Optimal Load Shedding in Uncertain Power System to Improve Voltage Stability

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ABSTRACT
This paper presents an efficient technique for optimum load shedding in an uncertain or dynamic power system network. If the normal control actions to improve the voltage stability are exhausted then the load shedding option works as the last line of defence to get the desired stability margin in power systems, hence it enables the system to withstand under worst loading conditions. In this paper a sensitivity index has been used to get the optimal buses on which load to be shed at heavy load conditions to get the desired value of voltage stability. An optimization problem aiming to minimize the load shedding at selected buses while satisfying all the inequality constraints to ensure the optimal power flow in the system has been developed in this paper. The load shedding is done on such buses whose sensitivity is higher. Black Hole algorithm has been used for optimum load to be shed at selected load bus. The proposed technique is implemented on IEEE 30 bus test system.

Keywords: Uncertain loads; Dynamic voltage stability, Black hole algorithm.

I INTRODUCTION

Voltage instability, voltage collapse and blackout are the cascading phenomenon in the power system networks. Various blackouts have been observed in the power system in the last few decades due to the increasing demand of electricity and failure of available control actions [1]. The non-deterministic nature of load and their representation in power system have been presented in [2]. The available control actions to maintain the system voltage stability are the Reactive compensation, On-load tap changers, and the Generator bus voltages are the first line of defense to prevent system from voltage instability conditions. All these control variables have certain limits of operation under which they try to maintain system voltage stability and after the exhaustion of their range under the increasing load conditions it becomes tough for system to withstand under heavier loading conditions and the voltage collapse may occur when the system is trying to support much more load than it can support [3]. On such cases the load shedding is an option to maintain the system operations under such conditions. But the foremost objective of power system operators and planners is to maintain system security which is nothing but the availability of power supply to consumers under contingent conditions [4]. Hence there is a need to optimize the load shedding so that only the small amount of load can be curtailed. The system frequency may violate due to one of the following reasons (i) sudden loss of generation or increase in load demand, (ii) overloading of transmission network, these causes leads to under frequency conditions which can later be solved by load shedding. The voltage stability enhancement scheme following the disturbances by load shedding is presented in [3]. The selection of most appropriate load shedding by Monte-Carlo scheme is given in [4,5]. Voltage stability enhancement and under frequency control techniques by optimal load shedding are given in [7,8,9]. For a given set of contingencies, a specified approach to enhance system characteristic by optimal load shedding scheme is given in [9,10]. In case of static voltage stability studies in power system the loading (real & reactive) of the system is increases in steps to the point of voltage collapse. The MW distance to this point may be a good measure of voltage stability limit of the system on the same time the minimum Eigen value of load flow jacobian approaches to zero at voltage collapse point which may also be treated as voltage collapse indicator. The one way to improve the system voltage stability at this point to increase the effective reactive reserve in the system by means of reactive power control variables or by reducing the reactive load demand of the system or by optimum load shedding. In this paper and optimization algorithm for optimum load shedding for improving the system voltage stability has been developed. Black Hole algorithm has been used for optimum load to be shed at selected load bus.

II BLACKHOLE OPTIMIZATION

A. Hatamlou [19] has proposed the modified population-based optimization technique inspired from the 'Black Hole' phenomenon. In the journey of a star towards the black hole, there may be a probability of crossing the event horizon. The stars or candidate solutions which cross the event horizon they are sucked by the black hole. The black hole optimization problem is formulated as follows:

$$r_i(k+1) = r_i(k) + rand\ (r_{BH} - r_i(k)) \quad (1)$$

Where $r_i(k+1)$ and $r_i(k)$ are the locations of the star at iterations't' and 't+1', respectively and r_{BH} is the location of the black hole in the search space, '$rand$' is a random number in the interval [0-1]. N is the number of stars (candidate solutions). Every time a candidate (star) dies, it is sucked in by the black hole, another candidate solution (star) is born and distributed randomly in the search space and starts a new search. In the BHA algorithm the event horizon radius is calculated by following equation:

$$r = \frac{F_{BH}}{\sum_{i=1}^{N} F_i} \quad (2)$$

Where 'f_{BH}' is the fitness value of the black hole

L-index

L-index varies between 0 to 1 [18]. If the index value of any bus approaches to unity means that bus is operating near its stability limit. The buses having the higher values of indexes are chosen as candidate buses. L-index if the L-index approaches to unity means system is approaching towards voltage instability and consequently voltage collapse state.

$$Lindex_k = \max_{k \in \beta_L} \left| 1 - \frac{\sum_{i \in \beta_G} F_{ki} V_i}{V_k} \right| \quad (3)$$

Where:

8_L is the set of load buses and 8_G is the set of generator buses and F_{ki} is the subset of hybrid matrix, which has been generated by Y-matrix. Stability condition lies between

0 < L-index < 1

III METHODOLOGY

(a) Read input data (line & bus data)
(b) Model the uncertain load
(c) Run the load flow program for all dynamic cases using N-R method
(d) Obtain the variation of minimum eigen value of load flow jacobian for all dynamic cases
(e) Find the critical case by using the minimum Eigen value of load flow jacobian for all dynamic cases.
(f) Obtain the candidate buses on which the load to be shed by using the L-index given in section 2
(g) Fix the limits of the inequality constraints for the base case and critical load levels
(h) Set objective function as minimum load shedding
(i) Set iteration count as 1 and fix the no. of iterations
(j) Generate and initialize the initial population of load shedding (bus16 & 19) as follows

Lds16(p)=(lshmax -lshmin)*rand()+lshmin(4) Lds19(p)=(lshmax lshmin)*rand()+lshmin(5)

(k) Where lshmin and lshmax are the lower and upper bounds of load shed. Which are the current positions of stars. Set theses stars as load vectors
(l) Run the load flow for the initial populations and monitor all the inequality constraints those vectors which do not satisfy the constraints they will be treated as non-feasible vectors.
(m) Calculate objective function for the feasible vectors.
(n) Based on the value of objective function, identify the best solution vector.
(o) The stars or solutions which crosses the event horizon they are sucked by the black hole and another candidate solution (star) is born and distributed randomly in search space the updated position of star can be formulated as
(p) [20] $r_i(k+1) = r_i(k) + rand\ (r_{BH} - r_i(k))$ (6)

Where and are the locations of the star at iterations 't' and 't+1', respectively and is the location of the black hole in the search space, ' ' is a random number in the interval [0-1].

(q) In the BHA algorithm the event horizon radius is calculated by following equation:

$$r = \frac{F_{BH}}{\sum_{i=1}^{N} F_i} \quad (7)$$

Where 'f_{BH}' is the fitness value of the black hole and 'fi' is the fitness value of the 'i^{th}' star. When the distance between a candidate solution and the black hole (best candidate) is less than R, that candidate is collapsed and a new candidate is created and distributed randomly in the search space.

(r) If the results of 10 consecutive cases are same or maximum iterations reached then stop the iteration otherwise repeat the steps from 10.

IV PROBLEM FORMULATION

It is a well-known fact that minimum quantity of loads should to be shed at minimum number of buses. After the selection of candidate buses the upper and lower bounds of load shed must be decide by the operating and stability consideration of the system. An optimization problem aiming to minimize the load shed at selected load bus can be formulated as follows:

Objective function

F1= min {load shed}

This objective function is subjected to following constraints

(a) Power flow constraints under the base operating point and critical load level
(b) L-index greater than 1
(c) minimum eigen value of load flow jacobian for base case and critical case greater than 1
(d) reactive generation for base case and critical case
(e) voltage limits
(f) Load shedding at selected load buses (80% 0f total load and remaining 20 % for emergency load conditions)
(g) Uncertain load adjustment factor [20]

V RESULTS AND DISCUSSION

The uncertain load models are taken from [20]

Table No. 1

Base case results minimum eigen value = 0.1875

Bus no.	IVI (pu)	δ (degree)	P_G (MW)	Q_G (MVAR)	L-index
1	1.000	0.000	218.208	-46.644	-
2	1.000	-5.043	60.970	46.267	-
3	0.969	-9.983	-	-	0.0433
4	0.968	-11.468	-	-	0.0422
5	0.985	-9.332	-	-	0.0302
6	0.967	-12.513	-	-	0.0372
7	0.964	-11.859	-	-	0.0500
8	0.965	-12.795	-	-	0.0382
9	1.004	-18.634	-	-	0.0333
10	0.979	-23.657	-	-	0.0296
11	1.004	-18.634	-	-	0.0333
12	0.987	-18.901	-	-	0.0481
13	1.000	-15.892	37.000	10.382	-
14	0.977	-20.123	-	-	0.0574
15	0.978	-20.604	-	-	0.0465
16	0.949	-20.039	-	-	0.0618
17	0.962	-22.858	-	-	0.0478
18	0.963	-22.560	-	-	0.0620
19	0.959	-23.486	-	-	0.0656
20	0.963	-23.597	-	-	0.0581
21	0.993	-26.562	-	-	0.0101
22	1.000	-27.175	31.590	115.857	-
23	1.000	-20.866	22.200	4.963	-
24	0.988	-24.312	-	-	0.0147

25	0.990	-22.445	-	-	0.0128
26	0.974	-22.979	-	-	0.0319
27	1.000	-20.857	28.910	38.292	-
28	0.954	-13.687	-	-	0.0332
29	0.978	-22.232	-	-	0.0333
30	0.965	-23.267	-	-	0.0564
Total P_G=398.878 MW			**Total Q_G= 169.117 MVAR**		
Total P_D= 372.450MW			**Total Q_D=138.460MVAR**		
Total P_{loss}= 26.428MW			**Total Q_{loss}=30.659MVAR**		

Table No. 2
Critical case results
Minimum Eigen value = 0.181932

Bus no.	|V| (pu)	δ (degree)	PG (MW)	QG (MVAR)	L-index
1	1.000	0.000	223.152	-26.204	-
2	0.990	-5.024	60.970	35.183	-
3	0.959	-10.159	-	-	0.0440
4	0.956	-11.695	-	-	0.0430
5	0.972	-9.454	-	-	0.0309
6	0.952	-12.761	-	-	0.0380
7	**0.949**	-12.071	-	-	0.0513
8	0.950	-13.077	-	-	0.0391
9	0.976	-19.299	-	-	0.0349
10	**0.942**	-24.259	-	-	0.0316
11	0.976	-19.299	-	-	0.0349
12	0.978	-19.561	-	-	0.0468
13	1.000	-16.525	37.000	16.477	-
14	0.972	-20.836	-	-	0.0543
15	0.973	-21.233	-	-	0.0412
16	**0.936**	-20.373	-	-	**0.0614**
17	**0.932**	-23.353	-	-	0.0498
18	**0.947**	-23.170	-	-	**0.0599**
19	**0.936**	-24.109	-	-	**0.0656**
20	**0.936**	-24.219	-	-	0.0588
21	**0.944**	-27.357	-	-	0.0129
22	0.950	-27.922	31.590	88.164	-
23	1.000	-22.006	22.200	16.845	-
24	0.962	-25.290	-	-	0.0168
25	0.979	-23.572	-	-	0.0152
26	0.963	-24.118	-	-	0.0347
27	1.000	-21.945	28.910	46.294	-
28	**0.940**	-14.137	-	-	0.0340
29	0.978	-23.321	-	-	0.0333
30	0.965	-24.355	-	-	0.0564
Total P_G =403.822MW			Total Q_G = 176.760MVAR		
Total P_D = 376.609MW			Total Q_D = 141.074MVAR		
Total P_{loss}= 27.213MW			Total Q_{loss}= 35.686MVAR		

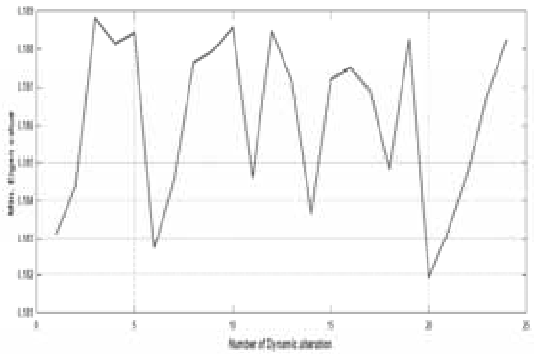

Fig No.1- variation of minimum eigen value of load flow jacobian

Table No. 3
Load shedding at selected buses

S.No.	Selected buses for load shed		Amount of load shed
1	16	Pd16	0.0062
		Qd16	0.3712
2		Pd19	0.1733
	19	Qd19	0.0581
Total load shed in pu			0.6088

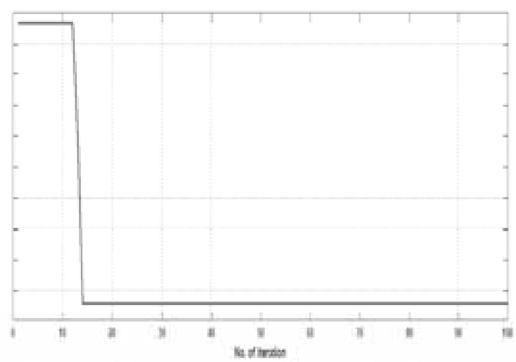

Fig No.2 Convergence of objective function

VI CONCLUSION

A black hole optimization algorithm technique has been used in this paper to get the optimal value of load shedding at selected buses in IEEE30 bus system to improve the voltage stability in uncertain load conditions.

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