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Optimal Load Shedding using Bacterial Foraging Optimization Algorithm

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***Abstract* – This paper presents an optimization technique for optimal load shedding in power system known as Bacterial Foraging Optimization Algorithm (BFAO). Load shedding is done by removing a certain amount of loads at appointed locations of a bus system. By doing so, the stability of the system can be improved, as well as the total power losses. The objective functions of total power losses and voltage stability index values are used in determining the optimal load shedding in that particular system. In this research, the technique is implemented into IEEE 30-bus bus system. Simulations of BFAO proved that it can give a better result when compared to the base case values of total power losses, minimum voltage and voltage stability index values of that particular bus system.**

***Keywords* – Bacterial Foraging Algorithm, optimal load shedding, voltage stability, total power losses.**

I. INTRODUCTION

Year by year, power system planners and operators have been thrown a big challenge in developing and developed countries as there is always a rapid growth in electricity demand. Past experiences indicates that the growth in load demand is always ahead of growth in generation [1]. As power systems are the systems that exist to supply reliable electric energy to users[2], it is a must to cut the load for the safety restrictions. Whenever there is any disturbance in power systems, the conditions of the system must be altered to make sure the system is in operation. As the system is not in a position to cater to its loads, owing to a generator shutdown or the opening of an important tie line, the frequency and voltages in the system reduce below normal specified limits.

There are two main reasons that will lead to voltage collapse events. It's either the transmission line is outage, in which the transmission inability of meeting the requirements, or the sudden outage of generator that cause drops in frequency which result in the instability in power-angle form which will lead to unbalance power [3]. In usual case, a fall in voltage, which happens gradually at first and rapid later, is one of the characters of voltage collapse phenomenon on the transmission system [4].

To overcome this phenomenon, load shedding can be the best solution and one of the most usable methods in avoiding voltage collapse in a power system. It might be the last option to be chosen but it really helps in this matter as it is cost-effective economical solution against long term voltage instability by large disturbance [5, 6]. Load shedding can be generally defined as an act, where a certain amount of load at that particular location must be removed from the system so that the system will operate successfully [7]. In [3], it is stated that there are two kinds of load shedding procedures. They are either for preparation or correction. For the preparation, a part of load will be cut to ensure the voltage stability margin in which the system is running near the critical state without collapse. As in for the correction, the load is cut once the voltage collapse because of faults, to make the system back to stability.

Load shedding can be categorized into two main schemes which are Undervoltage Load Shedding (UVLS) and Underfrequency Load Shedding (UFLS) schemes. This research's mainly focus is on the UVLS. This UVLS schemes has gained popularity in last few years as they proved to be an economical and effective technique to maintain voltage stability when compared to expensive and time consuming methods like shunt compensations, new additions to the main circuits etc [1]. The main part of a load shedding scheme is to determine the optimum location and the amount of load to be shed. It is a must to trip the right amount of load. Shedding the insufficient load may not help in preventing voltage collapse and too much trip will lead to overfrequency situation [8]. The shedding locations also hold an important factor when voltage stability is concern as shedding at less appropriate places requires more shedding [9].

There are a lot of different ways that can be used to determine both the location and minimum amount of load to be shed. In [8], the location is determined by deriving various sensitivities such as loadability margin sensitivity and sensitivity of voltage with respect to load while the amount of load to be shed is determine by the sensitivities of selected voltage to the load parameters. In [10, 11], the authors talk about the automatic load shedding done by comparing the voltage value,V, with the threshold value, V_{th}. As V is smaller than Vth, the amount of ΔP^{sh} of load is shed. Efficient method for undevoltage load shedding using Thevenin equivalent parameters estimation also has been introduced. In [12], the Thevenin equivalent parameters, i.e V_{th} and Z_{th}, were estimated to analyze the heavy load buses of voltage instability. An index, known as Voltage Instability Proximity Index (VIPI) will be used to determine the weakest bus that will involve for undervoltage load shedding scheme (UVLS). The VIPI is determined by estimating the ratio of the load impedance to the Thevenin impedance. The amount of load to be shed then being determined using the load control of demand side management (DSM). On the other hand, the [13] also talk about the Thevenin equivalent parameters but it uses hybrid method for changing the amount of load to be shed and the time for UVLS. The local measurement with recursive least square method will be used to estimate the Thevenin equivalent circuit of a power system seeing form a bus. The amount of load to be shed then being determined using the P-Q curve. On top of that, in [14], a combination of modal analysis and Differential Evolution Algorithm (DEA) is used to minimize load shedding and enhance the voltage profile, as well as the stability margin. The system's weak points will are determined using the modal analysis while DEA is used to determine the optimal load shedding level.

Besides all of those indexes being introduced, the new Fast Voltage Stability Index (FVSI) also introduced. This index can be used as voltage stability indicator in a system and also as numerical verification of the shedding location. It is proven in [15] that this index is a good indicator and it helps to verify the location of load to be shed and the shedding done at that point improves the stability of a system. A lot of techniques have been proposed so far to obtain the minimum load shedding such as Artificial Neural Network (ANN), Particle Swarm Optimization (PSO) and Artificial Immune System (AIS) and Evolutionary Programming (EP) [16-18]. This paper will discuss on the implementation of Bacterial Foraging Optimization Algorithm (BFOA) as an optimization technique so that the optimal load shedding can be found. BFOA is one of the latest optimization technique developed. It is based on the natural foraging behavior of E. coli bacteria [19, 20].

II. METHODOLOGY

A. Bacterial Foraging Optimization Algorithm.

The idea of BFOA is based on the foraging behavior of *E.Coli* bacteria present in human intestine. The fact that natural selection tends to eliminate animals with poor foraging strategies and favor those having successful foraging strategies becomes the base of this idea of BFOA. After many generations, poor foraging strategies are either eliminated or reshaped into good ones [20]. The *E.Coli* bacteria have a foraging strategy driven by four processes. They are Chemotaxis, Swarming, Reproduction and Elimination and Dispersal.

i. Chemotaxis

A process where flagella swim and tumble. The rotation of flagella of each bacterium does affect the movement. It's either moving in a predefined direction (swimming) or moving in different directions (tumbling) in the entire lifetime. A unit length of random direction is generated to represent a tumble. This will define the direction of movement after a tumble [21].

ii. Swarming

In order to reach the best food location, bacterium with the optimum path will try to provide a signal to the other bacteria so that they will swarm together to that particular location. The bacteria will then combine into groups and move together with high bacterial density [21].

iii. Reproduction

The healthiest bacteria will split into two bacteria, each, and placed in the same location while the least healthy will die. Therefore, the population of the bacteria is constant [20].

iv. Elimination and Dispersal

Events can kill all bacteria in a region and it is possible to destroy chemotactic progress. However, they also assist it as dispersal may put bacteria near the good food resource. The behavior of stagnation can be reduced by this elimination and dispersal process [21].

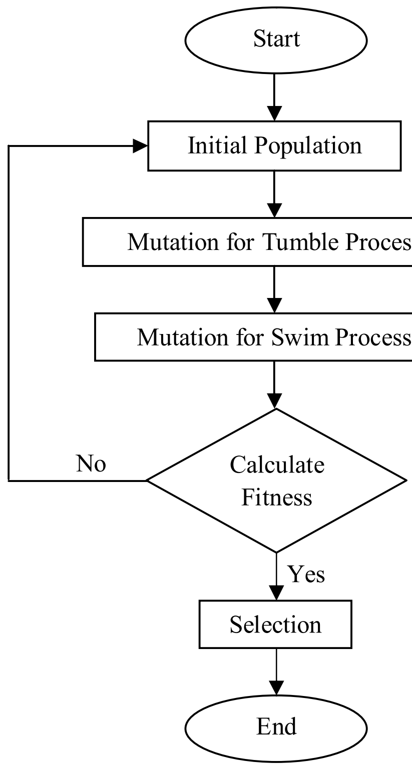

Fig. 1 BFAO Flowchart

A BFOA technique has 3 main stages. They are initialization, mutation (for tumble and swim processes) and selection. The details of each stage are explained as below;

a) Initialization

Initialization is a process where a form of 20 populations of load buses, as the locations of load to be shed, and the amount of load to be shed, i.e the real power, at each bus is generated. The parameters for the locations are referred as L1, L2, L3, L4 and L5 and the amount of load to be shed are P1, P2, P3, P4 and P5.

From the real power, reactive power to be shed, noted as Q1, Q2, Q3, Q4 and Q5 can be calculated using the Equation 1. The power factor of the system is assumed to be 0.85 and the stable limit for this system is set between 0.95 p.u and 1.05 p.u.

$$Q = (Q_{load} / P_{load}) * P \quad (1)$$

Where;
P = Real power to be shed
Q = Reactive power to be shed

The population generated must be within the required constraints to avoid system violation.

b) Mutation

Mutation is a method to execute the random number to produce offspring. An offspring in the population is determined by Equation 2 and Equation 3.

$$\eta'_i(j) = \eta_i(j) \exp(\tau' N(0,1)) + \tau Nj(0,1) \quad (2)$$

$$P'_i(\mathrm{j}) = Pi(\mathrm{j}) + \eta'_i(j) Nj(0,1) \quad (3)$$

Where;
$\tau = ((2(n)^{1/2})^{1/2})^{-1}$ and $\tau' = (2(n)^{1/2})^{-1}$

The offspring produced from the mutation process are tested for any constraints violation. The offspring that satisfy the constraint was selected for the next process.

c) Selection

The selection process totally depends on the objective function of total power losses (Tloss), voltage stability index value (Lindex) and total cost of shedded loads (cost). All of the members were sorted in ascending and/or descending order to produce the best twenty or the strongest twenty populations for the next generation.

III. Results and Discussions

This technique has been utilized for IEEE 30-bus data system. This system consists of 5 Generator (PV) Buses, 1 Slack Bus and 24 Load (PQ) Buses. This technique is applied for load buses as the locations of load shedding are determined between the load buses.

The methodology explained in the previous sections was used to find the optimal load shedding. This optimization technique, BFOA, is used, together with varieties of increments of loads in the bus data, so that the comparisons can be made by looking at the system's total loss, system's voltage stability and cost of loads to be shed. To obtain a much accurate results, the processes are repeated for several times. Table 1 presents the initial data for load increase from the loadflow of the IEEE 30-bus system used in this study.

TABLE 1
Base case value

Cases	PQ Load Increment	P Load Increment	Q Load Increment	1 Line Outage
Total Power Loss (MW)	43.5527	67.1366	20.0170	19.9343
Voltage Stability Index Value	0.3034	0.3450	0.2542	0.4509

As seen in the table, different load increments give different values of total power loss and voltage stability index. From here, those values will be compared with the values gained after the load shedding taken place by implementing BFOA. Table 2,3,4 and 5 represents the values gained after the implementation of load shedding using BFOA, with different way of determining the shedding locations for each cases, respectively.

TABLE 2
COMPARISON BETWEEN 3 OBJECTIVE FUNCTIONS FOR PQ LOAD INCREMENT FOR EACH TYPE OF LOCATION

OF	Locations	Tloss (MW)	Lindex
Tloss	Random	36.233	0.266
	Fixed	26.71	0.122
Lindex	Random	29.062	0.101
	Fixed	31.43	0.094
Cost	Random	42.383	0.293
	Fixed	42.235	0.287

TABLE 3
COMPARISON BETWEEN 3 OBJECTIVE FUNCTIONS FOR P LOAD INCREMENT FOR EACH TYPE OF LOCATION

OF	Locations	Tloss (MW)	Lindex
Tloss	Random	19.105	0.083
	Fixed	17.708	0.075
Lindex	Random	24.197	0.078
	Fixed	23.105	0.077
Cost	Random	31.781	0.247
	Fixed	31.027	0.226

TABLE 4
COMPARISON BETWEEN 3 OBJECTIVE FUNCTIONS FOR Q LOAD INCREMENT FOR EACH TYPE OF LOCATION

OF	Locations	Tloss (MW)	Lindex
Tloss	Random	10.577	0.174
	Fixed	12.06	0.133
Lindex	Random	12.398	0.108
	Fixed	12.566	0.122
Cost	Random	19.241	0.224
	Fixed	18.516	0.165

TABLE 5
COMPARISON BETWEEN 3 OBJECTIVE FUNCTIONS FOR 1 LINE OUTAGE FOR EACH TYPE OF LOCATION

OF	Locations	Tloss (MW)	Lindex
Tloss	Random	11.262	0.214
	Fixed	12.036	0.190
Lindex	Random	12.244	0.063
	Fixed	13.108	0.064
Cost	Random	18.130	0.402
	Fixed	18.229	0.309

Legend
*OF – Objective Function
*Bus No. – Bus Number of Load to be Shed
*Tload – Total Load to be Shed
*Tloss – Total Power Loss
*Lindex – Voltage Stability Index Value
*Cost – Total Cost of Shedded Loads
*Comp. Time – Average Computation Time

From Table 2 to Table 5, we can see differences in the Tloss and Lindex values for both randomly generated shedding locations and fixed shedding locations. For most cases and objective functions, fixed locations give a better improvement of Tloss and Lindex compared to the random locations shedding. This is probably because, during fixed locations shedding, the load shedding taken places in the 5 weakest load buses. So the process is mainly focus on those weak buses, compared to the randomly generated locations.

IV. CONCLUSION

This paper presents the optimal solution for load shedding using BFOA as the optimization technique. The purpose of achieving the optimal load shedding can be determined by looking at the three objectives which are total power losses of the system (Tloss), voltage stability index value (Lindex) and total cost of shedded loads (Cost).

For all cases, the results for all objective functions were improved when compared to the base case values and the values gained from fixed locations shedding are slightly better than the values gained from randomly generated locations. As a result, BFOA does prove that it can give better result according to the objective function when compared to the base case values.

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