

## Load Shedding Optimization in Power System Using Swarm Intelligence-Based Optimization Techniques

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### Abstract

*In this paper, an Optimal Load Shedding problem pertaining to system overloading is solved using two swarm intelligence based, bio-inspired algorithms, viz. the Firefly Algorithm (FA) and the Particle Swarm Optimization (PSO). The standard objective functions, viz. the amount of load shedding and the New Voltage Stability Index (NVSI), indicating the optimal location of load to be shed, are minimized using the proposed algorithms. The NVSI acts as a voltage stability indicator in transmission line and its minimization improves transmission line performance, thus improving voltage stability of the system. A standard IEEE 30-bus test system is used for solving load flow problem using Gauss-Siedel method. This paper compares the effectiveness of both the algorithms in solving the proposed multi-objective problem.*

**Keywords-** Load shedding, Firefly Algorithm, Particle Swarm Optimization, New Voltage Stability Index, Multi-objective Optimization.

### I. INTRODUCTION

The most common factor contributing to power blackouts is the voltage instability issue arising from the overloading of the transmission system, which may result in a cascading or islanding event leading to a blackout. During such conditions, accurate load shedding is crucial to prevent total system collapse. Optimum location of loads to be shed is required along with their optimum required quantity. As load shedding brings up large economic cost, dispatcher must try his best to protect majority of loads.

The voltage stability indices are powerful tools to identify the weakest bus and critical line. Minimization of total load shed and sum of New Voltage Stability Index (NVSI) at the selected buses are considered in [1] as two objectives to restore the power flow solvability. A non-linear optimization problem is solved for determining the best location and the minimum amount of the load to be shed in [2] for the event-driven-based load shedding schemes by converting it into a series of linear optimization problems. Also, to quickly identify the possible load shedding locations in the proposed multistage method, a novel multiport network model is proposed.

An overview of the computational intelligence techniques, applied to load shedding in power systems along with comparison of their advantages over conventional load shedding techniques is presented in [3] along with the limitation of computational intelligence techniques, which restricts their usage in load shedding in real time.

A novel method based on Hybrid Genetic Algorithm and Particle Swarm Optimization technique is proposed in [4] for solving Under Voltage Load Shedding (UVLS) problem. Customer interruption cost has been modeled as a quadratic function in five major load classifications.

The effects of the major parameters of FA were systematically investigated in [5] on some benchmark functions. The characteristics of FA parameters and guidelines to determine parameter values are described.

A multi-step load shedding scheme is proposed for voltage security assessment under disturbances in [6]. A new algorithm has been developed using the line-based voltage stability index as an instrument to measure the sensitiveness of a transmission line in a system. An optimal load shedding algorithm based on the concept of static voltage stability margin and its sensitivity value at the maximum loading point/collapse point is developed in [7].

An optimization model to minimize the load shedding required to restore the equilibrium of operating point with relaxation of restrictions has been proposed in [8]. It minimizes the load cuts, limiting them to their importance and establishing different stages for them through relaxation of the minimum limits of voltage and maximum limits of active power flows through transformers. A new algorithm for load shedding using the minimum Eigen value of load flow Jacobian as proximity indicator, obtained using continuation power flow methodology is proposed in [9].

The research and practical applications of power system optimization are discussed in [10] by studying all kinds of optimization methods to solve power system operation problems using both the traditional and new technologies, chapter wise for implementing in power system operation.

A consistent and unified approach to the latest developments in metaheuristic algorithms for solving optimization problems along their detailed descriptions are provided with MATLAB programs in [11].

Till date, several types of algorithms have been applied on optimal load shedding problem in power systems, using some or all of its objectives. This paper intends to verify the effectiveness of both the algorithms for the proposed problem under overloading conditions.

## II. PROBLEM FORMULATION

The objective of an optimal load shedding problem is to determine the design variables which minimize the objective function. The following index, applied with suitable constraints is used to formulate the same.

### A. Voltage Stability Index

A New Voltage Stability Index (NVSI) has been proposed [1], from the equation of a two bus network, by neglecting the resistance of transmission line, resulting in appreciable variations in both real and reactive loading. In general, the NVSI formulation connecting bus i to bus j can be given by:

$$NVSI_{ij} = \frac{2X\sqrt{(P_j^2 + Q_j^2)}}{2Q_jX - V_i^2} \quad (1)$$

Variable definitions are as follows:

X: line reactance,

Q<sub>j</sub>: reactive power at the receiving end,

V<sub>i</sub>: sending end voltage,

P<sub>j</sub>: real power at the receiving end.

The value of NVSI must be less than 1.00 in all transmission lines to maintain a secure system. With this index information, load buses can be ranked in decreasing order so as to identify the buses with large component of NVSI as weak buses to perform load shedding.

Power flow solvability can be restored through load shedding. Sum of the total active demand reduction and the sum of NVSI values are minimized for selecting weak buses for load shedding. The following objective function [1] is used for minimization.

$$x = w \sum_{i=1}^{LSB} NVSI + (1-w) \sum_{i=1}^{LSB} (-\Delta P_{0i}) \quad (2)$$

Here, LSB denotes load shed buses and  $\Delta P_{0i}$  is the load shedding at bus i.

### B. Load Shedding Constraints

Load shedding scheme has been implemented on power system under feasibility and solvability of power flow equations.

1. Power flow equations are equality constraints of load shedding, as follows:

$$P_{Gi}^0 - P_{Di}^0 + \Delta P_{Di} = \sum_{j=1}^N |V_i| |V_j| |Y_{ij}| \cos(\delta_{ij} + \delta_j - \delta_i) \quad (3)$$

$$Q_{Gi}^0 - Q_{Di}^0 + \Delta Q_{Di} = - \sum_{j=1}^N |V_i| |V_j| |Y_{ij}| \sin(\delta_{ij} + \delta_j - \delta_i) \quad (4)$$

Here, P<sub>Di</sub> and Q<sub>Di</sub> are the active and reactive power demands on bus i and other parameters are associated with the power flow studies [4]. Subscript “0” used above indicates parameter initial values, while prefix “Δ” indicates variation of that parameter. The reactive power generation constraint is considered in power flow algorithm and it is not required to consider it in load shedding modeling.

2. The power factor is maintained as the original in every load bus,

$$Q_{D0i} \cdot \Delta P_{D0i} - P_{D0i} \cdot \Delta Q_{D0i} = 0 \quad \forall i \quad (5)$$

Here, P<sub>D0i</sub> and Q<sub>D0i</sub> are the initial active and reactive power demands on bus i.

3. The voltage magnitudes at all buses after load shedding are within the maximum and minimum limits:

$$V_{i,min} \leq V_i \leq V_{i,max} \quad (6)$$

## III. THE FIREFLY ALGORITHM

The Firefly algorithm is one of the several swarm based optimization algorithms introduced by Dr. Xin She Yang [11] at Cambridge University in 2007 and is inspired by the mating or flashing behaviour of fireflies. It has proved to be much simpler in concept as well as implementation than other swarm based algorithms. Most fireflies can communicate only up to several hundred meters.

In the implementation of the algorithm, the flashing light is formulated such that it gets associated with the objective function to be optimized. Its distinct advantages are precision, robustness, easy and parallel implementation.

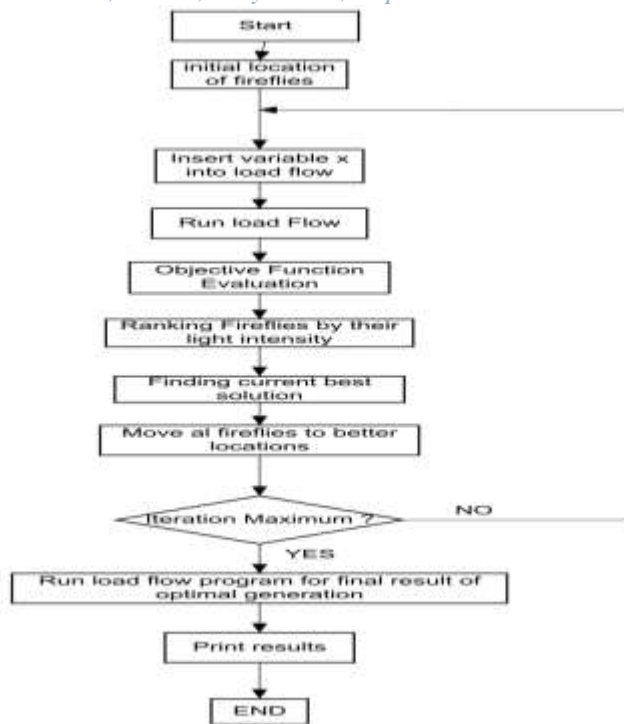


Figure 1. Flowchart of Firefly Algorithm  
IV. PSO ALGORITHM

Particle Swarm Optimization (PSO) is an evolutionary computation technique first introduced by Kennedy and Eberhart in 1995. It is based on simulation of social behavior of animals such as a flock of birds, a school of fish or a group of people pursuing a common goal in their lives.

A simple PSO is an iterative procedure in which the position of each particle is a candidate of the best solution. The particles are moving along the directions mainly determined by a meaningful combination of the best local and global information available to the agents in every iteration step.

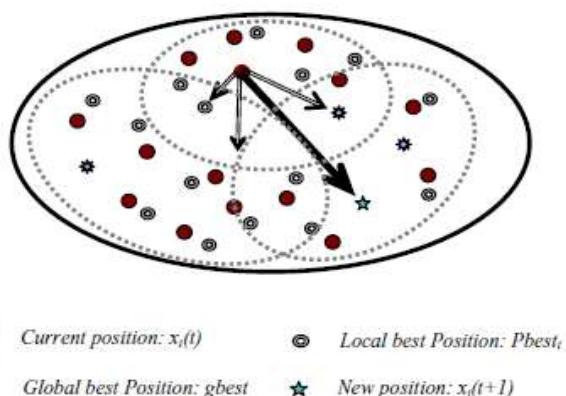


Figure 2. Particle's movement in the PSO algorithm [8]

## V. PROCEDURE

- 1) By executing with lower voltage limit as 0.85, increase the load with constant power factor at all buses until a

stage where no solution is reached, subject to the specified constraints.

- 2) Run OPF just ahead of insolvability for overloading condition or in a condition of line outage and calculate NVSI at all buses. Rank load bus in descending order, and select the buses with large value of NVSI as weak buses to perform load shedding.
- 3) Generate real random values lie between upper and lower boundaries. Proper selection of these boundaries can help get global optimal solution depending on the operator's knowledge and the cases considered like overloading. Assume suitable population size and maximum number of iterations.
- 4) Run OPF for all initial generated population with lower limit voltage increased to 0.9 p.u. Calculate the objective value from equation (2).
- 5) Determine the minimum objective values and identify the corresponding best particles by following the algorithm steps for all iterations.
- 6) If termination criterion specified is met, or maximum iteration is reached, the best solution is obtained. The difference between the upper boundary and the obtained value of each parameter in best particle will give the load shedding at a particular load bus.
- 7) After load shedding run OPF to analyze the performance of the system.

## VI. RESULTS AND DISCUSSION

- a) The limits of solvability were determined, following the specified procedural steps by gradually increasing the loading factor ( $\lambda$ ) until  $\lambda=1.68$ , where system becomes unsolvable. So, OPF results, just below  $\lambda=1.68$ , say 1.67 are recorded in Table 1.

Table 1. Different Loading values for weak buses

Bus	Base Loading	Heavy Loading	
		Solvable ( $\lambda=1.67$ )	Unsolvable ( $\lambda=1.68$ )
	P(MW)	P(MW)	P(MW)
5	94.2	157.314	158.256
10	5.8	9.686	9.744
30	10.6	17.702	17.808
11	0.00	0.00	0.00
12	11.2	18.704	18.816
7	22.8	38.076	38.304

- b) On calculating the NVSI values for all 41 lines for IEEE 30 bus system, these are sorted in the decreasing order to determine the first 7 lines with the highest NVSI values, as shown in Table 2, along with the associated weak buses. The NVSI values for all the lines are plotted as shown in Figure 3.

Table 2. Top 7 Weak Buses identified for Load Shedding

Line	Bus	NVSI	Rank
2-5	5	0.6820	1
6-10	10	0.2205	2
27-30	30	0.1900	3
29-30	30	0.1441	3
9-11	11	0.0995	4
4-12	12	0.0987	5
5-7	7	0.0855	6

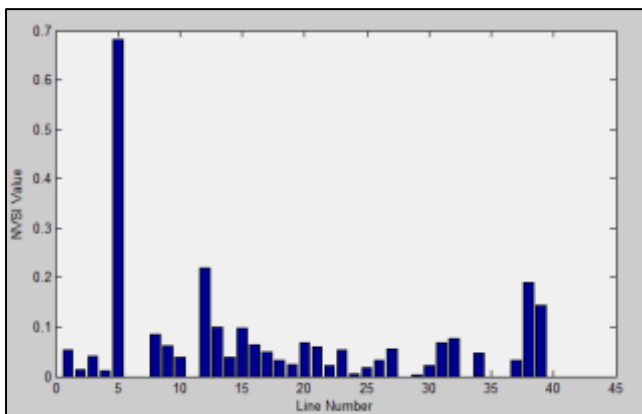


Figure 3. Transmission Lines and their NVSI Values

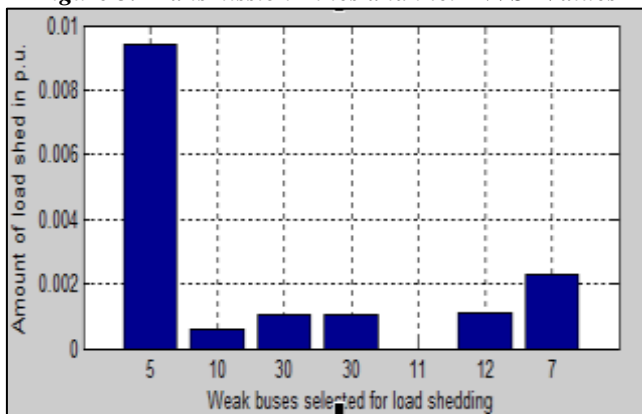


Figure 4. Load Shed Amount at Weak Buses<sup>1</sup>

- c) The control variable limits (upper and lower) for the heavy loading condition are set to restrict the load shedding within this desired range, as shown in Table 3.

Table 3. Control Variable Limits for Heavy Loading Condition

Parameter	Limits (MW)
$P_{L5}$	155.09--158.26
$P_{L10}$	9.55--9.74
$P_{L30}$	17.45--17.81
$P_{L12}$	18.44--18.82
$P_{L7}$	37.54--38.30

<sup>1</sup> All powers are calculated on per unit basis in both the algorithms, on a base of 100 MVA.

The upper limit of load demand is that obtained on boundary of insolvability, i.e. for  $\lambda=1.68$ . The lower limit is usually taken 2-3% less than the upper limit [1].

- d) Figure 4 indicates the relative amount of load shed at the selected weak buses, whereas Figure 5 shows the % contributions of the selected overloaded transmission lines to insolvability of system.

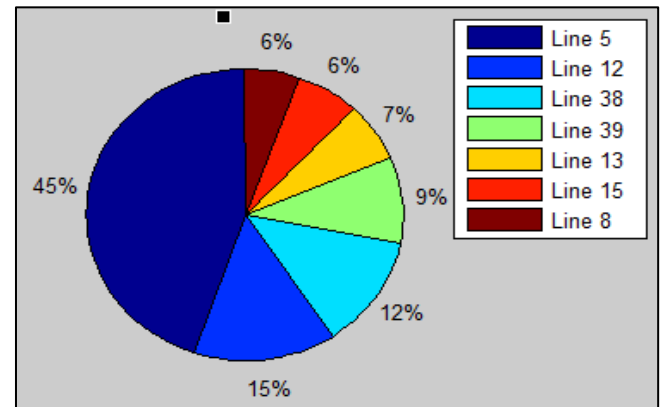


Figure 5. Contribution of lines in Overloading from NVSI values in %.

- e) Both the Firefly and PSO algorithms are run for the specified multi-objective function, comprising of optimal load shedding amount and bus locations with suitable weighting factors (0.5 and 0.5) and the results are plotted as shown in figure 6.

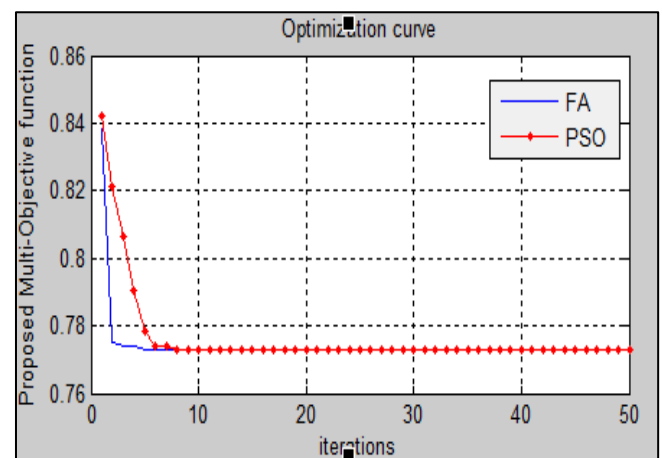


Figure 6. Objective Function Curve for both Algorithms

- f) The optimized values of active and reactive power demand at all the load shed buses are obtained as shown in Table 4.

Table 4. Optimized Results for heavy loading condition (PSO and FA)

Parameters	Best Compromised values
$P_{L5}$	157.31 MW
$P_{L10}$	9.69 MW
$P_{L30}$	17.70 MW
$P_{L12}$	18.70 MW

$P_{L7}$	38.08 MW
$Q_{L5}$	31.73 MVAR
$Q_{L10}$	3.34 MVAR
$Q_{L30}$	3.173 MVAR
$Q_{L12}$	12.525 MVAR
$Q_{L7}$	18.203 MVAR
Sum of NVSI (1-LSB)	1.5207
Total Load Shedding	1.5520 MW
Objective, OF	0.7729

- g) The optimum value of total load shedding was found to be 1.5520 MW using both PSO and Firefly algorithms. The optimal value of sum of first seven highest NVSI values of lines was found to be 1.5207.

## VII. CONCLUSION

An Optimal Load Shedding scheme to maintain power flow solvability of the system, based on two bio-inspired, swarm based techniques, viz. Firefly Algorithm and Particle Swarm Optimization has been proposed by which the optimal amount and bus location of loads is obtained. The test results on IEEE 30 bus system for the case of heavy loading shows that this load shedding method can be applied to restore power flow solvability in a computationally efficient manner.

The Objective function curves obtained using both the algorithms suggest that though both of them are quite robust and do converge to the same optimum value in the end, but the Firefly Algorithm converges faster than the PSO algorithm for this Optimal Load Shedding problem.

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