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Under Voltage Load Shedding Scheme Using Meta-heuristic Optimization Methods

***Abstract**. Load shedding has been extensively studied because of multiple power system failure occurrences worldwide. Reliable techniques are required to provide rapid and precise load shedding to avert voltage collapse in power networks. Meta-heuristic optimization approaches are currently the widely developed methods because of their robustness and flexibility in dealing with complex and non-linear systems. These methods include genetic algorithm, fuzzy logic control, particle swarm optimization, artificial neural network, ant colony optimization, big-bang big-crunch optimization, and many others. This study provides an overview of all the meta-heuristic methods implemented for under voltage load shedding in power systems.*

Streszczenie.** Pozbywanie się obciążenia jest istotne z punktu widzenia możliwego zapadu systemu przesyłu energii. Do tego celu wykorzystuje się optymalizację meta-heurystyczną głównie dzięki odporności i szerokim możliwościom. W skład metody wchodzą: algorytm genetyczny, logika rozmyta, algorytmy mrówkowe, sieci neuronowe. W artykule dokonano przeglądu tych metod. **Meta-heurystyczne metody optymalizacyjne wykorzystywane do szybkiego pozbywania się obciążenia sieci.

Keywords: meta-heuristic optimization, under voltage load shedding, voltage collapse.
Słowa kluczowe: optymalizacja mete-heurystyczna, zapad napięcia, pozbywanie się obciążeń

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Introduction

The escalating number of voltage stability events around the world has attracted a great deal of concerns among the power utility operators. Substantial development has been made in the research on the implementation of the load shedding schemes over the past few decades [2–8]. Among different countermeasures for the prevention of the voltage instability, load shedding is the final remedy of defense when there is no other substitute to stop an impending voltage collapse [1]. However, inadequate load shedding has led to a high number of voltage collapse occurrence. This was due to the excess load being shed or deficient load shed.

Ultimately, this problem has questioned the ability and dependability for existing conventional load shedding techniques. Hence, alternative techniques are required to enhance the reliability of today's modern, complex, and huge power systems. Considering the complexity of a power system network, researchers who aim to solve under voltage load shedding (UVLS) issues have directed considerable attention toward meta-heuristic methods. A meta- heuristic is a set of algorithmic concepts that can be used to define heuristic methods applicable to a wide set of different problems. In other words, a meta- heuristic is a general-purpose algorithmic framework that can be applied to different optimization problems with relatively few modifications [9]. Meta heuristic algorithms are also an algorithms which, in order to escape from local optima, drive some basic heuristic, which is either a constructive heuristic starting from a null solution and adding elements to build a good complete one, or a local search heuristic starting from a complete solution and iteratively modifying some of its elements in order to achieve a better one. The meta- heuristic part permits the low-level heuristic to obtain solutions better than those it could have achieved alone, even if iterated. Usually, the controlling mechanism is achieved either by constraining or by randomizing the set of local neighbor solutions to consider in local search [10].

Meta-heuristic methods, such as genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO), fuzzy logic control (FLC), big-bang big-crunch (BB-BC) optimization, and bacterial foraging optimization have been explored and implemented on test systems to analyze the working capability of the algorithms in terms of providing a precise solution, thus protecting the power system from power outage scenarios. This paper aims to review all meta-heuristic methods that have been implemented to solve the UVLS problem. This paper also discusses the advantages and disadvantages of the meta-heuristic approaches in terms of solving the UVLS problem.

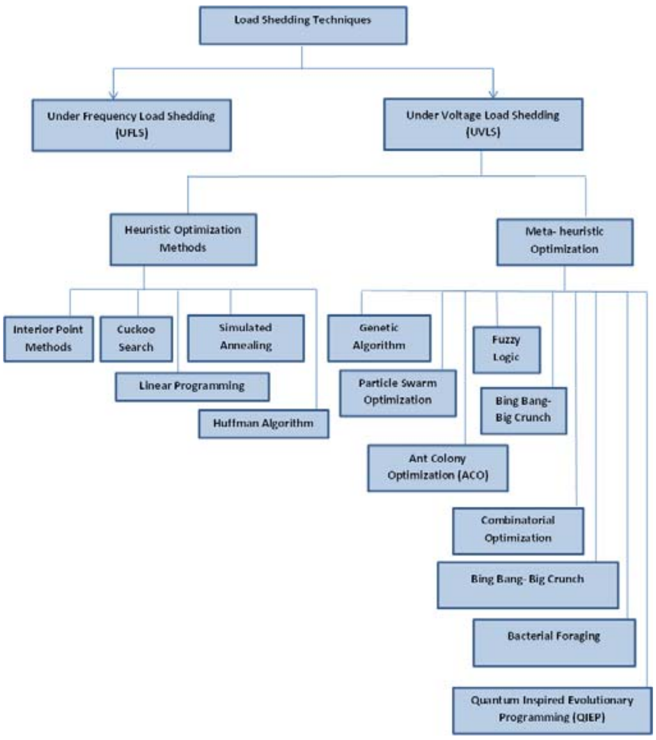

Fig. 1. Classification of Meta- heuristics Optimization Methods for Under Voltage Load Shedding (UVLS).

Application of Meta-heuristic Optimization Methods to Solve UVLS Problems

The emergence of meta-heuristics optimization techniques in power system has increased since the late 1980s. These techniques have been simulated and assessed in terms of their performance under a variety of power system factors, such as deregulation, dispersed generation, continuous load growth, and UVLS optimization.

The ever increasing dependence of modern society on reliable electricity supply has facilitated the development of such optimization techniques to preserve system integrity and to provide acceptable system performance. The adaptive techniques arising from meta-heuristic algorithms, particularly to solve the UVLS problem, are PSO, evolutionary programming, quantum inspired evolutionary programming (QIEP), GA, ACO, and many others. Figure 1 shows the types of load shedding and classification of meta- heuristic optimization methods for UVLS that has been explored by researchers' to date. These techniques have been implemented to solve the key issues of the UVLS scheme which include the optimum minimum amount of load shed, the optimum location to shed, and the timing of load shedding.

GA for UVLS

GA has received considerable attention as a robust stochastic search algorithm for solving optimization problems. GA mimics the metaphor of natural biological evolution and it functions on a population of possible solutions by applying the principle "survival of the fittest" to produce better approximations to a solution uninterruptedly. A new set of estimations is created at each generation of GA by selecting individuals according to their level of fitness in the problem field and regenerating them using operators borrowed from natural genetics. Consequently, this process facilitates the evolution of populations of individuals that are better suited to their environment than the individuals from which they were created as in natural adaptation [11]. The basic form of GA involves three types of operations, namely, selection, crossover, and mutation.

The implementation of GA to solve UVLS in [12] considered the load shed at each of the bus voltages in the IEEE 30-bus test system. Alongside GA, PSO is applied to solve generator outage and line outage cases for result validation. In this method, the fitness function was the minimization of service interruption, and weighting factors were obtained using the analytical hierarchy process (AHP). The GA results and the PSO responses in all the case studies were compared. The minimum amount of load shed was obtained using the GA technique.

Nevertheless, the study found that PSO has faster computation time than GA in finding the solution for the optimum amount of load to shed. By contrast, GA is employed to search for the optimal supply restoration strategy in distribution networks [13]. An integer permutation encoding scheme, in which each chromosome is a list of indices of switches, is adopted. The status of each of these switches is determined according to graph theory subject to the radiality constraint of the distribution networks. Instead of representing a switch, this flag keeps some disengaged parts of the network and thus enables the GA to identify the optimal load shedding strategy. This algorithm was successfully tested on a practical UK system and was proven to be an optimal post-fault supply restoration strategy aside from locating the optimal load shedding point in a contingency situation.

In [14], a new application of the GA optimization technique to solve a steady state load shedding problem was proposed. The objective function was to minimize the sum squares of the difference between the connected active and reactive loads, as well as between the supplied active and reactive powers. This technique was tested on the IEEE 14 bus and the IEEE 30-bus test systems. Compared with another two earlier methods [15], [16], the GA method provided fewer loads to shed in abnormal cases and produced more accurate results in all cases. The centralized UVLS has become possible with the recent developments in computer and network technology. Reference [17] proposed a centralized algorithm based on the improved GA. Initially, an optimization model with the objective of stabilizing the system voltage was developed. The GA technique was used to solve this problem and was then improvised by means of real number encoding. The rate and convergence of the algorithm were improved in terms of crossover and mutation. The effectiveness of the algorithm was significant according to the simulation on the IEEE 39-bus New England test system. Similarly, another study [18] presented an optimization tool based on GA known as automatic load shedding calculated through GAs, which was developed in Matlab. This optimization tool was applied to the calculation of the optimal load shed necessary to eliminate overloading of any series element of an electrical network. The system consists of a module that runs DC load flow to calculate the power flow for each branch or transformer and to verify whether no current violations exists relative to any equipment. The simulations for the optimum load shed amount calculation were conducted for the worst case contingencies in the 500 kV power system of Uruguay. The solution leaves a network with no overloaded elements in all cases after the load shed.

PSO for UVLS

PSO was introduced by Kennedy and Eberhart in 1995 [19]. Inspired by the social behavior of organisms, such as bird flocking and fish schooling, PSO belongs to the class of swarm intelligence techniques used to solve large scale non-linear optimization problems. This well-recognized technique has been proven robust and fast in solving multi-objective, non-linear problems. This technique has been widely implemented in various power engineering problems, including UVLS.

PSO has been successfully implemented in UVLS studies with an objective function of identifying the maximum loading point or collapse point, aside from the minimization of the service interruption cost [20]. This approach is based on the concept of the static stability margin and its sensitivity value at the maximum loading point. The voltage stability criterion is modeled as a soft constraint into the load shedding scheme. This method was implemented on the IEEE 14-bus system. The optimization problems are solved using both mathematical model known as General Algebraic Modeling System (GAMs) integrated with the development environment, Non Linear Optimization (CONOPT) and evolutionary PSO methods. The results obtained from PSO were compared with those from the GAMs and GA methods [21]. By providing a sufficient margin to collapse point, the loading margin index allocates the reactive power supply locally. Overall, PSO can identify the global optimum solution more quickly than the other two methods.

Another approach based on the hybrid PSO-based simulated annealing (SA) optimization technique was developed to solve the UVLS problem in [22]. This method, which is a combination of PSO and SA, has high efficiency in searching for the global minimum [22] because the strong point of SA can be used in PSO. The study created an optimal UVLS by justifying predefined voltage stability margin based on the technical and economical priority of loads. The simulations were performed on the IEEE 14-bus and IEEE 118-bus test systems. A relatively large-scale system, the IEEE 118-bus system is used for its suitability to verify the computational efficiency and optimality of this combination technique. Each test run reveals that this new method has a good solution for load shed amount and is capable of identifying a global optimum solution in minimum runs and, thus, high global convergence. This property can qualify whether the schemes to be used in UVLS applications need the minimum time to make the optimal decision. An application of PSO for UVLS considering dynamic security was presented in [23]. The designed model attempted to provide an adequate voltage stability margin for post-contingency situations by interrupting a percentage of loads at the minimum cost. The test system used was an IEEE 39-bus system, and the same scenario was tested and evaluated using GA algorithm. Results showed that PSO is a more powerful meta-heuristic method than GA because it could easily handle the non-linear dynamic problem. The speed and convergence characteristics obtained for all the situations are more superior when using PSO than when using GA. In addition, the results showed that PSO, which has simple rules, is more efficient than GA.

Total load shedding for a large power system network was presented in [24]. In contrast to local load shedding, which is usually considered in many papers, this approach eliminates transmission line over loadings in contingency conditions through total load shedding and generator scheduling as an optimization problem with non-linear constraints. To solve the issues of low convergence speeds faced by other meta-heuristic algorithms, this study proposed a new algorithm that combines the linear programming (LP) and PSO methods. To reveal the advantages of this LP-PSO algorithm, simulations were conducted on the IEEE 14-bus system in the event of two critical contingencies, and the results were compared with those obtained by using the LP and PSO methods. The LP method is found to be fast but cannot be used to solve non-linear problems. Thus, the results are impractical to use in a real UVLS problem. By contrast, PSO can be used as a practical method to solve this problem, but a longer solution time than that of LP is required. In addition, the proposed LP-PSO-based algorithm is a fast and rigorous method that considers all the constraints required to solve the UVLS problem in a power system [24].

Similarly, another approach in [25] presented optimal load shedding to enhance voltage stability by employing a combination of modal analysis and PSO. The initial stage of prevention control uses the best transformer tap setting as indicated by PSO optimization. The PSO is implemented to determine the most possible voltage stability margin. This process is followed by the corrective control action after contingencies, whereby the proposed technique is organized as a multi-objective optimization problem that reveals the best location and the lowest level of load shedding for special protection systems (SPS) to improve the voltage stability margin and the voltage profile. The approach was applied to the Gharb and Bakhtar areas of the Iranian transmission network in its annual peak load in year 2009. The results reveal that the proposed multi-objective optimization using modal analysis and PSO resulted in low amount of load shed with significant improvement in the voltage stability margin and average voltage profile of the system.

Quantum Inspired Evolutionary Programming (QIEP) for UVLS

Quantum-inspired evolutionary algorithm (QIEA) is based on the concept and principles of quantum computing, such as a quantum bit and superposition of states. Similar to the evolutionary algorithms, QIEA is characterized by the representation of the individual, the evaluation function, and the population dynamics [26]. However, instead of binary, numeric, or symbolic representation, QIEA uses a Q-bit as a probabilistic representation which is defined as the smallest unit of information. A Q-bit individual is defined by a string of Q-bits. The Q-bit individual has the advantage of being capable of probabilistically representing a linear superposition of states (binary solutions) in a search space. Thus, Q-bit representation has a better characteristic of population diversity than other representations. A Q-gate is also defined as a variation operator of QIEA to drive individuals toward better solutions and eventually toward a single state.

The application of QIEA in UVLS has recently gained the attention of power system researchers. As proposed in [27], a new technique for multi-objective optimization called QIEP was used to determine the optimal UVLS in a distribution system with load variation. This technique was implemented according to three levels defined by quantum individuals, quantum groups, and a quantum universe to improve the algorithm speed. QIEP is employed to search for the best location and amount of load to be shed based on multi-objective functions, which include power loss minimization, voltage profile improvement, and power interruption cost minimization. The effectiveness of the multi-objective QIEP optimization technique is illustrated by using the IEEE 33-bus distribution test system. The result was also compared with that of the GA technique in terms of fitness values. The proposed technique was also applied for IEEE 69-bus distribution test system and 141-bus distribution systems with variation of loading condition on the load curve. The results showed that the proposed QIEP technique can determine the optimal UVLS condition and thus improves system performance in all the tested cases [27].

Similar to the above approach, another new intelligence-based technique called QIEP-ANN was presented in [28]. This technique is used to predict the amount of load to be shed in a distribution system during UVLS. The ANN technique employed two hidden layers in a feedforward neural network with back propagation. Load buses and the minimum voltage are specified as the input with the amount of load shedding as the output. ANN is trained to perform a particular function by adjusting the values of the connections (weights) between elements, such that a particular input results in a specific target output. The network is trained based on a comparison of the output and the target until the network output matches the target. The parameters of ANN are optimally selected using the QIEP optimization technique for accurate prediction. The QIEP-ANN is developed to search for the optimal training parameters, such as the number of neurons in hidden layers and the learning and momentum rates. This method has been tested on the IEEE 69-bus distribution test system. The results show better prediction performance than the classical ANN in terms of mean square error and coefficients of determination [28].

ACO for UVLS

ACO [29] is a meta-heuristic technique for solving hard combinatorial optimization problems. The pheromone trail-laying and following behavior of real ants, which use pheromones as a communication medium, inspired the development of ACO. In an analogy to the biological example, ACO is based on indirect communication within a colony of simple agents, called (artificial) ants, mediated by (artificial) pheromone trails. The pheromone trails in ACO serve as distributed numerical information, in which the ants are used to construct probabilistic solutions to the problem being solved and adapt for their search experience during algorithm execution [30].

Reference [31] proposed an ACO-based algorithm to solve the optimal load shedding problem. The proposed method can flexibly be used to study the technical and economic aspects of the problem. Two key conditions are satisfied in the research in which, the first is fulfilled by analyzing the sensitivities of the voltage stability margin with respect to power demand changes at different buses. Only a few effective load buses are selected to participate in the load shedding program. The power interruption cost is minimized to satisfy the second condition. The performance of the proposed ACO-based method is demonstrated with a critical operating condition of the IEEE 30-bus test system. The recent ACO variant (ACOR) for global search in continuous domain is modified to handle constrained optimization problems. The developed ACOR is applied to solve the optimization problem formulated in the optimal power flow framework with full consideration of various network constraints. The simulation results show that the ACOR method can effectively improve the voltage stability of the power system and also processes at a fast speed. Statistical studies based on multiple independent runs also revealed the robustness of ACOR, owing to its capability to generate nearly identical results.

BB-BC Algorithm for UVLS

The newly emerged optimization technique known as the BB-BC algorithm is similar to the GA in that it creates an initial population randomly [32]. The creation of the initial population is called the big-bang phase. In this phase, the candidate solutions are spread uniformly over the search space. The big-bang phase is followed by the big-crunch phase. The big-crunch is a convergence operator that has several inputs but only one output or center of mass. The term “mass” refers to the inverse of the fitness function value.

In reference [33], optimal sizing of Flexible AC Transmissions (FACTS) to improve the voltage stability limit and voltage profile, as well as to minimize real power losses are demonstrated. The voltage stability limit improvement and real power loss minimization are tested on the standard IEEE 30-bus system under normal and N-1 line outage contingency conditions. The line stability index LQP, which is sensitive to changes in reactive power flows, is used to assess voltage stability. The susceptance model of SVC is considered to improve the voltage stability limit by controlling the power flows and maintaining the voltage profile. The nature-inspired meta-heuristic BB-BC algorithm is utilized to optimize the control variables and the performance is compared with that of the PSO algorithm. The coordinated control of the device and system parameters of FACTS in optimal power flow control to improve the voltage stability limit is demonstrated in the numerical results by comparing the system real power loss, voltage deviation, and voltage stability limit with and without the FACTS devices. Voltage stability improvement is more effective when it is conducted by coordinating the system and FACTS parameters. The numerical results on voltage stability limit improvement and real power loss minimization using the BB-BC algorithm are highly encouraging. The BB-BC algorithm is simple to implement for power system optimization because it only has a few operators. The BB-BC performed better than PSO and has good convergence characteristics. Therefore, BB-BC algorithm can be used to optimize power system operation and control.

Bacterial Foraging Optimization (BFOA) for UVLS

The BFOA has been widely accepted as a global optimization algorithm of current interest in power system optimization and control. This algorithm is inspired by the social foraging behavior of *Escherichia Coli* [34], and has drawn the attention of researchers because of its efficiency in solving real-world optimization problems emerging from several power system applications.

The application of BFOA to solve the UVLS problem has also gained the attention of researchers. In [35], the development of BFOA for optimal load shedding was presented. Load shedding is performed by removing a certain amount of load at appointed locations of a bus system for improving stability of a system, total power losses, and total costs of shed loads. The objective functions of total power losses, voltage stability index values, and total cost of shed loads are applied to determine the optimal load shedding in that particular system. In [35, the BFOA technique is implemented in the IEEE 30-bus bus system. For all cases, the results for all objective functions are improved compared with the base case values. The best objective functions for load increment cases are obtained for the voltage stability index known as, L_{index} and T_{loss} index. Simulations of BFAO proved that the load increment cases provide better results compared with the base cases in terms of total power losses and voltage stability index values of that particular bus system.

Fuzzy Logic based UVLS

Fuzzy Logic (FL) is a mathematical tool appropriate for modeling a system that is too complex and vaguely defined by mathematical formulation. FL has been widely applied in almost every part of a power system. Many researchers have applied FLC for load shedding application. A fuzzy controller has been used for intelligent load shedding to provide vulnerability control in a grid-connected power system [36]. The FLC performed accurate load shedding on the IEEE 300-bus test system during contingencies. The fuzzy logic application for preventing voltage collapse by shedding weak load buses is presented in [37]. The technique was tested on the Ward-Hale 6-bus system and the IEEE 14, 30, and 57-bus systems. The simulation results show that the FLC technique can be implemented on a system of any size. Sallam and Khafaga [38] applied FLC for load shedding to obtain voltage stability in an IEEE 14-bus system. Simulation results show that load shedding with the fuzzy logic controller stabilized the system and restored the voltage to a nominal value. Similarly, FLC technique applied to locate suitable load buses for load shedding by considering multi-contingencies through stability index tracing [39]. The amount of load power to be shed is determined via a modified version of the fuzzy system, which consists of improved membership functions by optimization algorithm. The experiment on IEEE 57-bus and 118-bus reliability test systems validates the feasibility of the FLC technique for real system application. In contrast to other methods, which are only workable on certain conditions, the FLC technique exhibits a potentially good performance in voltage stability regardless of the severity of the disturbances. Another application of FLC for load shedding specifically to arrest the dynamic voltage instability is presented in [40]. To develop the scheme, fuzzy indicators for all load control buses were first established and then correlated, with the real load shedding amount decided during the offline simulation study. The load shedding amount for previously unseen operating cases at each load control bus were conservatively predicted according to the zone within which the fuzzy indicator falls. Since the selected fuzzy variables are only related to the individual load control bus, this method was proven capable of being implemented for large power systems.

Combinatorial Optimization for UVLS

The historical roots of combinatorial optimization lie in problems in economics, which is the planning and management of operations and the efficient use of resources. Technical applications modeled as combinatorial optimization problems were soon introduced. The developed method for UVLS using combinatorial optimization was presented in [41]. The method design an automatic load shedding against voltage instability. In the first step, the methodology to find the minimal load shed is described. The second step studied the structural description of various controllers and the related parameters to be optimized. Third, an optimization approach to find the controller parameters that optimize the overall objective function is presented. Three types of UVLS controllers are discussed, namely, the two-rule Fixed Step Fixed Delay (FSFD), three-rule FSFD, and Variable Step Variable Delay (VSVD). The simulations are conducted on the Hydro-Quebec system, in which load shedding is presently planned. The results show that the VSVD controller is the most appropriate among the uncoordinated schemes. However, VSVD controllers are less effective than coordinated controllers in managing both load shedding and automatic shunt reactor switching.

The VSVD controller is required to collect measurements from remote locations and send controls to these locations. The higher communication complexity needs to be considered when assessing the overall protection reliability. A possible drawback of the proposed method is the risk of over-fitting the training set. Such risk could be solved by considering large training sets involving several stable and unstable scenarios. However, the computing time could be prolonged because of the combinatorial nature of the problem despite the effectiveness of the branch-and-bound method. Balancing computing time, over-fitting, and effectiveness can be achieved by performing the optimization in two steps. First, all the controllers yielding an objective function below a predefined level could be identified by using a limited number of scenarios taken from the large training set. Second, these controllers could be tested on the remaining scenarios to find the design with the best average performance from the whole training set [42].

Table 1 summarizes the meta- heuristics methods developed and its application in the power system.

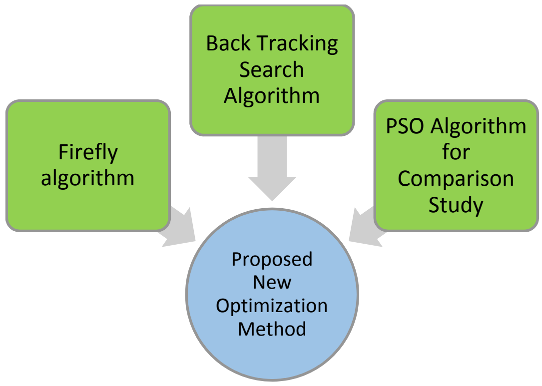

Fig. 2. Proposed New Meta- Heuristics Methods for UVLS Study.

Proposed Method

With the numerous developments of meta- heuristics methods for the purpose of finding optimized load shed amount signifies its importance for the stable and reliable power system operations globally. In this context, two types of meta- heuristics called Firefly Algorithm [43] and Backtracking Search Algorithm [44] were devised to find an optimal amount of load shed in a stressed IEEE14 Bus and IEEE 118 bus test system. Firefly Algorithm and Backtracking Search Algorithm are among the recent evolutionary models developed. The results obtained from these two methods are then compared with the PSO algorithm. Figure 2 shows the newly proposed algorithms for the UVLS study. Based on the preliminary study from the simulations conducted, it is observed that Firefly Algorithm followed by Backtracking Search Algorithm performed better for large test system in generating the optimal amount of load shed, although the speed of convergence for a large test system is found to be better by using PSO method. More advanced simulations are required in order to further prove the comparison studies of the proposed methods for a large power system network.

Table 1. Summary of Meta- heuristics Optimization Methods, its Applications and Results

Meta- heuristics Methods	Test System Application	Objective Function	Other Meta- heuristics methods for Comparison Study	Results
Genetic Algorithm	• IEEE 30 Test Bus System [12]	Minimization of service interruption cost	PSO	• GA produces minimum amount of load shed • PSO has faster computation time
	• Practical UK system [13]	Optimal amount for load shed in distribution networks	None	• Proven to be an optimal post- fault supply restoration strategy • Able to locate optimal load shed location in contingency cases
	• 500 kV Power System of Uruguay [18]	Optimal load shed amount	None	• Network has no overloaded elements post- load shedding procedure.
PSO	• IEEE 14 Test Bus System [20]	Minimization of service interruption cost and identification of maximum loading point	• Two models known as General Algebraic Modelling System (GAMs) and Non-Linear Optimization (CONOPT) • GA	• Global optimum solution was found faster using PSO.
	• IEEE 14 Test Bus System [22] • IEEE 118 Test Bus System [22]		PSO based Simulated Annealing (PSO- SA)	• PSO-SA has high global convergence • PSO- SA has better load shed amount • PSO- SA obtained global optimum solution in minimum runs

	• Gharb and Bakthar of Iranian transmission network [25]	• Best transformer tap setting • Most possible voltage stability margin • Multi- objective to give the lowest level of load shed amount and the best location to load shed.	PSO combined Modal Analysis	• PSO combined modal analysis gives lowest load shed amount and greater improvement in voltage stability margin.
Quantum Inspired Evolutionary Programming (QIEP)	• IEEE 33 Test Bus distribution system [27] • IEEE 69 &141 Test Bus system [27]	• Multi- objective optimization to locate best location and lowest amount of load shed	• GA	• QIEP gives the lowest load shed amount in all test cases.
	• IEEE 69 Test Bus system [28]	• Minimum amount of load shed in distribution network	• QIEP ANN compared with classical ANN	• QIEP ANN has better mean square error and coefficients of determination
Big Bang- Big Crunch	• IEEE 30 Test Bus System [14]	• Minimization of real power losses	• PSO	• Voltage stability limit improvement and real power losses minimization is better in BB- BC • BB- BC has good convergence characteristics
Combinatorial Optimization	• Hydro- Quebec System [41]	• Minimize load shed amount • Optimization	• FSFD • VSVD	• VSVD controller parameter optimization gives the most appropriate load shed amount for uncoordinated schemes, but not for coordinated schemes.

Conclusions

The reliability of conventional UVLS techniques becomes debatable when voltage collapse in power systems or blackouts occur. Blackouts are mostly caused by voltage collapse rather than under-frequency conditions. Conventional UVLS techniques are shown as unsuitable for existing large and complex power systems [45]. Thus, the emergence of meta- heuristic optimization techniques presents efficient handling of such modern power systems. This paper has presented a review of UVLS scheme using meta-heuristic optimization techniques. Various meta-heuristics optimization techniques that tackled the UVLS problem are overviewed. Besides, the paper also provides a general literature survey and a list of published references on the topic aiming to offer the essential guidelines regarding this active research area. This review is undertaken to explore and report that fast and accurate UVLS scheme developed based on meta- heuristics techniques are required to maintain system voltage stability. The followings are the significant point of conclusion. FL has the limitation as it relies greatly on good problem description and extensive domain knowledge, thus it requires experts' depth knowledge in problem definition. Thus, FL deserves scope for further study. By contrast, PSO accessed deep knowledge of system problems by well- established models. Compared with other meta-heuristics algorithms, such as GA, ACO, BB-BC, Bacterial Foraging and QIEP, PSO has foremost advantages which include simple implementation, small computational time and fast convergence. Thus, PSO is suitable to solve many problems for which it is difficult to find accurate mathematical models. However, PSO algorithm is also prone to setback into local minima and untimely convergence when dealing with complex optimization problems.

To conclude, all the optimization techniques have its advantages and disadvantages. Nonetheless, the implementation of the meta-heuristic methods for UVLS can decrease the likelihood of power failures and heighten the reliability of power system. However, further development of these techniques is required for possible practical use compatible with online and real-time applications.

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