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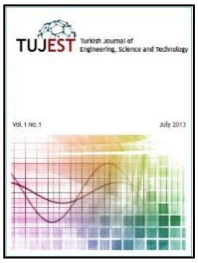

Network Reconfiguration and Capacitor Placement for Optimal Operation of Radial Distribution System

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Abstract

In this paper, the feeder reconfiguration and capacitor placement problem are solved to find the optimal operation of the distribution system. These are the complex combinatorial optimization process geared towards finding optimal operation of the distribution system. To determine the optimal operation of the distribution system, minimization of total active power loss and maximum node voltage deviation are considered as the main objectives. To solve this multi-objective problem, a goal optimization technique along with self adaptive harmony search optimization algorithm is implemented. The proposed algorithm is tested on standard IEEE 69-Bus Radial Distribution System and 84 Bus Practical Distribution Network Taiwan Power Company (TPC). Backward/ Forward sweep load flow algorithm is used for load flow analysis of radial distribution system. To find the effectiveness of the simultaneous feeder reconfiguration and capacitor placement, the results are taken for different loading conditions: with base load (100%) and 120% load. In order to prove the parameter independency of this algorithm, it is tested for 10 different combinations of parameters. For the comparison purpose real coded Genetic Algorithm (GA) and Music Based Harmony Search Algorithm (MBHSA) are also coded for this problem; it is observed that the proposed method performed well and results in a significant loss reduction with good voltage profile when compared to GA and MBHSA.

1. Introduction

Recently power systems across the world have been deregulated which results in competition among the power sellers. This results in increased more complexity of distribution networks. Further the planners and operators of the distribution system are facing new challenges that put emphasis on cost reduction and power quality.

The distribution feeders are configured radial in nature to increase the effectiveness and coordination among the protection devices. Distribution feeders can be reconfigured by opening and closing the switches to sectionalize the part of the distribution system for better operation and to maintain radial in nature. Under normal operating conditions, the distribution feeders are reconfigured to Minimize line losses, power quality, enhance network reliability and/or maintain load balance. After reconfiguration the distribution system must preserve radial structure and provide service to each and every load as required.

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The capacitor placement problem is the process of determination of the location, size and number of the capacitors to be placed in a radial distribution system in order to achieve one/more objectives without violating any constraints. Generally the Capacitors are installed in distribution systems for reactive power compensation.

Optimal feeder reconfiguration and capacitor placement has been investigated separately over decades. Various methods have been investigated by the researchers in order to find optimal planning/ operation of the distribution system. For a surprise, from the last two decades very few researchers are attempting simultaneous study of feeder reconfiguration and capacitor placement for optimal operation of the distribution system. These two problems are the complex combinatorial optimization process aimed at finding optimal operation of the distribution system. However, network reconfiguration cannot effectively reduce the power losses caused by reactive power flow for heavy reactive power loads and for heavy active power loads the capacitor placement alone is not effective. If these two problems are solved simultaneously, better solution for the operation of the distribution system will obtained than that of any method.

Pepnois et al. [1] proposed feeder reconfiguration and capacitor placement for optimal operation of distribution networks. In this paper capacitor placement is considered after feeder reconfiguration and a switch exchange method is used, it is ineffective for large systems. Baldick et al. [2] proposed Simulated Annealing (SA) algorithm in which network reconfiguration is considered as mater solution algorithm and capacitor placement was used a slave algorithm for combined optimization. Ching-Tzong et al. [3] also applied SA and showed that simultaneous feeder reconfiguration and capacitor placement reduces the loss more efficiently than by considering them separately. GA is proposed for loss reduction with feeder reconfiguration and capacitor placement by Rong et al. [4]. Dong Zhang et al. [5-6] proposed an improved adaptive genetic algorithm for capacitor control and the feeder reconfiguration is solved by using branch exchange method. In fact, they proposed, most efficient algorithm for capacitor control, the method used for feeder reconfiguration results to the final configuration depends upon the initial configuration, i.e., it leads to the local optimal but not the global optimum. Chung-Fu Chang [7-8] proposed Ant Colony Search Algorithm (ACSA) and Robust Searching Hybrid Differential Evolution to minimize active power loss and also added the violated voltage and current constraints along with the penalty factors. Leonardo et al. [9] proposed mixed integer nonlinear programming approach and Lagrange multiplier is used to calculate the sensitivity index for feeder reconfiguration. Its implementation needs very high programming skills. Srinivasa Rao [10] proposed a Harmony Search Algorithm (HSA) for loss reduction with combinational studies. Kasaei M.J. et.al., [11] implemented ant colony optimization algorithm for loss reduction with simultaneous feeder reconfiguration and capacitor placement. Horacio et.al., [12] and Madeiro et.al., [13] implemented genetic algorithm and hybrid genetic algorithm to minimize active power loss. Sarfaraz Nawaz et al. [14] proposed a different switch opening method and a trial and error method for capacitor placement. Discrete Genetic Algorithm is implemented by Farahani et.al., in order to minimize energy loss in the system with capacitor placement and improved reconfiguration. Tamer et al., [16] and Sedinghizadeh et.al., [17] proposed Selective Particle Swarm Optimization (SPSO) and improved binary particle swarm optimization respectively for a combination of capacitor placement and reconfiguration for loss reduction. Most the researchers concentrated main on the active power loss reduction and neglected maintaining a voltage profile. Some of the researchers implemented classical method for feeder reconfiguration which leads to time consuming for large systems and most of the times it leads to local optima. In our recent research conference papers [18-19] an improved music based harmony search algorithm is implemented for feeder reconfiguration to minimize the active power loss and a Self Adaptive Harmony Search Algorithm is used for optimal capacitor placement. In this paper a Self Adaptive Harmony Search Algorithm (SAHSA) is used to solve feeder reconfiguration and capacitor placement simultaneously in order to reduce the active power loss and to minimize the maximum node voltage deviation. Goal optimization technique is used to solve this multi objective problem. Backward/ Forward sweep load flow algorithm [20] is used for load flow analysis of radial distribution system. For the comparison purpose real coded Genetic Algorithm (GA) and Music Based Harmony Search Algorithm (MBHSA) are also coded for this problem; it is observed that the proposed method performed well and results in a significant loss reduction with good voltage profile when compared to GA and MBHSA.

2. PROBLEM FORMULATION

2.1. Objective functions

In this paper, minimization of total active power loss and maximum node voltage deviation are considered as objectives.

1. Active Power Loss Reduction:

Minimization of total active power loss is considered as one of the objectives for feeder reconfiguration and capacitor placement problems.

The power loss of a distribution system is described as:

$$P_{loss} = \sum_{i=1}^{nl} I_i^2 R_i \tag{1}$$

2. Maximum Node Voltage Deviation:

Minimizing the maximum node voltage deviation is considered as another objective function for feeder reconfiguration and capacitor placement problems.
The maximum node voltage deviation is calculated as

$$dV_{\max} = \max\left(\left|V_s - V_i\right|\right) \quad \text{for} \quad i=1,2,....nb \tag{2}$$

3. Operational constraints:

a. The voltage magnitude at each bus must be within a permissible range.

$$V_{min} \le V \le V_{max}$$

b. The current loading of distribution feeders must be within the rated current.

$$|I| \le I_{max};$$

c. The total reactive power of the capacitors placed must not exceed the total reactive power load of the system

$$\sum_{i=1}^{NCL} Q_{ci} \le \sum_{j=1}^{Nb} Q_D$$

d. No load must be left out of service and the radial network structure must be maintained.

The radial constraint is verified by using an incidence matrix (A).

If $|A| = 1 or -1$, the system is radial and

$|A| = 0$, the system is not radial.

4. Multi-Objective Fitness Function:

To solve this multi-objective optimization problem goal programming technique is used. With this technique goal is set with the ideal conditions of the system, so the solution must try to reach this goal in order to do optimization. For this, the solution fallen near to the goal is considered as the optimal solution. In other words optimal solution is obtained by minimizing the distance between the obtained solution and the goal value. In this paper minimization of active power loss and maximum node deviation are considered as objectives. These two objectives are in different dimensions so, for uniformity, these two objectives are normalized.

The normalization formula is
$$f(x) = \frac{f(x) - f_{\min}}{f_{\max} - f_{\min}} \tag{3}$$

The minimum and maximum values of active power loss are considered as zero(for ideal case) and active power loss of the original system(P_{Lo}) respectively.

From equation (3), the normalized value of active power loss is

$$F1(x) = \frac{P_{Loss}(x) - 0}{P_{Lo} - 0} = \frac{P_{Loss}(x)}{P_{Lo}} \quad (4)$$

Where, x represents the generated solution.
The minimum and maximum values of maximum node voltage deviation are considered as zero (for ideal case) and 1p.u. (substation voltage) respectively.
The normalized value of the maximum node voltage deviation is

$$F2(x) = \frac{\max\left|U_i(x) - U_s\right| - 0}{1 - 0} = \max\left|U_i(x) - U_s\right| \quad (5)$$

For ideal distribution system the active power loss value of any distribution system is 0 and the ideal value of the maximum voltage deviation is also 0. Therefore, the ideal goal set is (0,0). If the difference from each scalar with ideal goal value is minimized will results in the minimization of the active power loss and maximum node voltage deviation.
Thus, the difference from each normalized scalar with ideal goal value is

$$F(x) = \frac{1}{\sqrt{2}}\sqrt{(F1(x)-0)^2 + (F2(x)-0)^2} = \frac{1}{\sqrt{2}}\sqrt{(F1(x))^2 + (F2(x))^2} \quad (6)$$

Here minimization of F (x) is considered as the objective function. Since F (x) minimum value is zero, the minimization problem is converted to maximization problem. The fitness value given in equation (7) uses for Optimization Technique to perform a selection.

$$fitness = \frac{1}{1 + F(x)} \quad (7)$$

2.2. Self Adaptive Harmony Search Algorithm (SAHSA):

SAHSA employs a novel method for generating new solution vectors that enhance accuracy and convergence rate of Music Based Harmony Search Algorithm (MBHSA).

In MBHSA, new harmony is created from similar harmonies because of this, it loses its ability to search in state space. The detail description of the steps involved in MBHSA is given in [18&22]. Thus, the probability of reaching an optimum solution is reduced. In order to overcome this disadvantage Hadi Sarvari et.al. [23], Proposed to add a local search to the harmony search algorithm.

The steps in the procedure of Self Adaptive Harmony Search Algorithm (SAHSA) are:
Step 1: Initialize the problem and algorithm parameters.

Step 2: Initialize the harmony memory.

Step 3: Improvise a new harmony.

Step 4: Improvise a new harmony from best harmony (local Search).

Step 5: Update the harmony memory.

Step 6: Check the stopping criterion.

With the addition of a local search step, two New Harmony vectors are created with each repetition of the algorithm. The first harmony vector obtained according to the HSA and depends on initial parameters. But the second harmony vector attempts to improve the best harmony randomly to each repetition, regardless of the initial parameter values. This factor also leads to harmony variations at each iteration and increases the rate at which an optimal solution is reached. Adding step 4 reduces the defect of initial parameters across different problems. It also increases the convergence rate and accuracy. The pseudo code for steps 3, 4 and 5 for self adaptive harmony search algorithm are shown in Table I.

Table 1. Pseudo code for steps 3, 4 and 5 of self adaptıve harmony search algorıthm

```
Step3:  for i=1 to Maximp
          for j=1 to HMS
            if(rand<HMCR) then
              xj^new=xj^a where xj^a ∈{1,2,….,HMS}
                if(rand<PAR)
                  xj^new= xj^new±(rand*bw)        where rand∈ (0-1)
                endif
            else
                xj^new= xj^l ± (rand*(xj^u- xj^l))
          endif
Step4:    xj^new1= xj^best± (rand*bw1 (j))
                Where  bw1 (j) =|max (xj) -min (xj) |
          If  new< worst
Step5:      x^worst= x^new
          endif
          if  x^new1< x^worst
            x^worst= x^new1
          endif
        endfor
      endfor
```

3. METHODOLOGY

3.1. Capacitor Placement and Sizing

A methodology is used to determine the candidate nodes for the placement of capacitors using Loss Sensitivity Factors. The method for calculating loss sensitivity factors and selection of candidate nodes are given in [19]. The estimation of these candidate nodes basically helps in reduction of the search space for the optimization procedure.

Once the candidate buses are ide-ntified by using loss sensitivity factors, capacitor sizes are to be placed on candidate buses are computed by using SAHSA. The solution consists of the capacitor sizes chosen to place at candidate buses which is same as the number of capacitors tobe placed. For example, if three capacitors are to be placed means first three buses in the rank bus vector (it consists of the order of the bus numbers in which preference has to be considered for capacitor placement) are considered for capacitor locations and the solution from SAHSA consist of these three capacitor sizes.

The rank bus vector of IEEE 69 bus radial distribution system is {57, 58, 61, 60, 59, 15, 64, 17, 65, 16, 21, 19, 63, 20, 62, 25, 24, 23, 26, 27, 18, 22}. In this paper number of capacitor locations is considered as three, so that the first three buses “57, 58 and 61” in the rank bus vector are the chosen locations for the placement of the capacitors.

3.2. Optimal Network Reconfiguration (ONR)

For optimal operation of the distribution system, the status of the switches can be changed to reconfigure the system without violating the constraint, i.e., the system must maintain the radial structure and service must be provided to all the loads. Initially, it is assumed that all switches are closed and in order to maintain the radial structure and to avoid the generation of the more infeasible solution, each switch to be opened is selected from each loop vector without isolating any node and without forming any islands. The size of the solution vector is equal to the number of tie-lines in the system. Loop vectors formed in IEEE 69 bus radial distribution system by closing each tie line are given in Table II.

Table 2. Loop vectors formed in IEEE 69 bus radial distribution system by closing each tie line

Tie Line	Loop Vector
Loop1 69	69, 42, 41, 40, 39, 38, 37, 36, 35, 10, 9, 8, 7, 6, 5,4, 3
Loop2 70	70, 20, 19, 18, 17, 16, 15, 14, 13
Loop3 71	71, 45, 44, 43, 14, 13, 12, 11, 69
Loop4 72	72, 58, 57, 56, 55, 54, 53, 52, 49, 48, 47, 46, 8, 7, 6, 5, 4
Loop5 73	73, 70, 64, 63, 62, 61, 60, 59, 58, 57, 56, 55, 54, 53, 52, 26, 25, 24, 23, 22, 21, 12, 11, 10, 9

Then the number of decision variables for IEEE 69-bus radial distribution system is same as number of tie-switches, which is 5. The solution vector of the original configuration is HM1= [69 70 71 72 73]. Similarly, other possible solutions are generated by using SAHSA without violating the constraints. If the generated solution is feasible (the solution must obey all the constraints), evaluate the objective functions and fitness functions otherwise generate another solution.

3.3. ONR and Capacitor Location and Sizing

The solution vector size of the simultaneous Feeder Reconfiguration and Capacitor Placement is equal to the sum of the number of tie-switches and number of capacitors to be placed. This solution consists of sectionalized switches to be open and the size of the capacitors to be placed on selected buses. Selection of the buses for capacitor placement is same as in capacitor placement problem.

3.4. SAHSA for ONR and Capacitor Location and Sizing

In this paper, a Self Adaptive Harmony Search Algorithm is used for determining the optimal performance of the distribution system with Optimal Network Reconfiguration and Capacitor Placement. It is similar to playing aesthetic music by a musician. Selecting the problem is same as selecting the musical instruments, finding the variables for optimal operation is similar to the searching for harmony for pleasant music, setting minimum and maximum limits of the variables is similar to the pitch adjustment of the instruments, old solutions or the values of the variables is same as the experience of the musician and the number of generations of the solution is same as the practice made by the musician for aesthetic music. In SAHSA, local search included, it is similar to the experimenting for the aesthetic music from best harmony by adjusting some bandwidth.

The parameter values for MBHSA and SAHSA are HMS=20, HMCR=0.85, PAR=0.3, BW=1, maximum generations=1000.All algorithms are implemented in MATLAB and are test on Intel core i5 - 4200U CPU @ 1.60GHz 2.30GHz processor, 8GB RAM and 64-bit operating system.

4. RESULTS AND DISCUSSION

The proposed method is tested on both test and practical distribution systems.
System1: IEEE 69 Bus Test Radial Distribution System and
System 2: 84 Bus Practical Distribution Network Taiwan Power Company (TPC) [10].

To find the optimal operation of the distribution system, the following five scenarios are considered.
Scenario 1 (S1): Only Capacitor Placement is considered.
Scenario 2 (S2): Only Feeder Reconfiguration is considered.
Scenario 3 (S3): Both Capacitor Placement and Feeder Reconfiguration are considered. But, capacitor placement is carried out before feeder reconfiguration.
Scenario 4 (S4): Both Capacitor Placement and Feeder Reconfiguration are considered. But, capacitor placement is carried out after feeder reconfiguration.
Scenario 5 (S5): Both Capacitor Placement and Feeder Reconfiguration are considered and taken into account

simultaneously.

System1: IEEE 69 Bus Radial Distribution System

The IEEE 69 bus radial distribution system consists of 69 buses, 68 sectionalized switches and 5 tie-switches. The system substation voltage is 12.66 kV. The total active and reactive power loads on the system are 3802 kW and 2694 kVAr, respectively. The initial active and reactive power loss of this system are 225 kW and 102.16 kVAr. The lowest bus bar voltage is 0.909185p.u., occurs at bus 61. The results of this test system for five different scenarios with base loading and 120% loading are shown in table III and 4 respectively.

Table 3. IEEE 69 Bus Radial Distribution System results using SAHSA for five different Scenarios with the base loading condition

	Different Scenarios					
	Original System	S1	S2	S3	S4	S5
Tie Switches	69,70,71, 72,73	69,70,71, 72,73	14,58,61, 69,70	14,58,63, 69,70	14,55,61, 69,70	14,55,62, 69,70
Capacitors Placed on 57th bus(kVAr)	-	300	-	300	0	150
Capacitors Placed on 58th bus(kVAr)	-	0	-	0	150	150
Capacitors Placed on 61st bus(kVAr)	-	1200	-	1200	900	900
Total Reactive Power added (kVAr)	-	1500	-	1500	1050	1200
Active Power Loss (kW)	225	151.48	98.61	73.85	73.35	72.76
Reactive Power Loss (KVAr)	102.17	70.13	92.05	66.91	67.02	67.21
Minimum Node Voltage (p.u.)	0.9092 (61)	0.9318 (65)	0.9495 (61)	0.9676 (64)	0.9651 (62)	0.9655 (62)
Fitness	0.5	0.6766	0.7632	0.8114	0.8124	0.8136

From Table III, for 100% loading of the system, the active power loss of the system I is reduced to 72.76kW from 225kW with scenario 5, i.e., with simultaneous feeder reconfiguration and capacitor placement. The active power loss reduction is more in scenario 5 when compared to all other scenarios, but the scenario 3 shows the best result in maximum node voltage deviation reduction and also the reactive power loss is also reduced more in case of scenario 3 when compared to all other scenarios. By observing the values of Fitness F, scenario 5 is the best solution if both objectives the active power loss reduction and minimization of maximum node voltage deviation are considered. But the reactive power of the capacitors placed is more in scenario 3 when compared to scenario 5 and switching operations are same in both the cases. The reactive power of the capacitors placed is less in scenario4 when compared to all other scenarios and the active power loss and the maximum node voltage deviation are reduced significantly when compare to the original system and these values are near to the values of scenario 3 and 5. Scenario 4 can take as a best solution if the capacitor cost is considered and scenario 5 is a feasible solution for optimal operation of the system. The voltage profiles for five scenarios are shown in Fig.1 and the voltage profile is best for scenario 3 when compared to all other scenarios.

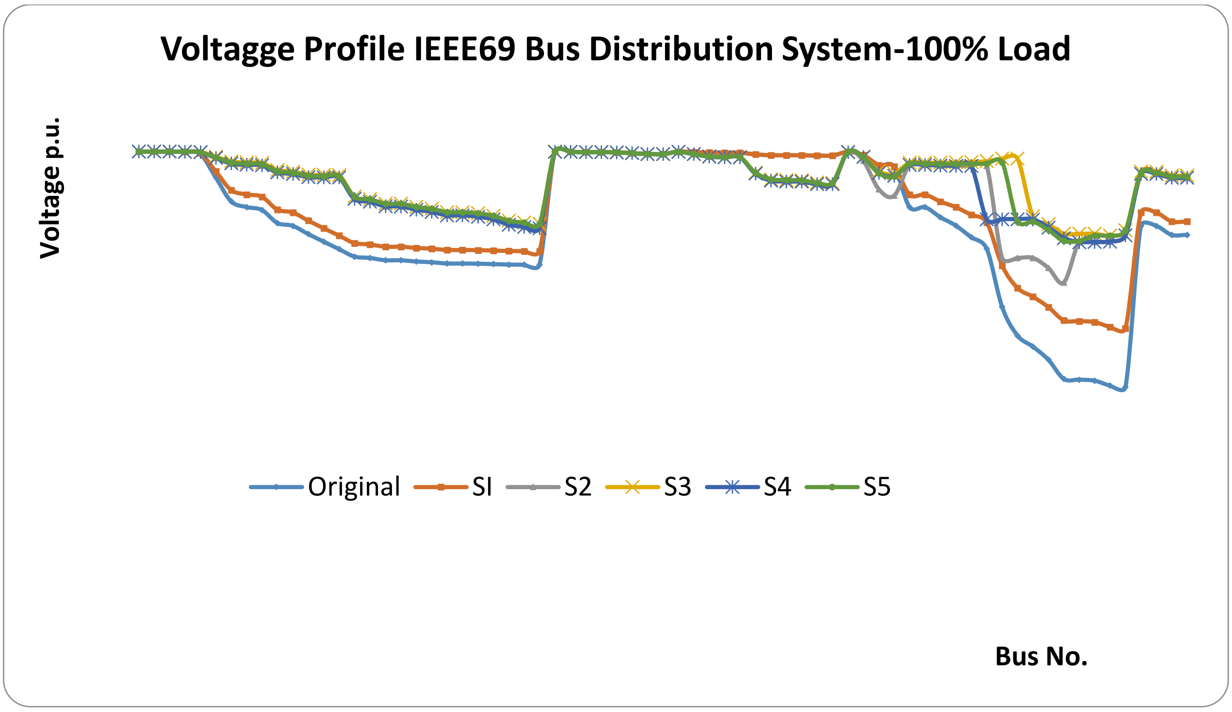

Figure 1. IEEE 69 Bus Radial Distribution System voltage profile using SAHSA for five different Scenarios with base load

The results for 120% loading of IEEE 69 bus radial distribution system are shown in Table 4. The active power loss of the system I for 120% loading is reduced to 106.08kW from 336.72kW with scenario 5, i.e., with simultaneous feeder reconfiguration and capacitor placement. The number of switching operations are same for both 100% and 120% loading, but one or two lines to be opened are changed from one line to its adjacent line. The sizes of the capacitors to be placed are increased with the increase in the reactive load. The minimum node voltage improves from 0.8887 p.u. to 0.9609 p.u. with senario3 and 0.9594 p.u. with senario5. For both power loss and node voltage deviation minimization scenario 5 can be considered as solution for optimal operation the distribution system. The Voltage profiles of these scenarios are shown in figure 2. From this figure, the voltage profile is best for scenario3.

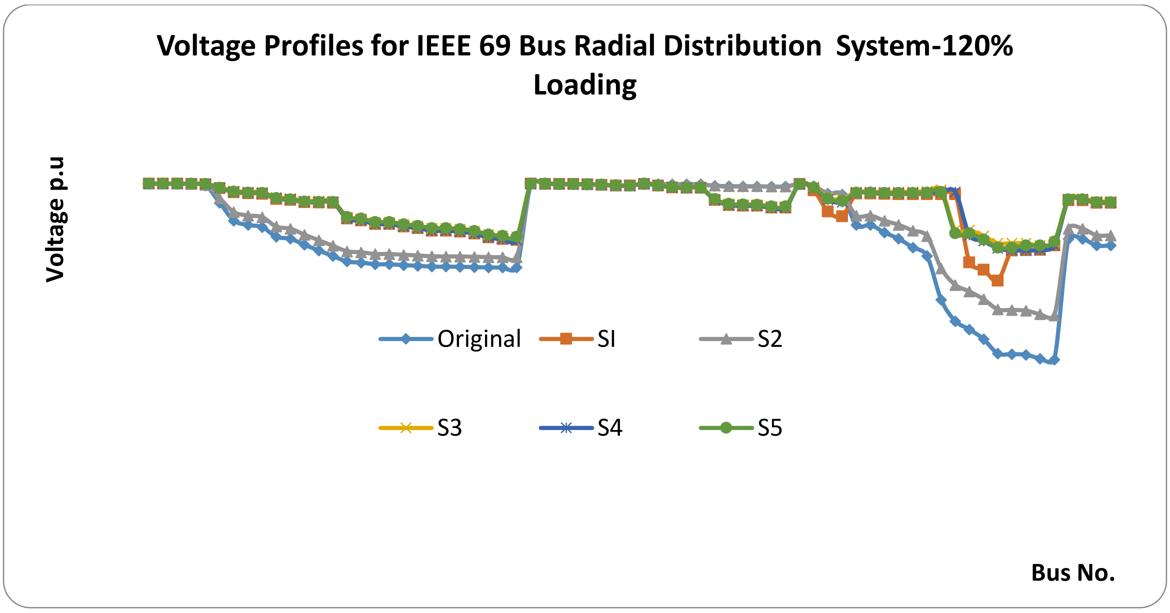

Figure 2. IEEE 69 Bus Radial Distribution System voltage profile using SAHSA for five different Scenarios with 120% loading

Table 4. IEEE 69 Bus Radial Distribution System results using SAHSA for five different Scenarios with 120% loading condition

	Different Scenarios					
	Original System	S1	S2	S3	S4	S5
Tie Switches	69,70,71, 72,73	69,70,71, 72,73	14,58,61, 69,70	14,58,63, 69,70	14,55,61, 69,70	14,58,61, 69,70
Capacitors Placed on 57th bus(kVAr)	-	300	-	300	150	150
Capacitors Placed on 58th bus(kVAr)	-	150	-	150	0	0
Capacitors Placed on 61st bus(kVAr)	-	1350	-	1350	1200	1200
Total Reactive Power added (kVAr)	-	1800	-	1800	1350	1350
Active Power Loss (kW)	336.72	224.10	144.60	107.12	106.61	106.08
Reactive Power Loss (KVAr)	152.56	103.57	134.86	97.02	97.83	97.38
Minimum Node Voltage (p.u.)	0.8887 (65)	0.9166 (65)	0.9387 (61)	0.9609 (64)	0.9578 (62)	0.9594 (62)
Fitness	0.5	0.6780	0.7632	0.8160	0.8166	0.8174

System2: 84 Bus Practical Distribution Network Taiwan Power Company (TPC)

This second system consists of 84 buses, 11.4kV, and radial distribution system. It consists of 11 feeders, 2 substations, 83branches and 13 tie-lines. The total active and reactive power loads in the system are 28350kW and 20700kVAr. The initial power loss of this system is 526.97kW and minimum bus voltage is 0.9285p.u. which occurs at node 10.

Table 5. 84 Bus Practical Distribution Network Taiwan Power Company (TPC) results using SAHSA for five different Scenarios with the base loading condition

	Different Scenarios					
	Original System	S1	S2	S3	S4	S5
Tie Switches	84,85,86,87, 88,89,90,91, 92,93,94,95, 96	84,85,86,87, 88,89,90,91, 92,93,94,95, 96	7,13,34,39, 42,55,62,72, 83,86,89,90, 92	13,34,39,42, 72,83,84,85, 86,89,90,92, 96	7,13,34,39, 42,55,62,72, 83,86,89,90, 92	7,13,34,39, 42,54,61,72, 83,86,89,90, 92
Capacitors Placed on 4 bus(kVAr)	-	450	-	450	150	750
Capacitors Placed on 5 bus(kVAr)	-	450	-	450	450	-
Capacitors Placed on 6 bus(kVAr)	-	1800	-	1800	900	1200
Total Reactive Power added (kVAr)	-	2700	-	2700	1500	1950
Active Power Loss(kW)	526.97	476.71	469.71	452.16	453.97	451.63
Reactive Power Loss(kVAr)	1364.02	1245.03	1247.64	1196.60	1210.03	1198.9
Minimum Node Voltage (p.u.)	0.9285 (10)	0.9479 (84)	0.9532 (72)	0.9532 (72)	0.9532 (72)	0.9532 (72)
Fitness	0.5	0.6092	0.6125	0.6219	0.6207	0.6220

From Table 5, by observing the fitness F values it can be illustrated that the scenario 5 is the best solution for optimal operation of the distribution system. With scenario 5 the active power loss is reduced from 526.97kW to 451.63kW i.e., this scenario gives less active power loss when compared to all other scenarios. The maximum node voltage deviation is same for scenarios 3, 4 and 5. However, the reactive power of the capacitors placed is different from these scenarios which is less in scenario 4 but the reactive power loss is more in this case when compared to scenarios 3 and 5. The switching operations are same in scenario 4 and 5. If the active and reactive power loss and maximum node voltage deviation are considered scenario 5 is will be best solution. The voltage profiles of all scenarios are shown in Fig.3, and from the figure it is better for scenario 3 when compared to all other scenarios.

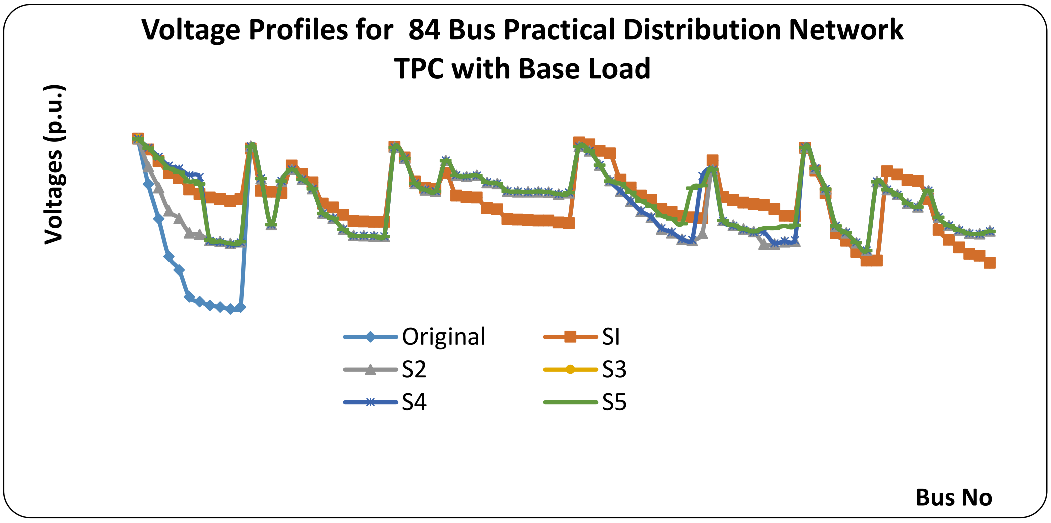

Figure 3. IEEE 84 Bus TPC Practical Radial Distribution System voltage profile using SAHSA for five different Scenarios with Base loading condition

Similar to the IEEE 69 bus system, for 84 bus practical system as shown in table 6, the configuration remains same for 120% loading of the system when compared to 100% loading and the capacitor size to be placed is increased. The active power loss is reduced from 773.44kW to 659.41kW with the scenario. The voltage profiles for original system and five scenarios are shown in figure 4. For 84 Bus practical distribution system, the maximum node voltage deviation or minimum voltage is same for scenarios 3,4 and 5. But, the switching operations and size of the capacitors are different.

Table 6. Bus 84 Bus Practical Distribution Network Taiwan Power Company (TPC) results using SAHSA for five different Scenarios with 120% loading condition

	Different Scenarios					
	Original System	S1	S2	S3	S4	S5
Tie Switches	84,85,86,87, 88,89,90,91, 92,93,94,95, 96	84,85,86,87, 88,89,90,91, 92,93,94,95, 96	7,13,34,39, 42,55,62,72, 83,86,89,90, 92	7,13,34,39, 42,72,83,84, 85,86,89,90, 92	7,13,34,39, 42,55,62,72, 83,86,89,90, 92	7,13,34,39, 42,54,61,72, 83,86,89,90, 92
Capacitors Placed on 4 bus(kVAr)	-	600	-	600	450	300
Capacitors Placed on 5 bus(kVAr)	-	900	-	900	300	300
Capacitors Placed on 6 bus(kVAr)	-	1800	-	1800	1200	1500
Total Reactive Power added (kVAr)	-	3300	-	3300	1950	2100
Active Power Loss(kW)	773.44	696.60	686.72	660.09	663.16	659.41
Reactive Power Loss(kVAr)	2002.25	1820.23	1824.63	1747.44	1768.33	1750.51
Minimum node Voltage(p.u.)	0.9126 (10)	0.9366 (84)	0.9431 (72)	0.9431 (72)	0.9431 (72)	0.9431 (72)
Fitness	0.5	0.6095	0.6124	0.6225	0.6209	0.6224

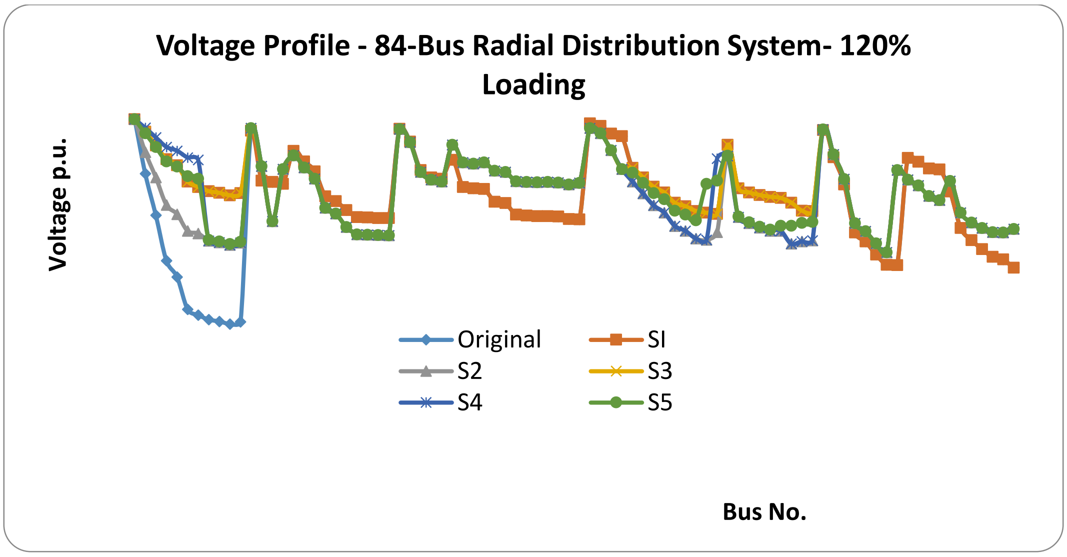

Figure 4. IEEE 84 Bus TPC Practical Radial Distribution System voltage profile using SAHSA for five different Scenarios with 120% loading condition

The feeder reconfiguration is more or less same for 100% and 120% loading of the system. So, for optimal operation of the system with different loading condition, installation of switched capacitors is the better solution and these capacitors are operated along with the combination of feeder reconfiguration gives the better optimal operation.

For evaluating the performance of the optimization technique, the scenarios 1, 2 and 5 are solved for active power loss reduction and maximum node voltage deviation using MBHSA and GA. The results are taken for 100 runs and these are compared in terms of best, worst and average fitness, standard deviation and average computational time per iteration.

Table 7. Bus 84 Bus Practical Distribution Network Taiwan Power Company (TPC) results using GA, MBHSA and SAHSA for Scenarios 1, 2 &5.

Optimization Techniques		Different Scenarios		
		Only capacitor placement	Only feeder reconfiguration	Reconfiguration and capacitor placement
GA	Best Fitness	0.609202	0.592341	0.602934
	Worst Fitness	0.608876	0.578212	0.581927
	Average Fitness	0.608294	0.560763	0.571293
	Standard Deviation	0.000269	0.013211	0.129346
	Average Computational Time per generation	0.07700	0.132061	0.141623
MBHSA	Best Fitness	0.609238	0.612523	0.621491
	Worst Fitness	0.609236	0.610293	0.611990
	Average Fitness	0.609237	0.611342	0.619158
	Standard Deviation	0.000001	0.001745	0.002173
	Average Computational Time per generation	0.062845	0.129018	0.129328
SAHSA	Best Fitness	0.609238	0.612523	0.622041

Worst Fitness	0.609238	0.612399	0.621727
Average Fitness	0.609238	0.612503	0.621988
Standard Deviation	0.000000	0.000056	0.000104
Average Computational Time per generation	0.125690	0.491356	0.466299

From Table 7, the results for Scenarios 1,2 and 5 of SAHSA are compared with MBHSA and GA. If the best, average and worst fitness and standard deviation are considered, the SAHSA show better results than MBHSA and GA in all the scenarios. The average computational time per generation is more for SAHSA because of its local search when compared to GA and MBHSA, but SAHSA reaches the global optimal solution in less number of generations. The fitness vs. generation curves for scenarios 2,3 and 5 are shown in figure 5.

These fitness vs generation curves are drawn up to 200 generations. From figure 5, for capacitor placement the performance of both MBHSA and SAHSA is similar. But, for feeder reconfiguration and simultaneous feeder reconfiguration and capacitor placement, SAHSA reaches a more optimal solution within less iterations when compared to MBHSA.

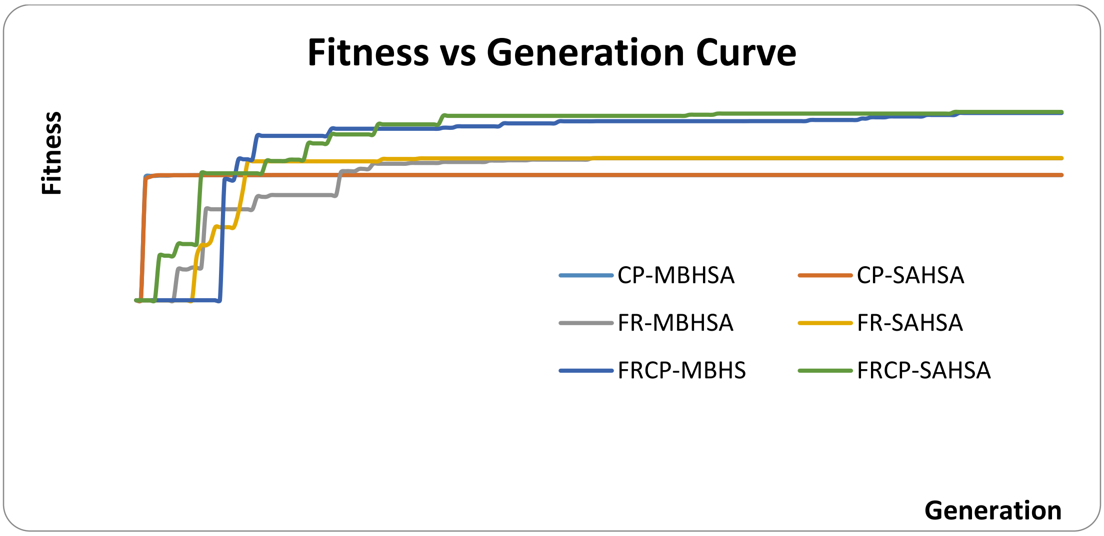

Figure 5. IEEE 84 Bus TPC Practical Radial Distribution System fitness vs. generation curves with SAHSA and MBHSA for scenarios 1, 2 and 5.

In order to explore the effect of parameters chosen for the performance of the algorithms MBHSA and SAHSA, the programs are executed for 100 times with ten different values for HMCR and PAR which are shown in Table 8.

Table 8. Values of HMCR and PAR for different cases

Case	1	2	3	4	5	6	7	8	9	10
HMCR	0.75	0.75	0.8	0.8	0.85	0.85	0.9	0.9	0.95	0.95
PAR	0.3	0.4	0.3	0.4	0.3	0.4	0.3	0.4	0.3	0.4

For the comparison purpose the best, worst and average fitness and standard deviation of the fitness for scenario 5 of 84 Bus Practical Distribution Network TPC with SAHSA are considered and compared with MBHSA. These figures are shown in Figure 6.

From figure 6a, the best solution for all ten cases is same with SAHSA and it reaches a global optimal, but, with MBHSA the best solution is varied with parameter varying. With MBHSA, the solution reaches the global optimal for cases 6 and 8 only. For the remaining cases solution falls in to local optima. Figure 6b shows that the average fitness variation in different cases is less for SAHSA when compare to MBHSA. Figure 6c and 6d shows the variation of worst fitness and standard deviation with different cases respectively. These values also depend upon the parameter values with MBHSA but, with SAHSA these are independent of the parameters. The worst fitness values with MBHSA are worse than the worst fitness values of SAHSA in all the cases. The standard deviation is more in the case of MBHSA when compared to SAHSA, i.e., occurrence of the global optimal solution is more with SAHSA when compare to MBHSA.

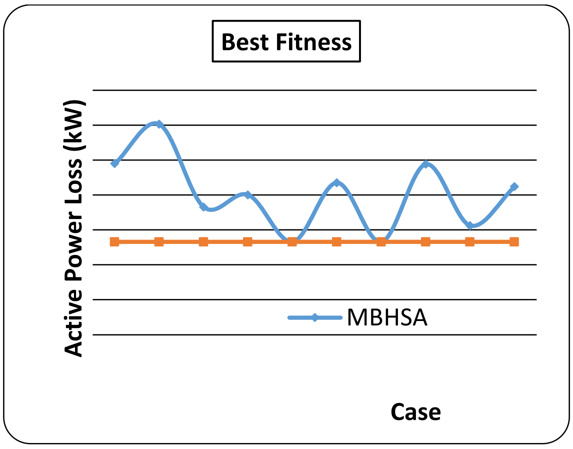

Figure 6a. Best Fitness Curve

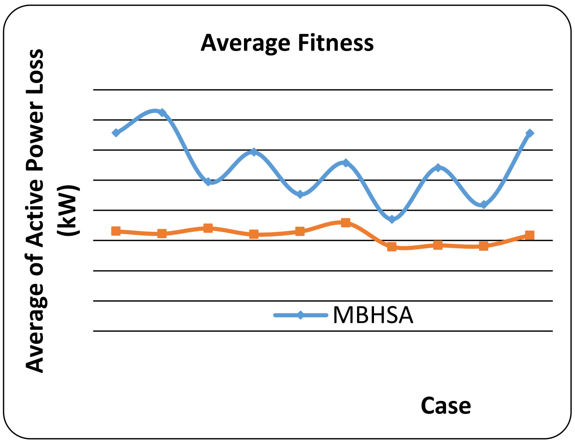

Figure 6b. Average Fitness Curve

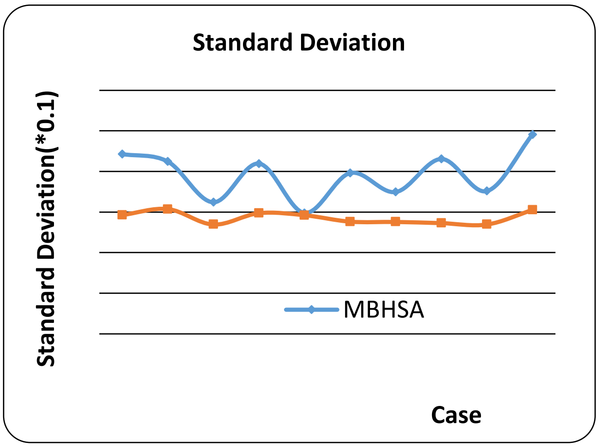

Figure 6c. Standard Devaition Curve

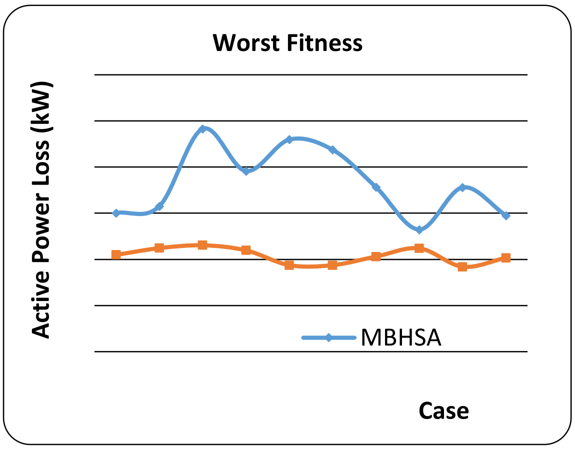

Figure 6d. Worst Fitness Curve

Figure 6. Fitness and Standard Deviation curves for different parameters for Scenario 5 of 84 Bus Practical Distribution Network TPC with SAHSA and MBHSA

From figure 6, it can illustrate that the performance of SAHSA is more or less same irrespective of parameters chosen but, with MBHSA shows the performance depends upon the parameters choice. MBHSA gives the best result for HMCR=0.85 and PAR=0.3. When compared to the cases of PAR value 0.4, the cases with PAR value 0.3 shows better results. SAHSA gives the best results in all the 10 cases.

5. CONCLUSION

A Self Adaptive Harmony Search Algorithm is implemented to solve simultaneous Capacitor Placement and Feeder Reconfiguration for optimal operation of the distribution system. Active power loss reduction and minimization of node voltage deviation are considered as objective functions. This multi objective problem is solved using goal optimization technique. SAHSA is tested on IEEE 69 bus radial distribution system and 84 bus practical distribution system TPC for five different scenarios. Scenario 5 gives the best result when compared to all other scenarios. For comparison purpose, along with SAHSA, GA and MBHSA are implemented for scenarios 1, 2 & 5 and then these algorithms are compared in terms of Best, Worst and Average Fitness, Standard Deviation and average computation time per iteration. The results showed that SAHSA performed well in terms of quality of solution and frequency of reaching global optimal. In order to check parameter dependency of algorithms, both the algorithms are tested for ten different cases with varying HMCR and PAR. From the results, it can be illustrated that SAHSA performances well, irrespective of the parameters chosen but, MBHSA performance depends upon the parameters chosen. The time taken per iteration is more when compared to MBHSA because of inclusion of local search but, the number of iterations to reach an optimal value is less when compared to MBHSA. So, SAHSA can be used for distribution system planning, extension and operation of the distribution system.

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Nomenclature

I_i	current flowing through line *'i'*
R_i	resistance of line *'i'*
nl	number of lines in the radial distribution system
Nb	number of buses in the radial distribution system
P_{Loss}	total system active power loss
P_{Lo}	active power loss of the original system
dU_{max}	maximum node voltage deviation;
U_s	voltage of substation in per unit;
U_i	voltage of 'i^{th}' node;
U_{min}	minimum bus voltage at bus 'i'
U_{max}	maximum bus voltage at bus 'i'
I_{max}	current rating of the feeder
F1	normalized active power loss
F2	normalized maximum node deviation voltage
F	Fitness
A	Incidence Matrix
HMS	Harmony Memory Size
HMCR	Harmony Memory Considering
PAR	Pitch Adjusting Rate
HM	Harmony Memory
NI	Number of Improvisations
Q_{Di}	Reactive power demand at node 'i'
Q_{Ci}	Reactive power of the i^{th} capacitor
NCL	No. of Capacitors to be Placed in the distribution system