An Algorithm Based Load Shedding Optimization In Power System

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Abstract- *In this paper, an Optimal Load Shedding problem pertaining to system overloading is solved using cuckoo search algorithm. 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 algorithm. 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 Newton Raphson Method.*

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.

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:

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

Variable definitions are as follows:
X: line reactance,
Qj: reactive power at the receiving end,
Vi: sending end voltage,
Pj: 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.

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

Here, LSB denotes load shed buses and ΔP0i 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, PD_i and QD_i 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 modelling.

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

$$Q_{Di}.\Delta P_{D0i}\text{-}P_{D0i}.\Delta Q_{D0i} = 0\ \forall i \qquad (5)$$

Here, PD0i and QD0i 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:

$$V_{i,\,min} \leq V_i \leq V_{i,\,max}$$

III. METHODOLOGY

Cuckoo search is a relatively recent nature-inspired metaheuristic algorithm, developed by Xin-She Yang and Suash Deb in 2009. CS was inspired by the brood parasitism of some cuckoo bird species, in combination with the Lévy flights random walks. Cuckoos are catching scientists' interest because of their aggressive reproduction strategy. Some species lay their eggs in communal nests of other host birds (often other species), and may remove others' eggs to increase the hatching probability of their own eggs.

CS idealized rules can be summarized as:

1. Each cuckoo lays one egg at a time, and dumps its egg in a randomly chosen nest.
2. The best nests with high quality of eggs will carry over to the next generations.
3. The number of available host nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability, where the host bird can either throw the egg away, or abandon the nest and build a completely new nest.

These rules are used to draw the basic cuckoo search algorithm in Pseudo code 1.

Pseudo code 1: cuckoo search algorithm

Objective function f(x),x=(x1,….xd);
Initialize a population of host nests/solutions;
Define the Lévy flights step size factor;
While is not stop criteria
Find new nests, using Lévy flights as:
For (all nests)
For (all dimensions)
End for
End for
Evaluate the new nests against the objective function and calculate their quality/fitness;
Rank and keep the current best nests as:
For
If is better than
Replace
End if
End for
Replace a fraction of nests as:
Get two random permutation arrays and of length;
For
For
If
End if
End for
End for
Evaluate the new nests;
Rank and keep the current best nests;
Get the current best nest;
End while

While exploring new solutions, it is necessary to control the Lévy flights random walks, to avoid large moves, causing the solutions to jump outside of the search space. A step size factor that is defined according to the scale of the problem of interest should be used for this purpose. This might be an interesting subject for more research, studying the optimal utilization of the Lévy flight in optimization; for simplicity, a typical step size factor of 0.01, as suggested by the authors, is being used in this study.

The proposed algorithm, one rank cuckoo search (ORCS), applies two behavioural amendments to the original cuckoo search algorithms, in aim to improve convergence rate, and consequently achieve a better performance and accuracy. These behaviours are defined in the following subsections.
One Rank (Combined Evaluation)

The original algorithm generates new nests using Lévy flights (exploration phase) and evaluates their fitness, then replaces a fraction of nests (exploitation phase) and evaluates and ranks their fitness once more. Instead, the proposed algorithm generates new solutions using Lévy flights, replaces a fraction of them, and finally evaluates and ranks their fitness at once. This behaviour allows a more conservative consumption of the function evaluations, by merging together the new solutions generated by the exploration and exploitation phases before evaluating them, and hence consuming (population size) evaluations per iteration by the proposed algorithm against evaluations by the original algorithm.

A one rank ratio is initiated by 1, to allow the proposed algorithm to combine all the explorations and exploitations, until it fails to find better nests for iterations, to trigger a gradual decrease of the one rank ratio as in Eq. 1, where is the iteration number and is the number of objective function dimension.

It is required to enforce the constraints defined by an objective function for all the solutions generated during the optimization process, particularly when using algorithms with some random nature components, such as the cuckoo search algorithm. The draw on Lévy flights for exploring the search space, rather than uniform random walks, tends to increase the probability for the generated solutions to get out of the defined constraints, and accordingly an increased need for a better bound behaviour than a simple minimum-maximum bound.

The proposed algorithm enforces the integrity over an out of constraints solution by replacing its invalid dimensions by the corresponding dimensions drawn from randomly selected solutions among the current best solutions. A ratio of the replaced dimensions is utilizing the current best solutions found so far, and the rest is being randomly drawn by further exploring the search space. A bound by best ratio is defined as in Eq. 2, and the basic bound by best solutions behaviour is presented in Pseudo code 2.

Pseudo code 2: Bound by best procedure

Objective function f (x1,.xd),x ϵ [min, max];
Define bound by best ratio as in Eq. 2;
For each dimension in new solution
If not
If
Select a solution randomly from the current best solutions,;
;
Else
;
End if
End for

One Rank Cuckoo Search Algorithm

The one rank/combined evaluation and bound by best solution functionalities, have been added to the original cuckoo search algorithm, and used to draw the basic one rank cuckoo search algorithm in Pseudo code 3.

The proposed ORCS algorithm introduced one more parameter, one rank ratio update trigger, in addition to the two parameters employed by the original CS algorithm, population size and abandon rate. This parameter has not been meta-optimized to select the best performing setting; however the preliminary tests undergone during the algorithm development, demonstrated insensitivity in this parameter to have a major impact on the algorithm performance.

IV. CONCLUSION

Cuckoo search is a nature-inspired metaheuristic algorithm, based on the brood parasitism of some cuckoo species, along with Lévy flights random walks. In this paper, a modified version is proposed, where the new solutions generated from the exploration and exploitation phases are combined, evaluated and ranked together, rather than separately in the original algorithm, in addition to imposing a bound by best solutions mechanism to help improve convergence rate and performance. The proposed algorithm was tested on a set of ten standard benchmark functions, and applied to a real-world problem of algorithmic trading systems optimization in the financial markets. Experimental analysis demonstrated improved performance in almost all benchmark functions.

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