Invasive Weed Optimization for Optimal Capacitor Placement on a Radial Distribution System

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Abstract:—In this study, Invasive Weed Optimization (IWO) is presented to optimize the size of capacitors in a radial distribution system to reduce power loss and improve voltage profile. In this research, the Power Loss Index is used to identify weak buses in the distribution system, and IWO was used to determine the size of capacitors that should be installed at the weak buses to reduce power losses and enhance the voltage profile. The proposed method was created in MATLAB and tested using a variety of conventional tests. In terms of power loss, the simulation results generated by the proposed methodology were compared to the base case system, and the results were compared to the existing approaches available.

Key-words: —Invasive weed optimization, capacitor placement, Power Loss Index and Radial distribution system.

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1. Introduction

An electric distribution system is a link between the sub-transmission system and the consumers [1]. The electric distribution system consists of many non-linear loads, which significantly affect the quality of power supply and reactive currents. Reactive currents lead to more power loss in the distribution system. Minimizing the power loss and enhancing the voltage profile at each bus is one of the major challenges in the radial distribution network. Capacitor placement is one of the useful methods in reducing the power loss and improving the voltage profile. Installation of capacitor provides benefits economically when these are placed at weak buses in order to reduce the power losses and to improve the voltage profile. Mathematically, the optimal capacitor placement is a combinatorial optimization problem, as it involves the optimization of size of the capacitor, to minimize the power loss and improve the voltage profile.

Various bio-inspired algorithms have been proposed over several years in different fields in engineering [2]. A load flow technique for radial distribution networks has been developed in [3]. Loss sensitivity factors are used in [4] to determine the potential location of capacitors required for compensation. A forward and backward sweep algorithm for evaluating the node voltages iteratively has been presented in [5]. A MATLAB program for load flow analysis using Gauss-Siedel method has been developed in [6]. The bus-injection to branch-current matrix and the branch-current to bus-voltage matrix have been used in [7] to obtain unbalanced three phase load flow solutions. A simple three phase load flow method to solve three-phase unbalanced radial distribution system (RDS) has been developed.

In the past decade, many heuristic and modern heuristic methods have been applied for capacitor problem. In[8], Capacitor placement and sizing are done by Loss Sensitivity Factors and Particle swarm optimization. Self-adaptive harmony search algorithm is used in [9] to determine the capacitor sizes in order to reduce the power loss and improve the voltage profile. A direct search algorithm for capacitive compensation in radial distribution systems has been proposed in [10] and the results are compared with results of particle swarm optimization and genetic algorithm. The total distribution loss is significantly less than the one obtained in the other two methods. In [11], multi-objective approach for determining the optimum values of fixed and switched shunt capacitors to improve the voltage profile and maximizing the net savings in a radial distribution system has been suggested. The Cuckoo search algorithm has been proposed in [12] for solving capacitor placement problem to minimize the system losses and improve the voltage profiles at different load levels.Teaching learning based optimization [13] is proposed for capacitor placement problem. Mixed integer non-linear programming is suggested in [14] for optimal placement of capacitors.

In the recent past, the Invasive Weed Optimization (IWO)[15-17] has been proposed to solve different problems in optimal operation of power system. In capacitor placement problem, there is a need to reduce the power loss problem by selecting the proper sizing of the capacitors at weak buses. Hence, in this paper, IWO is selected to address optimal capacitor placement.

Rest of the paper is organized as follows. Section II provides the problem formulation of capacitor placement. Section III describes overview of Power Loss Index for identifying weak buses. Section IV provides the details about the proposed approach. Section V presents the case studies on distribution networks and simulation results. Section VI outlines the conclusions.

2. Radial Distribution System Capacitor Placement

A brief description of the problem statement is provided here.

2.1 Objective function

The goal of this function is to reduce power loss in the electric distribution system network.
A distribution system's power loss is computed as follows:

$P_{loss} = \sum_{i=1}^{n} I_i^2 R_i$
(1)

B) Constraints
The following constraints apply to the objective function.
1) Voltage restrictions:

$V_{min} \leq V \leq V_{max}$
(2)

3. Power Loss Index for Identifying weak buses in a radial distribution system

3.1. Distribution Load Flow

Fig 1 shows Two bus radial distribution system

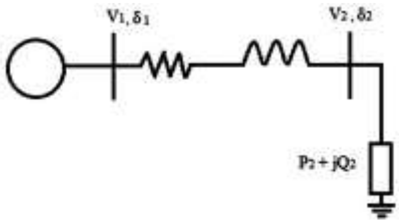

Fig. 1. Two bus radial distribution system

The complicated power S at each bus 'i' is described by:

$S_i = P_i + Q_i$ (3)

At the ith node, the real and imaginary powers are Pi and Qi.

1) Bus-injection to branch current matrix (BIBC):

[N] = [BIBC][S] (4)

2) Line loss to node power matrix (LLNP):

[N']=[LLNP][S_L] (5)

N + N' is the effective load at each node.

3) Algorithm for solving the load flow problem

1. Read the system data (V1= 1.0 pu). In the first iteration, line losses are assumed to be zero.
2. Create the BIBC and LLNP matrices.
3. Calculate Peffective + j*Qeffective at each node using
4. [N] = [BIBC][S]
5. Set the iteration count to one.
6. Determine the receiving end voltages
7. Using the following formulas, calculate power loss on all lines:

$$P_{loss}[j] = \frac{P_2^2+Q_2^2}{V_2^2} R[j] \quad (6)$$

$$Q_{loss}[j] = \frac{P_2^2+Q_2^2}{V_2^2} X[j] \quad (7)$$

$$S_{loss} = P_{loss} + jQ_{loss} \quad (8)$$

7.To obtain the N' matrix, multiply the power loss column matrix, SL, by the LLNP matrix.
8.The effective load at each node is N + N' B.Using the Power

3.2 Loss Index (PLI) to Determine Potential Buses

Consider a distribution line that connects 'p' and 'q' buses.

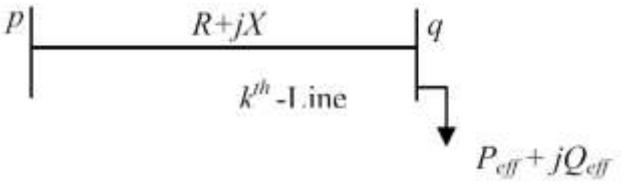

Fig. 2. Radial distribution system with load.

Active power loss in the k^{th} line is given by $[I_k^2]$*R[k], which can be expressed as,

$$P_{line\ loss}[q] = \frac{P_{eff}^2[q]+Q_{eff}^2[q]}{V^2[q]}R[k] \quad (9)$$

Similarly the reactive power loss in the k^{th} line is given by

$$Q_{line\ loss}[q] = \frac{P_{eff}^2[q]+Q_{eff}^2[q]}{V^2[q]}X[k] \quad (10)$$

The PLI value for the mth node can be calculated using

$$PLI(m) = \frac{LR(m)-LR_{min}}{LR_{max}-LR_{min}} \quad (11)$$

(i)Compute the initial real power loss and bus voltages using LF.
(ii) Repeat with the exception of the slack bus.
(iii) Determine the maximum and minimum LRs.
(iv) Determine the PLI for each bus, excluding slack.
(v)Sort the PLI values for each bus in ascending order.
(vi)Prospective capacitor implantation candidates are identified as buses with voltages less than 95%.
The measures to be taken to determine the high potential buses for capacitor allocations using PLI are as follows:

4. Invasive Weed Optimization for capacitor sizing

The sizing of capacitors is done at the potential locations which are obtained by PLI. The IWO [21] is implemented by taking size (kVAR) of capacitor as an individual in the population. The number of decision variables is the number of locations at which capacitor is to be placed. The procedure for implementing the IWO algorithm in solving optimal capacitor placement problem is summarized here.

Step 1: Import line data and load data of the radial distribution system.

Step 2: Run DLF for the given data to find the voltage profiles and power losses at different buses.

Step 3: Using PLI, find the potential locations for capacitor placement.

Step 4: Randomly generate the population and initialize the parameters

Step 5: Perform operators and run DLF for whole population

Step 6: Compare the power loss of new generation with the previous one for each individual. Replace the one with lesser power loss compared to previous ones

Step 7: If maximum iterations are reached, then stop. Otherwise repeat step 5-7

5. Case Studies and Simulation results

The proposed approach has been developed in MATLAB (R2012 A) on a personal computer (Intel R *i*3, 2.10 Ghz, 4 GB RAM). It has been tested on 10-bus, 15-bus, 34-bus and 69-bus systems in order to prove the applicability of the proposed approach. All case studies including the simulation results have been presented in the following sections.

5.1 10- Bus system

The data of 10 bus system is taken from [18]. The 10-bus system is shown in Fig.3. The line and bus data of 10 bus system are given in TABLE I and II. The base voltage of the 10-bus system is 23 kV.

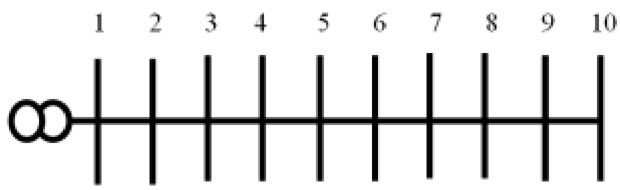

Fig. 3. 10-bus system

The initial active power loss for given line data and load data is 742.61 KW. The ideal power loss in the absence of any reactive power flow in the system is 654.33 KW.

TABLE 01 LINE DATA OF 10- BUS SYSTEM

Sending end node	Receivingend node	R (Ω)	X (Ω)
1	2	0.1233	0.4127
2	3	0.014	0.6057
3	4	0.7463	1.205
4	5	0.6984	0.6084
5	6	1.9831	1.7276
6	7	0.9053	0.7886
7	8	2.0552	1.164
8	9	4.7953	2.716
9	10	5.3434	3.0264

Table 02 BUS DATA OF 10- BUS SYSTEM

Bus No.	P (kW)	Q (kVAR)
1	0	0
2	1840	460
3	980	340
4	1790	446
5	1598	1840
6	1610	600
7	780	110
8	1150	60
9	980	130
10	1640	200

Voltage profile at each bus is shown in Fig 4.

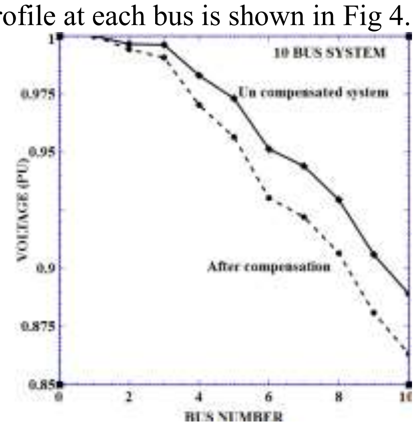

Fig. 4. Voltage profiles at each bus.

Iteration versus Power loss of differential algorithm is shown in Fig. 5.

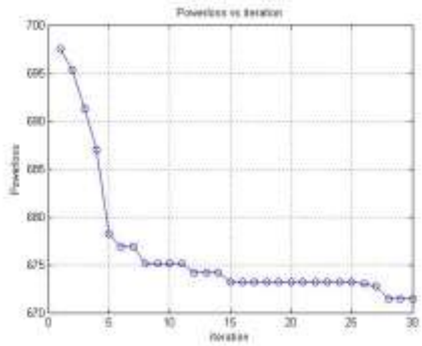

Fig. 5. Iteration versus Power loss of 10- bus system

Placement and sizing by the proposed method is given in TABLE III.

TABLE III PLACEMENT AND SIZE OF CAPACITORS

BUS POSITION	KVAR NEEDED
5	1834
6	590.6
7	68.4
8	39.9
9	137.6

The results of the proposed method are compared with the results of PSO [8], Plant Growth Simulation algorithm [18] and MINLP [14] and provided in TABLE IV.

TABLE IV RESULT COMPARISON

	POWER LOSS AFTER COMPENSATION			
	PSO	**PGSA**	**MINLP**	**IWO**
LOSS (KW)	696.21	694.93	673.44	674.47
LOCATION	6,5,9,10	6,5,9,10	5,7,8,9	5,6,7,8,9
SIZE (kVAR)	1174, 1182, 264 and 566	1200, 1200, 200 and 407	400, 2000, 200 and 1400	1834, 590.6, 68.4, 39.9, 137.6

On a personal computer (Intel R i3, 2.10 Ghz, 4 GB RAM), the proposed approach was built in MATLAB (R2012 A).

5.2 34-bus system

A 34-bus radial distribution test system was used to test the proposed Invasive Weed Optimization technique. The 34-bus system's base voltage is 11 kV. The uncompensated system has an active power loss of 281.59 KW. After correction, the suggested algorithm results in a power loss of 213.97 KW. TABLE VI shows the capacitor sizing and position for the proposed approach.

TABLEV PLACEMENT AND SIZE OF CAPACITORS

BUS	kVAR NEEDED
5	74.4075
6	74.84
7	125.6412
8	54.3786
9	40.4364
10	11.8985
11	30.4926
12	47.0203
13	52.026
14	96.6416
15	19.4063
16	15.595
17	10.2742
18	187.7663
25	261.4697
26	64.9964
27	8.9817
28	39.2533
29	220.1478
30	721.6123
31	104.7411
32	68.1765

Voltage profiles at each bus is shown in Fig. 7.

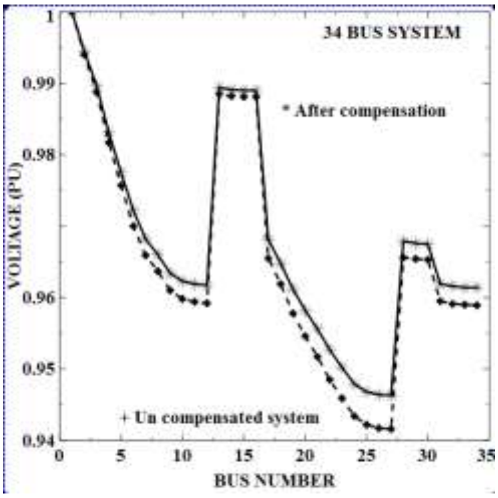

Fig. 6. Voltage profiles at each bus

Figure 7 depicts the algorithm's performance (power loss) as a function of the number of rounds.

TABLE VI PLACEMENT AND SIZE OF CAPACITORS

	Without capacitor placement	After capacitor placement
Active Power Loss(kW)	281.59	213.9742

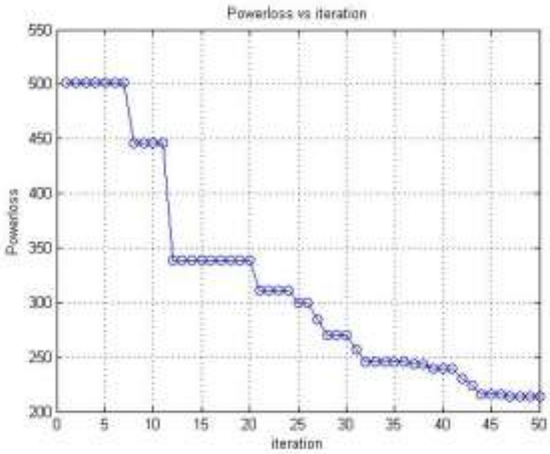

Fig. 7 Iteration versus Power loss of 34- bus system

A. 69-bus system

The proposed capacitor placement approach was tested on a 69-bus radial distribution test system [3]. The 69-bus system's base voltage is 11 kV.

The uncompensated system has an active power loss of 316.29 kW. The proposed algorithm results in a power loss of 263.53 kW. TABLE VII shows the capacitor sizing and position for the proposed approach.

TABLE VII PLACEMENT AND SIZE OF CAPACITORS

BUS	kVAR NEEDED	BUS	kVAR NEEDED
12	116.8177	26	165.4415
13	37.1070	27	26.6493
14	69.7524	55	112.9828
15	23.3592	56	140.1527
16	144.0179	57	1.1146
17	159.2589	58	0.9405
18	23.9761	59	72.3299
19	23.1080	60	20.5321
20	17.8712	61	902.8874
21	72.0277	62	229.8538
22	2.2721	63	71.8771
23	87.3877	64	149.2492
24	18.8037	65	24.7863
25	34.8973	68	2.7583

6. Conclusions

Invasive Weed Optimization (IWO) is presented for optimizing the size of capacitors in a radial distribution system to reduce power loss and improve voltage profile. The proposed solution has been tested on systems with 10, 15, 34, and 69 buses. The simulation findings show that the technique generates good outcomes in terms of fewer locations with optimal sizes and significant savings in initial investment and ongoing maintenance.

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