A Novel Optimization Approach For Solving Optimal Load Shedding Problem Considering Different Voltage Stability Indices

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Abstract: Due to the increase in the complexity of the power system and the increase in electricity consumption. The power system no longer remains in equilibrium. In this paper, to restore the equilibrium in power system network, a proposal is made with the novel optimization technique to solve optimal load shedding problem by curtailing less amount of load at the optimal location and improving voltage profile. In this methodology, the risk of voltage instability and the critical buses are ranked based on NVSI. In this method, the NVSI constraint is used in the problem formulation in two ways: (a) New voltage stability index constraints added along with OPF formulation (b) Index is used in objective function formulation. The Modified Adaptive Harmony Search (MAHS) algorithm based on the improvisation of a musical tune approach is used to solve OLS strategies. The effectiveness of the proposed techniques is considered in terms of the location of load shedding and the amount of shedding. The effectiveness of the proposed method is tested on the standard IEEE-30 bus system. Simulation results show the minimum amount of load shedding using MAHS, while the NVSI provides an optimal load shedding location. By using this method, various power system blackouts can be prevented.

Index Terms: Optimal Load Shedding, Improved adaptive Harmony Search Algorithm, Voltage collapse, Active and Reactive power.

1 INTRODUCTION

OPTIMAL load shedding problem solving methods aim to reduce the quantity of load curtailment, and at the same time, they aim to locate the optimal location for load shedding. It is a multi-objective constrained optimization problem. There are many types of optimal load shedding problems like load curtailment, location of load shedding, and active and reactive power loss. Due to increased demand and modernization, the entire power system is operating extremely near to their operational limit. Using the stability index as a constraint in the OPF formulation increases its robustness against voltage instability. Instability of so many defense techniques for voltage instability problems still many blackouts occurring in a different part of the world.The optimal load shedding problem is addressed by many types of research with various approaches. OLS is a powerful tool for restoring stability after a large disturbance in the power network. In order to solve the OLS problem many computational intelligence techniques such as Raghu C N [1] in their work have conducted an exhaustive study on research towards methods adopted for load shedding in power system such as Genetic Algorithms (GA), Simulated Annealing (SA), Tabu Search (TA), Ant colony optimization (ACO),Practical Swarm optimization (PSO), Artificial Bee Colony (ABC) , Maximum Loading Point (MLP) , Backtracking search algorithm, fuzzy logic , Artificial Neural Network, and Harmony Search (HS), Empirical approach. This paper is organized with the following contents. In Sec. 2, the mathematical formulation is laid out to solve the network power flow equations. In Sec.3, different constraints are defined. In Sec. 4, detail of basic harmony search algorithm is presented along with the new features from improved adaptive harmony search algorithm. In Sec. 5, simulation results are presented for 14-Bus and 30-Bus systems. Finally, the conclusion is drawn in Sec 6.

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2 VOLTAGE STABILITY PROBLEM FORMULATION IN LOAD SHEDDING.

2.1 Problem formulation.

Under a certain situation like heavily increasing in the system demand and sudden loss of generation some of the system constraints are violated. Under these circumstances to enhance system security and stability, some load has to be curtailed to restore system stability. Actually, in present days to attain the optimal OLS many artificial intelligence techniques are employed which are capable of providing a fast and optimal solution for the load shedding (LS) problem. In view of the fact that the location of load shedding affects the efficiency of an algorithm [2]. In this paper, two types of voltage stability index (VSI) are presented, which are used to locate the constructive load bus for load shedding. FVSI proposed by Musirin [3],[4] used to identify and analyze the stability of the line and identify the critical line. It is formulated based on the reactive power flow in the transmission lines of the network. FVSI is formulated as follows:

$$FVSI = (4Z^2 Q_r)/(V_s^2 X) \quad (1)$$

Qr is the receiving end reactive power.
Vs is the sending end voltage.
Z is the impedance of line connected between the ith and jth buses.X is the line reactance of line connected between the ith and jth buses. R is the line resistance of line connected between the ith and jth buses.
Secondly, NVSI has been established on the fundamental concept of power flow and which is more susceptible to varying in real and reactive power [4],[5]. Finally, NVSI is explained as.

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

3 OLS PROBLEM FORMULATION.

To minimize the voltage stability level and load curtailment, the objective function is formulated. And to restore the solvability of power flow a multi-objective optimization problem is originated by taking into consideration VSI, active and reactive power demand in the objective function[6],[7]. Effectiveness of different voltage stability indices in optimal load shedding is evaluated. A MAHS algorithm is used to minimize the objective function.

$$\text{Min } x = \alpha \sum_{i=0}^{LSB}(VSI_i) + \frac{(1-\alpha)}{2}\sum_{i=0}^{LSB}(P_{Gi} - P_{Di})^2 + \frac{(1-\alpha)}{2}\sum_{i=0}^{LSB}(Q_{Gi} - Q_{Di})^2 \quad (3)$$

Where VSIi (FVSIi or NVSIi) → Voltage stability indices for line connected to ith Bus.
PGi and QGi→ Generated Real and reactive power at ith Bus.
PDi and QDi→ Connected Real and reactive power load at ith Bus.
α→ Penalty factor.
For the good fit of the above objective function penalty factor, α has to be properly chosen.

4 METHODOLOGY

The MAHS is one of the meta-heuristic optimization algorithm motivated by the procedure of improvisation in the musical tune. Moreover, MAHS algorithm is presented in this section is to solve the OLS problem by integrating real and reactive power load [8] and system losses as control variables. To impose the limit on these control variables an adaptive penalty based limiting method is proposed.

4.1 Modified Adaptive Harmony search algorithm(MAHS).

In this section, the MAHS algorithm presented in this section to solve the OLS problem defined. As stated in literature traditional harmony search algorithm shows better performance an engineering optimization problem.The main short full of the traditional method is that lack of convergence to the optimal solution and converge to the near local optimal value. And then secondly the number of iteration for convergence is also made. Due to the flexibility and well-balanced mechanism of the traditional algorithm to improve the search ability in locally and globally. The following modification is proposed.

4.2 Modification of PACR, BW, and PAR

In conventional HS algorithm, the value of PACR, BW and PAR are not dynamic interns these values are constant. Improvisation proposed by Mahdavi et.al[8] the new solution vector generated by dynamically changing of the PAR and BW parameters value doing this there is an improvement in accuracy and convergence rate. Limin Zhang[ICCSE 2015] in his improvisation in order to ensure the diverse in solution, HMCR parameter in HS algorithm adopt the linear increasing strategy.HMCR(t)=[HMCR]_Max([(HMCR]_Max[HMCR]_Min)*t (4)t→ Present iteration, NI→ Number of iterationsHMCRMax→ Maximum harmony memory consideration Rate.HMCRMin→ Minimum harmony memory consideration Rate. In order to avoid optimization end at local optima adaptive or dynamic value of PAR is introduced its formula is as follows:PAR=([PAR]Max-PAR]Min)/(π/2)*arctant+[PAR]Min
(5) In conventional HS algorithm uses a fixed value of BW and PAR. The value remains constant throughout the optimization process. In MAHS algorithm using nonlinear regressive strategy, the dynamic value of BW is formulated as

BW(t)=([BW]Max-[BW]Min)*e^t+[BW]_Min (6)
BWMax→ Maximum BW value.

4.3 Global search operator.

Furthermore, the effective global search is obtained by incorporating the genetic operator as follows.
For i=1: N
Penalty i=abs(xibest-xiworst)
xiNew=xibest+ penalty;
If rand≤T
xiNew=ximin+ rand * (ximax-ximin)
end end The parameter penalty increases the efficiency of the global search operation. In conventional HS algorithm after some iteration the factor penalty research to zero, and thereby the search algorithm reaches saturation (stagnated) Flow chart shown in figure 1 illustrates a schematic of the procedure involved in implementing MAHS for Load shedding problem.

FIGURE 1. *FLOW CHART FOR IMPLEMENTATION OF MAHS FOR OLS PROBLEM.*

5 RESULTS AND DISCUSSIONS

IEEE-30 bus system consists of six generators with a maximum generating capacity of 360.2, 140,100,100,100,100 MW at buses 1,2,3,6 and 8 respectively and 20 transmission line. The total network base value of real and reactive load demand is 283.4 MW and 126.6 MVAR correspondingly. The network has 4 tap changing transformers, the load bus voltage swings between the minimum and maximum value of 0.95 PU and 1.05 PU respectively. For this base load case, all the loads are increased in steps of 10% till the power flow reaches to unsolvability at load increment factor ξ=1.62. Because of the network overloading, the voltage at the buses starts falling and hitting its minimum limit. The voltage stability index like FVSI and NVSI are calculated for all lines. The PQ buses (except the PQ buses with zero loads) connected to the line having large stability index value is ranked in ascending order. The ranking of the buses using FVSI and NVSI values for under heavily loading condition in the system. And top five weak buses are selected for load shedding using FVSI and NVSI stability index as tabulated in Table 1. Clearly shows the top 5 weakest bus based on FVSI and NVSI index. The weakest bus is defined as the buses which have a value close to one.

TABLE 1.
LIST OF TOP 5 WEAK BUS

Rank	Line No	FVSI	Line No	NVSI
1	4-12	0.1779	2-5	0.16572
2	2-6	0.1176	6-10	0.15575
3	2-4	0.1077	27-30	0.14172
4	6-10	0.1059	4-12	0.12007
5	1-3	0.0953	2-4	0.08887

TABLE .2

SHOWS LOADING CONDITION AT DIFFERENT BUS UNDER A SIMULATED STRESSED CONDITION. BECAUSE OF OVERLOADING, THERE IS A SEVERE VIOLATION OF BUS VOLTAGES.

Rank	Ranked Bus No using FVSI	Base load P(MW)	Heavy loading		Ranked Bus No using NVSI	Base load P(MW)	Heavy loading	
			Solvability (λ=1.62)	Unsolvability (λ=1.63)			Solvability (λ=1.62)	UnSolvability (λ=1.63)
1	12	11.2	18.14	18.25	5	94.20	152.60	153.546
2	4	7.6	12.31	12.38	10	5.8	9.39	9.454
3	10	6.8	11.01	11.08	30	10.6	17.17	17.2
4	3	3.91	6.33	6.37	12	11.2	18.14	18.25
5	7	22.80	89.14	37.16	4	7.6	12.31	12.38

On the other hand, it is desirable to specify the control variable limit dimensionality so that the convergence time of the algorithm is not excessive. By tuning the weights of the objective function the optimal value of selected after 25 iterations of evaluation.

TABLE 3.

BEST COMPROMISED VALUE OF REAL AND REACTIVE POWER AT CRITICAL BUSES AFTER LOAD SHEDDING.

Bus No.	FVSI		Bus No	NVSI	
	Optimal Real power value in MW	Optimal reactive power value in MVAR		Optimal Real power value in MW	Optimal reactive power value in MVAR
5	151.92	30.346	5	152.42	30.417
4	12.103	2.597	10	9.342	3.21
10	10.826	3.228	30	17.127	3.0675
3	6.347	1.9348	12	18.192	12.189
7	36.216	17.507	4	12.263	2.554
Total	217.412	55.6128	Total	209.354	51.4375

Table 3 also shows the effectiveness of the ranking of stressed buses using NVSI over FVSI in finding the best optimal value using the proposed optimization method. The total amount of load shedding using proposed optimization technique using FVSI index is 1.7902MW. Whereas using NVSI is 1.568MW which proves the NVSI gives better results than using FVSI.
Although each voltage stability index has the same collapse condition, the index formulation is different therefore each index provides different results. As NVSI is formulation using both real and reactive power, therefore NVSI should be more accurate than FVSI which is formulated using only real power. VSI is formulated as part of the objective function, which gave minimum load shedding value and minimum loss for the system.Figure 2. shows the convergence characteristics of the objective function by applying the MAHS method for IEEE-30 Bus system. It can be noted that objective function converged very fast with less iteration.

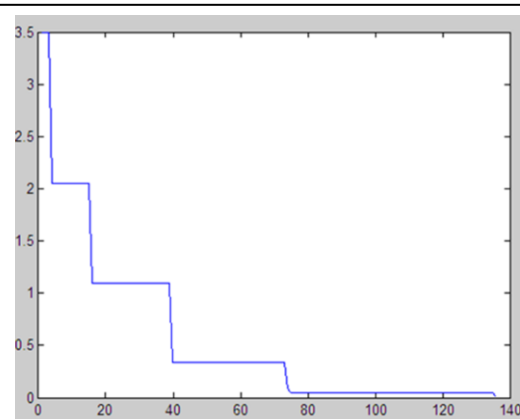

Figure 2.*MAHS objective function convergence characteristics for IEEE-30 Bus*

6 CONCLUSION:

In the proposed work, MAHS is applied for the OLS problem in which objective function is formulated by introducing voltage stability factor, a notable advantage is successfully excelled. The novelty of the MAHS algorithm is the self-adjusting or dynamic nature of the parameter such as BW, PAR, and PSAR during the optimization process. The load buses have been ranked using VSI (FVSI and NVSI). The merits of the NVSI are explored in an OLS problem. Load flow solution using NR power flow method using MATPOWER is achieved. The best optimal amount of real and reactive load is achieved using the proposed algorithm. To assess the fulfillment of the objective by the proposed algorithm has been tested on IEEE-30 bus system by including two VSI index (FVSI and NVSI) in the objective function. From the simulation results, it is seen that compare to FVSI, NVSI gives better performance with the proposed technique.

7 References

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