Applications of Flower Pollination Algorithm in Electrical Power Systems: A Review

SAHIL LALLJITH, ISMAIL FLEMING, UMESHAN PILLAY, KIVESHEN NAICKER, ZACHARY NAIDOO, AKSHAY KUMAR SAHA (Member, IEEE)
Discipline of Electrical, Electronic and Computer Engineering, University of KwaZulu-Natal, Durban 4041, South Africa
Corresponding author: Akshay Kumar Saha (e-mail: saha@ukzn.ac.za).

ABSTRACT The use of metaheuristic, nature inspired algorithms for solving complex optimization problems with non-linearity and multimodality, has become a popular tool in the field of science and engineering. Presently, there has been much development of such tools, with academics creating new nature-inspired algorithms that could potentially be more efficient and effective. One such algorithm is the Flower Pollination Algorithm (FPA) developed by Xin-She Yang in 2012. This metaheuristic algorithm is modelled after the evolutionary process of flowering plants and has been useful in many fields of science and engineering, particularly electrical Power Systems, which forms the basis for modern day life and is responsible for meeting worldwide needs for reliable generation, transmission, and distribution of power. With the rapid expansion of industries and population growth, power utilities are faced with the arduous task of satisfying these needs. In addition, utilities are met with common problems, such as economic load dispatch, power quality improvement etc. To assist in solving these problems, FPA has been used to successfully determine optimal solutions efficiently and has proven to be more effective than other popular metaheuristic algorithms, such as Particle Swarm Optimization and Genetic Algorithm. Thus, this paper provides a comprehensive review of applications using FPA, to successfully determine optimal results to non-deterministic polynomial-time hard problems in electrical power systems. In addition, modifications of FPA to improve its performance have also been highlighted, with a review of FPAs applications in other fields.

INDEX TERMS Optimization, Algorithms, Flower Pollination Algorithm, Genetic Algorithms, Metaheuristic Algorithm, Particle Swarm Optimization, Non-deterministic Polynomial-time.

ABBREVIATIONS

| Algorithm                                      | Abbreviation   |
|------------------------------------------------|----------------|
| Artificial Bee Colony                         | ABC            |
| Antennae Positioning Problem                  | APP            |
| Binary Control Flow Analysis                  | BCFA           |
| Binary Clonal Flower Pollination Algorithm    | BCFP           |
| Bacteria Foraging Algorithm                   | BFA            |
| Binary Flower Pollination Algorithm           | BFPA           |
| Bee Flower Pollination Algorithm              | BeFPA          |
| Binary Particle Swarm Optimization Algorithm  | BPSC           |
| Binary Modified Chaos Flower Pollination      | BMCFPA         |
| Algorithm                                      |                |
| Chaos Modified Flower Pollination Algorithm   | CHAOS-MFPA     |
| Congestion Management                         | CM             |
| Clonal Selection Algorithm                    | CSA            |
| Differential Evolution                         | DE             |
| Distribution Generation                       | DG             |
| Distribution Network Reconfiguration           | DNR            |
| Dynamic Differential Evolution                | DynDE          |
| Economic Dispatch Problem                     | EDP            |

| Terms                                           | Abbreviation   |
|------------------------------------------------|----------------|
| Electroencephalogram                           | EEG            |
| Elite Opposition-Based Flower Pollination       | EOFP           |
| Flexible AC Transmission System                | FACTS          |
| Flower Pollination Algorithm                   | FPA            |
| Fractional Order Proportional Integral          | FOPID          |
| Fast Voltage Stability Index                    | FVSI           |
| Genetic Algorithm                              | GA             |
| Global Maximum Power Point                     | GMPP           |
| Global Maximum Power Point Tracking            | GMPT           |
| Harmony Search Algorithm                       | HAS            |
| Hybrid Flower Pollination and Genetic          | HFPGA          |
| Incremental Conductance                        | IC             |
| Information and Communication Technologies      | ICT            |
| Independent System Operator                    | ISO            |
| Load Balancing Index                           | LBI            |
I. INTRODUCTION

In many engineering and industrial design applications, there is a great need to find optimal solutions to complex problems under difficult constraints. These constrained optimization problems are often highly non-linear and so, finding optimal solutions is a difficult challenge as conventional optimization techniques are inefficient in solving problems with non-linearity and multi-modality [1], [2], [3], [4]. As such, meta-heuristic algorithms are chosen to solve these types of problems. These algorithms are modelled after successful processes in nature, which have been solving difficult problems for billions of years to achieve certain evolutionary goals. The efficacy of meta-heuristic algorithms depends on the use of explorative and exploitative ranges across a search space [5], [6]. The exploitation process is achieved by using the information obtained from past iterations to guide the search towards its objective. Xin-She Yang [1] proposed a new population-based metaheuristic algorithm, known as the Flower Pollination Algorithm (FPA). This algorithm imitates the process of flower pollination to solve optimization problems and is proven to perform better than other more popular algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) [1], [7], [8]. The algorithm uses long-distance pollinators and flower consistency to achieve a balance between exploitative and explorative ranges modality [1], [2]. The interaction of these ranges, as well as the selection of the best solution, contributes to the efficiency of the algorithm. The extensive use of this algorithm in the field of power systems has been successful in solving many optimization problems of varying complexity [3], [4]. Electrical power systems play an important role in modern society, as it provides the consistent and efficient supply of electricity, which are vital to the functioning of our civilization [3]. However, this field faces many problems such as economic and emission dispatch, optimizing renewable energy generation, optimizing distribution systems, and solving problems related to energy transmissions, such as power flow, power loss and congestion management [9], [10], [11], [12], [13].

Various reviews have been carried out which investigate FPA techniques in various optimization fields. The authors in [14] provide a review of the engineering applications of FPA and its variants. The applications include chemical engineering, civil engineering, energy and electrical power systems, mechanical engineering, electronic and communication engineering, computer science and others; however, focus is not into the various types of modifications and hybridisations of the FPA. A further review into the applications and variants of FPA is provided in [15]; however, although various variants of FPA are mentioned, very little focus is given to the applications of FPA to solve real world complex problems. The distribution of published research on FPA from a variety of publishers, including IEEE, SpringerLink, and others, was determined in [16]. Figure 1 depicts the percentage of the number of articles in which the FPA algorithm is used in various optimization fields [16].

![Distribution of published research on FPA](image-url)
results to non-deterministic polynomial-time hard problems in electrical power systems as well as provide an overall summary of the FPA algorithm, including its characteristics, modifications, hybridizations, and applications in other fields. Hence, this paper is organized in a manner to present a brief overview of metaheuristic algorithms and the characteristics of FPA in Section II. Section III of this paper introduces and describes the various types of modifications and hybridizations of the FPA. Section IV aims to discuss the different applications FPA is used to optimize in electrical power systems, and Section V will discuss the different applications of FPA to solve problems in fields outside of power systems.

II. GUIDELINES FOR MANUSCRIPT PREPARATION

A. OPTIMIZATION PROBLEMS AND SEARCH TECHNIQUES

Throughout history, mankind has encountered many problems that require sophisticated methods or techniques to determine a solution. These problems, and the techniques developed to solve these problems, can date back as far as 2200 years ago when Archimedes utilized the method of exhaustion to compute the area inside a circle and also developed the principle of buoyancy that is pivotal to fluid mechanics [17], [18]. As civilizations continued to evolve, standard approaches and methods to solving common problems were established. However, some methods cannot be applied to every problem and therefore, require new techniques that can be applied practically to provide a feasible result within a reasonable time frame. One such case is with regards to optimization, in which the aim is to determine the best solution from all possible outcomes to conserve resources or reduce costs [7], [8]. Some of the earliest well-defined procedures for determining optimum solutions come from conventional-based approaches. Presently, combinatorial optimization problems have become far too complex for such methods (e.g., calculus and linear programming) to solve efficiently [1], [6]. Thus, the need for non-conventional techniques such as heuristics and meta-heuristics has grown. While early forms of problem-solving may have existed in the form of heuristics and meta-heuristics (trial and error) as in the case of Archimedes method of exhaustion, the recent development into these forms of non-conventional approaches and their application to real-world problems has been widely observed [17], [19]. Figure 2 illustrates the various solution search techniques developed over the years.

B. NON-CONVENTIONAL SEARCH TECHNIQUES

In recent years, non-conventional search techniques have become popular for obtaining feasible solutions in polynomial time, as conventional optimization techniques are challenged by non-linearity and may be trapped in the local optimum [1], [20]. To address the challenge of non-linearity and multi-modality of optimization problems, approximate algorithms can be used instead. More specifically, one may use heuristics or meta-heuristics to determine optimal solutions with greater efficiency and without the search being trapped in the local optimum. Heuristics, like approximate algorithms, generate near-optimal solutions for non-deterministic polynomial-time hard problems (NP-hard) through trial and error [19], [20], [21]. However, unlike approximate algorithms, these algorithms have no known proof of their correctness and could potentially generate solutions that are unfeasible [6], [19], [21], [22]. It is, therefore, risky to apply such algorithms with loosely defined rules to optimization problems. However, they have proven useful for problems that do not have a known solution method or formulation [8], [22]. Heuristics can be an alternate method to exact solution methods that would otherwise be computationally intensive and are developed to address specific problems in optimization [21], [22]. In contrast to heuristic algorithms, metaheuristics are strategic problem-solving frameworks that guide underlying problem-specific heuristics to improve their performance by effectively combining exploration of a solution search space and basic heuristic methods in higher-level structures aimed at efficiency and can be modified to solve an array of optimization problems with little computational time [6], [21]. An important attribute of meta-heuristics that set it apart from other algorithms is the dynamic balance between exploration and exploitation of the solution search space, in which a good balance between these two characteristics results in efficient performance [6], [19]. However, like heuristics, there is no guarantee that an algorithm will work, though there are many meta-heuristic algorithms that have been successfully utilized in optimization. Some of these include Particle Swarm Optimization (PSO) [23], Simulated Annealing (SA) [24] and Genetic Algorithm (GA) [20]. With regards to the comparison of their performance to each other, there exists No Free Lunch (NFL) theorems in the field of optimization which imply that there is no universally better algorithm with regards to optimization problem solving, and one may either select an algorithm that is most suitable for a given problem or develop improved algorithms that solve most types of problems [19], [25]. This choice can be made based on comparative studies of algorithms in application, which evaluate an algorithms performance in a particular category of problems and compare the result with other popular algorithms used for the same problem. There are a variety of algorithms to choose from in the category of meta-heuristics, however, nature-inspired meta-heuristics have become powerful tools for optimization, especially NP-hard problems [1], [6].
III. THE FLOWER POLLINATION ALGORITHM

The Flower Pollination Algorithm (FPA), implemented by Xin-She Yang in 2012 [26], is an evolutionary, meta-heuristic algorithm inspired by the natural process of flowering plant pollination. The flow chart for FPA is shown in figure 3. The flower pollination process aims to transfer pollen between the same or different plant species for reproductive purposes [1], [7], [27], [28]. FPA focuses on the pollination process and aims to mimic its movements to produce an efficient and optimum system. Pollination occurs via two primary methods with the first being local pollination which consists of pollen from the same flower or different flowers from the same plant [1], [7], [27], [28]. Global pollination occurs when pollen from flowers of different plant species is involved. Global pollination occurs at long distances and requires pollinators to travel large regions over which this phenomenon occurs [1], [7], [27], [28]. The modelling of biological processes and algorithms requires complex variables to be considered. Simplification of biological processes is required to model the algorithm mathematically and form an algorithm. The FPA simplifies the natural flower pollination process into four idealized characteristics. The first rule being the global pollination rule, which is modelled after the natural global pollination process which consists of living organism and cross-pollination, with pollinators such as birds, bees etc., performing Lévy flights. The rule can be expressed as the phase that replicates global search through the solution search space in terms of Lévy flights [1], [7], [27], [28]. Pollination within the same flower (known as abiotic pollination) can be classed as local pollination, which can be demonstrated at the exploitation stage [1], [7], [27], [28]. This guides the search towards a better solution and is governed by the local pollination rule [1], [7], [27], [28]. The reproductive probability refers to flower consistency and is proportional to the degree of similarity between the flowers involved. This is governed by the reproduction probability rule, which imitates flower consistency behaviour which replicates pollinators tendencies to fecundate certain flowers [1], [7], [27], [28]. The switch probability rule functions as an operator that regulates the switching process between global and local pollination. The switching probability (p) is defined as 

\[ p = \frac{1}{s} \] (1)

Due to the deviation of their variance, long jumps occur on all scales showing groups of shorter jumps scattered by long excursions on all levels [29], [30], [31]. Lévy Flight distributions represent the limit distributions of random variables with diverging variance [29], [30], [31]. Thus, Lévy Flights are used to update the pollen as they can mimic the random path taken by pollinators in nature (during the global pollination method), this is expressed mathematically by [1], [7], [27], [28]:

\[ x_{i+1}^j = x_i^j + L(x_i^j - g_j) \] (2)

This uses the variable \( x_i \) to represent a single gamete [29, 30, 31]. The variable \( g \), represents the fittest gamete which is transported through global pollination [29], [30], [31]. \( t \) represents the current iteration and \( L \) denotes the step size corresponding to the strength of the pollination. \( L \) is drawn from the Lévy flight distribution and can be expressed as [1], [7], [27], [28]:

\[ L \sim \frac{(\beta + 1) \times \sin \left( \frac{\beta \pi}{2} \right)}{\pi} \times \frac{1}{s^{\beta + 1}}, (s \gg s_0 > 0) \] (3)

\( \beta \) is the gamma function, which is initially selected before implementation [29], [30], [31]. The Levy distribution is valid for large steps where \( s > 0 \), this is used to emulate the steps taken within a global pollination process in nature [29], [30], [31].

B. LOCAL POLLINATION CONSIDERING FLOWER CONSTANCY

If a selected value is less than the switch probability P, the resulting type of pollination that occurs is local [1], [7], [27], [28]. This uses flower consistency within a small region to decrease the exploitation time and is shown by the following equation [29, 30, 31]:

\[ x_{i+1}^j = x_i^j + \epsilon (x_j^j - x_k^j) \] (4)

In this equation \( x_j^j \) and \( x_k^j \) represent individual gametes from plants at different locations. This indicates a local random walk if \( \epsilon \) is drawn from a uniform distribution (0,1) [1], [7], [27], [28]. Rule 4 (switch probability) is used to switch between local and global pollination, since flowers in nature may not occur far away from each other and are more likely to be polinated by local gametes [1], [7], [27], [28].

C. ELITIST SELECTION

The candidate solution \( x_{i+1}^j \), is obtained through either global or local pollination and compared with past solutions of \( x_i^j \). If the fitness value of \( x_i^j \) is greater than previous \( x_i^j \), it replaces the past solution otherwise the initial \( x_i^j \) remains in the population. This elitist selection operation can be represented by [1], [7], [27], [28]:

\[ x_{i+1}^j = \begin{cases} x_i^j, & \text{if } f(x_i^j) > f(x_k^j) \\ x_k^j, & \text{otherwise} \end{cases} \]
The FPA can also be represented as a flow diagram [1], [7], [27], [28]:

![Flowchart of FPA algorithm](image)

**FIGURE 3. Flowchart of FPA algorithm [7], [27], [28]**

### IV. MODIFICATIONS TO THE FLOWER POLLINATION ALGORITHM

The characteristics of algorithm can be improved through modification. The nature of FPA allows it to be open to various enhancements and as such this section highlights the various modifications of FPA and their applications in many fields.

**MODIFIED FLOWER POLLINATION ALGORITHM BASED ON OPERATORS (MFPA)**

FPA determines new solutions based on either local or global pollination, which are the algorithm’s core operators. FPA can easily be used to solve low-dimensional unimodal optimization problems but falls short in handling multi-modal optimization problems. To solve this issue, operators may be modified to produce an optimum solution. Yamany *et al.* [31] proposed a mutation to enhance the solution diversity of the basic FPA. The modification is expressed mathematically in [31] and allows for more efficient handling of large search spaces. The MFPA was tested against datasets in [31], and was compared to GA and PSO. The results in [31] demonstrate that MFPA operates more efficiently that GA and PSO and produces better quality solutions. Multi-level image thresholding is a crucial aspect required for image segmentation, with traditional methods for image segmentation being deemed highly costly due to the large amount of computational memory required for the exhausting search strategy [32]. Shen *et al.* [32] modified FPA by enhancing both the local and global pollination aspects to improve the exploration capabilities of the algorithm [32]. The modified flower pollination algorithm (MFPA) was tested by using a combination of real-life images and datasets shown in [32]. MFPA provided the greatest optimization and image quality and was compared to five other metaheuristic algorithms, including FPA, PSO, CE [32]. In the field of renewable energy, development of accurate PV cell models is essential for efficient optimization but is difficult due to the non-linear characteristics of PV cells, which make accurate estimation of parameters challenging [33], [34], [35]. Khursheed *et al.* [33] proposed a modification to FPA which doubled the base switch probability and added a dynamic step size function. The MFPA was applied to solve the non-linear optimization problem challenging PV cells and was tested on both single and double diode PV models. The tests in [33] found that the MFPA exhibited an increased convergence rate as compared to the standard FPA but lacked accuracy in single diode PV model test [33]. The use of super alloys in industrial processes has exponentially risen over the last decade, however the machining of these alloys with conventional processes is extremely difficult [36, 37]. Rao *et al.* [36] proposed MFPA to optimize the wire electrical discharge machining technique to process these alloys. The MFPA implemented in [36] aimed to use a two-stage initialization process to increase the speed and accuracy of the standard FPA [36]. The MFPA was tested using standard benchmark WEDM data against the standard FPA and RSM methods and was found to outperform the algorithm in comparison and produce satisfactory results.

**B. THE ELITE OPPOSITION-BASED FLOWER POLLINATION ALGORITHM (EOFPA)**

The MFPA presented in Yamany *et al.* report [31], produced satisfactory results, however the validity of the modifications to FPA in practical situations require more research. Zhou *et al.* [38] presented an elite opposition based FPA (EOFPA) and applied the algorithm to civil engineering design problems. The modifications are implemented by making changes to the global and local search function of the base FPA [38]. The EOFPA performance was validated by tests conducted in [38]. EOFPA had a faster convergence speed, increased stability and accuracy compared to the other population-based algorithms it was tested against [38]. In other fields, the quadratic assignment problem (QAP) is one of the most popular combinational optimization problems due to the numerous practical applications involved with it [39], [40], [41]. Abdel-Baset *et al.* [41] propose a EOFP which aimed at modifying similar characteristics as [38] to improve global and local search functions. Abdel-Baset *et al.* [41] conducted a test using set benchmarks from the QAP library and compare EOFP against the highest performing algorithms from various literatures. Both graphical and numerical results indicate that EOFP exhibited the shortest convergence speed.
and produced the most accurate results amongst the standard FPA, GA and PSO algorithms [38].

C. BINARY FLOWER POLLINATION ALGORITHM (BFPA)

The original FPA was designed to solve continuous optimization problems; however, modifications are needed to solve combinatorial optimization problems [16]. The Binary Flower Pollination Algorithm (BFPA) models the search such that continuous optimization is implemented within a solution [42]. Rodrigues et al. [42] presented a comparison of BFPA against various other binary population-based algorithms (BFA, BPSO) on six datasets. The findings show that BFPA produced the most efficient results amongst the compared algorithms [42]. The literature by Rodrigues et al. [43] applied BFPA to reduce the number of sensors used for person identification based on EEG signals. BFPA experiments results displayed in [43] showed that BFPA resulted in increased recognition rates, provided the best convergence and diversity of solutions as compared to the metaheuristic algorithms it was tested against. Dahi et al. [44] conducted tests to evaluate BFPA’s performance in solving the Antennae Positioning Problem (APP). BFPA was tested using datasets with different dimensions and was compared with efficient algorithms in APP optimization. The results in [44] display that BFPA achieved the best solution in APP optimization and possessed the fastest convergence rates when tested against popular algorithms in the APP field. Single nucleotide polymorphism (SNP) is a genetic trait responsible for the differences in characteristics of individual living species [45], [46]. Rathasamuth et al. [45] implemented a modified BFPA that uses the cut-off-point-finding threshold and combines it with a GA bit-flip operator [47] and was assessed in terms of capability to identify SNPs with the highest genetic potential against various metaheuristic algorithms in the field. Rathasamuth et al. [45] found that the modified BFPA produced the fastest convergence rate and required the least number of iterations out of the compared algorithms with a commendable accuracy of 95% [45]. The feature selection problem is a complex issue that plagues many industries, it involves the selection of features that maximizes a fitness function and is a crucial part in optimizing a function [42], [48]. Rodrigues et al. [42] conducted tests on numerical datasets in which BFPA is tested and compared to the performance of PSO, HS and FA to assess its ability in solving the fitness function. The results conclude that the BFPA algorithm was the slowest in terms of convergence speed but the most accurate [42]. These papers validate the use of BFPA and proves that modifications to FPA may result in better solutions to optimization problems as compared to established algorithms in those fields of application.

D. CHAOS MODIFIED FLOWER POLLINATION ALGORITHM (CHAOS-MFPA)

The Chaos Modified Flower Pollination Algorithm (CHAOS-MFPA) makes use of chaotic maps to replace the random sequences that generate the initial population in the FPA [49]. This improves the diversity of the initial population, by making the distribution more uniform [49]. Meng et al. [49] implemented and tested the ability of the CHAOS-MFPA to solve a variety of mechanical engineering design problems. It was found that the non-repetition of the chaotic sequences allowed for optimal solutions to be found in each case. Analog diagnostics makes use of a support vector machine (SVM) technique to identify fault samples [50], [51]. The SVM technique is vulnerable to the selection process problems described in [50], [51]. Cui et al. [50] implemented a Binary Modified Chaos- FPA (BCCFPA), which makes use of the chaos maps and cloud model to enhance the solution quality of the base FPA [50]. The BCCFPA was tested against various binary modified metaheuristic algorithms to determine which could produce the optimal solutions to the selection challenges present with the SVM technique [50]. The results display that the BCCFPA possessed the strongest optimization capabilities amongst the tested algorithms and overcame the premature convergence of FPA [50]. Kaur et al. [52] investigated the effectiveness of four variants of the CHAOS-FPA by conducting tests on nine benchmarks of high dimensional functions. The CHAOS variants examined used different chaotic maps, such as the logistic [53], sine [54], tent and dyadic maps [55]. The test results found displayed that the CHAOS variants each outperformed the standard FPA, with the sine map variant able to produce the best results in terms of accuracy but it lacked the fast convergence speed that the dyadic map variant possessed [52]. The CHAOS-MFPA is one of the most promising variants of the modified base FPA and is also one of the most used algorithms for optimization within various sectors of power systems. An in-depth review of CHAOS-MFPA in power system applications is explored in greater detail in the review section.

E. MULTI-OBJECTIVE VERSIONS OF FLOWER POLLINATION ALGORITHM (MOFPA)

Engineering design optimization problems often contain conflicting objectives that can increase the complexity of the solution required [27]. Yang et al. [27] implemented the Multi-Objective Flower Pollination Algorithm (MO-FPA) to solve engineering optimization problems, through a random weighted sum method [16]. The paper [27] evaluated MO-FPA using various engineering optimization problems and despite the complexity, MO-FPA was found to produce optimal results. These findings were compared to various algorithms including the base FPA. Yang et al. [27] presented unique modifications to the MO-FPA by proposing several multi-objective test functions and two bi-objective design benchmarks. The algorithm was tested using various engineering design problems in [27], and was able to efficiently produce optimal solutions in each case, further validating the MO-FPA for optimization in practical design situations. Emary et al. [56] implemented MOFPA for retinal vessel localization. The suggested method used FPA to determine the ideal clustering of the retinal images. This method was tested using a dataset in [56] and revealed that MO-FPA was able to increase accuracy and sensitivity of the results. The benefits of modifying FPA are evident in the
literature presented. Modifications allow for improvement on specific aspects of the algorithm which can be used to solve unique and complex challenges within various industries.

V. HYBRIDISATION OF THE FLOWER POLLINATION ALGORITHM

Every algorithm is prone to having limitations which creates the challenge of striking the right balance between global-wide searches and local searches [57], [58]. Some algorithms alone can meet the requirements in place others require a combination of the most desirable characteristics of two or more separate algorithms to carry out a specific task [58], [59]. This is a basic understanding to how hybridization is carried out. The approach combines two separate metaheuristic algorithms to produce a more efficient algorithm [60]. Hybridized FPA can solve discrete problems as well as to find a balance between global and local searches [57]. Some optimization problems are multi-objective in nature, this means that a basic algorithm would not be able to compute a solution [61]. However, a modified or hybridized FPA would be able to provide a solution. The following section provides an understanding of the various methods as well as the different types of metaheuristic algorithms used to create hybridized FPA. Some of the algorithms fall in different categories which represent a general type of algorithm, which is then combined with the FPA. Other algorithms are just stand-alone algorithms that are combined with FPA to produce a hybridized algorithm. Their individual advantages and disadvantages are discussed as well as their advantages and disadvantages when combined with FPA to form a hybridized FPA.

A. TYPES OF HYBRIDISATIONS

1) LOCAL SEARCH

The local search algorithm is a form of hybridized FPA that uses SA. This algorithm has two main phases which are annealing schedule and acceptance probability function. The SA algorithm is applicable to optimization problems since it allows the system to reach a stable state [24]. The combination of SA algorithm is applicable to optimization problems since it uses SA. This algorithm has two main phases which are

2) SWARM-BASED

Swarm-based algorithms comprise of various metaheuristics combined with FPA. The resulting effect of these combinations differ on the type of algorithm that FPA is combined with. For example, FPA can be combined with the Harmony Search Algorithm (HSA) which aims at mimicking the improvisation process that musicians go through to find the right pitch and harmony [64]. The HSA-FPA algorithm can improve search accuracy as well as efficient results [27]. Alternatively, FPA can be combined with the Artificial Bee Colony (ABC) optimization which is an algorithm that focuses on the foraging behaviour of honeybees to conduct numerical optimization problems [65], [66]. This algorithm was first proposed to solve unconstrained optimization problems and displayed advanced performance in determining optimal solutions for this type of problem [65], [67]. The combination of FPA and ABC creates the Bee Flower Pollination Algorithm (BeFPA). This combination not only decreases simulation time and improves the robustness of the algorithm, but it also is able to provide a faster execution and greater quality of convergence to global optimal solution [66]. In addition, BeFPA was able to solve the photovoltaic parameter determining problem as the combination resulted in faster execution, increased convergence rates, and a better optimal solution [38]. Kalra et al. [68] introduced a hybridized FPA by combining the standard FPA with a Firefly Algorithm (FA) which uses the bioluminescence trait of fireflies and their attraction behaviour to solve multimodal functions [69]. The FA algorithm provides good performance on solving low-dimensional problems but is unable to solve the more complex high dimensional problems. The combination of FPA and FA algorithm can provide faster computations, execution, an improved quality in the solution and convergence to global optimal solutions [43]. In addition, the hybridized algorithm has an improved ability of not converging prematurely [68]. Another hybridized, swarm based FPA algorithm is the combination of FPA with PSO. This algorithm is based on the hunting tactics that birds use and was proposed by Kennedy et al. [23] in 1995. The algorithm mimics these tactics by treating the bird as a weightless object with no volume and the required solution being food that the bird searches for, which allows the algorithm to manage both global as well as part searching [23]. The hybrid version of this algorithm can increase search accuracy as well as provides an accurate and efficient algorithm to obtain optimal solutions this results in a better convergence speed [70].

3) DIFFERENTIAL EVOLUTION

The Differential Evolution (DE) algorithm, which focuses on the natural evolution characteristics of a population, was combined with the FPA to mimic the strength and power of both algorithms thus creating the DE-FPA [71]. The DE
algorithm is robust in the sense that the globalization takes place in evolution and was suggested by Storn et al. [44], to solve the Chebyshev polynomial fitting problem. A variation to the DE algorithm is one that can solve multi-objective optimization problems [72]. This specialized variation is termed Dynamic Differential Evolution (DynDE) algorithm and is capable of effectively solving the moving peaks benchmark function [73]. The standard DE algorithm has a simple methodology and efficient operation, and iteratively evaluates and updates the contender solutions in the population. The algorithm is guided by the norm pattern of evolutionary algorithms and is made up of steps for each iteration. Chakraborty et al. [49] presented a hybridized FPA which combined the DE algorithm with FPA and used five test functions to compare this hybridized algorithm with its individual counterparts. This combination of DE and FPA was made possible since the DE algorithm can find optima among erratically chosen trajectories but lacks the ability to move towards the global optimum. The algorithm also possesses a better capability in searching for a sufficiently good solution and can escape from local optima [71], while the FPA algorithm is only able to provide global and local search strategies. This hybrid algorithm improves performance and uses a modified FPA that eliminates the need for the switch probability. Thus, increasing performance stability. The results of the five test functions in [49] show the DE-FPA outperforms both DE and FPA as the hybridized algorithm has better stability and a smaller deviation. The algorithm also provides better performance and convergence rate which presents an advantage in real world applications such as high-performance computing [49]. The variation in the DE-FPA is one which can solve multi-objective optimization problems [71].

4) MULTI-SCALE RETINEX

This hybridized algorithm combines the Multi-Scale Retinex (MSR) algorithm with the standard FPA to form MSR-FPA. The main application of this algorithm is to improve the effectiveness of remote sensing image enhancement and remedy the deficiency that traditional wavelet algorithms face, such as losing bits of information when image enhancement is conducted [74], [75]. MSR is classified as a frequency domain enhancement technique which enhances Single Scale Retinex (SSR) as well as images that are taken in nonlinear lighting conditions. The advantage of MSR is that it can compute numerous scales with appropriate weights for greater enhancement. In terms of image enhancement, the MSR algorithm can preserve more detail but has a downside of producing unnatural colour appearance [75], [76]. The algorithm is regarded as the most suitable for gray images. Due to the poor advantages and disadvantages of the standard MSR, a hybridized algorithm Multi-Scale Retinex-Flower Pollination Algorithm (MSR-FPA), is formed in [77] and uses FPA to assign appropriate values to ensure an ideal weight at every scale of the Gaussian filter and is done using global and local searches. The algorithm in [77] is found to be the best and most efficient algorithm for enhancement of gray images. This allows for further processes such as segmentation, classification, and feature extraction, as well as preservation of the original image [77]. Tests conducted by Shad et al. [77] to find a self-regulating proposal for image enhancement using MSR, incorporated FPA to obtain parameters by tuning MSR values. FPA used in combination with the MSR can converge to the global minimum. The experiments measured performance by recording the Peak to signal-to-noise ratio (PSNR), Mean standard deviation (SD) and the Root mean square error (RMSE) [27], [56]. Based on the test results obtained MSR-FPA outperformed various other algorithms, provided better accuracy, and produced a reliable convergence rate. Figure 4 is a diagram that summarizes the MSR operation.

![FIGURE 4. Process of MSR on a gray image [74], [75].](image)

A. CLASSIFICATION OF APPLICATIONS

The applications of FPA in this paper are categorized into three subtopics of power systems, namely power generation, distribution systems, and transmission. In addition, other applications of FPA outside the field of power systems are explored.

1) POWER GENERATIONS

The power generation sector is responsible for the production of electricity with the primary source being various forms of fossil fuels. However, over the past decades, the growing energy demand has caused an exponential rise in fuel costs, which in turn increased the operational costs of the power stations [13], [78], [79]. Within certain constraints, the economic dispatch problem (EDP) governs the active power output from distributed generators to maintain the demand [13], [78], [79]. Metaheuristic algorithms, such as the FPA are used to solve complex EDP to minimize costs and losses, while maintaining optimal power transfer [13], [78], [79]. The EDP is currently one of the major issues plaguing generation systems, with numerous metaheuristic algorithms displaying satisfactory performance as an optimization tool for this issue. FPA’s unique switching and exceptional convergence characteristics, as well as its performance in solving the EPD, has received a considerable amount of interest [13], [78], [79].

VOLUME XX, 2017

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see https://creativecommons.org/licenses/by/4.0/
The scheduling of hydro and thermal power plants in small durations are complex optimization problems in power generation systems due to issues such as the time delay concerning hydro sub-system and the non-convex nature of thermal valve point loading [80], [81], [82]. Hydrothermal scheduling optimization is used to keep the cost of energy generated by thermal power plants to a minimum for the scheduled duration, which not only has obvious financial benefits for both the consumer and producers but also for the environment [80], [81], [82]. The non-linearity of the hydrothermal scheduling problem plays into the hands of metaheuristic algorithms in a similar manner as EDP, with the interesting FPA features mentioned and the exciting prospect of hybridization and modifications to FPA, its effect on hydrothermal scheduling optimization is compelling [80], [81], [82].

The devastating effects of global warming are becoming more evident, the excessive use of fossil fuels as a means of energy generation identified as one of the primary contributors to the thinning of the ozone layer and the diminishing resources of hydrocarbon deposits the world has turned to more sustainable renewable forms of energy generation [66, 83, 84]. The use of renewable energy sources is not perfect, in that their reliance upon specific weather conditions to ensure optimal efficiency are one of their key drawbacks [66], [83], [84]. One of the solutions to the low efficiency rates of DG units are the inclusion of maximum power point trackers (MPPT) which allows for the maximum power to be extracted irrespective of unpredictable weather conditions [66], [83], [84]. Researchers have employed numerous algorithms, namely the P&O and IC algorithms, to ensure the optimization of MPPT controllers for various forms of DG units, however the conventional MPPT algorithms require a large number of parameters to be initialized nor only increases their complexity but also hinders their accuracy [66], [83], [84]. This has opened the door for modern metaheuristic algorithms such as the FPA to revolutionize MPPT optimization [66], [83], [84]. The integration of DG units in hybrid power systems impacts the system frequency, which in turn influences the overall stability of the system and may result in generation outages and load disconnections [85], [86], [87]. To assist in solving this problem, FPA optimized PID controllers have been employed ensure that nominal system frequency and that the steady state of a power system is maintained despite the inclusion of DG units at various nodes [85], [86], [87].

2) TRANSMISSION SYSTEMS

The transmission sector of power systems consists of the transportation of electrical energy from a generation site, this can range from a power station to an electrical substation [88]. In this substation the voltage is either stepped up or stepped down and distributed for industrial and residential use it can also be sent to other substations to obtain the required voltage [89], [90]. The transmission sector of a power system consists of the most widespread elements and represents the backbone of a power system. In terms of size and distance, the transmission sector is the biggest part of a power system [88], [91]. Transmission system operators (TSOs) oversee equipping the system as well as monitor the system by tracking the state of the system during normal operation and detecting any abnormalities or disturbances [92]. Transmission can be done using 3-phase, 3-wire AC systems which is then split into sub sections known as primary transmission and secondary transmission [93]. Primary transmission can be found at the edges of the city, due to the power loss in the transmission lines which is proportional to the square of the line current the voltage is stepped up to reduce these line losses [92]. Secondary transmission is found in the city and has the voltage stepped down at receiving stations and transmitted to substations [92], [94]. Transmission lines have a mesh structure which allows for alternative paths for power to flow from the generators to the load points, increasing reliability of the system [94]. These systems can be of various types such as single, two and three phase AC systems as well as DC systems [93]. Scenarios that would impact the operation of a power system generally occur in or near the transmission network, therefore monitoring and employing various countermeasures need to be taken into consideration to ensure the stability and reliability of the power system [95]. The problems that the transmission sector of a power system face include large amounts of power loss in the transmission line which is termed as transmission line losses. This issue can be resolved by using the FPA to determine optimal placement of Flexible AC transmission system (FACTS) devices [10], [96]. In addition, optimal power flow problem in power systems, with the use of FPA along with SVC’s, real power losses in transmission lines are mitigated, which allow the cost of real power generated to be reduced [9], [11]. Congestion in power systems is another problem that requires unique solution search techniques and occurs when transmission lines are operated beyond standard limits due to high demand resulting in a greater load. This problem can be resolved by using the FPA and MFPA to provide optimized generator rescheduling which was able to improve congesting management as well as power flow in transmission lines, the algorithm was able to use the least amount of iterations to find a solution this saved on time and costs [12], [97], [98]. Total active power loss minimization and bus voltage profile improvement problem has also been resolved using the FPA to solve single-objective optimization problems which provided a solution to the above-mentioned topic. The algorithm can outperform all other algorithms in reducing fuel costs, total active power and fuel costs that relate to valve effect and voltage profile improvement [13], [99]. These are just some of the issues relating to the transmission sector of power systems that the FPA can either improve or solve [93].

3) DISTRIBUTION SYSTEMS

Distribution systems aim at providing electrical energy to consumers and industrial areas at lower voltages, reliably and efficiently. However, studies have shown that approximately 70% of energy is lost in the distribution phase with only 13% of generated energy lost because of the joule effect [100],
Such losses have great financial and environmental implications, as well as affects the overall efficiency of the grid. Therefore, to meet the demands of energy generation whilst addressing key environmental issues, determining new methods to reduce power losses and improve the distribution network performance remains necessary and can be achieved by adopting reactive power compensation, network reconfiguration, distributed generation and hybrid methods [100], [103], [104]. Although, all these proposed methods experience certain challenges. One such case is with regards to DG placement and sizing. Since the location and size of DG units greatly impacts the voltage profile, power losses, and power flow, the non-optimal and sizing of DG units within the grid can actually increase system losses and reduce the voltage profile past permissible limits [100], [101], [102] [104]. Therefore, to avoid the non-optimal placement, DG planning is essential. Incorporating DG into the grid can help reduce active power losses, but does not necessarily assist with reactive power losses, and so one frequently adopted method to suppress reactive power losses is through optimal capacitor or D-STATCOM placement and sizing within the distribution network [105], [106], [107]. Alternatively, minimizing the distribution system energy losses can be achieved by reconfiguring the network and involves changing the structure of the distribution system, which is also useful for restoring power to loads in areas where faults occur [30], [108]. Additionally, distribution network systems can be optimally scheduled to improve system performance [86], [109]. However, the above-mentioned methods are considered highly complex, and so FPA and its variants have been proposed as a possible tool for providing optimal solutions to these optimization problems.

VII. APPLICATIONS OF THE FLOWER POLLINATION ALGORITHM IN POWER GENERATION

This section discusses the applications of FPAs in electrical power generation systems. Table 1 provides an overview of such applications encompassing areas of problem solving and significant findings.

A. THE ECONOMIC DISPATCH PROBLEM

The literature [9], [78], [110] implement FPA on various sized power systems to investigate its effectiveness as an optimization technique to solve the EDP. All three papers use MATLAB simulation software to conduct the experiment. Sarijya et al. [9] conducted the test on an IEEE 30-bus test system, the results of the simulations are presented and analysed [9]. However, it was found that FPA reduced the total fuel cost from the initial condition and enhanced the voltage magnitude of the system. FPA displayed the most efficient results amongst the metaheuristic algorithms it was compared to in [9]. However, FPA was only applied to a single generating system in the paper by Sarijya et al. [9]. Maity et al. [78] implemented FPA on three different sized generation units. The results illustrated in [78] showed that in all three cases the fuel cost of the systems decreased after FPA was used to optimize the system. These papers confirm that FPA is efficient in obtaining the optimal economic fuel cost in various power generation systems. This is attributed to the algorithm’s great convergence characteristics, computational efficiency, and robustness. The two papers [9], [78] discussed the application of FPA on various generation systems. Dhayalini et al. [110] integrated thermal generators with wind units and used FPA to solve the dispatch problem with the addition of a renewable wind farm to the generation system. The paper conducted tests on the wind farm and showed comparison between the fuel cost before and after FPA was applied on the two thermal systems [110]. The paper found that system costs decreased, can confirm FPAs success and efficiency in economic dispatch problems to obtain an optimal solution in a variety of cases in power generation systems. In other literature, the initial population and switching processes was modified to form the MFPA, described in [111], [112], and [113], and was applied by Sarijya et al. [79] on a custom 10-generator system and Regalado et al. [13] who conducted the test on a standard IEEE 30-bus system. The results show that in both cases FPA and MFPA were able to reduce the costs of the system. However, MFPA was able produce a better optimal solution in both cases due to its faster convergence rate.

| References | Problem solved | Optimization technique | Important findings |
|------------|----------------|------------------------|-------------------|
| [9], [78], [110], [79], [13] | Economic Dispatch Problem - optimal sizing and placement of generating units in a power system to ensure efficient power generation through the minimization of fuel losses and correct active and reactive power outputs at each generating unit. | FPA | Modifications to the switching and pollination processes results in enhanced optimization [79], [13]. |
| [81], [80], [82] [114] [111] | Scheduling of Hydrothermal stations - optimised scheduling of Hydrothermal stations in smart/distribution grids to minimize operational costs. | FPA | Addition of a scaling factor and an additional exploitation phase can greatly enhance the performance of FPA in this sector [111]. |
B. SCHEDULING OF HYDROTHERMAL STATIONS

Balachander et al. [81] provided a mathematical breakdown on the hydrothermal scheduling problem and used FPA on a test scenario in which a single hydro and thermal power plant were used. The test results presented in [81], and [80], demonstrated FPA’s superior search capabilities and potential to obtain global solutions in less settling time than traditional approaches (GA, PSO, BFA). Sutradhar et al. [114] tested the validity of the MFPA to solve the Hydrothermal Scheduling problem. The literature [114] conducted the simulation on a test system in [120]. MFPA was compared to various algorithms (FPA, P-DE), and outperformed the above-mentioned algorithms significantly in terms of convergence time and accuracy. Dubey et al. [111] enhance the base FPA through the enhancement of the local pollination process, with the addition of a scaling factor and an additional exploitation phase. The IFPA was tested against various algorithms (including the standard FPA) on three different cases to determine the efficiency in solving the short-term hydrothermal scheduling problem. The results conclude that the IFPA can produce higher quality solutions with superior convergence characteristics on all cases [111]. The papers [81], [80], [111], [114] provide sufficient evidence which concludes that the use of FPA’s strong search capabilities through global and local pollination techniques makes it a viable solution to solving the hydrothermal scheduling problem.

C. RENEWABLE ENERGY GENERATION EFFICIENCY

Generation of electricity through renewable energy sources has increased over the past decade. The two biggest forms of renewable energy sources, solar and hydro plants, are limited by the availability sunlight and water respectively [66, 83]. Recent studies have used metaheuristic algorithms to optimize MPPT controllers to maximize PV output under varying climate. The literature by Ram et al. [66] and Elbehairy et al. [83] both implement FPA on MPPT controllers to determine whether global peak can be achieved. The tests in [66] and [83] were conducted on triple and single array solar panel systems, in which both tests utilized simulation software under different shading conditions such as low, medium, and high shading. The test results illustrated in [66] and [83] showed that FPA was able to detect the maximum power point at different conditions of partial shading. Elbehairy et al. [83] also tested FPA and compared it to PSO. The literature in [83] demonstrated that both PSO and FPA methods have similar scope in reaching the GMPP. However, FPA was able to produce the optimal global peaks under the strong shading condition which PSO could not achieve, thereby justifying FPA as a more suitable algorithm [83]. Murdianto et al. [116] investigated the prospect of adding a DC-DC BUCK converter to a DC microgrid to improve the grid stability. Murdianto et al. [116] tested the hypothesis by using the FPA to optimize the MPPT tracking of a proportional integral (PI) controller in the system. The results displayed that the FPA optimized PI controller was capable of accurately tracking the MPPT and thus resulted in a more stable system (due the regulated voltage). Murdianto et al. [116] also highlighted the fact that using FPA to track the MPPT is advantageous due to the simplicity to implement as compared to conventional techniques such as IC and P&O algorithms due to it requiring far less parameters to tune [116]. Murdianto et al. [84] investigates FPA MPPT capabilities further by attempting to track the MPP of a SEPIC converter under partial shading conditions. FPA was tested against MPSO and GWO algorithms, with the results further highlighting FPA’s superior MPPT capabilities. The tests concluded that FPA was able to produce extremely accurate results in the least amount of convergence time [84]. FPA proved in simulation to be an efficient method in finding the GMPP. However, with the unpredictability of nature, it is unknown whether this method would pass the test in a practical situation. Elbehairy et al. [83] implemented a practical PV unit system with the hardware implementation being described in [83]. The practical experiment made use of a MPPT controller optimized with the FPA under various shading conditions and concluded that FPA was capable of tracking MPP irrespective of shading patterns created [83]. This validates the practical use of FPA as a means of optimization to practically track the MPP. A modified Chaos FPA was developed and implemented by Yousri et al. [117]. The paper aimed to test the modified C-FPA against the base FPA to determine which algorithm can produce better results with regards to tracking GMPT in solar generation units. Yousri et al. [117] conducted the simulation-based test on a solar generation unit under various shading conditions. The results obtained in [117] showed that C-FPA variants were able to track the GMPP efficiently and assisted in producing a

| [66], [115], [83], [116], [84], [117], [118] | Conventional/Renewable energy generation optimization – use of FPA to optimize conventional energy generation units. | FPA manufacturers to demonstrate the potential of FPA to optimize the MPPT controllers to maximize PV output under various conditions. Yousri et al. [117] conducted the simulation-based test on a solar generation unit under various shading conditions. The results obtained in [117] showed that C-FPA variants were able to track the GMPP efficiently and assisted in producing a | [83], [84], [117]. |
| --- | --- | --- | --- |
| [85], [87], [119] [86] | Power System Frequency Stabilization – Use of FPA optimization to ensure frequency stabilization of system. Optimal integration of renewable energy generation sources into distribution grids. | FPA to track the solar MPPT is advantageous due to it requiring far less parameters to tune [83], [84], [117]. | FPA was found to be an extremely effective algorithm for tuning of PID parameters and exceeded the performance of conventional PID optimization techniques [85], [87], [119] [86]. |
greater amount of power in a shorter space of time compared to FPA. Sun et al. [115] proposed a new wave energy converter (WEC) which uses FPA to achieve maximum power absorption under all conditions within a wave energy generation system. A complete model of a WEC system and controller was constructed in [115]. Simulation based tests conducted on a WEC system implemented on MATLAB in [115] found that FPA was able to increase the average power output under various conditions. Steam turbines are a key component to production of energy within conventional power plants and optimal tuning plays an important role in ensuring that the efficiency and lifespan of machinery remain sustainable [118]. Kumar et al. [118] proposed a closed loop speed control system through a fractional order proportional integral derivative (FOPID) controller for an industrial turbine [118]. The FOPID’s parameters were tuned using the MO-FPA and the effectiveness of the optimization was assessed by examining the disturbance rejection, overshoot and rise time of the system. The results displayed that the system exhibited beyond satisfactory performance with an overshoot less than 1% and satisfactory minute rise and settling time values [118]. The most notable characteristic was the effective disturbance rejection of the system, thus highlighting MO-FPAs PID optimization capabilities [118].

D. POWER SYSTEM FREQUENCY STABILIZATION
Hussain et al. [85] presented a hybrid power system and tested the ability of an FPA optimized PID controller against a PI controller to determine their effectiveness in optimizing an unstable system in which DG units were incorporated into the network. The test results in [85] show that both controllers were able to maintain the system frequency within the permissible limits. However, the FPA optimized controller outperformed the PI controller as it had optimal settling times and better search capabilities which allowed for better convergence and greater system stability. Joshi et al. [86] implemented the Chaos modified FPA to incorporate a large wind unit into a distribution network. The test results obtained in [86] show that C-FPA was able successfully obtain a stable system. The chaotic maps and random nature of the chaos modified FPA allowed it to achieve the lowest operational cost and greatest system stability amongst other metaheuristic algorithms tested against [86]. Jagatheesan et al. [87] aimed to solve the load frequency instability issues that exists within conventional power systems with the use of a FPA optimized PID controller. Jagatheesan et al. [87] conducted the tests on a power system consisting of three identical thermal generation plants. Power systems are subject to voltage fluctuations because of load disconnection, overcurrent, and overvoltage faults [119]. These voltage sags are extremely dangerous and may permanently damage the generators within the system. As such Sambariya et al. [119] attempted to optimize a PID controller for the AVR of a power system using FPA. The literature in [119] obtained the proportional integral derivative (PID) tuning parameters using FPA and FPA-PID.

The performance of the optimized controllers in [119] was tested for over 156 plant conditions and was compared with established literature in the field. The exceptional performance in terms of settling time, peak value and system stability were noted with comparisons to other optimization techniques highlighting the FPA tuned PID systems superiority [119].

VIII. APPLICATIONS OF THE FLOWER POLLINATION ALGORITHM IN TRANSMISSION SYSTEMS
This section discusses the applications of FPAs in electrical power transmission systems. Table 2 provides an overview of such applications encompassing areas of problem solving and significant findings.

A. TRANSMISSION LINE PLANNING
Presently, the supply of electricity has decreased considerably due to unsuitable power system designs which are unable to satisfy the increasing load requirements. As a result, there is an increase in the number of private companies that assist in meeting the requirements, which would otherwise cause problems in the security of the power system, voltage fluctuations and system breakdown due to transmission line losses [10]. To solve these problems, new transmission lines are being built. However, this task is becoming more difficult due to governmental and ecological challenges [10], [96]. To preserve voltage stability, minimize transmission line losses and enhance power system security, flexible AC transmission system (FACTS) devices are used. These can be further categorized into thyristor-controlled series capacitors (TCSCs) which monitor and react much faster compared to other FACTS devices. TCSC is a better regulator of transmission line impedance and can reduce it by changing reactance values which in turn increases power flow in the system [10]. To ensure that the TCSC is optimally positioned in transmission lines to achieve maximum power flow, the fast voltage stability index (FVSI) factor is used [10]. The flower pollination algorithm is employed to determine the optimal setting for the FACTS device. D.L. Pravallika et al. [10] suggested a method for optimal positioning of the TCSC in a network using the FVSI and the optimal configuration of the TCSC value using FPA. The paper [10] built a program using MATLAB software, with the aim to reduce transmission line losses on an IEEE 14-bus system [10]. Tests were conducted to determine the:

- Fast Voltage Stability Index values for different IEEE 14-bus test lines.
- Incorporation of TCSC with Newton-Raphson (NR) method or with Flower Pollination Algorithm (FPA) method.
- Variable Values using FPA by TCSC and variable values without using FPA by TCSC.

The results observed and recorded in tables seen in [10] found that the optimal TCSC power flow based on FPA produced efficient results as compared to NR. Thus, the positioning of the TCSC using FPA decreased the response value by 9.5% [10]. An 11.76% power loss was also
observed after the TCSC was used, which was further decreased by 40.3% after setting the FPA parameters [10]. This suggests that the use of FPA has a positive effect on the reduction of transmission line losses [10]. Thus, the paper by Pravallika et al. [10] confirms the good convergence rate and accuracy of FPA when positioning TCSC devices in a transmission network.

B. POWER SYSTEM MANAGEMENT

Modern power system’s face a variety of difficulties due to their complicated function and multifaceted structure [11].

| References | Problem solved | Optimization technique | Important findings |
|------------|----------------|------------------------|--------------------|
| [10], [96] | Transmission Line Planning – Optimal placement and setting of FACTS devices, such as TCSCs using the FVSI and FPA, to achieve maximum power flow, and regulate transmission line impedance and reduce it by changing reactance values. | FPA | It was found that the optimal TCSC power flow based on FPA produced efficient results as compared to NR. Thus, the positioning of the TCSC using FPA decreased the response value [10]. A power loss was also observed after the TCSC was used, which was further decreased by after setting the FPA parameters [10]. |
| [9], [11] | Power System Management – Optimising the power flow in a power system using FPA with SVCs in order to mitigate the loss of power in transmission lines and the cost of real power generation. | FPA | It was found that the total active power needed to be produced was reduced and that the real power loss was reduced using FPA with SVCs [11]. In addition, FPA was proven to be more efficient in solving OPF problems than Gradient Method, and less efficient than Artificial Bee Colony [9]. |
| [12], [97], [98] | Congestion Management – Optimising generator rescheduling using FPA to improve congestion management in power systems. | FPA MFPA | It was found that the FPA solution provided the least minimum congestion cost as well as a reduced power flow in both previously congested lines as compared to the other algorithms [12]. FPA successfully reduced system losses and congestion management costs in less iterations [12], [98]. |
| [13], [99] | Bus Voltage Profile Improvement – Using FPA to solve single-objective optimization problems that are focused on valve effect, and voltage profile improvement. | FPA MFPA | The proposed MFPA solution had a minimum active power loss which is significantly less when compared to PSO and CSA [13]. |

To improve OPF in power systems, various factors apart of generation, transmission and distribution need to be improved. As such, this section will investigate how FPA is implemented to solve problems involving optimal power flow. Kumar et al. [11] and Sakti et al. [9] suggested methods to solve the Optimal Power Flow problem using the Flower Pollination Algorithm. B.S. Kumar et al. [11] outlined an approach to solve the multi-objective challenge of power system optimization. In the paper [11] a FACTS shunt device, called the Static Var Compensator (SVC), was used to achieve optimum power flow. The aims of this approach are to mitigate the loss of power in transmission lines and the cost of real power generation. The results presented in the study were obtained through simulation using MATLAB on an IEEE 14-bus method for OPF problems using FPA without SVC and SVC. In the method proposed by Kumar et al. [11], the simulation results showed that the total active power needed to be produced reduced by 1.19% and that the real power loss was reduced by 41.45% using FPA with SVC [11]. In the study [11], the results simulated were compared to results produced with the Genetic Algorithm (GA), and it was concluded that FPA was more efficient than GA. Sakti
et al. [9] suggested the approach of using FPA to be extended to problems with OPF, with the key goal of minimizing the average cost of fuel while maintaining constraint conditions. Control variables used in this approach include generator generation of active power and voltage magnitude, tap-transform ratio configuration, and reactive power injection on shunt capacitance. These control variables were selected as they can be modified and therefore be used to obtain the lowest possible value of the objective function [9]. The method suggested by Sakti et al. [9] applied FPA to an OPF problem on an IEEE 30-bus test system with a total power of 283.40 MW. The simulation was conducted numerous times to ensure consistency and efficiency, with results for line active losses after FPA implementation being 9.045 MW. This result was then compared with other meta-heuristic methods, and FPA was proven to be 13.7% more efficient than Gradient Method with line losses of 10.486 MW and 0.13% less efficient than Artificial Bee Colony with line losses of 9.0328 MW. The two methods proposed in [11] and [9] are testament to the robustness and effectiveness that FPA has in enhancing the power flow in Power Systems.

C. CONGESTION MANAGEMENT

Congestion in transmission lines occurs when the line is operated beyond its standard transfer limits. This can occur due to the greater demand for electricity required by consumers, which strains the lines and forces them to work close to their MVA limit. Congestion impacts transmission reliability and system security, which can increase electricity tariffs. To resolve this problem, Congestion Management (CM) was introduced to reduce tariff accumulation for relieving congestion in transmission lines [12]. In [97] and [98], it is stated that congestion management is done by load shedding, using flexible alternating current systems (FACTS) and generator rescheduling. The chosen method is left at the discretion of an independent system operator (ISO). In this paper, generator rescheduling will be reviewed to determine the effects it has on improving congestion management in transmission systems. Verma et al. [12] explored the approach of generator rescheduling by focusing on equality and inequality constraints, where equality is the cost of rearranging the active power of the generator output and inequality is the set operating limits of the power system. These constraints are expressed as a mathematical model which considers the number of buses, generators, loads and transmission lines as well as other factors such as the real and reactive power that is produced and consumed. The test was conducted using a modified IEEE 30-bus and IEEE 57-bus systems, with each bus system having two test scenarios. FPA was used to optimize the generator rescheduling with the foremost solution discussed in [12]. In both these lines, power flow had exceeded the maximum MW allowed, which is 130 MW. More specifically, lines 1-7 had a flow of 147.46 MW and lines 7-8 had a flow of 136.29 MW. The overloaded lines had then been alleviated by applying optimal rescheduling of the generators using the proposed FPA. These results were tabulated in [12] and compared with other optimization algorithms results such as SA, PSO and RSM. It was observed that the FPA solution provided the least minimum congestion cost as well as a reduced power flow in both previously congested lines as compared to the other algorithms. This result was consistent in both test scenarios. FPA successfully reduced system losses and congestion management costs in fewer iterations [12].

D. BUS VOLTAGE PROFILE IMPROVEMENT

To improve OPF in power systems, various factors within generation, transmission and distribution need to be improved. In the literature [13], tests are conducted using the various optimization algorithms and are then compared with each other. This paper focuses on solving single-objective optimization problems and focuses on four main aspects, i.e., fuel cost minimization, total active power losses minimization and fuel cost minimization concerning valve effect and voltage profile improvement. The latter two single-objective optimization problems will be discussed as they relate to transmission systems. These single-objective optimization problems have been translated into a formula in which the combined active power losses determine the combined line flows active power losses, and the improvement of load bus voltage is used to improve the system voltage profile and reduce the voltage changes. Tests are conducted on a standard IEEE 30-bus test system which consists of six generators and four transformers with off-nominal tap ratios [99]. The OPF problem is written mathematically to represent a single objective function composed of dependent state variables and independent control variables. The equality constraints related to load flow are provided as a formula that considers active power, reactive power, voltages, susceptance, phase difference and conductance between buses, and the number of buses and number of generator buses. The inequality constraints are written as a formula and considers generator limits, tap limits transformer, compensator limits, voltages at loading buses and power flow line limits [13]. The MFPA used in [13] focuses on two factors; looking for the foremost initial condition, which looks for a closer solution while simultaneously looking at the opposite guesses; this allows for the best initial condition to be chosen and an appropriate solution point as well as eliminating the need for the switch probability, which improves the switch between local and global searches. It is tabulated against other optimization algorithms the active power losses using the minimization function. The proposed MFPA had a minimum active power loss of 2.8877 MW which is significantly less compared to PSO and CSA, which had an active power loss of 3.0745 MW and 3.0437 MW, respectively. There is also graphical analysis done by [13], which shows the convergence profile of the various algorithms used. MFPA progress time does not deviate from the other optimization algorithms, which stipulate that the changes done to the standard FPA do not affect its capability to deal with similar computational problems. A deviation of 5% to 10% from the nominal voltage profile is acceptable; the bus voltage profile is an.
excellent indicator to determine the quality and system security [13]. The voltage profiles from various optimization algorithms and the power flow solution are analyzed scientifically in [13] with voltage limits marked at 0.95 p.u. and 1.05 p.u. and buses from 1-30 showing their voltage p.u. values. MFPA shows better results and lies almost exactly in the middle of the two limits. It is noted by [13], that the load bus voltage profile formula does not give data pertaining to the voltage deviation distribution among the system. This resulted in the authors developing a MATLAB interface that was able to display the voltage bus map. This map displays the IEEE 30-bus single line power system diagram and each bus p.u. value from 0.95 p.u. to 1.10 p.u. This map indicates that the voltage profile estimated by the MFPA does not exceed 1.025 p.u. or go below 0.965 p.u. indicating a stable bus voltage profile. Thus, the MFPA was able to reach convergence using fewer iterations and a reduced processing time. Overall, the MFPA performed better than the basic FPA and was able to find fitter initial solutions as well as improve switching probability.

IX. APPLICATIONS OF THE FLOWER POLLINATION ALGORITHM IN DISTRIBUTION SYSTEMS

This section discusses the applications of FPAs in electrical power distribution systems. Table 3 provides an overview of such applications encompassing areas of problem solving and significant findings.

A. DISTRIBUTION SYSTEM PLANNING

Distribution generation (DG) is electrical power generation that is located near the consumer [104]. This form of generation is tasked with supplying the grid with active power in the event of load instability [106]. The increasing interest in optimally placing DG units and determining the optimal size is largely attributed to its ability to improve voltage profile and minimise power losses [102]. Research has estimated that approximately 20% of new generation installations are DG [100]. However, non-optimal placement of DG can instead reduce voltage profile and increase system losses [100].

| References | Problem solved | Optimization technique | Important findings |
|------------|----------------|------------------------|--------------------|
| [102], [121], [103], [106], [100], [122], [123] | Distribution network planning - optimal placement and sizing of DG units in distribution systems together with optimal placement of Capacitors and D-STATCOMs in distribution networks to suppress reactive power losses, optimal placement of transformers in distribution networks to reduce installation costs, maintain high efficiency of operation, and satisfy customer expectations. | FPA | FPA with loss sensitivity factor (LSF) is so versatile that it can be imposed on different distribution systems effectively [106]. FPA is simple to implement, converges to a better solution and provides preferable performance over other algorithms in terms of voltage profiles, active and reactive power losses, and net savings [102], [103], [121], [100], [122], [123]. |
| [86], [109] | Distribution system operation - optimised scheduling of microgrids in smart, distribution grids. | FPA-GSA, CHAOS-FPA | CHAOS-FPA exhibits a lower standard deviation (S.D.) than FPA [86]. |
| [30], [108] | Distribution system automation – optimal placement of sectionalising and tie lines for distribution network reconfiguration (DNR), minimising load balancing index (LBI) of a radial distribution network (RDN). | FPA, MO-FPA | FPA and its variants yields better solutions in less computational time compared to other optimization algorithms used for this application [30], [108]. |
| [105] | Voltage and reactive power control – optimal capacitor placement and sizing in distribution networks to reduce costs and power losses. | FPA | FPA outlasts other algorithms in determining optimal solutions to the size and location of capacitors in a distribution system [105]. |

Sizing is another important topic that must be planned before installation as changing the DG size with varying demand is not economically feasible [100]. One approach to searching for optimal locations and sizes of DG is to use meta-heuristic optimization techniques. Several works such as [100], [102], [103], [106], [122], [123] have utilized this method for DG placement and sizing using popular meta-heuristic algorithms including the recently developed FPA. Authors in [100], [102], [122], [123] applied FPA to determine the optimal location and size of DG in distribution systems. The approach by Reddy et al. [102] involved determining the optimal size and location of DG for IEEE 15, 34, and 69-bus systems using FPA. The vector index method was used in [102] to minimise the search space, with the algorithm achieving effective results due to better convergence characteristics. Oda et al. [100] evaluated FPA on IEEE 33, 69, and 136-bus test systems with single and multi-DG allocations. FPAs performance was compared in
[100] to other popular optimization algorithms used in DG placement and sizing, such as artificial bee colony (ABC), backtracking search optimization algorithm (BSOA), and clonal search algorithm (CSA). The results verify that FPA is efficient and robust, outperforming ABC, BSOA, and CSA in optimal DG sizing and placement demonstrated in [100]. Prasetyo et al. [122] explored optimal placement of PV based DG in Semanu substation, Gunung Kidul Yogyakarta, to reduce PV penetration that may reverse power flow, in addition to improving the voltage profile. FPA was chosen as the optimization algorithm in [122] and reduced active power losses by approximately 68%. While the objective is to choose an optimal location and size of DG units to reduce active power loss, one must keep in mind that power losses include reactive power as well. Recent works indicate that optimal placement of capacitors (in conjunction with DG) to suppress reactive power losses, can greatly increase system efficiency [106]. The literature [103], [106], and [123] indicate that optimal placement of capacitors (in conjunction with DG) to suppress reactive power losses, can greatly increase system efficiency. The work presented in [103], [123] explored the optimal placement of DG with shunt capacitors simultaneously using the FPA to decrease power losses and increase the voltage profile. Sudabattula et al. [103] used the algorithm to optimally place multiple capacitors and 1 DG unit using a 69-bus system under different load conditions and effectively achieved the main objective of improving voltage profile and reducing losses. Manimegalai et al. [123] tested various DG and capacitor combinations on an IEEE 33-bus system using FPA and found that the best result was achieved using multiple DG with capacitor. However, studies have shown that capacitors can be replaced by D-STATCOM with effective results [107]. A more recent approach to improving voltage profile was explored by Vittal Bhat et al. [106], in which DG placement and sizing was searched for simultaneously with D-STATCOM placement in RDS using FPA with LSF, which is an important aspect to consider when determining the selection of buses for DG and D-STATCOM installation. The system was tested on 15, 33, and 69-bus RDS, and achieved optimal results using FPA, thereby producing greater efficiency in the distribution network. Transformer placement is another difficulty encountered in distribution network planning by power utilities, as installation cost, customer satisfaction, and high efficiency of operation are some of the variables that need to be considered [121]. Huang et al. [121] explored the placement of distribution transformers in a low-voltage grid with FPA as the proposed method of approach with the above variables in mind. Several other approaches such as tabu search involved complex processes, and popular search algorithms such as PSO require adequate selection of parameters for satisfactory performance [121]. With regards to FPA, tuning of only two control parameters is sufficient for satisfactory performance with less computational time [103]. Huang et al. [121] validated the effectiveness of FPA in distribution transformer placement using two grid networks and found that the algorithm converged to better quality solutions compared to other published methods on this topic.

B. DISTRIBUTION SYSTEM OPERATION

Conventional electrical power grids have been reconstructed to form smart grids which use information and communication technologies (ICT) to allow for more efficient and reliable operation of power systems [86]. The future development of such smart grids will consist of many DG microgrids for grid-connected power generation [109]. Many of these DG units consist of renewable energy sources that are unpredictable and volatile. For example, PV generation is dependent on solar irradiance which can be obstructed by clouds. Wind farms require strong currents of air, which is not always available, to produce electrical energy. Therefore, research in optimised scheduling of distribution network systems with microgrids has become vital. Zhan et al. [109] utilized FPA of gravitational search mechanism to determine the optimal reactive power distribution of a distribution network with a PV microgrid. However, reactive power optimization is related to active power optimization of the network with a PV microgrid, and so these optimization schedulings were performed separately with active power optimization performed first. FPA was combined in [109] with the gravity search algorithm to accelerate its convergence speed and improve exploration. The algorithm in [109] reduced network loss by 14.7% and improved voltage qualification rate. In another paper, Pandya et al. [86] modified FPA using Gauss map chaotic equations to optimally schedule distribution energy resources (DERs) in an attempt maximise profits of an aggregator. The proposed CHAOS-FPA in [86] was tested on a 33-bus distribution network and its performance was compared to FPA, cuckoo search algorithm (CSA), and differential search algorithm (DSA). Results in [86] illustrate that CHAOS-FPA has a lower standard deviation in comparison to FPA, CSA, and DSA and produced the greatest increase in profits from all other algorithms used in [86].

C. DISTRIBUTION SYSTEM AUTOMATION

Distribution systems consist of two categories of lines i.e., sectionalising and tie lines [30]. Distribution network reconfiguration (DNR) involves rearranging the structure of the system by optimally changing the position of these lines to maintain the radial topology [30], [108]. Network reconfiguration can provide better solutions to minimise power losses in a distribution system and can restore loads in areas that experience a fault [108]. However, DNR is highly complex and requires innovative techniques to solve. Proposed methods include the heuristic and meta-heuristic algorithms to search for an optimal solution. Salman et al. [108] explored DNR using FPA with a graphical user interface (GUI) to minimise power losses in a grid. The proposed method was tested on an IEEE 33-bus system using MATLAB software for the simulation. The use of FPA was compared to other popular meta-heuristic algorithms such as
PSO and MPSO. The results in [108] confirm FPA’s efficiency in searching for an optimal solution as it reduced power losses by 31.12% in 14.3 seconds compared to MPSO, which took 52.23 seconds to reduce losses by the same percentage. The voltage improvement of the system in [108] after applying FPA to reconfigure the network was approximately 2.64%. Although network reconfiguration can minimise power losses considerably in a distribution network, DNR alone cannot increase the voltage profile of the system to an optimal level [30]. Ganesh et al. [30] presented a reconfiguration methodology that utilises a combination of FPA and CSA to form the multi-objective modified Flower Pollination Algorithm (MO-MFPA), which was then used to decrease power losses, improve voltage profile, and minimise the load balancing index in a radial distribution network with PV based DG and D-STATCOM. The suggested method was tested on an IEEE 33, 69, and 118-bus distribution system. To compare the performance of MO-MFPA in [30], the algorithm was compared to MO-FPA. Results from the simulation confirm that MO-MFPA yields better solutions and that MO-MFPA in [30] optimally reduced power losses and minimised the LBI whilst improving the voltage profile considerably in all three bus distribution systems.

D. VOLTAGE AND REACTIVE POWER CONTROL

Capacitor placement and sizing on its own is also a challenging task as many proposed meta-heuristic techniques have failed to reach optimal costs [105]. Abdelaziz et al. [105] suggested the use of FPA to determine optimal placement and sizing of capacitors in distribution networks to decrease power losses. The algorithm was tested on IEEE 15, 69, and 118-bus systems and its effectiveness were compared to numerous other algorithms including PSO, GA, and harmony search algorithm (HSA). The proposed scenario of testing in [105] involved FPA selecting the optimal location from the initial candidate buses based on higher Power Load Index (PLI). In each test, FPA gave the highest power loss reduction and net savings.

X. APPLICATIONS OF THE FLOWER POLLINATION ALGORITHM IN OTHER FIELDS

This section discusses the applications of FPAs in other engineering field. Table 4 provides an overview of such applications encompassing areas of problem solving and significant findings.

A. MICROBIOLOGY

In the field of science, the need for innovative optimisation techniques is imperative to obtain solutions to optimisation problems as efficiently as possible. Mohamed A Tawhid et al. [124] recently proposed the development of a hybrid algorithm consisting of FPA and GA to minimise the molecular potential energy function and is referred to as the hybrid flower pollination and genetic algorithm [124]. Algorithm (HFPGA). Minimising the molecular potential energy function is required to understand the 3-dimensional structure of proteins. Some of the current methods of minimising the molecular energy function are futile as they are costly and time-consuming. This serves as a reason to develop a nature-inspired algorithm to obtain solutions to these problems. The HFPGA numerically demonstrates its efficiency compared to other types of algorithms.

| References | Problem solved | Optimization technique | Important findings |
|------------|----------------|------------------------|--------------------|
| [124]      | Microbiology - minimisation of Non-Convex Potential Energy function of molecular structure. | HFPGA | The experimental outcomes showed that the suggested algorithm comparatively performs better to obtain the global minimum of the potential energy function [124]. |
| [125], [126] | Chemical engineering - Optimization of food-related thermodynamic problems, minimising the size of triaxial porcelain. | FPA MFPA | Numerically the modified FPA performed better than the standard FPA [125], [126]. |
| [49] | Mechanical engineering - Tubular Column material and construction cost minimisation, Speed Reducer weight minimisation. | MFPA | The modified flower pollination algorithm provides an efficient solution to this minimisation problem as compared to other nature-inspired algorithms [49]. |
| [127] | Civil engineering - truss structure weight minimisation, optimal tuning of mass dampers. | FPA | The results numerically show FPA is far more efficient than other metaheuristic algorithms [127]. |

B. CHEMICAL ENGINEERING

The Flower pollination algorithm is a relatively new method of solving optimisation problems in the field of chemical engineering. However, there are some studies conducted by researchers about the applications of FPA in chemical engineering. Merzougui et al. [125] applied FPA for phase equilibrium calculations of a Liquid-Liquid Equilibrium system in which the algorithm had been utilized for
parameter identification of UNIQUAC and NRTL models from ternary and quaternary systems. A modified FPA had also been presented and compared to the standard FPA. Numerically the modified FPA performed better than the standard FPA. Zainudin et al. [126] combined FPA and Taguchi design to produce a hybrid algorithm to resolve problems related shrinkage of triaxial porcelain composed of palm oil fuel ash.

C. MECHANICAL ENGINEERING

In the field of mechanical engineering, many hybrid flower pollination algorithms have been developed for optimisation problems to obtain efficient design solutions. The flower pollination algorithm was modified and utilized in the design of tubular columns to minimise the material and construction costs [49]. Speed reducer designs require the total weight of the device to be minimised. The modified flower pollination algorithm provides an efficient solution to this minimisation problem as compared to other nature-inspired algorithms.

D. CIVIL ENGINEERING

Efficient optimisation techniques are vital in the field of civil engineering since many of related design problems tends to be non-linear with uncompromised constraints. These constraints include cost, physical and architectural requirements which often leads to a design problem of severe complexity. Bekdas et al. [127] investigated the use of the FPA to minimize the weight of trusses and sizing design variables. The algorithm had been applied to minimize both two and three-dimensional truss weight minimization problem. The results numerically show FPA is far more efficient than other metaheuristic algorithms. Nigdel et al. applied the flower pollination algorithm to optimize design of tuned mass dampers. This optimization includes the optimum mass, period, and damping ratio.

XI. CONCLUSION

The Flower Pollination Algorithm was developed using the interesting features presented by the evolution of flowering plants. This robust and efficient algorithm can be used to solve many multi-objective optimization problems, which are challenging in both industry and engineering. Since its inception in 2012, FPA has been well received by the science and engineering community for its performance in solving optimization problems more efficiently than other popular nature-based algorithms reviewed in other works of literature, such as Genetic Algorithm and Particle Swarm Optimization. FPA and its many variations have outperformed many prevalent algorithms used for solving complex optimization problems in power systems and with promising results. Some of these problems include the well-known economic dispatch, distribution generation and optimal power flow problem in power systems. With its successful application in multiple engineering fields, the prospect of FPA, and its variations, benefiting other fields of science as well as electrical power systems, is highly probable.

REFERENCES

[1] X.-S. Yang, “Flower pollination algorithm for global optimization,” Unconventional Computation and Natural Computation, vol. 7445, pp. 240-249, 2012.
[2] Y. Wang, D. Li, Y. Lu, Z. Cheng and Y. Gao, “Improved Flower Pollination Algorithm Based on Mutation Strategy,” in 9th International Conference on Intelligent Human-Machine Systems and Cybernetics, Hefei, 2017.
[3] A. E. Kayabekir, G. Bekdas, S. M. Nigdeli and X.-S. Yang, “A Comprehensive Review of the Flower Pollination Algorithm for Solving Engineering Problems,” in Nature-Inspired Algorithms and Applied Optimization, Springer, Cham, 2018, pp. 171-188.
[4] X.-S. Yang, Nature-Inspired Algorithms and Applied Optimization, Springer, Cham, 2018.
[5] A. Al-Omoush, A. Alsewari, H. Alamri and K. Zamil, “Comprehensive Review of the Development of the Harmony Search Algorithm and its Applications,” IEEE, vol. 7, pp. 14233-14245, 2019.
[6] C. Blum and A. Roli, “Metaheuristics in Combinatorial Optimization: Overview,” ACM Computing Surveys, vol. 35, no. 3, p. 268–308, 2003.
[7] S. Pant, A. Kumar and M. Ram, “Flower pollination algorithm Development: A State of Art Review,” International Journal of System Assurance Engineering and Management, vol. 8, pp. 1858-1866, 2017.
[8] H. Chiromaa, N. L. M. Shuib, S. A. Muaz, A. I., L. B. Il and J. Z. Maitama, “A Review of the Applications of Bio-Inspired Flower Pollination algorithm,” in The 2015 International Conference on Soft Computing and Software Engineering (SCSE 2015), 2015.
[9] Sariyia, F. P. Sakti and S. P. Hadi, “Optimal Power Flow Based on Flower Pollination Algorithm,” in IEEE, Kuta, 2018.
[10] D. L. Pravallika and B. V. Rao, “Flower Pollination Algorithm Based Optimal Setting of TCSC to Minimize the Transmission Line Losses in the Power System,” Procedia Computer Science, vol. 92, pp. 30-35, 2016.
[11] B. S. Kumar, M. Suryakalavathi and G. V. Nagesh Kumar, “Optimal Power Flow with Static VAR Compensator Based on Flower Pollination Algorithm to Minimize Real Power Losses,” in Conference on Power, Control, Communication and Computational Technologies for Sustainable Growth (PCCCTSG), Kurnool, India, 2015.
[12] S. Verma and V. Mukherjee, “A Novel Flower Pollination Algorithm For Congestion Management In Electricity Market,” in International Conference on Recent Advances in Information Technology (RAIT), Dhanbad, 2016.
[13] J. A. Regalado, E. B. E and E. Cuevas, “Optimal Power Flow Solution Using Modified Flower Pollution Algorithm,” in IEEE, Ixtapa, 2015.
[14] A. E. Kayabekir, G. Bekdas, S. M. Nigdeli and X.-S. Yang, “A Comprehensive Review of the Flower Pollination Algorithm for Solving Engineering Problems,” Springer International Publishing, vol. 744, pp. 171-188, 2018.
[15] M.-u.-N. Khursheed, M. F. Nadeem, A. Khalil, I. A. Sajjad, A. Raza, M. Q. Iqbal, R. Bo and W. u. Rehman, “Review of Flower Pollination Algorithm: Applications and Variants,” in 2020 International Conference on Engineering and Emerging Technologies (ICEET), Lahore, Pakistan, 2020.
[16] Z. A. Alyasser, A. T. Khader, M. A. Al-Beta, M. A. Awadallah and X. -S. Yang, “Variants of the Flower Pollination Algorithm: A Review,” Springer, vol. 744, pp. 91-118, 2017.
[17] The Editors of Encyclopedia Britannica, “Archimedes’ Principle,” Encyclopedia Britannica, 29 May 2020. [Online]. Available: https://www.britannica.com/science/Achimedes-principle. [Accessed 17 March 2021].
[18] P. Mahazzab, “Archimedes’ Principle Revisited,” Journal of Applied Mathematics and Physics, vol. 5, no. 4, pp. 836-843, 2017.
This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/ACCESS.2021.3138518, IEEE Access
611–627, 2016.

[57] D. Chakraborty, S. Saha and S. Maity, “Training Feedforward Neural Networks using Hybrid Flower Pollination/Gravitational Search Algorithm,” in 2015 1st International Conference on Futuristic trends in Computational Analysis and Knowledge Management, Kolkata, 2015.

[58] Y. Dan, L. Yuanhui, G. Jianqing and Z. Junna, “Analysis of Pumping Test Data Based on Improved Pollen Algorithm,” Investigation Science and Technology, vol. 33, no. 5, pp. 10-13, 2016.

[59] W. Wenbin, L. Zhiheng and W. Zhenhua, “Hybrid Flower Pollen Algorithm based on Modified Search Strategy,” in 2017 International Conference on Robots & Intelligent System, Jiangxi, 2017.

[60] V. Tamilselvan, T. Jayabarathi and V. Tamilselvan, “Multi Objective Flower Pollination Algorithm for Solving Capacitor Placement in Radial Distribution System using Data Structure Load Flow Analysis,” Archives of Electrical Engineering, vol. 65, pp. 203-220, 2016.

[61] D. Goridakis, “Application of Flower Pollination Algorithm to Multiobjective Objective Environmental/Economic Dispatch,” International Journal of Management Science and Engineering Management, vol. 11, no. 4, pp. 213-221, 2016.

[62] B. H. Ulutas and S. Kulturel-Konak, “A Review of Colonial Selection Algorithm and its Applications,” Artificial Intelligence Review, vol. 36, pp. 117-138, 2011.

[63] S. A.-F. Sayed, E. Nabil and A. Badr, “A Binary Clonal Flower Pollination Algorithm for Feature Selection,” Pattern Recognition Letters, vol. 77, pp. 21-27, 2016.

[64] A. Askarzadeh and E. Rashedi, “Harmony Search Algorithm: Basic Concepts and Engineering Applications,” in Harmony Search Algorithm, Kerman, Kerman Graduate University of Advanced Technology, 2017, pp. 1-36.

[65] D. Karaboga and B. Basturk, “An Artificial Bee Colony (ABC) Algorithm for Nu-meric function Optimization,” IEEE Swarm Intelligence Symposium 2006, Indiana, 2006.

[66] J. P. Ram and N. Rajasekar, “A Novel Flower Pollination Based Global Maximum Power Point Method for Solar Maximum Power Point Tracking,” IEEE Transactions on Power Electronics, vol. 32, no. 11, pp. 8486-8499, 2017.

[67] R. Wang, Y. Zhou and S. Qiao, “Flower Pollination Algorithm with Bee Pollinator for Custer Analysis,” Elsevier, vol. 116, no. 1, pp. 1-14, 2016.

[68] S. Kalra and S. Arora, “Firefly Algorithm Hybridized with Flower Pollination Algorithm for Multimodal Functions,” Proceedings of the International Congress on Information and Communication Technology, vol. 438, pp. 207-219, 2016.

[69] L. Wenjing, Z. He, J. Zheng and Z. Du, “Improved Flower Pollination Algorithm and its Application in User Identification Across Social Networks,” IEEE Access, vol. 7, pp. 44359-44371, 2019.

[70] O. Abdell-Raouf and M. Abdell-Baset, “A New Hybrid Flower Pollination Algorithm for Solving Constrained Global Optimization Problems,” International Journal of Applied Operational Research–An Open Access Journal, vol. 4, no. 2, pp. 1-13, 2014.

[71] D. Chakraborty, S. Saha and O. Dutta, “DE-FPA: A Hybrid Differential Evolution Flower Pollination Algorithm for Function Minimization,” IEEE, pp. 1-6, 2014.

[72] T. Robic and B. Filipic, “Demo: Differential Evolution for Multi Objective Optimization Evolutionary Multi-Criterion Optimisation,” Proc. IEEE, vol. 3410, pp. 520-533, 2005.

[73] R. Mendes and A. S. Mohais, “DynDE: A Differential Evolution for Dynamic Optimisation Problems,” IEEE, vol. 2, pp. 2808-2815, 2005.

[74] D. Jobson, Z. Rahma and G. Woodell, “A Multi-Scale Retinex for Briding the Gap between Color Images and the Human Observation of Scenes,” IEEE Transactions on Image Processing, vol. 6, no. 7, pp. 965-976, 1997.

[75] A. K. Vishwakarma and A. Mishra, “Color Image Enhancement Techniques: a Critical Review,” Indian J computer science eng., vol. 3, no. 1, pp. 39-45, 2012.

[76] K. Siddhesha and K. Narayan, “Frequency Domain Based Method for Color Image Enhancement,” International journal of research in engineering and advanced technology, vol. 2, no. 4, pp. 1-5, 2014.

[77] S. T. Mohamed, H. M. Ebeid, A. E. Hassainien and M. F. Tolba, “A Hybrid Flower Pollination Optimization Based Modified Multi-Scale Retinex for Blood Cell Microscopic Image Enhancement,” in 2017 Third international conference on research in computational intelligence and communication networks (ICRCICN), Kolkata, 2017.

[78] D. Maity, S. Banerjee and C. K. Chanda, “Analysis of Load Allocation Problem Using Flower Pollination Algorithm with Constraints,” in 2019 16th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), Pattaya, 2019.

[79] Sarijya, P. H. Putra and T. A. Saputra, “Modified Flower Pollination Algorithm for Nonsmooth and Multiple Fuel Options Economic Dispatch,” in 2016 8th International Conference on Information Technology and Electrical Engineering (ICITTEE), Yogyakarta, 2016.

[80] T. Balachander, P. A. Jeyanth and D. Devaraj, “Short Term Hydro Thermal Scheduling Using Flower Pollination Algorithm,” in 2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCONS), Tamilnadu, 2017.

[81] T. Balachander, P. A. Jeyanth and D. Devaraj, “Application of Flower Pollination Algorithm for Solving Short Term Hydro Thermal Scheduling Problem with Prohibited Operating Zones,” in 2019 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCONS), Tamilnadu, 2019.

[82] H. M. Dubey, B. K. Panigrahi and M. Pandit, “Improved Flower Pollination Algorithm for Short Term Hydrothermal Scheduling,” in International Conference on Swarm, Evolutionary, and Memetic Computing, 2015.

[83] N. M. Elbeihairy, R. A. Swief, A. M. Abdin and T. S. Abdelsalam, “Maximum Power Point Tracking For a Stand Alone PV System Under Shading Conditions Using Flower Pollination Algorithm,” in IEEE, Cairo, Egypt, 2019.

[84] F. D. Murdianto, M. Z. Efendi, R. E. Setiawan and A. Hermawan, “Comparison Method of MPSO, FPA, and GWO Algorithm in MPPT Sepic Converter Under Dynamic Partial Shading Condition,” in IEEE, Surabaya, Indonesia, 2017.

[85] I. Hussain, S. Ranjan and D. C. Das, “Performance Analysis of Flower Pollination Algorithm Optimized PID Controller for Wind-PV-SMES-BESS-Diesel Autonomous Hybrid Power System,” IJRES, vol. 7, no. 2, pp. 643-651, 2017.

[86] S. K. Joshi and K. S. Pandya, “CHAOS Enhanced Flower Pollination Algorithm for Optimal Scheduling of Distributed Energy Resources in Smart Grid,” in IEEE, Singapore, 2018.

[87] K. Jagatheesan, B. Anand, S. Samanta, N. Dey, V. Santhi and A. Ashour, “Application of Flower Pollination Algorithm in Load Frequency Control of Multi-Area Interconnected Power System with Nonlinearity,” Neural Computing and Applications volume, vol. 28, p. 475–488, 2017.

[88] X. Chen, Y. Xu and X. Cao, “Nonlinear Time Series Analysis of Frequency Control of Multi - Area Interconnected Power System,” IEEE Transactions on Automatic Control, vol. 28, p. 475–488, 2017.

[89] X. Chen, Y. Xu and X. Cao, “Nonlinear Time Series Analysis of Frequency Control of Multi - Area Interconnected Power System,” IEEE Transactions on Automatic Control, vol. 28, p. 475–488, 2017.

[90] L. Hecker, D. Osborn and J. Lawhorn, “Inter-Regional Transmission Development for Eastern Wind Integration and Transmission Study,” in IEEE PES General Meeting, Minneapolis, 2010.
[90] P. M. S. Carvalho and L. A. F. M. Ferreira, “Distribution Quality of Service and Reliability Optimal Design: Individual Standards and Regulation Effectiveness,” IEEE, vol. 20, no. 4, pp. 2086-2092, 2005.

[91] D. A. Polyakov, V. N. Pugach and K. I. Nikitin, “Power Transmission Lines Monitoring System,” in 2018 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), Omso, 2018.

[92] O. Samuelsson, M. Hemmingsson, A. H. Nielsen, K. H. Pedersen and J. Rasmussen, “Monitoring of Power System Events at Transmission and Distribution Level,” IEEE Transactions on Power Systems, vol. 21, no. 2, pp. 1007-1008, 2006.

[93] T. J. Hammons, V. F. Lescale, K. Uecker, M. Haessler, D. Retzmann, K. Stachus and S. Lepy, “State of the Art in Ultrahigh-Voltage Transmission,” IEEE, vol. 100, no. 2, pp. 360-390, 2012.

[94] S. de la Torre, A. J. Conejo and J. Contreras, “Transmission Expansion Planning in Electricity Markets,” IEEE Transactions on Power Systems, vol. 23, no. 1, pp. 238-248, 2008.

[95] D. Karlsson, M. Hemmingsson and S. Lindahl, “Wide Area System Monitoring and Control,” IEEE Power Energy Magazine, vol. 2, no. 5, pp. 68-76, 2004.

[96] N. G. Hingorani and L. Gyugyi, Understanding FACTS : Concepts and Technology of Flexible AC Transmission Systems, Wiley-IEEE Press, 2000.

[97] M. Shahidehpour and M. Alomoush, “Restructured Electric Power Systems,” IEEE Computer Applications in Power, vol. 15, no. 2, pp. 60-62, 2002.

[98] M. Shahidehpour, H. Yamin and Z. Li, Market Operations in Electric Power systems, John Wiley & Sons, Inc., 2002.

[99] K. Y. Lee, Y. M. Park and J. L. Ortiz, “A United Approach to Optimal Real and Reactive Power Dispatch,” IEEE Power Engineering Review, Vols. PER-5, no. 5, pp. 42 - 43, 1985.

[100] E. S. Oda, A. A. Abdelsalam, M. N. Abdel-Wahab and M. M. El-Saadawi, “Distributed Generations Planning using Flower Pollination Algorithm for Enhancing Distribution System Voltage Stability,” Ain Shams Engineering Journal, vol. 8, no. 4, pp. 593-603, 2017.

[101] J. J. Jamian, M. M. Aman, M. W. Mustafa, G. B. Jasmon, H. Mokhli, A. H. A. Bakar and M. N. Abdullah, “Optimum Multi DG units Placement and Sizing Based on Voltage Stability Index and PSO,” in 2012 47th International Universities Power Engineering Conference (UPEC), Uxbridge, 2012.

[102] P. D. P. Reddy, V. V. Reddy and T. G. Manohar, “Application of Flower Pollination Algorithm for Optimal Placement and Sizing of Distributed Generation in Distribution Systems,” Journal of Electrical Systems and Information Technology, vol. 3, no. 1, pp. 14-22, 2016.

[103] S. Sudabatula and K. M., “Distributed Energy Resources Allocation using Flower Pollination Algorithm in Radial Distribution Systems,” Energy Procedia, vol. 103, pp. 76-81, 2016.

[104] R. S. Al Abri, E. F. El-Saadany and Y. M. Atwa, “Optimal Placement and Sizing Method to Improve the Voltage Stability Margin in a Distribution System Using Distributed Generation,” IEEE Transactions on Power Systems, vol. 28, no. 1, pp. 326-334, 2013.

[105] A. Y. Abdelaziz, E. S. Ali and S. M. Abd Elazim, “Optimal Sizing and Locations of Capacitors in Radial Distribution Systems via Flower Pollination Optimization Algorithm and Power Loss Index,” Engineering Science and Technology, an International Journal, vol. 19, no. 1, pp. 610-618, 2016.

[106] V. B. M. and M. N., “Flower Pollination Algorithm Based Sizing and Placement of DG and D-STATCOM Simultaneously in Radial Distribution Systems,” in 2018 20th National Power Systems Conference (NPSC), Tiruchirappalli, 2018.

[107] A. Valderrabano and J. M. Ramirez, “DSTATCOM Regulation by a Fuzzy Segmented PI Controller,” Electric Power Systems Research, vol. 80, no. 6, pp. 707-715, 2010.

[108] S. S. K. S. B. C and K. M. V., “Distribution Grid Reconfiguration For Power Loss Reduction Using Flower Pollination Algorithm With Reduction Using Flower Pollination Algorithm,” in 2018 4th International Conference for Convergence in Technology, Mangalore, 2018.

[109] F. Zhan, H. Xiong and F. Chen, “Flower Pollination Algorithm for Distribution Network Optimization Scheduling Including Microgrid,” in 2019 IEEE 8th Joint International Information Technology and Artificial Intelligence Conference (ITIAC), Chongqing, 2019.

[110] K. Dhayalini and A. Prabhu, “Optimization of Wind Thermal Coordination Dispatch using Flower Pollination Algorithm,” in 2019 2nd International Conference on Power and Embedded Drive Control (ICPEDC), Chennai, 2019.

[111] S. Satravid, D. Choudhury and N. Sinha, “Hydrothermal Scheduling using Modified Flower Pollination Algorithm: A Parallel Approach,” in IEEE, Singapore, 2016.

[112] H. M. Dubey, M. Pandit and B. K. Panigrahi, “A Biologically Inspired Modified Flower Pollination Algorithm for Solving Economic Dispatch,” Cognitive Computation, vol. 7, pp. 594-608, 2015.

[113] Z. Sun, A. Zhao, L. Zhu, K. Lu, W. Wu and F. Blaabjerg, “Extremum-seeking Control of Wave Energy Converters using Two-objective Flower Pollination Algorithm,” in IEEE, Shenzhen, 2018.

[114] F. D. Murdianto, A. R. Nursur, A. L. Hermawan, E. Purwanto, A. Jaya and M. M. Rifaidil, “Modeling and Simulation of MPPT SEPIC – BUCK Converter Series Using Flower Pollination Algorithm (FFA) - PI Controller in DC Microgrid Isolated System,” in 2016 IEEE International Electrical Engineering Congress (iEECON), Krabi, 2018.

[115] D. Yousri, T. S. Babu, D. Allam, V. K. Ramachandaramurthy and M. B. Ebita, “A Novel Chaotic Flower Pollination Algorithm for Global Maximum Power Point Tracking for Photovoltaic System Under Partial Shading Conditions,” IEEE Access, vol. 7, pp. 121432-121445, 2019.

[116] P. Kumar, N. Katal and S. Narayan, “Multi-Objective Flower Pollination Algorithm for Optimal Design of Fractional Order Controller for Robust Isolated Steam Turbine,” in 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICEPEICES), Delhi, 2016.

[117] D. K. Sambiriya and T. Gupta, “Optimal Design of PID Controller for an AVR System Using Flower Pollination Algorithm,” Journal of Automation and Control, vol. 6, no. 1, pp. 1-14, 2018.

[118] R. Wang and Y. Zhou, “Flower Pollination Algorithm with Dimension by Dimension Improvement,” Hindawi, 2014.

[119] K. Lu and H. Li, “Quantum-Behaved Flower Pollination Algorithm,” in 2015 14th International Symposium on Distributed Computing and Applications for Business Engineering and Science (DCABES), Guiyang, 2015.

[120] J. Zhang, J. Wang and C. Yue, “Small Population-Based Particle Swarm Optimization for Short-Term Hydrothermal Scheduling,” IEEE Transactions on Power Systems, vol. 27, no. 1, pp. 142-152, 2012.

[121] S.-J. Huang, P.-H. Gu, W.-F. Su, X.-Z. Liu and T.-Y. Tai, “Application of Flower Pollination Algorithm for Placement of Distribution Transformers in a Low Voltage Grid,” in 2015 IEEE International Conference on Industrial Technology (ICIT), Seville, 2015.

[122] T. Prasetyo, S. Sariyaya and L. M. Putranto, “Optimal Sizing and Siting of PV-Based Distributed Generation for Losses Minimization of Distribution using Flower Pollination Algorithm,” in 2019 International Conference on Information and Communications Technology (ICIOCCT), Yogyakarta, 2019.

[123] R. Manimegalai, S. Visalakshi and S. L. Devi, “Optimally Locating
Microgrid for the Minimization of Losses,” in 2017 Third International Conference on Science Technology Engineering & Management (ICONSTEM), Chennai, 2017.

[124] M. A. Tawhid and A. F. Ali, “A Hybrid Flower Pollination and Genetic Algorithm for Minimizing the Non-Convex Potential Energy of Molecular Structure,” Trends in Artificial Intelligence, vol. 1, no. 1, pp. 12-21, 2017.

[125] A. Merzougua, N. Labed, A. Hasseine, A. Bonilla-Petriciolet, D. Laiadi and O. Bacha, “Parameter Identification in Liquid-Equilibrium Modeling of Food-Related Thermodynamic Systems Using Flower Pollination,” The Open Chemical Engineering Journal, pp. 59-73, 2016.

[126] A. Zainudin, C. K. Sia, P. Ong, O. L. C. Narong and N. H. M. Nor, “Taguchi Design and Flower Pollination Algorithm,” IOP Conference Series: Materials Science and Engineering, 2017.

[127] G. Bekdas, S. M. Nigdeli and X.-S. Yang, “Sizing Optimization of Truss Structures using Flower Pollination Algorithm,” Applied Soft Computing, vol. 37, pp. 322-331, 2015.

SAHIL LALLJITH was born in Durban, South Africa, in 1999. He is currently pursuing a B.Sc. degree in electrical engineering. His research interest includes renewable energy and power system protection.

ISMAIL FLEMING was born in Durban South Africa, in 2000. He is currently studying towards a B.Sc. degree in electrical engineering at the University of KwaZulu-Natal. His research interests include renewable energy power system design and advancements in the protection of high voltage equipment.

UMESHAN PILLAY was born in Durban South Africa. He is currently a final year B.Sc. electrical engineering student and is also a member of the prestigious International Golden Key Society. His research interest are power systems contingency and protection of high voltage equipment.

KIVESHEN NAIKER was born in Malvern, Queensburgh, South Africa, in 1999. He is currently pursuing a B.Sc. degree in electrical engineering at the University of KwaZulu-Natal. His research interests include advancement in power system protection and advancement in high voltage engineering.

ZACHARY JOSE NAIDOO was born in Chatsworth, Durban, South Africa, in 1999. He is currently pursuing the B.Sc. degree in electrical engineering from the University of KwaZulu-Natal. His interests include power systems, high voltage engineering, electrical machines, and power electronics.

AKSHAY K. SAHA (Member, IEEE) is currently an Associate Professor and Academic Leader Research and Higher Degrees at the School of Engineering, University of KwaZulu-Natal, Durban, South Africa. He is also a registered Professional Engineer with the Engineering Council of South Africa and a Fellow of the South African Institute of Electrical Engineers, South African Academy of Engineering. He is also a Senior Member of SAIMC, Member of Academy of Science of South Africa (ASSAf) and an Individual Member Cigre. His research works are related to advances of power systems in various areas including engineering education. He has published more than 35 articles in top-tier international journals and over 100 international conference papers in relevant areas. He was awarded the Best Lecturer Electrical Engineering in 2013-2014, 2016-2019 by the School of Engineering, and Research Excellence Award in the years 2015-2019 by the University of KwaZulu-Natal. He is also acting as an Editorial Board Member for a number of top-tier international journals.