristic optimization technique based on Ant Lion Optimizer (ALO) for solving OPF problem. A Multi-Objective Ant Lion Optimization (MOALO) algorithm was proposed by [36] to determine the Pareto optimal front for the multi-objective OPF to produce good solutions of Active and Reactive OPF problem through simultaneous optimization of the conflicting objective functions.

III-10- Social Spider Algorithm (SSA)

Social spiders are another set of organisms that live in clusters. They are lonely with aggressive characters among their own species. Their foraging behaviours and cooperation in the accomplishment of daily tasks inspired the social spider algorithm (SSA) model [37]. The creation of two different evolutionary operators is based on spiders' gender to divide tasks for predation, web design and mating. This algorithm is capable of solving a vast variety of continuous optimization problems as well as minimization of molecular potential energy function [38]. SSA has been tested on standard benchmark problems to examine its performance. A Novel Improved Social Spider Optimization (NISSO) algorithm for the solution of OPF problem was proposed in [39] which can independently optimize fuel cost of generation, power loss, emission of pollutant, voltage deviation and voltage stability index. [40] proposed an Opposition Based Social Spider Optimization (OSSO) for optimal sizing of hybrid renewable energy system incorporating solar and wind energy power generations as a hybrid renewable form of energy for compensation of power demand.

III-11- Flower pollination Algorithm (FPA)

Flower Pollination Algorithm is a nature-inspired population-based algorithm proposed by Xin-She Yang in 2012. The goal of living things is to produce offspring for the next generation, which plants are not an exception. The process of transfer of pollen grains from the anther of a male flower to the stigma of a female flower is called pollination. The model of the flower pollination algorithm is formed from the process of spreading the male pollen grains (stamen) from the anther to the ovule-bearing organ (stigma) during pollination [41]. Shilaja and Ravi [42] presented an Enhanced Flower Pollination Algorithm (EFPA) to solve OPF problem formulation based on multiple objective functions such as minimization of fuel cost of generation, transmission line losses, improvement of voltage stability and thermal emission of power plants. [43] proposed a metaheuristic technique for OPF problems in power system based on flower pollinated algorithm for the minimization of fuel cost with voltage magnitude and line capacity as a constraint. An Adaptive Flower Pollination Algorithm (AFPA) for system planning strategy and successful applications in solving security OPF problems was presented by [44] to ensure FPA performance.

III-12- Krill Herd Algorithm (KHA)

The krill herd algorithm is one of the metaheuristic search algorithms which the formulations and simulations are based on the herding behaviour of krill individuals using a Lagrangian model. This algorithm was developed in 2012 by Gandomi and Alavi. The objective function of KHA is based on the least distance between the food location and position of a krill.

[45] developed a hybrid cuckoo search algorithm and krill herd algorithm (CS-KHA) technique to solve optimal power problems, formulated as a non-convex optimization problem with inconsistent objectives exposed to both equality and

inequality constraints in which its validity was tested on IEEE 57 and IEEE 118-bus systems with five case studies. [46] proposed an improved krill herd algorithm (IKHA) to minimize the tendency of falling into local optimum and ensured the variation of the inertia weight and the step-length scale factor parameter values. Arsalan Abdollahiet al [47] presented an optimal power flow combining FACTS devices and stochastic wind power generation using Krill Herd Algorithm (KHA), incorporated in the optimization problem using Weibull probability density function modelling to find the decisions variables' values, considering different objective functions.

III-13- Cuckoo Search Algorithm (CSA)

Cuckoo is a new nature-inspired optimization method introduced by Yang and Deb in 2009. Cuckoo Search Algorithm (CSA) is one of the recent meta-heuristic optimizations [48]. CSA was inspired by the compulsory brooding parasitic behavior of some cuckoo species in combination with Levy flight behaviour of some birds and fruit flies [49]. Optimal placement and sizing of Distribution Generation (DG) using Cuckoo Search Algorithm (CSA) on Nigerian distribution network using Ayede 34-bus system as a case study to minimize real power loss, voltage stability index (VSI) and reactive power loss using weight method [50]. A Gbest-guided cuckoo search algorithm with feedback control strategy and constraint dominated rule to be guided by the best global solution to strengthen the exploitative ability was also presented [51].

III-14- Moth Swarm Algorithm (MSA)

The Moth Swarm algorithm is a stochastic algorithm inspired by the navigational style of moths which was introduced in 2017. It is a newly inspired intelligent algorithm formulated out of inspired behaviour of Moth searching for food, phototaxis and celestial movement in dark environment.

Elattar formulated an OPF problem of power system incorporating stochastic wind power system [52] using a Modified Moth Swarm Algorithm (MMSA) for the minimization of operating cost, reduction in transmission power losses and voltage profile enhancement where efficient results were obtained. [53] presented an OPF problem solution based on Moth Swarm optimizer (MSO) considering minimization of fuel cost of production, reduction of emission rate, and network power losses as objective functions. Shilaja and Arunprasath proposed a hybrid approach based on Moth Swarm Algorithm and Gravitational Search Algorithm (MSA-GSA) to solve an OPF problem made of wind energy sources [54] where Weibull Distribution Function (WDF) was used to illustrate the alternative nature of wind farm.

III-15- Coyote Optimization Algorithm (COA)

The Coyote Optimization Algorithm is a bio-inspired optimization algorithm formed out of unique intelligent behaviour of coyotes. COA formation is based on the social organization of the coyotes and its adaptation to the environment to proffer solution to optimization problems.

[55] Presented a novel method based on Coyote Optimization Algorithm that can simultaneously solve OPF problem of network configuration and distribution generation (DG) location to reduce real power losses. [56] proposed a Coyote Optimization Algorithm (COA) to solve the large scale Mixed-Integer Nonlinear Programming Photovoltaic Distributed Generation (MINLP PV-DG) sizing problem considering different load levels that are suitable for large scale PV-DG planning problem in distribution network systems. [57] proposed an Improved Optimization Algorithm (ICOA) for location and sizing of solar photovoltaic distribution generation units (PVDGUs) in radial distribution systems in which the obtained results confirmed its outstanding performance. Li et al proposed a Modified Coyote Algorithm (MCOA) for determination of very effective solutions of OPF problems including renewable energy related problems [58].

III-16- Dragonfly Algorithm (DA)

Dragonfly Algorithm is an emerging swarm intelligence metaheuristic optimization algorithm formulated to mimic the dynamic and static swarming behaviours of artificial dragonflies. DA has been proven to be effective and superior over several other known metaheuristic algorithm reported in literature.

Rahman and Rashid [59] presented a vivid survey on dragonfly algorithm and its application in engineering most interestingly in the area of economic load dispatch and loss minimization. [60] proposed a hybrid bat-dragonfly algorithm for OPF in the wind-solar power system through controller parameters' tuning. [61] proposed a hybrid algorithm called DA-PSO which is a combination of dragonfly (DA) and particle swarm optimization (PSO) to determine optimal solutions in power systems. [62] proposed a Non-Dominated Sorting Dragonfly Algorithm (NSDA) for multi-objectives optimal flow problem solution in such a manner that it finds all non-dominated Pareto optimal results at the end of each iteration.

III-17-Glowworm Swarm Optimization

The Glowworm Swarm Optimization is an original swarm intelligence algorithm for optimization developed by Krishnanand and Ghose in 2005, which emulates the blinking behaviour of glowworms [63]. Individually, glowworm transmits a luminescence amount called luciferin, which is decided by the function value of glowworm's present location. In the course of movement, glowworm recognizes its neighbours based on local-decision area and chooses a neighbour with higher luciferin value than itself using a probabilistic mechanism and moves towards it [64]. A solution to multi-objective OPF problem in a wind-thermal power system where total cost of generation, transmission power losses and voltage stability improvement were considered as the three objective functions, the single objective optimization problems were solved using the glowworm swarm optimization (GSO) algorithm while the multi-objective OPF problems used the multi-objective glowworm swarm optimization (MO-GSO) algorithm [65].

III-18- Biogeography-Based Optimization (BBO)

Biogeography-Based Optimization is an evolutionary algorithm that can optimize a function stochastically and iteratively through improvement of candidate solutions with respect to a given measure of quality or fitness function. BBO is used on discontinuous functions and it's known to include numerous variations, and does not make assumptions about the problem and can be applied to wide variety of problems which makes it metaheuristic. [66] presented a biogeography-based optimization algorithm for solving constrained OPF problems in power systems putting into cognizance generators' valve point non-linearity characteristics. [67] presented an adaptive real coded biogeography-based optimization (ARCBBO) for solving OPF problems in power system in which minimization of fuel cost, voltage profile improvement and voltage profile stability were considered as objectives functions. Herbadji et al [68] proposed a hybrid metaheuristic algorithm based on the combination of Biogeography-based optimization (BBO) with Differential Evolution (DE) for solving OPF problem with emission control.

III-19- League Championship Algorithm (LCA)

League Championship Algorithm is a stochastic population-based algorithm suitable for continuous global optimization which mimic a championship atmosphere where artificial teams play an artificial league for several weeks (iterations). For artificial match model analysis, each team creates the required changes in its formation (generation of a new solution) for the next week contest and the championship goes on for several seasons (stopping condition).

An efficient optimization method known as League Champion Algorithm used for solving OPF problems was presented [69] in which fuel cost of generation, emission and voltage profile stability enhancement were considered as the objective functions. Maru and Padma [70] proposed a novel LCA for solving OPF problems for minimization of generation fuel cost, improvement of voltage profile, minimization of real power loss and stability enhancement index.

III-20- Imperialist Competitive Algorithm (ICA)

Imperialist Competitive Algorithm is a heuristic optimization method developed by AtashpazGargari and Caro Lucas in 2007 [71]. Imperialist Competitive Algorithms (ICA) are computation methods used in solving optimization problems of different kinds in computer science and engineering [72]. ICA is seen as social counterpart of Genetic Algorithms (GAs). ICA depicts the mathematical model and the computer simulation of human social evolution while the GAs is based on biological evolution of species.

[73] proposed a new Multi-Objective Modified Imperialist Competitive Algorithm (MOMICA) for multi-objective OPF problem, considering fuel cost, emission, voltage deviation and active power loss as objective functions. Ghasemi et al [74] proposed a novel hybrid algorithm of Imperialist Competitive Algorithm and Teaching Learning Algorithm (TLA) for optimal power flow problem with non-smooth cost functions to address the shortcomings associated with the original ICA and TLA. [75] presented an original Hybrid Imperialist Competitive and Grey Wolf Algorithm (HIC-GWA) to solve twelve different case studies comprising of both simple and multi-objective OPF problems for modern power systems. [76] presented a work on the optimization of distributed systems using Imperialist Competitive Algorithm (ICA) to investigate the optimal location and sizing of Distribution Static Compensator (DSTATCOM).

III-21- Teaching Learning-Based Optimization (TLBO)

The TLBO is based on the effect of the influence of a teacher on the output of learners in a class. The teacher puts his hard work and makes all the learners of a class educated. Then the learners interact with themselves to further modify and improve their gained knowledge.

Farahani and Rashidi [77] introduced a Modified Teaching-Learning-Based Optimization (TLBO) algorithm for solving OPF problems considering high voltage direct current (HVDC) link in power systems to improve quality of solutions and speed up of velocity convergence. [78] proposed a novel flexible planning strategy based on the teaching-learning-based optimization (TLBO) algorithm and pattern search (PS) algorithm to improve the security optimal

power flow (SOPF) through minimization of total fuel cost, total power loss and total voltage deviation. [79] presented a Teaching-Learning based optimization approach for determining size and location of distributed generation for real power loss reduction on Nigerian power system using Backward/Forward Sweep technique. [80] proposed a relatively new optimization technique known as the Teaching-Learning Based Optimization (TLBO) to solve TSC-OPF problem efficiently.

III-22- Symbiotic Organism Search Algorithm (SOSA)

Symbiotic Organisms Search Algorithm is a new metaheuristic optimization algorithm developed in 2014 inspired by symbiotic interactions within a paired organism relationship that are used to search for the fittest organism applicable in mutualism, commensalism, and parasitism for survival in the ecosystem, which does not require algorithm-specific control parameters.

Zamani et al [81] presented a paper on the implementation of Chaotic Immune Symbiotic Organism Search (CISOS) optimization technique to solve optimal Thyristor Controlled Series Compensator (TCSC) problem in a power system to improve voltage. [82] presented a novel variant to the existing Symbiotic Organisms Search (SOS) algorithm to handle the OPF problems considering effects of valve-point loading (VE) and prohibited zones (POZ). [83] proposed a Symbiotic Organism Search (SOS) algorithm to find the optimal network configuration and the placement of distributed generation (DG) units that minimized the real power loss in radial distribution networks using symbiotic relationships.

III-23- Colliding Bodies Optimization Algorithm (CBOA)

Colliding Bodies Optimization is a new heuristic population-based evolutionary algorithm which uses an analogy of the laws of a collision between objects.

[84] presented an article on a new heuristic algorithm called colliding bodies optimization (CBO), used in solving OPF problem in electrical power systems in which minimization of the total fuel cost, voltage profile improvement, minimization of active power loss and enhancement of voltage stability were the considered objective functions. [85] proposed an Improved Colliding Bodies Optimization (ICBO) algorithm to efficiently solve the optimal power flow problem and numerous objectives, constraints and formulations at normal and preventive operating conditions. Mahender et al [86] presented an evolutionary algorithm called Colliding Bodies Optimization to solve OPF problem in a power network in which total fuel cost with valve point loading effect and minimization of emission profile were considered as the objective functions.

III-24- Opposition Based Gravitation Search Algorithm (OPBGSA)

Oppositional Based Gravitation Search Algorithm is an improvement of the Gravitational Search Algorithm (GSA) based on the law of gravity and the interaction between masses. This involves the collection of masses and their interactions based on Newtonian laws of gravity and motion.

[87] presented a paper, non-dominated sorting multi-objective opposition based gravitational search algorithm (NSMOOGSA) for solving different single and multi-objective optimal power flow (OPF) problems in which the oppositional learning concept was employed to improve the current population toward some optimal solutions. [88] presented an evolutionary-based approach to solve the optimal power flow (OPF) problem based on opposition-based gravitational search algorithm (OGSA) for optimal settings of OPF control variables. B. Shaw presented an improved optimization performance of Gravitational Search Algorithm (GSA) opposition-based learning employed in opposition-based gravitational search algorithm (OGSA) for population initialization and also for generation jumping [89].

III-25- Black Hole Optimization Algorithm (BHOA)

Black Hole is a new bio-inspired metaheuristic approach based on the observable fact of black hole phenomena. A black hole is referred to as a region of space-time whose gravitational field is so strong such that nothing enters it, nor even escapes including light. It is a population-based algorithmic approach like other metaheuristic algorithms. [90] presented a black hole (BH) optimization algorithm for the solution of OPF problem considering the cost of generation, voltage deviation reduction and voltage stability enhancement as objective functions. The black hole algorithm simulates the black hole phenomenon, which rely on pull operations, the star absorption and star sucking and its performance illustration has been tested on the IEEE 30 and IEEE 57-bus systems and the obtained results proved promising when compared with other algorithms reported in literature. Another developed approach termed black-hole-based optimization was tested on 59-bus Algerian bus network [91].

III-26- Gravitation Search Algorithm (GSA)

The Gravitational Search Algorithm (GSA) proposed by Rashedi et al is a new algorithm based on the law of gravity. The agents in GSA are considered as objects with masses. Agents attract each other by the force of gravitation. The greater the quality, the stronger the gravity, and the location of the agent with the largest mass is the optimal solution. [92] proposed a novel method of determining the optimal daily configuration based on variable photovoltaic (PV) generation output and the load profile data in which Gravitational Search Algorithm (GSA) was applied to determine the optimum tie switches' positions for a 33-Bus distribution system. [93] presented a gravitational search algorithm (GSA)-based approach for the solution of OPF problem in a distribution network with distributed generation (DG) units. A paper on the Optimal Power Flow Incorporating FACTS Devices using Gravitational Search Algorithm (GSA) to minimize fuel cost function in the problem was presented by [94]. A hybrid algorithm based on the particle swarm optimization and gravitational search algorithms for solving optimal power flow in power systems was presented by [95], which has an advantage over both PSO and GSA as a result of its combined performance.

III-27- Backtracking Search Optimization (BSO)

The Backtracking Search Algorithm (BSA) is a population-based evolutionary algorithm for numerical optimization problems. BSA has a powerful global exploration capacity, though its local exploitation capability is relatively poor which affects the convergence speed of the algorithm. [96] presented solution technique for OPF with valve-point effect and prohibited operating zones of power systems using backtracking search algorithm (BSA) which has been successfully applied as a solution tool to OPF using different cases. [97] presented a highly constrained multi-objective optimization known as Multi-Objective Backtracking Search Algorithm (MOBSA), used as the main optimizer for optimal adjustments of the power system control variables of the OPF problem. Another Backtracking Search Optimization Algorithm (BSA) approach was applied for solving the optimal power flow problem [98] whereby fuel cost, multi-fuels options, valve-point effect and other complexities were considered.

III-28- Artificial Fish Swarm Optimization (AFSO)

Artificial Fish Swarm Algorithm (AFSA) is one of the best optimization methods among the swarm intelligence algorithms first developed by Li et al in 2012. AFSA is inspired by the communal movement of the fish and their numerous social behaviours. Due to instinctive behaviours, the fish constantly try to maintain their colonies and accordingly demonstrate intelligent behaviours. A couple of social interactions such as food search, immigration and the ability to handle enemies result in intelligent social behaviour. [99] presented a weighted Artificial Fish Swarm Algorithm (wAFSA) based model for the placement of Distribution Static Compensator (DSTATCOM) in distribution systems. [100] proposed a multi-objective OPF problem based on an improved Artificial Fish Swarm Algorithm (AFSA) in which objective function such as total cost of generation and constraints conditions were separately treated. A similar approach was proposed by [101] for optimal placement and sizing of static Var compensator (SVC) to enhance system voltage profile.

III-29- Whale Optimization Algorithm (WOA)

Whale Optimization Algorithm is one of the emerging optimization algorithms proposed in the year 2016 which mimic the hunting mechanism of humpback whales [102]. A hybrid method based on the combination of Squirrel Search Algorithm (SSA) and Whale Optimization Algorithm (WOA) was introduced by [103] which resulted to Squirrel Search Algorithm Whale Optimization (SSAWO) for Power Flow Management (PFM) of a Hybrid Renewable Energy Source (HRES) connected Micro-Grid (MG) system. [104] presented an OPF problem based on Whale Optimization Algorithm (WOA) to solve multi-objective real power loss and bus voltage deviation reduction for micro-grid power systems. [105] presented a Line Overload Severity Index (LOSI) for the analysis of the system. [106] proposed a Centralized/Decentralized Controlled Power Flow Applying Whale Versus Genetic Optimization Algorithms to achieve minimum production cost.

III-30- Squirrel Search Algorithm (SSA)

Squirrel Search Algorithm is a novel biological-inspired optimization algorithm has been confirmed to be very effective in solving unimodal, multimodal and multidimensional optimization problems just as other swarm intelligence-based algorithms. For better convergence, an Improved Squirrel Search Algorithm was proposed by [107] where an adaptive strategy of predator presence probability was introduced to balance the exploration and exploitation capabilities of the algorithm. [108] proposed SSA for solving optimal reactive power dispatch (ORPD) problem of power system whereby the Power Injection Modeling (PIM) and Current Injection Modeling (CIM) were considered and compared for determination of



the best UPFC modeling technique incorporated in the power system. [109] presented a DuponcheliaFovealis Optimization (DFO) algorithm and Enriched Squirrel Search Optimization (ESSO) algorithm designed to solve the optimal reactive power problem.

IV. CONCLUSION

In this review paper, a detailed review of 30 optimal power flow (OPF) Intelligent methods inclusive of incorporation of Flexible Alternating Current Transmission System (FACTS) devices have been presented. The general mathematical representation of optimal power flow problem explaining the objective function along with nonlinear equality and inequality constraints is also presented. Contribution by researchers in each of the methods has been comprehensively captured in terms of the type of algorithm used, objective functions, the type of system used for validations as well as advantages and disadvantages of the method to help readers to quickly understand the significant contributions and striking features of the contributions made by researchers as referenced.

The presented intelligent methods are suitable in solving multiple objective problems as they are versatile in handling qualitative constraints with numerous advantages such as learning ability, fast convergence and their suitability for nonlinear modeling. It is clear from the review that the majority of the studies concentrated on the cost of generation and minimization of transmission losses particularly the economic dispatch. The scope of OPF formulations can be extended to house other operational constraints and objectives with the consideration of FACTS controllers, hydro-plants, distributed generations, as well as combinatorial (hybrid) optimization techniques to solving OPF problems to further enhance the performance and operation of the power system.

REFERENCES

- [1] M. Ebeed, S. Kamel and F. Jurado “Optimal Power Flow Using Recent Optimization Techniques”. Available from: ResearchGate eBook collection, 2018, ch.7, (Accessed 20th December, 2020), pp. 158 – 182.
- [2] A. N. Afandi and H. Miyauchi, “Improved artificial bee colony algorithm considering harvest season for computing economic dispatch on power system”, IEEJ Transactions on Electrical and Electronic Engineering, Vol. 9, Issue 3, pp. 251-257, 2014
- [3] W. Bai, I. Ekeand K. Y. Lee, “An improved artificial bee colony optimization algorithm based on orthogonal learning for optimal power flow problem”, Control Engineering Practice, Vol. 61, pp. 163–172, 2017.
- [4] P. Shankya, A. Parwaz and V. K. Jain, “Artificial Bee Colony Algorithm for Solving Optimal Power Flow Problem”, International Journal of Computer, Volume 178, No. 49, pp. 8-10, September 2019.
- [5] J. C. Bansal, S. S. Jadon, R. Tiwari, D. Kiranand B. K. Panigrahi, “Optimal power flow using artificial bee colony algorithm with global and local neighborhoods”, Int J Syst Assur EngManag, December, 2014.
- [6] M. N. Nwohu, A. Isah, A. U. Usman and A. A. Sadiq, “Optimal Placement of Thyristor Controlled Series Compensator (TCSC) on Nigerian 330kv Transmission Grid to Minimize Real Power Losses”, International Journal of Research Studies in Electrical and Electronics Engineering (IJRSEEE) Volume 2, Issue 4, PP 18-26, 2016.
- [7] O. A. Komolafe and M. O. Lawal, “Optimal Power Flow Analysis of Nigerian Power Network Including FACTS devices, NSE Technical Transaction, Vol. 49, No .1 January – March 2015.
- [8] J. K. P. MousumiBasu and D. P. Dash, “Optimal Power Flow with FACTS Devices using Artificial Immune Systems”, IEEE International Conference on Technological Advancements in Power and Energy (TAP Energy), IEEE, 2017.
- [9] J. B. Hmida, M. J Morshed, J. Lee and T. Chambers, “Hybrid Imperialist Competitive and Grey Wolf Algorithm to Solve Multi-objective Optimal Power Flow with Wind and Solar Units”, Energies, 24 October 2018.
- [10] A. A. Mohamed1, A. A. M. El-Gaafary, Y. S. Mohamed, A. M. Hemeida, “Multi-Objective Modified Grey Wolf Optimizer for Optimal Power Flow”, IEEE, 2016.
- [11] L. Dilip, R. Bhesdadiya, I. Trivedi and P. Jangir, “Optimal Power Flow Problem Solution Using Multi-Objective Grey Wolf Optimizer Algorithm”, Intelligent Communication and Computational Technologies, Lecture Notes in Networks and Systems 19, 2018.
- [12] Y. S. Sunday, J. Boyi, O.P. Ubeh, A. A. Saïdu and M. I. Onimisi, “Transmission Line Capacity Enhancement with Unified Power Flow Controller Considering Loadability Analysis”, Journal of Electrical Engineering, Vol. 18, No. 3, pp. 8-12, 2019.

- [13] T. Niknam, M. RasoulNarimani, M. Jabbari and A.R. Malekpour, "A modified shuffle frog leaping algorithm for multi-objective optimal power flow." *Energy*, Vol. 36, No. 11, pp.6420-6432, 2011.
- [14] K. Lenin, B. R. Reddy and M. S.Kalavathi, "A Modified Shuffled Frog-Leaping Optimization Algorithm for Solving Optimal Reactive Power Dispatch Problem", *International Electrical Engineering Journal*, Vol. 4, No. 2, pp. 1049-1058, 2013.
- [15] R. Azizpanah-Abarghoee, M. R. Narimani, B. Bahmani-Firouzi, and T. Niknam, "Modified shuffled frog leaping algorithm for multi objective optimal power flow with FACTS devices", *Journal of Intelligent & Fuzzy Systems*, Vol. 26, pp. 681–692, 2014.
- [16] A. K. Khamees, A. El-Rafei, N. M. Badra and A. Y. Abdelaziz, "Solution of optimal power flow using evolutionary-based algorithms", *International Journal of Engineering, Science and Technology*, Vol. 9, No. 1, pp. 55-68, 2017.
- [17] K. Pandiarajan and C. Babulal, "Fuzzy harmony search algorithm based optimal power flow for power system security enhancement". *Int. J. Electr. Power Energy Syst.*, Vol. 78, pp. 72–79, 2016.
- [18] A. Jalili and N. Ghadimi, "Hybrid harmony search algorithm and fuzzy mechanism for solving congestion management problem in an electricity market", *Complexity*, Vol. 21, pp. 90–98, 2016.
- [19] Z. W. Geem, Y. Yoon, "Harmony search optimization of renewable energy charging with energy storage system", *Int. J. Electr. Power Energy Syst*, Vol. 86, 120–126, 2017.
- [20] J. Saadat, P. Moallem and H. Koofigar, "Training echo state neural network using harmony search algorithm", *Int. J. Artif. Intell.* Vol. 15, pp. 163–179, 2017.
- [21] P. Ren and N. Li, "Optimal Power Flow solution using the Harmony Search Algorithm", *Applied Mechanics and Materials Vols 599-601*, pp. 1938-1941, 2014.
- [22] X. Meng, Y. Liu, XZ. Gao and H. Zhang, "A new bio-inspired algorithm: Chicken swarm optimization", *Advances in Swarm Intelligence. ICSI, Lecture Notes in Computer Science*. Springer; Vol. 8794, pp. 86-94, 2014.
- [23] S. Sivasakthi and N. Muralikrishnan, "Chicken Swarm Optimization for Economic Dispatch with Disjoint Prohibited Zones Considering Network Losses", *Journal of Applied Science and Engineering Methodologies*, Vol. 2, No.2, pp. 255-259, 2016.
- [24] Y. Yuan, X. Wu, P. Wang and X. Yuan, "Application of improved bat algorithm in optimal power flow problem", Springer Science Business Media, LLC 2017.
- [25] K. Rayudu, G. Yesuratnam, and A. Jayalaxmi, "BAT algorithm and Ant Colony Optimization based Optimal Reactive Power Dispatch to Improve Voltage Stability", *EJERS, European Journal of Engineering Research and Science* Vol. 2, No. 6, June 2017.
- [26] B. Venkateswara Rao and G.V. Nagesh Kumar, "Optimal power flow by BAT search algorithm for generation reallocation with unified power flow controller", *Electrical Power and Energy Systems* Vol. 68, pp. 81–88, 2015.
- [27] S. M. Lim and K. Y. Leong, "A Brief Survey on Intelligent Swarm-Based Algorithms for Solving Optimization Problems: Nature-inspired Methods for Stochastic, Robust and Dynamic Optimization", *Intechopen*, 2018.
- [28] G. A. Ajenikoko, O. E. Olabode and A. E. Lawal, "Application of Firefly Optimization Technique for Solving Convex Economic Load Dispatch of Generation on Nigerian 330 kV, 24-BUS Grid System", *EJERS, European Journal of Engineering Research and Science* Vol. 3, No. 5, May 2018.
- [29] O. Herbadji and T. Bouktir, "Optimal Power Flow Using Firefly Algorithm with Consideration of FACTS Devices (UPFC)", *International Journal on Electrical Engineering and Informatics*, Vol. 7, No.1, March 2015.
- [30] C.N. Ravi, and D.B.G. Reddy, "Optimal Power Flow Solutions Using Firefly Algorithm", *International Journal of Current Engineering and Scientific Research (IJCESR)*, Vol. 5, Issue 4, 2018.
- [31] A. Khan, H. Hizam, N. I. bin Abdul Wahab, and M. L. Othman, "Optimal power flow using hybrid firefly and particle swarm optimization algorithm", *PLoS ONE* 15(8), 2020
- [32] M. Seyedali. "The ant lion optimizer." *Advances in Engineering Software*, Vol. 83, pp.80-98, 2015.
- [33] S. Mouassa, T. Bouktir and A. Salhi, "Ant lion optimizer for solving optimal reactive power dispatch problem in power systems", *Engineering Science and Technology, an International Journal*. 2017.
- [34] B. Mahdad, "Improvement optimal power flow solution considering SVC and TCSC controllers using new partitioned ant lion algorithm", *Electrical Engineering*, 4 June 2020.
- [35] A. Salhi, D. Naimi and T. Bouktir, "Optimal Power Flow Solution using Ant Lion Optimizer Algorithm", *Proceedings of the International Conference on Recent Advances in Electrical Systems, Tunisia*, pp.13-18, 2016.

- [36] O. Herbadji, L. Slimani and T. Bouktir, "Optimal Power Flow with Four Conflicting Objective Functions Using Multi-Objective Ant Lion Algorithm: A Case Study of the Algerian Electrical Network", Iranian Journal of Electrical and Electronic Engineering, Vol. 15, No. 1, March 2019.
- [37] Yu JJQ, Li VOK. "A social spider algorithm for global optimization", Applied Soft Computing. Vol. 30, pp. 614-627, 2015.
- [38] MA. Tawhid and AF. Ali, "A hybrid social spider optimization and genetic algorithm for minimizing molecular potential energy function", Soft Computing. Springer; Vol. 21, No. 21, pp. 6499-6514, 2017.
- [39] T. T. Nguyen, "A high performance social spider optimization algorithm for optimal power flow solution with single objective optimization", Energy. Vol. 171, pp. 218-240, 2019.
- [40] S. R. Sandeep and R. Nandihalli, "Optimal Sizing in Hybrid Renewable Energy System with the Aid of Opposition Based Social Spider Optimization", Journal of Electrical Engineering and Technology, May 2019.
- [41] X-S, Yang, "Flower pollination algorithm for global optimization. In: Unconventional Computation and Natural Computation", Lecture Notes in Computer Science. Vol. 7445, pp. 240-249 2012.
- [42] C. Shilaja and K. Ravi, "Multi-Objective Optimal Power Flow Problem Using Enhanced Flower Pollination Algorithm", Journal of Science, Vol. 30, No. 1, pp. 79-91, 2017.
- [43] S. F. Prima Sakti and S. Pramono Hadi, "Optimal Power Flow Based on Flower Pollination Algorithm", 10th International Conference on Information Technology and Electrical Engineering (ICITEE), pp. 329 – 334, 2018.
- [44] B. Mahdad and K. Srairi, "Security constrained optimal power flow solution using new adaptive partitioning flower pollination algorithm, Appl. Soft Comput. Vol. 46 pp. 501–522, 2016.
- [45] A. Khelifi, B. Bentouati, S. Chettih, R. A. El-Sehiemy, "A hybrid cuckoo search algorithm and krill herd technique for solving problems of optimal power flow in power systems", Journal of electrical system 15-3, pp. 375-391, 2019.
- [46] G. Chen, Z. Lu and Z. Zhang, "Improved Krill Herd Algorithm with Novel Constraint Handling Method for Solving Optimal Power Flow Problems", Energies, 2018.
- [47] A. Abdollahi, A. A. Ghadimi, M. R. Miveh, F. Mohammadi, and F. Jurado, "Optimal Power Flow Incorporating FACTS Devices and Stochastic Wind Power Generation using Krill Herd Algorithm", Electronics, June, 2020.
- [48] H. P. Ly, T.N Thang and H.D Bach, "Adaptive cuckoo search algorithm for economic emission load dispatch problem", International Journal on Electrical Engineering and Informatics, Vol. 8, No. 1, pp. 76-92. 2016.
- [49] M. Mareli and B. Twala, "An adaptive Cuckoo search algorithm for optimization", Applied Computing and Informatics, 2017.
- [50] G. A. Adepoju1, S. A. Salimon, H. A. Aderinko and A. O. Bisiriyu. "Optimal Placement and Sizing of Distributed Generation in a Nigerian Distribution Network Using Cuckoo Search Algorithm", Current Journal of Applied Science and Technology, Vol. 38, No. 6, pp. 1-12, 2019.
- [51] G. Chen, S. Qiu, Z. Zhang, Z. Sun and H. Liao, "Optimal Power Flow Using Gbest-Guided Cuckoo Search Algorithm with Feedback Control Strategy and Constraint Domination Rule", Hindawi Mathematical Problems in Engineering, Volume 2017.
- [52] E. E. Elattar, "Optimal Power Flow of a Power System Incorporating Stochastic Wind Power Based on Modified Moth Swarm Algorithm", IEEE Access, Vol. 7, July 23, 2019.
- [53] M. F. Kotb and A. A. El-Fergany, "Optimal Power Flow Solution Using Moth Swarm Optimizer Considering Generating Units Prohibited Zones and Valve Ripples", J. Electr. Eng. Technol. Vol. 15, pp. 179–192, 2020.
- [54] C. Shilaja and T. Arunprasath "Optimal power flow using Moth Swarm Algorithm with Gravitational Search Algorithm considering wind power", Future Generation Computer Systems, Vol. 98, pp.708–715, 2019.
- [55] T. Thanh Nguyen, T. Trung Nguyen, N. Au Nguyen and T. L. Duong, "A novel method based on coyote algorithm for simultaneous network reconfiguration and distribution generation placement", Ain Shams Engineering Journal, June, 2020.
- [56] G. W. Chang and N. C. Chinh, "Coyote Optimization Algorithm-Based Approach for Strategic Planning of Photovoltaic Distributed Generation", IEEE Access, January 28, 2020.
- [57] T. T. Nguyen, D. T. Pham, L. C. Kien and L. V. Dai, "Improved Coyote Optimization Algorithm for Optimally Installing Solar Photovoltaic Distribution Generation Units in Radial Distribution Power Systems", Hindawi Complexity, Volume 2020.
- [58] Z. Li, Y. Cao, L. V. Dai, X. Yang and T. T. Nguyen, "Optimal Power Flow for Transmission Power Networks Using a Novel Metaheuristic Algorithm", Energies, 2019.
- [59] M. C. Rahman and T. A. Rashid, "A Survey on Dragonfly Algorithm and its Applications in Engineering", Journal of Computational Design and Engineering, 2020.

- [60] V. Gonal and GS Sheshadri, "A hybrid bat–dragonfly algorithm for optimizing power flow control in a grid-connected wind–solar system", *Wind Engineering* 1–14, 2019.
- [61] S. Khunkitti, IA. Siritaratiwat, S. Premrudeepreechacharn, R. Chatthaworn and N. R. Watson, "Energies, 29 August 2018.
- [62] S. B. Pandya and H. R. Jariwala, "Non-Dominated Sorting Dragonfly Algorithm for Multi-Objectives Optimal Power", *Innovations in Power and Advanced Computing Technologies, IEEE*, 2019.
- [63] K. N Krishnanand and D. Ghose, "Glowworm swarm optimization: a new method for optimizing multimodal functions". *Int. J. Computational Intelligence Studies*, Vol. 1, No.1, pp.93-119, 2009.
- [64] T. Kalaiselvi, P. Nagaraja and Z. A. Basith, "A Review on Glowworm Swarm Optimization", *International Journal of Information Technology (IJIT)*, Vol. 3 Issue 2, Mar - Apr 2017.
- [65] S. R. Salkuti, "Optimal power flow using multi-objective glowworm swarm optimization algorithm in a wind energy integrated power system", *International Journal of Green Energy*, *International Journal of Green Energy*, 2019.
- [66] P. K. Roy, S. P. Ghoshal and S. S. Thakur, "Multi-objective Optimal Power Flow Using Biogeography-based Optimization", *Electric Power Components and Systems*, Vol. 38, No.12, pp. 1406-1426, 2010.
- [67] A. R. Kumar and L. Premalatha, "Optimal power flow for a deregulated power system using adaptive real coded biogeography-based optimization", *Int. J. Electr. Power Energy Syst.* Vol. 73, pp. 393–399, 2015.
- [68] O. Herbadji, L. Slimani and T. Bouktir, "Solving Bi-Objective Optimal Power Flow using Hybrid method of Biogeography-Based Optimization and Differential Evolution Algorithm: A case study of the Algerian Electrical Network", *Journal of Electrical Systems*, Vol. 12, No. 1, pp. 197-215, 2016.
- [69] H. Boucekara, M. Abido, A. Chaib and R. Mehasni, "Optimal power flow using the league championship algorithm: a case study of the Algerian power system", *Energy Convers. Manag.* Vol. 87, pp. 58–70, 2014.
- [70] Y. S. Maru and K. Padma, "Optimal power flow solution using League Championship Algorithm for Indian utility 62 bus system", *Andhra University, College of Engineering, Electrical Engineering Department*, 2019.
- [71] F. Preethi, "A brief review on imperialist competitive algorithm limitations & future directions" Vol. 10, pp. 22613-22618, 2015.
- [72] S. Hosseini and A. Al Khaled, "A survey on the Imperialist Competitive Algorithm metaheuristic: Implementation in Engineering Domain and Directions for Future Research". *Applied Soft Computing*, Vol. 24: 1078–1094, 2014.
- [73] M. Ghasemi, S. Ghavidel, M. M. Ghanbarian, M. Gharibzadeh and A. A. Vahed, "Multi-objective optimal power flow considering the cost, emission, voltage deviation and power losses using multi-objective modified imperialist competitive algorithm", *Energy*, Vol. 78, pp. 276–289, 2014.
- [74] M. Ghasemi, S. Ghavidel, S. Rahmani, A. Roostaand H. Falah, "A novel hybrid algorithm of imperialist competitive algorithm and teaching learning algorithm for optimal power flow problem with non-smooth cost functions", *Engineering Applications of Artificial Intelligence*, Vol. 29, pp. 54–69, 2014.
- [75] J. B. Hmida, M. J. Morshed, J. Lee and T. Chambers, "Hybrid Imperialist Competitive and Grey Wolf Algorithm to Solve Multi-objective Optimal Power Flow with Wind and Solar Units", Vol. 11, No. 11, 2018.
- [76] M. Sedighzadeh1 and A. Eisapour-Moarref "The Imperialist Competitive Algorithm for Optimal Multi-objective Location and Sizing of DSTATCOM in Distribution Systems Considering Loads Uncertainty" *INAE Lett*, Vol. 2, pp. 83–95, 2017.
- [77] H. F. Farahani and F. Rashidi "An improved teaching-learning-based optimization with differential evolution algorithm for optimal power flow considering HVDC system", *Journal of Renewable and Sustainable Energy*, Vol. 9, 2017.
- [78] B. Mahdad and K. Srairi, "Optimal Power Flow Improvement Using a Hybrid Teaching-Learning-based Optimization and Pattern Search", *I. J. Modern Education and Computer Science*, Vol. 3, pp. 55-70, 2018.
- [79] M. O. Okelola, O. E. Olabode and T.O. Ajewole, "Teaching-Learning Based optimization Approach for Determining Size and Location of Distributed generation for Real Power Loss Reduction on Nigerian Grid", *UNIOSUN Journal of Engineering and Environmental Sciences*, Vol. 1, No. 1, March, 2019.
- [80] A. Mukherjee, Sourav Paul, P. K. Roy, "Transient Stability Constrained Optimal Power Flow Using Teaching Learning Based Optimization", *18 International Journal of Energy Optimization and Engineering*, Vol. 4, No. 1, pp. 18-35, January-March 2015.
- [81] M. K. M. Zamani, I. Musirin, S. I. Suliman, S. A. S. Mustafa, N. Z. M. Ali, M. H. Mansor and Z. A. Hamid, "Optimal TCSC Allocation via Chaotic Immune Symbiotic Organisms Search for Voltage Profile Improvement", *E3S Web of Conferences*, Vol. 152, 2020.
- [82] A. Saha, A.K. Chakraborty and P. Das, "Quasi-reflection-based symbiotic organisms search algorithm for solving static optimal power ow problem", *Scientia Iranica D*, Vol. 26, No. 3, pp. 1664 – 1689, 2019.

- [83] T. T. The, S. N. Quoc and D. V. Ngoc, "Symbiotic Organism Search Algorithm for Power Loss Minimization in Radial Distribution Systems by Network Reconfiguration and Distributed Generation Placement", Hindawi, Mathematical Problems in Engineering, 2020.
- [84] H. Pulluri, R. Naresh, V. Sharma and Preeti, "A new colliding bodies optimization for solving optimal power flow problem in power system", IEEE, 2016.
- [85] H. R. E. H. Boucekara, A. E. Chaib, M. A. Abido and R. A. El-Sehiemy, "Optimal power flow using an Improved Colliding Bodies Optimization algorithm", Applied Soft Computing, 2015.
- [86] K. Mahender, M. Vyshnavi, S. Patange, H. Pulluri, "Solution of Optimal Power Flow Problem Using Colliding Bodies Optimization", International Conference on Multifunctional Materials (ICMM), 2019.
- [87] A. R. Bhowmik and A. K. Chakraborty, "Solution of optimal power flow using non dominated sorting multi-objective opposition based gravitational search algorithm", Electrical Power and Energy Systems, Vol. 64, pp. 1237–1250, 2015.
- [88] B. Shaw, A. Banerjee, V. Mukherjee and S. P. Ghoshal, "Solution of Optimal Power Flow by an Opposition-Based Gravitational Search Algorithm", Intelligent Computing and Applications, Advances in Intelligent Systems and Computing, Vol. 343, 2015.
- [89] B. Shaw, V. Mukherjee and S.P. Ghoshal, "Solution of reactive power dispatch of power systems by an opposition-based gravitational search algorithm", Electrical Power and Energy Systems, Vol. 55, pp. 29–40, 2014.
- [90] Z. Hasan, and M. E. El-Hawary, "Optimal power flow by Black Hole Optimization Algorithm", Electrical Power and Energy Conference, 2014.
- [91] H. R. E. H. Boucekara, "Optimal power flow using black-hole-based optimization approach", Appl. Soft Comput. Vol. 24, pp. 879–888, 2014.
- [92] K. G. Ing, H. Mokhlis, H. A. Illias, M. M. Aman and J. J. Jamian, "Gravitational Search Algorithm and Selection Approach for Optimal Distribution Network Configuration Based on Daily Photovoltaic and Loading Variation", Hindawi Publishing Corporation Journal of Applied Mathematics, Volume 2015.
- [93] J. Radosavljević, M. Jevtić, N. Arsić and D. Klimenta, "Optimal power flow for distribution networks using gravitational search algorithm", Vol. 96, pp. 335–345, 2014.
- [94] Y. Sonmez, S. Duman, U. Guvenc and N. Yorukeren, "Optimal Power Flow Incorporating FACTS Devices using Gravitational Search Algorithm", IEEE, 2012.
- [95] J. Radosavljević, D. Klimenta, M. Jevtić and N. Arsić, "Optimal Power Flow Using a Hybrid Optimization Algorithm of Particle Swarm Optimization and Gravitational Search Algorithm", Electric Power Components and Systems, 2015.
- [96] U. Kılıç, "Backtracking search algorithm-based optimal power flow with valve point effect and prohibited zones", Electr. Eng., 2014.
- [97] F. Daqaq, R. Ellaia and M. Ouassaid, "Multi-objective Backtracking Search Algorithm for solving Optimal Power Flow", 3rd International Conference on Electrical and Information Technologies ICEIT, 2017.
- [98] A. Chaib, H. R. E. H. Boucekara, R. Mehasni and M. Abido, "Optimal power flow with emission and non-smooth cost functions using backtracking search optimization algorithm", Int. J. Electr. Power Energy Syst. Vol. 81, pp. 64–77, 2016.
- [99] M. Umar, G. A. Bakare, M. A. Shehu and U. Abubakar, "DSTATCOM Placement in Distribution Systems using weighted Artificial Fish Swarm Algorithm", IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON), 2017.
- [100] W. Wei, F. He, C. Xia, S. Ma, and Z. Bo, "Multi-Objective Optimal Power Flow Calculation Based on The Improved Artificial Fish Swarm Algorithm", 5th International Conference on Electricity Distribution, Shanghai, 5-6 Sept; 2012.
- [101] S. M. Aminu, T. H. Sikiru, B. Jimoh, and U. Musa, "Svc Placement for Voltage Enhancement in Power Systems Using Weighted Artificial Fish Swarm Algorithm", 1st FUOYE International Engineering Conference, 2018.
- [102] M. Seyedaliand A. Lewis. "The whale optimization algorithm." Advances in Engineering Software, Vol. 95, pp. 51-67, 2016.
- [103] M. Durairasan and D. Balasubramanian, "An efficient control strategy for optimal power flow management from a renewable energy source to a generalized three-phase microgrid system: A hybrid squirrel search algorithm with whale optimization algorithm approach", Transactions of the Institute of Measurement and Control 1–17, 2020.



- [104] Ang, U. Leeton, T. Kulworawanichpong and K. Chayakulkeeree, “Multi-Objective Real Power Loss and Voltage Deviation Minimization for Grid Connected Micro Power System Using Whale Optimization Algorithm”, International Energy Journal, Vol. 18, 297 – 310, 2018.
- [105] H. A. Devi, R. Kannan and S. Padma, “Optimal Placement of FACTS Devices Based on Whale Optimization Algorithm for Power System Security Enhancement”, International Journal of Innovative Technology and Exploring Engineering (IJITEE) Vol. 9 Issue 3, January 2020.
- [106] N. M. Hassan, R. A. Swief, M.Z. Kamh, H. M. Hasanien and A. Y. Abdelaziz, “Toward Centralized/Decentralized Controlled Power Flow Applying Whale Versus Genetic Optimization Algorithms”, International Journal of Recent Technology and Engineering (IJRTE), Vl. 8, Issue 4, November 2019.
- [107] T. Zheng and W. Luo, “An Improved Squirrel Search Algorithm for Optimization”, Hindawi- Complexity, Vol. 2019.
- [108] M. Balasubbarreddy and D. Dwivedi, “Squirrel Search Algorithm for Solving Optimal Reactive Power Dispatch Problem with FACTS Device”, International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol. 9 Issue 3, January 2020.
- [109] K. Lenin, “Real power loss reduction by Duponcheliafovealis optimization and enriched squirrel search optimization algorithms”, Soft Computing, Springer Nature 19 May, 2020.



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