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A Novel Approach for Optimal Placement of Hv/Mvsubstation and Distributed Generation Simultaneously by Cuckoo Optimization Algorithm

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Abstract
The long-term planning of distribution network expansion planning has different complexities, because this problem has a lot of decision-making variable. The optimal placement problem of HV/MV substations with distributed generations simultaneously for supplying the capacity required for power system are analyzed in this paper. In the mathematical model, objective function together with constant, varied variables and constraints related to limitations for the operation of substations and distributed generation resources as well as network limitations are formulated. Despite of distributed generation resources, the simultaneous placement must be so that firstly load points to be supplied and secondly loss costs of the network to be reduced. In addition, the voltage profile improvement and reduction of network reconfiguration costs are considered. At the end, we will observe the power quality improvement in load points. To solve this problem, optimization of one of new algorithms named cuckoo optimization algorithm has been applied. The study period for performing this test by means of dynamic-pseudo method for a long-term study will be within the design period. Finally, tests will be provided for proving the efficiency of this offered optimization algorithm.

Keywords: HV/MV optimal placement, power system, network reconfiguration, Cuckoo optimization algorithm

1. INTRODUCTION

Design and development of the distribution network are one of the most important and complex problems in electrical networks. Considering the high volume of investment for utilization of HV/MV substations and increasing the energy and equipment costs, using the distributed generation resources seems to be necessary that is attractive for utility company. The distributed generation resources such as wind, PV, fuel cell has offered a new option in design and development of power systems, to the designers and planners of such networks. The presence of distributed generation resources in power system provides advantages such as support of network generation capacity, network capacity liberalization, postponing the investment cost in power system, peak shaving, improvement of power quality (voltage and reactive power), loss reduction, spinning reserve and like this. Accordingly, the presence of distributed generation resources is raised as an alternative in the electrical networks. Determination of optimal place and HV/MV substations capacity as well as the optimal placement of distributed generation resources has been analyzed in the different papers. A lot of methods have

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been presented for solving the network planning (1-9). In (12) this problem has been analyzed by genetic algorithm and uncertainty in load. (13) Presented the network planning by means of new cost function and applying simulated annealing algorithm. (14) Studied on network expansion planning by means of DCGA and LP hybrid method and considering the distributed generations. (15 and 16) examined this problem using meta-heuristic algorithm without regardless of distributed generations. (17) Studied on sub-transmission substationnetworks expansion planning using learning automata algorithm in the real network. In (19)optimization of the network configuration based on the plant growth algorithm was presented that is related to a large scale network. (20) Presents the initiative method for placement of DGs in the distribution network. (21 and 22) offered a model and numerical results for multistage planning in the distribution network. The concept of hybrid hub in optimal electrical distribution system expansion planning (OEDSEP) has been used in (10). In (23), a model has been considered using a hybrid algorithm for distribution network expansion planning considering the multistage distributed generations. A study has been presented in (11) for determining the place of distributed generation resources in the distribution network. Nonetheless, no integrated model has been presented that can take the HV/MV substations together with distributed generation resources into consideration. In this paper, optimization problem includes HV/MV substations that seeks for an optimal place for loss reduction and initial investment and operation costs reduction, as well as distributed generation resources for improving the power quality and economic load dispatch, and in power demand sector seeks for power supply and load forecasting, and ultimately responding the electricity market, input power values to downward grid, moreover the electricity purchased from upward grid. In this paper, the simultaneous placement of HV/MV substations and distributed generation (DG) are analyzed by cuckoo optimization algorithm. Determination of optimal place, capacity and size of HV/MV substations together with distributed generation are assumed as the objectives of this study. Two scenarios provided in this paper; one without distributed generation resources and the second applying the distributed generation resources. In order to prove the efficiency of this method, we describe it in a basic example. In addition, we selected genetic algorithm for its comparison. In second and third parts, the objective function and constrains its related constraints are analyzed. In part four, cuckoo optimization algorithm in introduced and in part five, a case study is applied. The efficiency of above algorithm and discussion and simulation are presented and in part six, conclusion will be provided.

2.PROBLEM FORMULATION

The objective of simultaneous placement of HV/MV substations and DGs is supplying the required capacity for feeding the network load by these resources, secondly reducing the network loss costs, as well as voltage profile improvement and network reconfiguration costs reduction, so that in addition to observing the available limitations, to minimize the establishment and operation costs of system, that will be discussed in next part.

3. OBJECTIVE FUNCTION

3.1. Cost Function

The costs of this project may be divided into two general categories; first category: fixed costs (investment costs) that are paid only one time during construction of substation and DG; second category: variable costs including substations and DGs operation costs. Accordingly, objective function is formulated as follows [1-3]:

$$\begin{aligned} MinCostFunction &= AccessCost_{ss} + InvestmentCost_{ss} + InvestmentCost_{DG} \\ &+ OperationCost_{ss} + OperationCost_{DG} + AccessCost_{LP} \end{aligned} \tag{1}$$

$AccessCost_{ss}$ Includes the cost of accessing to HV/MV substations including site, substations and their connections to upward grid purchasing costs, which is formulated as follows:

$$AccessCost_{ss} = \sum_{i=0}^{n_{ss}} Access\cos t_i (1 - \exp^{-ZP_{ss,i}}) \qquad (2)$$

$$P_{ss,i} = \max_{d=1,2,\dots,n_{ld}} \sum_{j=0}^{n_{lp}} \beta_{ij} P_{j,d}^{ss} \qquad (3)$$

$AccessCost_{ss}$: Cost of accessing to HV/MV substation i ($)

$P_{ss,i}$: Loading peak of HV/MV substation $(MVA)i$

Z: Large positive number

β_{ij} : Zero or one binary decision-making variable for indicating the connection or non-connection of load point j to i

n_{ss} : Number of candidate places for construction of HV/MV substation

$Investment\cos t_{ss}$:Construction cost of HV/MV substations cost of transformers and other equipment's related to HV/MV substations that are dependent to its loading. The substations capacity has a discrete nature and may choose specific numbers that is formulated as below:

$$InvestmentCost_{ss} = \sum_{i=1}^{n_{ss}} C_{ss}(P_{ss,i}) \qquad (4)$$

$Investment\cos t_{DG}$: includes construction cost of DG resources that considering the capacity of distributed generations that is usually lower than 10 MVA, these units occupy lower area than HV/MVsubstations and contrary to the HV/MV substations, the site is not its main parameter and only includes the equipment's purchasing and installation costs that is formulated as below:

$$InvestmentCost_{DG} = \sum_{i=1}^{n_{DG}} C_{DG}(P_{DG,i}) \qquad (5)$$

$$P_{DG,i} = \max_{d=1,2,\dots,n_{ld}} (\sum_{j=1}^{n_{lp}} \gamma_{ij,d} P_{j,d}) \qquad (6)$$

$P_{DG,i}$: loading peak of distributed generation resources $i(MVA)$

C_{DG} : DG resources cost includes fuel, repair and maintenance cost of units based on ($/ Mwh)

C_{DG}: DG resources establishment cost as a function of its loading ($)

$OperationCost_{ss}$: Cost of operating the HV/MV substations in a competitive power market, that the utility companies must pay for the electrical energy cost required for network under their cover through HV/MV substations. The active power received from HV/MV substations includes two parts: one part is distribution network load and the other includes the resistance loss of medium voltage feeder. On the other side, the active power price in peak hours is higher and lower in non-peak hours. The mathematical equation for substations operation is as follows:

$$OperationCost_{ss} = \sum_{t=1}^{n_y} \left((F_m)^t \sum_{i=1}^{n_{ss}} \sum_{j=1}^{n_{lp}} \sum_{d=1}^{n_{ld}} \gamma_{ij} [P_{j,d}^{ss}.Pf_j + RL_{ij} (\frac{P_{j,d}^{ss}}{V_{j,d}})^2] T_m . F_{ss,i,d} \right) \qquad (7)$$

$$F_m = \frac{1 + \inf r}{1 + \operatorname{int} r} \qquad (8)$$

$F_{ss,i,d}$: Price of electricity purchasing from transmission network in HV/MV substation i and load level d ($/ Mwh)

Pf_j : The load power factor in consumer point j

R: Resistance of medium voltage network (*Ω*/ km)

L_{ij} : Distance between HV/MV substation or generation unit i and load point j based on km.

$V_{j,d}$: Voltage of load point j in load stage d (KV)

T_m : Load stage duration *(hour) d*

Inf r: Annual inflation rate

Int r: Annual interest rate

n_y : Equipment's useful lifetime based on year

$OperationCost_{DG}$: Cost of operating the distributed generation resources, power generation in DG resources requires spending cost for supply of its input energy resource as well as units' repairs and maintenance cost. The generation rate of each one of load stages or load point that is fed by each one of DG resources is specified by $\gamma_{ij,d}$ variable; therefore the current value of operation cost is as follows:

$$OperationCost_{DG} = \sum_{t=1}^{n_y}\left((F_m)^t \sum_{i=1}^{n_{DG}}\sum_{j=1}^{n_{lp}}\sum_{d=1}^{nld}[(P_j.Pf_j\gamma_{ij,d} + \gamma_{ij,d}RL_{ij}(\frac{P_j}{V_{j,d}})^2]T_d.C_{DG})\right) \tag{9}$$

$AccessCost_{LP}$: Cost of accessing to load points (establishment of medium voltage network or medium voltage feeder). Note that the load points hypothetically are located in gravity center of electrical zones and for accessing to load point, its distance from substations must be routed through the streets, thus it's finding radial or straightly is not logical because of its short distance. The method selected for finding the distance includes routing through calculation of vertical and horizontal distances and then their summation to each other that this distance of substation or distributed generation resources with coordinates (X_i, Y_j), to load point j is modeled as follows. Applying this cost in cost function of project through avoiding the feeders prolonging, facilitates the access to more practical response

$$L_{ij} = \left|X_i - X_j\right| + \left|Y_i - Y_j\right| \tag{10}$$

$$AccessCost_{LP} = \left(\sum_{i=1}^{n_{ss}}\sum_{j=1}^{n_{lp}} L_{ij}(1-\exp^{-Z\beta_{ij}}) + \sum_{i=1}^{n_{DG}}\sum_{j=1}^{n_{lp}} L_{ij}(1-\exp^{-Z\sum_{d=1}^{nld}\gamma_{ij,d}})\right).G_F \tag{11}$$

G_F : Cost of medium voltage network establishment (\$/*km*)

3.2. Constraint

Due to applying the reliability constraint and operation requirements for HV/MV substations, the loading limit because the substations are located in their permitted area. The loading rate of each unit of distributed generation resources has limited capacity. To determine the permitted voltage drop in accordance with standards, it must be kept in permitted range that according to the standard, this permitted voltage drop is 5%. In this paper, the distributed generation resources have been stimulated as PV.

$$V_{\min} \le V_{j,d} \le V_{\max}$$

$V_{\max}$: Maximum permitted voltage drop in load points (*KV*)

$V_{\min}$: Minimum permitted voltage drop in load points (*KV*)

$V_{j,d}$: Voltage drop of load point i in load staged

Feeding of all load points must be conducted only by one HV/MVsubstation that shows the radial constraint of network configuration. On the other side, any load point must be fed by several distributed generation resource but the connection of distributed generation resources to the load points must be equal in all load levels.

$$\sum_{i=1}^{n_{ss}} \beta_{ij} = 1 \tag{12}$$

$$j = 1,2,\ldots,n_{lp} \tag{13}$$

$$j = 1,2,\ldots,n_{lp} \tag{14}$$

$$\sum_{i=1}^{n_{ss}} (1 - \exp^{-z\sum_{d=1}^{n_{td}} y_{id}}) \le 1 \tag{15}$$

Commonly establishment of substation in a location faces the technical and geographical limitations. This constraint has been applied in this problem. Balancing the power between total energy purchased from upward grid and generated power of distributed resources with loss power among medium voltage feeders and consumed power of loads must be met as one of constraints that may be formulated as below:

$$\sum P_{UtilityfromUpwardGrid} + \sum P_{DG} = \sum P_{LossinFeeder} + \sum P_{DemandLoads} \tag{16}$$

4. CUCKOO OPTIMIZATION ALGORITHM

Cuckoo optimization algorithm is one of the strongest and newest optimization methods that was presented for the first time by Ramin Rajabioun in 2011 (18), and this algorithm has been inspired from living style of a bird in the name of cuckoo. In figure 1, flowchart of mentioned algorithm is observed. At first, this algorithm with initial population that is a population consisted of cuckoos begins its work. This population of cuckoos has some eggs that will be put in nest of some host birds. Some of these eggs that have more similarity to host bird eggs have more chance for growth and transforming to matured cuckoo. Other eggs are identified by the host and eliminated. The value of grown eggs demonstrates the suitability of the nestsof that zone. Whatever more eggs are able to live in a zone, to the same extent, higher interest (tendency) is allocated to that zone. The cuckoos for maximizing the rescue of their eggs seek for the best zone. After the chicks hatch and transformed to matured cuckoo, form groups that each group seeks for the best zone for living. So, all groups immigrate to the best zone (figure 2).

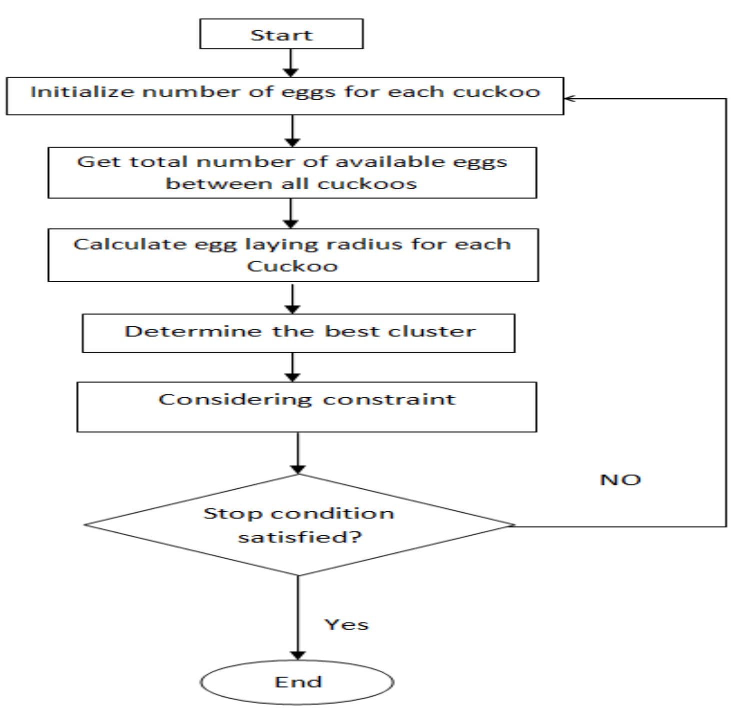

Figure 1. Flowchart of cuckoo optimization algorithm.

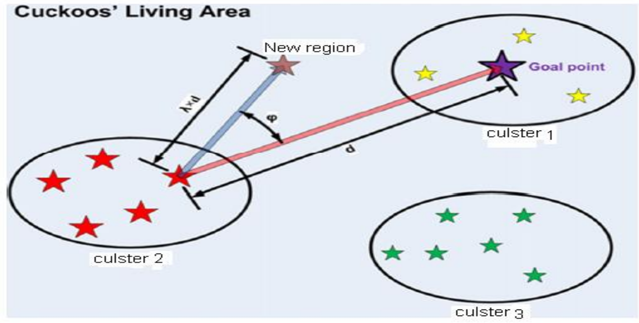

Figure 2. Immigration of sample cuckoos to the best settlement.

5. SIMULATION AND RESULTS

The study zone for load forecasting is divided into smaller zones (electrical area). Supply to load points and find feeders are the results of this division. The specification of buses and candidate bus are shown in Table 1.

Table1. ***The specification of existing and candidate substation***

Construction capacitive	substation Number
30,45,60,75	1candidate
30,45,60,75	2 candidate
45,60,75	1 existing
45,60,75	2existing
30,45,60,75	3 candidate
30,45,60,75	4candidate
30,45,60,75	5 candidate
30,45,60,75	6candidate

The Technical and cost parameters are shown in Table 2.

Table2. ***Technical and cost parameters***

value	**parameter**
4500	($/km) Cost of construction MV network
66	Cost of transmission electric system in all substation at First stage($/MWh)
45	of transmission electric system in all substation at second stage Cost ($/MWh)
32	Cost of transmission electric system in all substation at Third stage ($/MWh)
5	Maximum permissible voltage drop in load points (%)
350000	Cost of construction DG($/MVA)
30	Cost of DG generation power($/MWh)
0.129	Resistance per length of MV network(***Ω***/km)
0.120	Reactance per length of MV network(***Ω***/km)
20	Duration of study (year)
0.22	Annual inflation rate
0.19	Annual interest rate

The study zone includes electrical divided parts and the candidate places for finding substations and distributed generations which are shown in Figure 3 and 4, respectively. There are many candidate places of distributed generation resources than candidate places of the substation. According to, selective manner of distribution generation is not the same as substation manner selection.

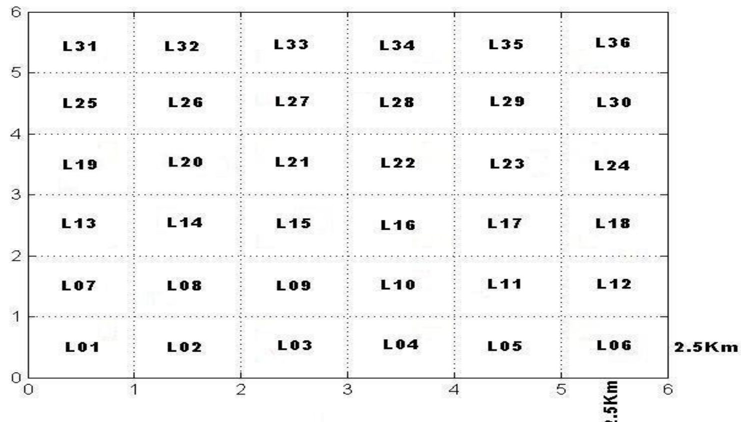

Figure 3.Area for case study.

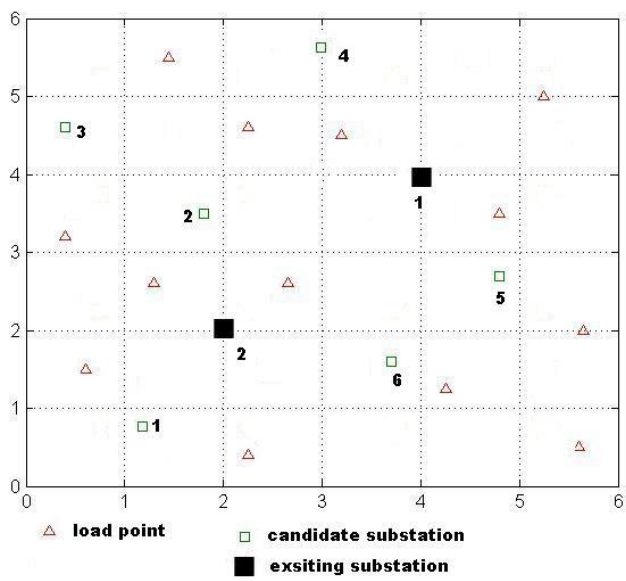

Figure 4. Candidate places for finding substations and DG.

Results of load forecasting data are shown in Table 3. The dynamic pseudo method is presented long term design for estimation of 20 year time horizon. This method is the multilevel method that is suitable for long term planning. The power factor is considered 0.9.In this paper three periods of load forecasting are studied which increase of load is adapted to these periods.

Table 3: ***Results of load forecasting***

load point	First stage(MVA)	second stage(MVA)	Third stage(MVA)
1	٩	٥,٥	٣
2	٧	٤	٢
3	٧,٥	٤,٥	٢,٥
4	٨	٧	٤
5	٦	٤,٥	٢,٥
6	٦,٥	٤,٥	٢,٥
7	٨,٥	٥,٥	٣,٥
8	١١	٧	٤
9	٩,٥	٦,٥	٣,٥
10	٧,٥	٥,٦	٣,٥
11	٩,٥	٦,٣	٣,٥
12	٨,٥	٥,٥	٣,٥
13	٤	٣	٢,٥
14	٩,٥	٦,٥	٣,٥
15	١١	٧	٤
16	١٠	٦	٤,٥
17	٩	٨	٤
18	١٢	٧	٤
19	٥	٣	٢,٥
20	٨,٥	٦	٣
21	٧	٥	٢
22	٩	٨	٥
23	١٠	٧,٥	٥,٥
24	٥,٥	٤,٥	٣
25	٦	٥	٣
26	٧	٤,٥	٣,٥
27	٨	٧	٥
28	٧	٣,٥	٢,٥
29	٧,٥	٤,٥	٥,٥
30	٧,٥	٦,٥	٥
31	٣,٥	٢,٥	١
32	٥,٥	٤,٥	٢,٥
33	٦	٣	٢
34	٥,٥	٣,٥	١
35	٧	٥,٥	٢,٥
36	٨	٥	١

Table 4: ***Specification of substation including the access costs***

Constrictive capacity	Assess Cost	Substation number
30,45,60,75	70000	1candidate
30,45,60,75	190000	2 candidate
45,60,75	٠	1existing
45,60,75	٠	2existing
30,45,60,75	200000	3 candidate
30,45,60,75	110000	4candidate
30,45,60,75	170000	5candidate
30,45,60,75	150000	6candidate

The access cost of a substation for candidate substation is according to Table 4. These values are affected by the following factors: Nearness of the substation to centers of current and future loads, nearness to transmission lines and HV/MV substation, nearness to substation of main road and act.

Two scenarios for the study case are considered. First Scenario: First of all allocation of substation without considering of distributed generation and expansion of the substation is studied.

In long term forecasting this supposition is considered. The results are as shown in Table 5.

Table 5. ***Results of first scenario***

substation number	capacity(MVA)	loading(MVA)			load allocation
		stage1	stage2	stage3	
existing1	٤٥	٣٩	٢٨	٢١,٥	٢٢،٢٣،٢٤،٢٨،٢٩
existing2	٤٥	٤١	٢٧	١٥	٨،٩،١٤،١٥
candidate1	٤٥	٤٤	٣١	١٧,٥	١،٢،٣،٤،٧،١٣
candidate2	٤٥	٣٥,٥	٢٥,٥	١٦	١٩،٢٠،٢١،٢٦،٢٧
candidate3	٣٠	٢١	١٥	٨,٥	٣١،٣٢،٣٣،٢٥
candidate4	٣٠	٢٨	٢٠,٥	١٠	٣٠،٣٤،٣٥،٣٦
candidate5	٦٠	٥٤,٥	٣٧,٥	٢٢,٥	١١،١٢،١٦،١٧،١٨
candidate6	٣٠	٢٠	١٤,٦	٨,٥	٦،٥،١٠

According to the capacity of the substation at long term studied, to supply the load points, 6 substations are needed. In addition, construction costs, during of construction and install of utilities to power systems impose many costs. 30 MVA, 45 MVA and 60 MVA are capacity of 6 candidate substations. A cost of the first scenario without considering of distributed generations is shown in Table 6. The value of the cost function without considering of distributed generations is 839.266 * 10^6. In addition, in this scenario the voltage profile for different load points is described in Figure 1. Without considering of distributed generations in certain nodes decrease of voltage is raised. Number of appropriation of loads for substation of 3 and 6 are 4 and 3 load points, respectively.

Table 6. ***Results of second scenario***

Substation number	capacity(MVA)	loading(MVA)			load allocation
		stage1	stage2	stage3	
existing1	٤٥	36.5	25.75	21.5	22,23,24,28,29
existing2	٤٥	39	26	15	8,9,14,15
candidate1	٤٥	31	22.5	17.5	1,2,3,4,7,13
candidate2	30	28.25	19.5	16	19,20,21,26,27
candidate4	45	37.75	29.5	18.5	25,30,31,32,33,34,35,36
candidate5	75	65.5	45.85	17	5,6,10,11,12,16,17,18,24

Second scenario: Allocation of substations and distributed generations are done together, which the results are presented in Table 7. According to comparison of Tables 4 and 5 and both scenarios following results are presented. Results of load allocation consort with DGs capacity is presented in Table 6. According to simulation results, instead of 6 new substations, 4 substations are installed،Because of presence of distributed generations in the network, the cost of construction and operation is decreased. In first scenario, 6 candidate substations are considered which have 45 MVA, 30 MVA and 60 MVA capacities. In this state, costs of investment and operation of the substations are high. In addition, Figure 5 is presented of load allocation.

Table7. ***Results of load allocation to DG with capacity DG***

load allocation	stage3	stage2	stage1	capacity(MVA)	DG number
1	-	1.5	2	3	1
3	-	2	3.5	4	2
4	-	3	4.5	5	3
6	-	3	4	5	4
13	-	2	3	4	5
15	-	1	2	3	6
16	-	1	2	3	7
18	-	1	1.5	2	8
19	-	3	2.75	4	9
21	-	3	4.5	5	10
22	-	1	1	2	11
24	-	1.25	1.5	3	12
31	-	1.75	3.25	4	13
33	-	2	3	4	14
34	-	3	4	5	15
36	-	2	3	4	16

In the presence of distributed generation capacity of 30 MVA of candidate substation 2 is decreased. Also, the candidate substation 3 is omitted and candidate substation 4, with a capacity of 45 MVA, is replaced. Because of presence of DG resources in this study, the candidate substation 6 is omitted and candidate substation 5, with a capacity of 75 MVA, is replaced, too. Load allocation of omitted substations is shared to another candidate substation. The expectation of these substations is overloaded of new load points, but because of DGs presence overload is not taking place. The overload substation is provided by DGs. The second scenario and load allocation are presented in Figure 6.

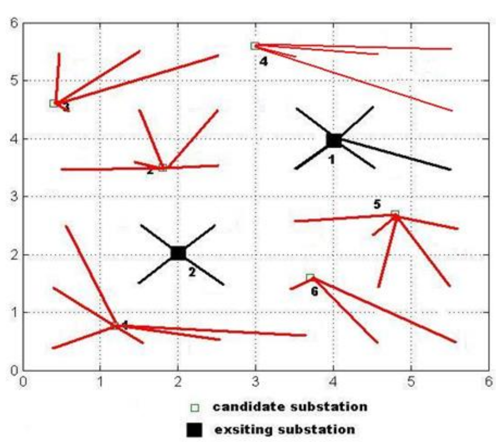

Figure 5. Results of first scenario.

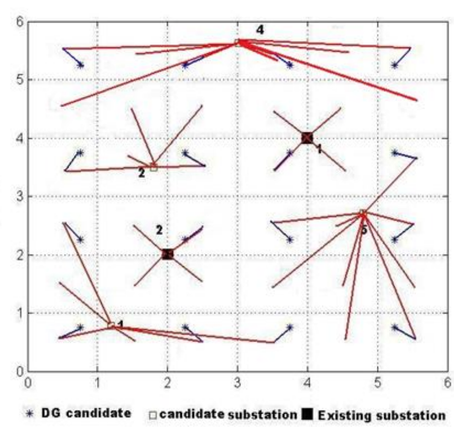

Figure 6. Results of first scenario.

The differential value of the cost function is shown in Table 8. As Table 8, total cost function in the first scenario without considering of DG resources is higher than second scenario. This shows that with considering of DGs the operation investments would be decreased. In Figure 1, results of both scenarios voltage profiles are presented which these values are obtained from load flow at load points. Whereas, voltage profile at second state is improved than the first state. Figure 7 shows the comparison of both states. But, at some nodes drop is sensed which it is improved at second scenario. Presence of DGs decreased the costs and improved the voltage profile at load points. The voltage profile is one of power quality parameters in electrical power systems that it is improved by presenting method.

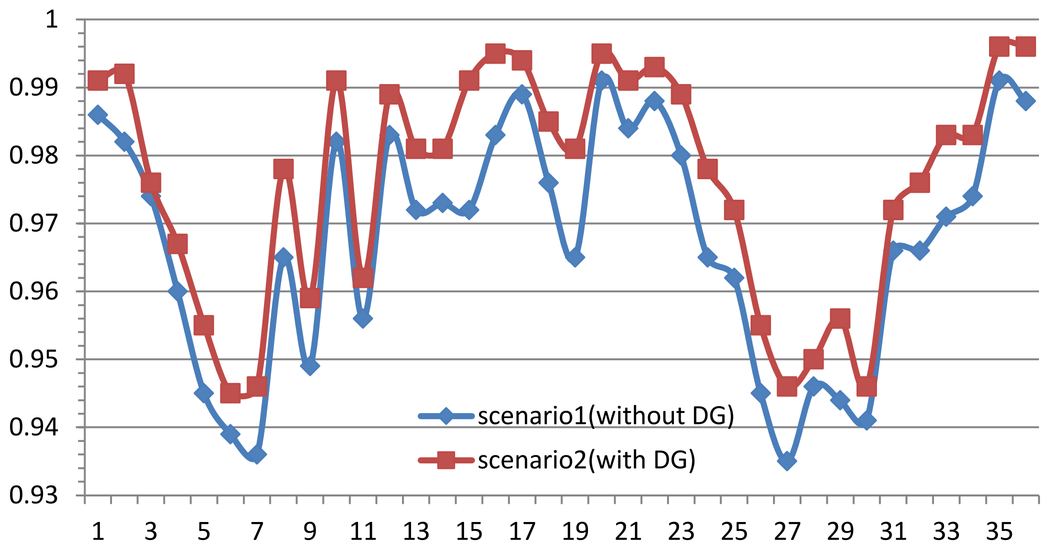

Figure 7.Comparison of both scenarios for voltage profile .

Table 8. ***Different values for cost function***

scenarios2	scenarios1	Cost Function
۵۴۰۰۰۰	۸۹۰۰۰۰	Cost of accessibility HV/MVsubstation($)
۳۷۱۰۰۰۰	۶۳۳۰۰۰۰	Cost of HV/MVsubstation Investment($)
۲۱۰۰۰۰۰۰	۰	Cost of DG Investment($)
۶۶۵,۳۵۶۴*۱۰^{۶}	۸۲۴,۷۳۱*۱۰^{۶}	Cost of HV/MVsubstation operation($)
۱۱۵,۲۷۱۴*۱۰^{۶}	۰	Cost of DG operation($)
463500	315000	cost of construction MV network($)
*۱۰^{۶}806.3413	1. *۱۰^{۶}832.266	Total of cost function($)

The cuckoo algorithm parameters are shown in Table 9.

Table 9. ***Cuckoo algorithm parameters***

cuckoo algorithm parameters	
۱۰	number of initial population
۲	minimum number of eggs for each cuckoo
۴	maximum number of eggs for each cuckoo
۲	number of clusters that we want to make
۱۰	maximum iterations of the Cuckoo Algorithm
۲۰۰	maximum iterations

The performance of the cost function of the cuckoo optimization algorithm and genetic algorithm is presented in Figures 8 and 9, respectively.

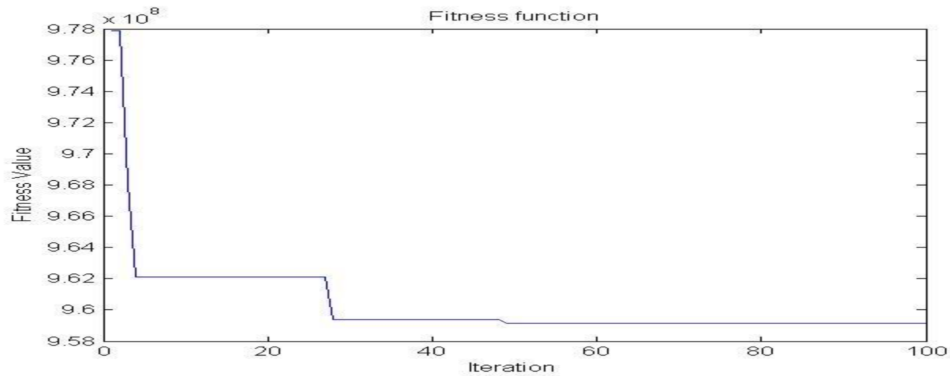

Figure 9.Results of running genetic algorithm.

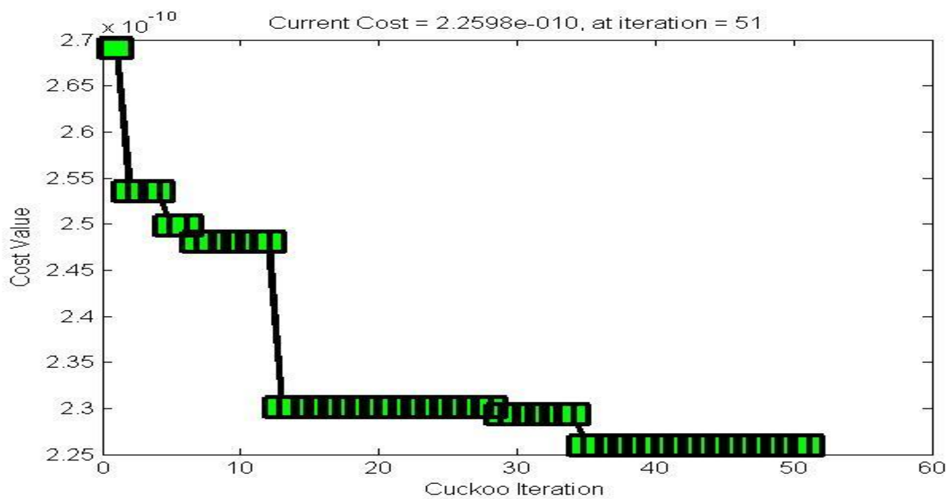

Figure 9.Results of running COA.

This study is performed using MATLAB software 2011.Number of iterations of a genetic algorithm and the cuckoo optimization algorithm is shown in Figures 7 and 8, respectively. Genetic algorithm with 100 and cuckoo optimization algorithm with 51 iterations optimum the study cases. The results show that the cuckoo optimization algorithm has better performance than genetic algorithm. The used algorithm has a reliable and rapid answer than genetic algorithm.

6. CONCLUSION

The optimal placement problem of HV/MV substations with distributed generations simultaneously for supplying the capacity required for power system are analyzed in this paper. The distributed generation resources such as wind, PV, fuel cell has offered a new option in design and development of power systems, to the designers and planners of such networks .In the mathematical model, objective function together with constant and varied variables and constraints related to limitations for operation of substations and distributed generation resources as well as network limitations are formulated. At the end, it will observe the power quality improvement in load points. To solve this problem, optimization of one of new algorithms called cuckoo optimization algorithm has been applied. The results show that the cuckoo optimization algorithm has better performance than genetic algorithm. The used algorithm has a reliable and rapid answer than genetic algorithm.

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