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# Optimal Under-voltage Load Shedding using Cuckoo Search with Levy Flight Algorithm for Voltage Stability Improvement

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**ABSTRACT :** *Voltage stability has become a serious threat of modern power system operation nowadays. To tackle this problem properly, load shedding is a countermeasure taken as a last resort. However, its consequences might result in huge technical and economic losses. Therefore, this control measure should be optimally and carefully carried out. This paper proposes Cuckoo search with Levy flights (CSwLF) based algorithm for solving the optimal load shedding problem. The amount of load shedding at each bus is determined by applying CSwLF to solve a nonlinear optimization problem formulated in the optimal power flow framework. The performance of the proposed CSwLF based method is tested on the operating conditions of IEEE 14-bus test system.*

**KEYWORDS -** *Metaheuristic algorithm, Voltage stability, under voltage load shedding, cuckoo search, Levy flights.*

## I. INTRODUCTION

T The emergency state may occur in a power system as a consequence of a sudden increase of system load, the unexpected outage of a transmission line, a generator, or failure in any of the system components. This state may result in some problems such as line overloading, voltage instability and eventually voltage collapse [1]. Generation rescheduling and/or load shedding can be used to overcome the mentioned problems effectively. Load shedding is a usual operation in emergency and extreme emergency states in which the controllers of the power system cannot drive the system to an equilibrium state and has to be applied as soon as possible.

Various numerical optimization techniques have been proposed to solve load shedding problem. Specifically, there are Kuhn-Tucker method, second-order gradient method, linear programming, nonlinear optimization method and artificial neural networks. Among these methods, the linear programming method is one of the earliest and simplest approaches to address the load shedding problem. Due to nonlinear nature of power system problems, approximation is necessary for applying linear programming techniques which affect the accuracy of the solution. Nonlinear optimization techniques can be applied to any network configuration. If the problem is well-formulated these techniques can find the optimal solution accurately. However, for application in bulk power systems, they have been proved to be computationally very costly [2]

Nowadays, stochastic search algorithms are used to solve the combinatorial optimization problems in power system. The genetic algorithm (GA) is an optimization and search technique based on the principles of genetics and natural selection and is a well-established technique applied to the problem of load shedding problem.

Particle swarm optimization (PSO), first introduced by Eberhart and Kennedy in 1995, is a form of stochastic search techniques in which the behavior of a biological social system is simulated. PSO has been compared to other stochastic methods and its shorter computation time and better convergence characteristic are addressed by many researchers. It has been found that the PSO method quickly finds the high-quality optimal solution for many power system optimization [3]. Like other stochastic search methods, PSO may trap in a local minimum. If we do nothing to solve this tendency to converge quickly, we could end up in a local rather than a global minimum.

A new metaheuristic search algorithm, called cuckoo search (CS), based on cuckoo bird's behavior has been developed by Yang and Deb [4]. It is a very new population based metaheuristic for global optimization and only few papers have been published about it. [5][6]. However, the new stochastic search method, (CS), has not been applied to steady and dynamic state load shedding problem yet. This paper aims at establishing the applicability of this algorithm into load shedding.

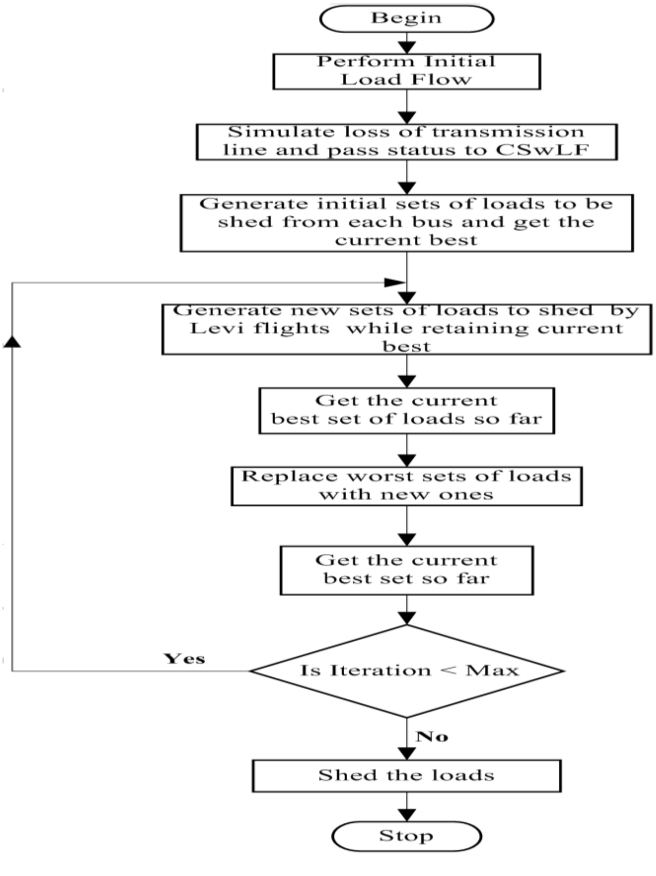
## II. CUCKOO SEARCH ALGORITHM WITH LEVY FLIGHTS

The CS is derived from the bleeding behavior of some cuckoo species of laying their eggs in the nests of host birds. Female cuckoos from some species of can imitate the patterns of the eggs of a few chosen host birds. This decreases the possibility of the eggs being abandoned and, therefore, increases their re-productivity [7]. If host birds discover the eggs are not their own, they will either throw them away or simply abandon their nests and build new ones, elsewhere. Parasitic cuckoo chooses a nest where the host bird just laid its own eggs and since the cuckoo eggs hatch slightly earlier than their host eggs, the first instinct action of the first cuckoo chick hatched is to evict the host eggs. This behaviour results in increasing the cuckoo chick's share of food provided by its host bird. In addition, Moreover, cuckoo chick can imitate the call of host chicks to gain access to more feeding opportunity [7]. .

The Cuckoo Search models such breeding behavior. Yang and Deb discovered that the performance of the CS can be improved by using Lévy Flights instead of simple random walk. The variance of Levy flight increases exponentially as compared with random walk whose variance increases linearly. Therefore the convergence is faster with where step size is generated using Levy flights. Levy flights are more efficient in exploring unknown large scale search space [8], [9].

A solution is represented by an egg in the nest. A new solution is represented by a cuckoo egg. The CS endeavors to replace not-so-good solutions in the nests by the new and potentially better solutions represented by cuckoo's eggs. In the simplest form, each nest has one egg. The CS is based on three rules:

- Each cuckoo randomly lays one egg at a time in a nest;
- The best nest with high quality of eggs (solutions) will carry over to the next generations;
- The number of available host nests is fixed, and a host can discover an alien egg with probability $p_a \in [0,1]$ . In this case, the host bird can either throw the egg away or abandon the nest to build a completely new nest in a new location [9]. The last assumption can be approximated by a fraction pa of the n nests being replaced by new nests, having new random solutions. Based on the above-mentioned rules, the basic steps of the CS can be summarized as the pseudo code, as follows [9]



Levy flights are random walk whose step length is drawn from the Levy distribution, often in terms of simple power-law formula.

$$L(u) = t^{-\lambda}, \qquad 1 < \lambda \leq 3 \qquad (1)$$

When generating new solutions $xi\ (t+1)$ for the i$^{th}$ cuckoo, the following Lévy flight is performed

$$xi\ (t+1) = x_i(t) + \alpha \oplus Levy(\lambda) \qquad (2)$$

where $\alpha > 0$ is the step size.

The product $\oplus$ means entry-wise multiplications [9]. The generation of random numbers with Levy Flights consists of two steps: the choice of random direction which should be drawn from uniform distribution and generation of steps which obey Levy distribution. The generation of these steps is achieved using Mantegna algorithm for a symmetric Levy distribution. Here symmetric that the steps can be positive and negative. [10]. In Mantegna's algorithm, the step length s can be calculated by

$$s = \frac{u}{|v|^{1/\beta}} \qquad (3)$$

Where $u$ and $v$ are drawn from normal distribution. That is

$$u \sim N(0, \sigma_u^2), \qquad v \sim N(0, \sigma_v^2)$$

Where

$$\sigma_u = \left\{ \frac{\Gamma(1+\beta)\sin\left(\frac{\pi\beta}{2}\right)}{\Gamma[(1+\beta)/2]\beta 2^{(\beta-1)/2}} \right\}^{1/\beta}, \sigma_v = 1 \qquad (4)$$

In the application of the CS in load shedding, a nest has one egg. Therefore a nest or an egg represent a solution. One given solution comprises of the loads to be shed from each and every bus in the system. The number of available possible solutions was represented by the number of host nests available which was fixed. The initial solution was determined randomly with normal distribution. Its fitness was determined considering the equality and inequality constraints of the system. The best initial fitness is then carried over to the next set of solutions generated using CS with levy flight. The fitness of the solutions is determined and the best solution is found. The worst solutions are discarded and replaced with new ones and the fitness of the new set is again determined. The best solution is again found. The fitness of this best solution is checked to whether it is within the acceptable tolerance. If it's not, the process starts over again

## III. PROBLEM FORMULATION

During a contingency like loss of a transmission line or a generator, there is great mismatch between power demand and supply. These may lead to voltage instability in a system if it's not immediately addressed. Load shedding is generally applied to network to avert the possible voltage collapse. However there should be minimum load interruption during load shedding so that the utility companies and customers pay the least amount of cost energy not supplied. This scenario is therefore formulated as an optimization problem with nonlinear constraints as follows:

$$Min \sum_{i=1}^{N} \left[ \alpha_i \left(P_{Di}^{p} - P_{Di}^{0}\right)^2 + \beta_i \left(Q_{Di}^{p} - Q_{Di}^{0}\right)^2 \right] \qquad (5)$$

This equation can be written as

$$Min \sum_{i=1}^{N} \left[ \alpha_i \Delta P_{Di}{}^2 + \beta_i \Delta Q_{Di}{}^2 \right] \qquad (6)$$

Where

$\alpha_i$ and $\beta_i$ are the importance factors for curtailed active and reactive power load of the $i^{th}$ bus.
$P_{Di}^{0} = Active\ power\ demand\ in\ normal\ state$
$P_{Di}^{p} = Active\ power\ demand\ in\ contigency\ state$
$Q_{Di}^{0} = Reactive\ power\ demand\ in\ normal\ state$
$Q_{Di}^{p} = Reactive\ power\ demand\ in\ contigency\ state$
$P_{Di}^{p} - P_{Di}^{0} = \Delta P_{Di}$
$\Delta P_{Di}\ is\ the\ curtailed\ active\ power\ of\ the\ i^{th}\ bus$
$Q_{Di}^{p} - Q_{Di}^{0} = \Delta Q_{Di}$
$\Delta Q_{Di}\ is\ the\ curtailed\ reactive\ power\ of\ the\ i^{th}\ bus$

Equality Constraints

Since

$$P_i = V_i \sum_{j=1}^{N} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = P_{Gi} - P_{Di} \qquad (7)$$

And

$$Q_i = V_i \sum_{j=1}^{N} V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) = Q_{Gi} - Q_{Di} \qquad (8)$$

Then

$$P_{Gi}^{p} - P_{Di}^{p} - V_i{}^{p} \sum_{j=1}^{N} V_j{}^{p} Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \qquad (9)$$

$$but \quad P_{Di}^{p} - P_{Di}^{0} = \Delta P_{di}$$

$$i.e \quad P_{Di}^{p} = P_{Di}^{0} + \Delta P_{di}$$

*Therefore*

$$P_{Gi}^{p} - P_{Di}^{0} - \Delta P_{Di} - V_i{}^{p} \sum_{j=1}^{N} V_j{}^{p} Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \qquad (10)$$

*Similarly*

$$Q_{Gi}^{p} - Q_{Di}^{0} - \Delta Q_{Di} - V_i{}^{p} \sum_{j=1}^{N} V_j{}^{p} Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \qquad (11)$$

Where:
$P_{Gi}$ and $Q_{Gi}$ are active and reactive power generations at the $i$th bus.
$V_i$ and $\delta_i$, are system bus voltages magnitudes and phase angles.
$Y_{ij}$ and $\theta_{ij}$ are bus admittance matrix elements

Assuming that the increasing or decreasing of the active power generation of all generators was limited to 20% of their current generation, then:

$$0.8{P_{Gi}}^{0} \leq P_{Gi}^{p} \leq 1.2{P_{Gi}}^{0} \qquad (12)$$

$$0.8{Q_{Gi}}^{0} \leq Q_{Gi}^{p} \leq 1.2{Q_{Gi}}^{0} \qquad (13)$$

Assuming that load shedding in bus i could not be greater than 50% of the load demand in this bus, then:

$$0 \leq \Delta P_{Di} \leq 0.5{P_{Di}}^{0} \qquad (14)$$

$$0 \leq \Delta Q_{Di} \leq 0.5{Q_{Di}}^{0} \qquad (15)$$

## IV. METHODOLOGY

The IEEE 14-bus system was selected for the study. The data for the system is readily available. The power flow analysis was first carried out using the Newton Raphson power flow technique to establish the loading levels of various transmission lines in the system. The main idea in this step is establish the heavily loaded line whose loss is likely to affect the performance of the entire system. This analysis was carried out using Power system Analysis Toolbox (PSAT). PSAT is a Matlab toolbox for static and dynamic analysis and control of electric power systems

A MATLAB code was developed to simulate loss of a transmission line through opening of circuit breaker associated to that line at time $t = 10s$, immediately capture this post contingency system status and pass it to the Cuckoo Search with Levy Flight algorithm to determine how much load need to be shed considering various constraints and finally simulate the load shedding.

Transient voltage stability is characterized by a large disturbance like loss of a transmission line and a rapid response time of generators' automatic control devices is necessary. The time frame for these devices is 1 to 10 seconds. An average fault time of 5 seconds was chosen for this study to allow the devices to repond after which forced load shedding is implemented.

After the algorithm determines the optimal load that need to be shed, the load shedding is simulated through opening of circuit breaker at time $t = 15s$. The system status and parameters were again captured after the load had been shed to determine the effect of the load shedding. These results were then compared with other results from similar study done in the recent past [11] which includes linear programming (LP), particle swarm optimization (PSO) and linear programming with particle swarm optimization (LPwPSO) and results tabulated.

## V. RESULTS AND ANALYSIS

Table I shows the results obtained from power flow. Line 11 connected between Bus 1 and Bus 2 was the most heavily loaded line and its loss would be significant to the performance and equilibrium of the system. It's for this reason that this line was chosen for investigation.

Fiigs 1, 2, 3 and 4 shows the voltage behavior on the most critical buses when line 11 was lost. It can be seen from these figures that the voltages in these bus becomes unstable.

Immediately line 11 was lost, the process of determining the amount of load to be shed was carried out using the cuckoo search algorithm. The amount of load to be shed from each bus is shown in table 2. It can be noted that although bus 10 was one of the critical buses that would contribute to voltage stability, there was no load to be shed from this bus. This was due to constraints that had to be satisfied otherwise these constraints would be violated. Similarly, no load was to be shed from bus 4. Only reactive power was to be shed from bus 3 if the constraints were to be upheld.

When the indicated load was shed from the system as indicated in table 2, the voltage behavior with time of the critical bus was determined and the results plotted in figs 5, 6, 7 and 8. From these figures it can be seen that the voltage stability was restored in those buses.

The amount of load to be shed using the cuckoo search algorithm was compared with other method that have been used before and the results were tabulated in table 3. It can be seen from the table that the percentage of load shed while using cuckoo search with levy flight (CSwLF) algorithm was the least in all the four algorithms compared. This is considered very encouraging since there will be minimum load curtailment and hence little interference to the supply of power to the customers.

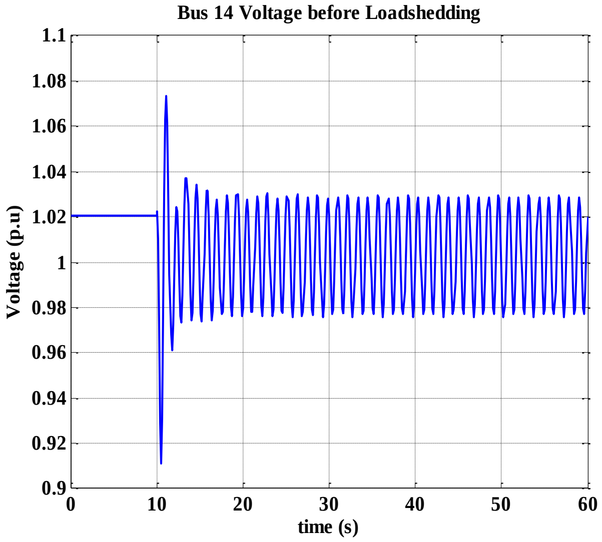


Figure 1 Bus 14 voltage before load shedding

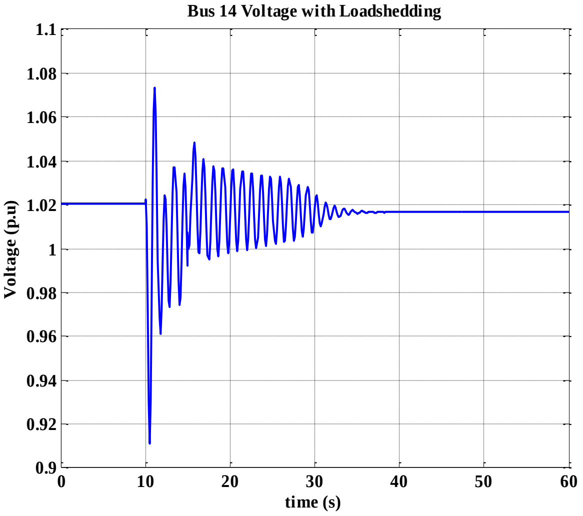


Figure 5 Bus 14 voltage after load shedding

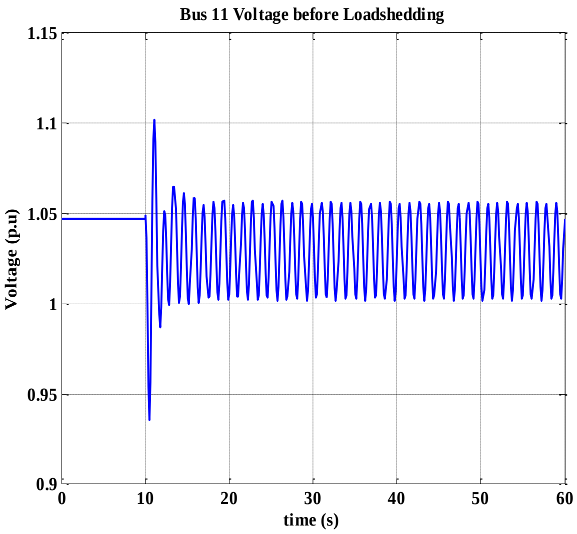


Figure 2 Bus 11 voltage before load shedding

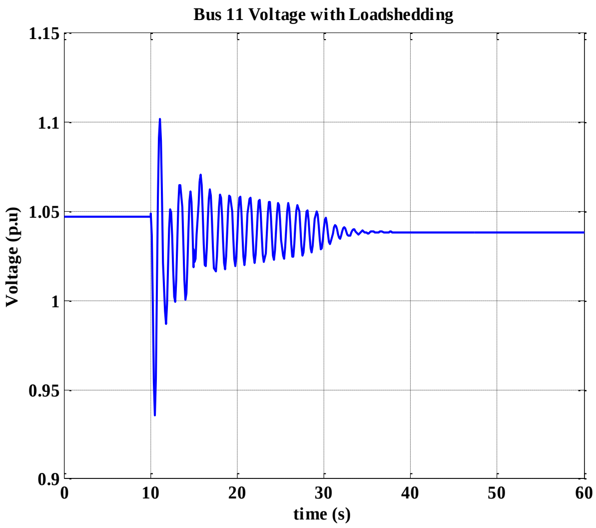


Figure 6 Bus 11 voltage after load shedding

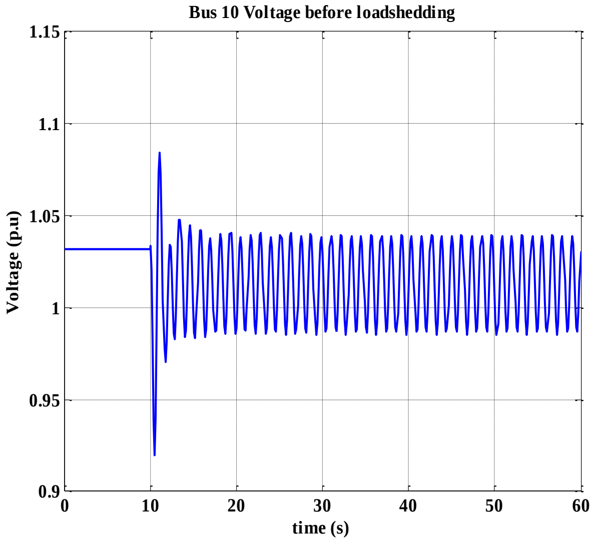


Figure 3 Bus 10 voltage before load shedding

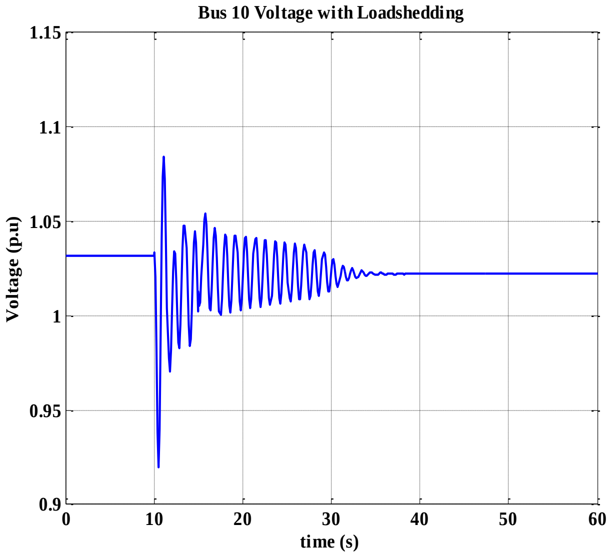


Figure 7 Bus 10 voltage after load shedding

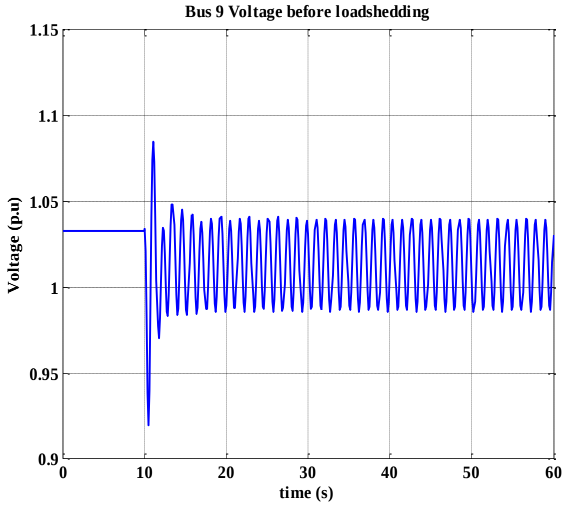


Figure 4 Bus 9 voltage before load shedding

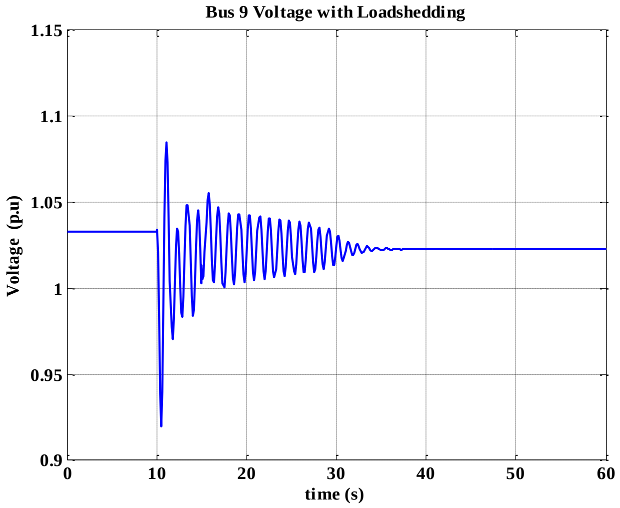


Figure 8 Bus 9 voltage after load shedding

*Table 1 Power Flow Results*

| From Bus | To Bus | Line | P Flow [p.u] | Q Flow [p.u] | Q Loss [p.u] | P Loss [p.u] |
|---|---|---|---|---|---|---|
| Bus 2 | Bus 5 | 1 | 0.4171 | 0.03219 | 0.00921 | -0.008 |
| Bus 6 | Bus 12 | 2 | 0.08037 | 0.03119 | 0.0008 | 0.00166 |
| Bus 12 | Bus 13 | 3 | 0.01857 | 0.01353 | 0.00011 | 0.0001 |
| Bus 6 | Bus 13 | 4 | 0.18272 | 0.09743 | 0.00248 | 0.00488 |
| Bus 6 | Bus 11 | 5 | 0.0818 | 0.08439 | 0.00115 | 0.0024 |
| Bus 11 | Bus 10 | 6 | 0.04565 | 0.06399 | 0.00046 | 0.00108 |
| Bus 9 | Bus 10 | 7 | 0.04487 | -0.00475 | 6.00E-05 | 0.00016 |
| Bus 9 | Bus 14 | 8 | 0.08719 | 0.00597 | 0.00091 | 0.00194 |
| Bus 14 | Bus 13 | 9 | -0.06272 | -0.04597 | 0.00099 | 0.00202 |
| Bus 7 | Bus 9 | 10 | 0.27203 | 0.1619 | 0 | 0.01001 |
| **Bus 1** | **Bus 2** | **11** | **1.5712** | **-0.2046** | **0.04311** | **0.07312** |
| Bus 3 | Bus 2 | 12 | -0.71124 | 0.01683 | 0.02337 | 0.05222 |
| Bus 3 | Bus 4 | 13 | -0.23076 | 0.06689 | 0.00397 | -0.02524 |
| Bus 1 | Bus 5 | 14 | 0.7546 | 0.05482 | 0.02771 | 0.06135 |
| Bus 5 | Bus 4 | 15 | 0.6019 | -0.09207 | 0.00478 | 0.00192 |
| Bus 2 | Bus 4 | 16 | 0.55939 | 0.01595 | 0.01672 | 0.01117 |
| Bus 5 | Bus 6 | 17 | 0.45689 | 0.10973 | 0 | 0.04682 |
| Bus 4 | Bus 9 | 18 | 0.15504 | 0.02799 | 0 | 0.01266 |
| Bus 4 | Bus 7 | 19 | 0.27203 | -0.06506 | 0 | 0.01528 |
| Bus 8 | Bus 7 | 20 | 0 | 0.25163 | 0 | 0.00939 |

Table 2 Load to be shed

| Bus No. | Voltage Magnitude | Consumption Power | | Load to Shed | |
|---|---|---|---|---|---|
| | (p.u) | MW | Mvar | MW(p.u) | Mvar(p.u) |
| 1 | 1.06 | 0 | 0 | 0 | 0 |
| 2 | 1.05 | 0.217 | 0.127 | 0.0638 | 0.003 |
| 3 | 1.01 | 0.942 | 0.19 | 0 | 0.0163 |
| 4 | 1.01 | 0.478 | 0.04 | 0 | 0 |
| 5 | 1.02 | 0.076 | 0.016 | 0.0161 | 0.008 |
| 6 | 1.07 | 0.112 | 0.075 | 0 | 0.0061 |
| 7 | 1.05 | 0 | 0 | 0 | 0 |
| 8 | 1.09 | 0 | 0 | 0 | 0 |
| 9 | 1.03 | 0.295 | 0.166 | 0.0295 | 0.023 |
| 10 | 1.03 | 0.09 | 0.058 | 0 | 0 |
| 11 | 1.05 | 0.035 | 0.018 | 0.0056 | 0.005 |
| 12 | 1.05 | 0.061 | 0.016 | 0.0107 | 0.0079 |
| 13 | 1.05 | 0.135 | 0.058 | 0.0095 | 0.0035 |
| 14 | 1.02 | 0.149 | 0.05 | 0.0587 | 0.0006 |
| **TOTAL** | | **2.59** | **0.814** | **0.1939** | **0.0734** |

Table 3 Comparison of cuckoo search algorithm with others

| **Bus No.** | **Voltage Magnitude** | **Percentage of loadshedding (Active Load)** | | | |
|---|---|---|---|---|---|
| | (p.u) | % CSwLF | % LP | % PSO | % LPwPSO |
| 1 | 1.06 | 0 | 0 | 0 | 0 |
| 2 | 1.05 | 29.40 | 49.7 | 30.13 | 29.04 |
| 3 | 1.01 | 0.00 | 40.7 | 49.99 | 49.99 |
| 4 | 1.01 | 0.00 | 43.3 | 38.91 | 41.89 |
| 5 | 1.02 | 21.18 | 26.8 | 0.06 | 0.03 |
| 6 | 1.07 | 0.00 | 29.2 | 0.004 | 0.008 |
| 7 | 1.05 | 0.00 | 0 | 0 | 0 |
| 8 | 1.09 | 0.00 | 0 | 0 | 0 |
| 9 | 1.03 | 10.00 | 39.6 | 48.29 | 45.9 |
| 10 | 1.03 | 0.00 | 28.1 | 44.59 | 45.54 |
| 11 | 1.05 | 16.00 | 25.9 | 30 | 31.74 |
| 12 | 1.05 | 17.54 | 26.8 | 49.35 | 46.25 |
| 13 | 1.05 | 7.04 | 30.9 | 46.75 | 45.92 |
| 14 | 1.02 | 39.40 | 31.9 | 49.86 | 49.85 |
| Total Shed Load (p.u) | | 0.1939 | 1.01 | 1.0831 | 1.0861 |

## VI. CONCLUSION

The above results shows that cuckoo search with Levy flight is a superior algorithm than particle swarm optimization or linear programming and that if used in load shedding, minimal load is shed. This results are very encouraging since fewer customer will have their power interrupted.

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