Computational Research Progress in Applied Science & Engineering
©PEARL publication, 2016

ISSN 2423-4591

CRPASE Vol. 02(04), 173-180, October 2016

Distribution Simultaneous Sizing, Sitting, and Service Area Determination of Sub-transmission Substations and Distributed Generations Considering Load Uncertainty by GSO Algorithm

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Keywords

Sub-transmission Substations,
Distributed Generations,
Fuzzy Model,
Load Uncertainty,
GSO Algorithm.

Abstract

In this paper, a method is proposed for sizing, sitting and service area determination of sub-transmission substations from among candidate and available substations considering distributed generations. In this way, an economic objective function along with required constraints are utilized for the implementation of an economic-technical design. In addition, with regard to the uncertainty in load forecasting, each of the load centers is considered as a fuzzy model. Moreover, fuzzy sets are employed to model uncertainties. Due to the problem complexity and several factors involved, problem optimization is completed using robust GSO algorithm. Several tests on a realistic network have been carried out to demonstrate the effectiveness of the present optimization method.

1. Introduction

Supplying load demand of consumers in an appropriate manner is among the main objectives of utilities. It should be noted that optimization of sub-transmission substations and connecting network are primary requirements in this regard. Current sub-transmission network should be able to supply distribution substations in a reliable manner. Otherwise, this network fails to supply load demand and it should be developed further in construction. The aim of planning the sub-transmission network development is to estimate it and, if required, add new equipment in order to respond load demand growth with the least possible cost and proper reliability. Generally, various alternatives exist to develop substations and feeders in order to supply system load growth. That is, an objective function, consisting of constant and current costs, is formed which is used to measure the effectiveness of the related alternatives. Thus, regarding appropriate placement of substations in the presence of distributed generations, response to electric consumption growth is met by considering economic and technical efficiency. Given the uncertainty of load forecasting in areas, the abovementioned method is proposed based on load amount's fuzzy model of electric areas.

In [1], an approach is presented for optimum sizing and service areas determination. The load uncertainty is modeled using fuzzy members' LR method in load point. An optimization tool for optimizing transmission system development was extended through linearized power flow modeling and genetic [2]. In [3], a mathematical model and a dynamically transfer planning method were proposed using optimization structure. In [4], distributed generation (DG) units were taken as a novel alternative in order to use sub-transmission systems' load. Ref. [5] suggests a multistage model based on a hybrid non-linear integer programming for programming sub-transmission system development. Khodr et. al utilized probabilistic approach to select optimal placement of distribution substations. Proposed algorithm selects the best time-varying (hourly) locations of substations using heuristic approach. In this regard, each substation coordinates are weighted considering total load of area (obtained by load forecasting) and the best statistical distribution level. Since statistical distribution levels used in the proposed algorithm are employed to minimize the weighted deviations' square [6]. In [7], improved genetic algorithm (GA) was employed to optimally design distribution system in large scales. Accordingly, optimum size and site of medium voltage (MV) and high voltage (HV) substations as well as LV feeders routing were achieved considering long-term load growth of distribution system. Network design problem is divided into two sib-problems. The first one is optimum placement of HV substations; and the other one is MV substation placement and MV feeders routing. In [8], an algorithm was invented to design distribution network. In this algorithm, the location of transformers was selected automatically obviating the need

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Received: 21 September 2016; Accepted: 05 December 2016

for prior knowledge about location of candidate substations. Optimum arrangement of feeders and proper size of distribution network conductors are determined regarding line current capacity and voltage drop limitations as well as heuristic rules. An algorithm was invented in order to find optimum feedering route and substations' location with regard to power loss minimization. In [9], an improved differential evolutionary algorithm was presented to solve planning problem of transmission system in static manner using alternating current model and by considering reactive power compensation. Ref. [10] proposed a novel dynamic method to solve transmission system's planning development problem. In [11], optimum placement of substation and distribution network design were evaluated simultaneously using a novel hybrid algorithm of quasi-Newton and genetic algorithm. In [12], a novel model of planning for sizing, locating, and scheduling of distribution substations and corresponding service area is extended.

In this work, sizing, sitting and determining service area of subtransomission substations in the presence of DG resources as a novel alternative is modeled and solved in order to supply required capacity in a static manner in a time period for minimization of costs and by considering technical and economical constraints.

2. Fuzzy Model of Load Points

Fuzzy model of triangle and normal LR used to balance forecasted power in each point and in each time period is according to Fig. (1) and Eqs. (1) and (2)

$$M(x)=\begin{cases}\dfrac{x-(m-L)}{L} & x\le m\\[2ex] \dfrac{(R+m)}{R}-\dfrac{X}{R} & x\ge m\end{cases}\tag{1}$$

$$L_{ij}=\left|X_i-X_j\right|+\left|Y_i-Y_j\right|\tag{2}$$

where m, L, R and m(x) denote load average, left and right extend, and membership function, respectively [1].

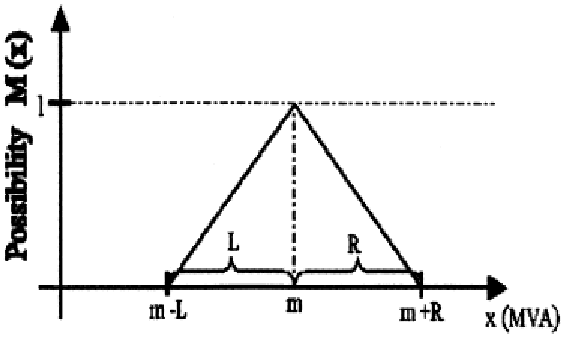

Figure 1. Fuzzy model of load point power

3. Problem Formulation

In this section, mathematical formulation of sizing sub-transmission substations and DGs in a set of candid locations is performed to establish substation and DG. In this section, the aim is to minimize costs related to connecting lines of substations and loads, power loss of lines and sub-transmission substation transformers, constructing or extending sub-transmission substations, installation of DGs, operation of sub-transmission substations, operation of DGs, and accessibility of upstream network by substations. In addition to reduction of abovementioned costs investigated in most of the reported works, other design constraints are also considered in problem formulation: uncertainty in load and other economic parameters, violation of voltage permissible limitations in load points, increased cost of supplying network energy, overloads in DGs (violation of DGs' maximum capacity).

3.1. Economic Objective Function

Costs related to investment, and operation of sub-transmission substations and DGs as well as connecting lines of sub-transmission substation and loads, and power loss cost can be represented in a single objective function. Thus, economic objective function is deined by Eq. (3)

$$\begin{aligned}
&Min\tilde{F}_C=\sum_{i=1}^{ns}[AC(i)(1-\exp(H.P_{s\max}(i))+CS(P_{s\max}(i))\\
&+CF\sum_{j=1}^{nl}D_{ij}.(1-\exp(-H.\alpha_{ij}))]+\sum_{i=1}^{ndg}[CDG(P_{DG}(i))+\\
&CF\sum_{j=1}^{nl}D_{gij}.(1-\exp(-H.(1-\sum_{k=1}^{ns}\alpha_{kj})))]+\\
&\sum_{t=1}^{nt}[(F_{pw})^t[[\sum_{i=1}^{ns}\sum_{j=1}^{nl}\alpha_{ij}.(\tilde{P}_l(j).pf_j+R.D_{ij}.(\frac{\tilde{P}_l(j)}{\tilde{V}(j)})^2)*8760*\tilde{K}_s(i)]\\
&+[\sum_{i=1}^{ndg}\sum_{j=1}^{nl}PR(i).pf_j+R.D_{gij}(\frac{PR(i)}{\tilde{V}(j)})^2*8760*K_{DG}(i)]]]
\end{aligned}\tag{3}$$

$$PR(i)=\begin{cases}P_{DG}(i) & i=j\\ 0 & i\neq j\end{cases}\tag{4}$$

$$f_{pw}=\frac{1+\inf r}{1+\operatorname{int} r}\tag{5}$$

where ndg, nl, and ns denote the number of candidate locations for installation of DG, the number of system load points, and the number of candidate locations for installation of sub-transmission substations, respectively. *AC(i)* is the cost of access to sub-transmission substation I ($), $P_{s\max}(i)$ loading peak of sub-transmission substation *i* (MVA) and *H* is a large number. α_{ij} specifies binary decision variable, indicating connection or disconnection of load point *j* to substation *i*. *CS* and *CF* are respectively the cost of installing a sub-transmission substation and LV network ($/km). D_{ij} and D_{gij} are the distances between sub-transmission substation i and load point *j* (km) and the distance between generating unit i and load point *j* (km). *CDG* ($P_{DG}(i)$) is the installation cost of DG and pf_j is the power factor of load in consumption point *j*. *R* and $\tilde{V}(j)$ are resistance of MV network (Ω/km) and voltage drop in load point *j* (kV). Annual inflation rate and annual interest are shown by infr and intr, respectively. $K_S(i)$ is electricity purchase price from transmission system in sub-transmission substation *i* ($/MWh) and nt is effective life time of equipment (in year).

$P_i(j)$, $K_{DG}(i)$ and $P_{DG}(i)$ are load of point *j*, generation cost in DGs ($/MWh) and *i*th source power, respectively.

3.2. Problem Constraints

Objective function along with a set of constraints forms overall model of sub-transmission substation and DGs. With regard to observing of constraints in network as well as operation of equipment, consideration of following limitations is necessary in optimization model.

3.2.1. Loading Limitation of Sub-Transmission Substations

In order to consider reliability constraint and operational consideration, a loading limit is considered for sub-transmission substations such that loading of each substation should be in the permissible range. Mathematically, this constraint is defined by Eq. (6)

$$0 \le P_{SS.j} \le K_i .S_{SS.j} \qquad i = 1,2,\ldots,nss \;, S_{SS.i} \in \Omega_i \tag{6}$$

where K_i is the maximum loading capacity of sub-transmission substation *i* (as a percentage of nominal capacity), *Sssj*, the capacity of sub-transmission substation *i* (MVA) and Ω*j* stands for the total installable capacities in substation location *i*.

3.2.2. Operational Limitation of DGs

Loading amount of each generating unit should be less than the capacity of that unit.

$$0 \le P_{DG.i} \le S_{DG.j} \qquad i = 1,2,\ldots,ndg \tag{7}$$

where $S_{DG,\,j}$ is the capacity of *i*th generating unit (MVA).

3.2.3. Voltage Drop Limit

Voltage drop in load points should be in permissible range in each load levels. Since each load point is supplied by a sub-transmission substation and one or more DGs in the proposed model and if generating units exist, power flows is used to calculate voltage drop amount in consumption point. If ΔVjd is voltage drop of load point j in load level d, thus we have

$$0 \le \Delta V_{j.d} \le \Delta V_{MAX} \qquad j = 1,2,\ldots,nlp \;, d = 1,2,\ldots,nld$$

(8)

where ΔV_{MAX} is the maximum permissible voltage drop in load points (kV). It should be noted that this constraint is considered to prevent connection of load points to substations and DGs far away from them. It should be mentioned that the parameter of ΔV_{MAX} in the proposed model may be considered as a criterion to control the maximum distance between load points connected to substations and DGs, such that these maximum distances will be decreased by selecting lower amounts for ΔV_{MAX}.

3.2.4. Load Points Supplied by Generating Units Limit

In distribution networks, design in the presence of DGs, it is tried to supply loads mainly through sub-transmission substations as the main source, and DGs should not meet the network load demand. Thus, in the present problem, maximum power limit that can flow through each load point and supplied by DG is given by

$$\sum_{i=l}^{ndg} \beta_{ij.d} \le 0.35 \qquad j = 1,2,\ldots,nlp \qquad d = 1,2,\ldots,nld \tag{9}$$

3.2.5. MV Network Radiality Limit

Supplying all load points of system is considered one of the main constraints in design and development of distribution systems. In addition, each load point should be supplied from one sub-transmission substation which holds network radiality.

Considering abovementioned discussion, radiality limit of load points' supply from sub-transmission substations can be expressed as

$$\sum_{i=l}^{nss} \alpha_{ij} = 1 \qquad j = 1,2,\ldots,nlp \tag{10}$$

3.2.6. Substation Installation and DG in Candidate Locations

In general, installation of substation in a candidate location or development of available substations considering technical and geographical constraints are limited, such that installing substations with a capacity more than specified values or developing available substations are not allowed. This limit is given by Eq. (11)

$$0 \le S_{SS,I} \le S_{SS,i}^{MAX} \qquad ,i = 1,2,\ldots,nss \tag{11}$$

In this relation, $S_{SS,i}^{MAX}$ is the maximum installable capacity in location of substation *i* (MVA). Although installing DGs is less limited than substations in terms of position, there exists a maximum limit in terms of installable capacity of DG in each candidate location for installation of generating unit which can be given by

$$0 \le S_{DG,j} \le S_{DG,j}^{MAX} \qquad i = 1,2,\ldots,ndg \tag{12}$$

where S^{MAX} is maximum installable capacity of DG in position *i* (MVA).

3.3. Modeling of Sub-Transmission Substations and DG

Considering the functions presented in previous sections, single-function model of placement is presented by Eq. (13)

$$F_{Total} = F_c + C_p \times PF_T \tag{13}$$

$$d_i = \begin{cases} 0 & G_i \le b_i \\ (G_i - b_i)/b_i & otherwise \end{cases}$$

$$PF_T = \sum_{ilc} di \tag{14}$$

where PF_T is the inactivity value of particle, and *Cp* is penalty factor (a large number). If *h* is the *i*th constraint of the problem, the impracticability of particle is obtained by above relationship. In addition, *di* is the value of passing from *i*th constraint and Ic is a set of constraints violated by the chromosome.

Due to greatness of penalty factor *Cp*, in first iterations of searching process and until the practical solutions are obtained, the algorithm searches solutions with less impracticality in order to make the second term of objective function (F_{Total}) zero.

4. Problem Optimization Based on Global Search Optimizer (GSO) Algorithm

GSO algorithm is an optimization process inspired by animals searching behavior. GSO algorithm is implemented based on producer-scrounger model. It should be noted that based on the above pattern, scanning mechanisms of animals are considered symbolically in this algorithm to solve optimization problem. In order to find foods, living organisms move from one point to the other point to approach food source. And determining that a food source is the best one is evaluated by specifying objective functions. Optimization which, indeed, is finding the optimum point in search space is comparable with food search process by animals. GSO algorithm which benefits from population-based logic is an appropriate option for optimizations in electrical engineering. Each particle in population is named member. GSO comprises of three operators:

Producers, that are group leaders, search for food and share their information with the other members in group. The number of producers is considered equal to the number of discussed objective functions. Scroungers pursue producers and the uncovered food searching process is done by them, which 80% of the group members are selected randomly as scroungers. The rest of the group members are rangers. They move randomly in search space and their behavior allows the group to explore food sources in remote places. This algorithm optimizes the problem based on the following relationships. The flowchart of implementing GSO algorithm is observed in Figure 2. Figures 3 and 4 represent field view and coding procedure of decision variables in the problem [13].

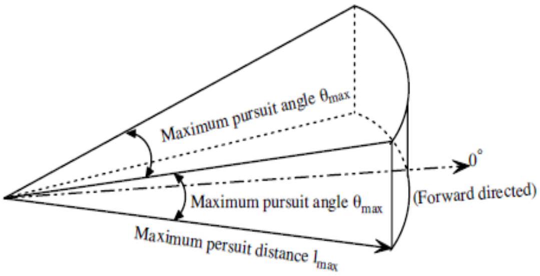

Figure 3. View field in 3-D space

As can be seen, each of population is expressed as Figure 4 where each population is comprised of two substring. The first substring is related to the way of connecting substations and loads and it specifies which substations supplying loads. The second substring is related to DGs and specifies each source capacity and type in corresponding location

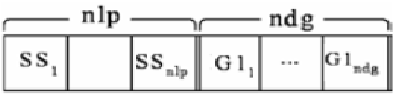

Figure 4. Proposed chromosome structure

5. Study Results on Realistic Network

In this section, in order to show the efficacy of the proposed algorithm, the problem is implemented on a realistic network. In this paper, considering the possibility of installing DGs in each candidate locations that can be connected directly to the load points, the problem is solved for simultaneous placement of substations and generating units. Other input information and conditions are given below. This network is a part of Zanjan City sub-transmission network, and its data are presented in Table A.1 and depicted in Figure 5. The region under study has 26 load points which their predicted load data are in fuzzy load framework. The economical and technical data required by these numerical studies are given in Table A.2. Eight candidate locations are considered in order to install DGs. Locations 5 and 7 can be used for installing hybrid wind and solar generation. The other locations are used for installing diesel generator with proposed prices. The maximum installable capacity in all locations is 5 MW. In this research, DGs are assumed in module form and as 1-MW proportion and are connected to load points directly. In addition, calculations are obtained by power flow of load distribution which is, in fact, the branched routs from each sub-transmission substation to the load. In addition, Newton-Raphson method is used for DGs where diesel generators and loads are considered as PQ bus, hybrid power plants are taken as PV bus, and substations are regarded as slack bus.

In this section, two tests are carried out on system. First test is completed in the absence of DGs and system loads are supplied through substations. And the second test is performed in the presence of DGs. Next, the obtained results are compared.

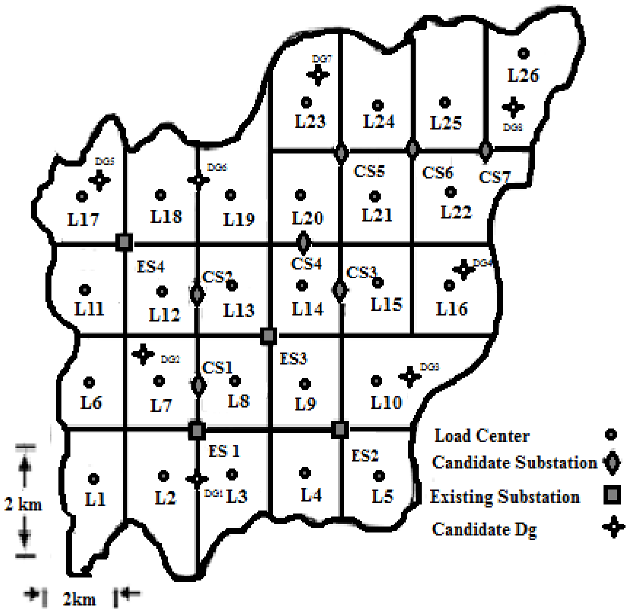

Figure 5. The region under study

In this section, the obtained results from the tests are presented in the following tables. By completing multiple tests, GSO parameters in the numerical study are regulated as given by Table 1. Results of selected substations and servicing area of each substation are given in Table 2 and Figure 6.

Table 1. Algorithm parameters

Var_{max}	Var_{min}	Number of Generation	Number of population
10	0	100	200

Table 2. Selected substations' results

Load point	Capacity	Number of substation
1,2,3,7	60	1
4,5,9,10	60	2
8,15,16	45	3
11,12,17,18,19	45	4
-	0	5
6,13	30	6
-	0	7
14,20,21	45	8
-	0	9
22,23,24,25,26	60	10
-	0	11

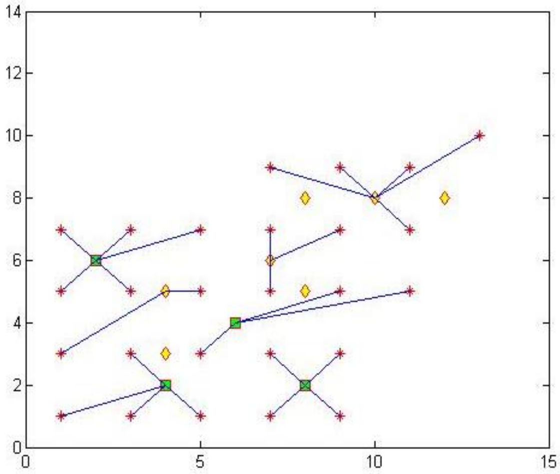

Figure 6. Servicing area of each substation in obtained results by GSO algorithm

DG capacities are presented in Table 3. By employing proposed method of sub-transmission substation and DG placement as well as GSO-based searching method, problem solutions are obtained in the distribution system under study. Figure 7 depicts convergence trend by GSO algorithm.

Table 3. Results of selected DG

Capacity (MW)	DG
4	1
4	2
4	3
4	4
6	5
4	6
6	7
4	8

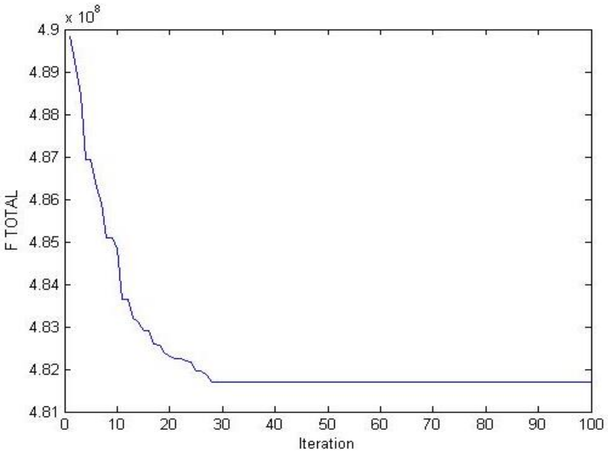

Figure 7. Convergence trend by GSO algorithm

The numerical results related to the best solution by GSO algorithm are presented in Table 4 for various parts of the objective function.

6. Conclusions

In this paper, an optimization model for sub-transmission substation in the presence of DGs are presented where an economical objective function along with proper constraints are utilized to implement an economical and technical design for problem formulation. Due to the available uncertainty in the load forecasting, load centers are considered as a fuzzy model. Minimization of costs related to investment and operation as well as power loss reduction along with observing economical and technical constraints were main objectives of this paper. For modeling of uncertainties available in loads, fuzzy set theory was utilized and GSO algorithm was employed for optimization of the problem. By employing the proposed method, effective solutions of the problem were obtained. The solutions indicate interaction between plan objectives in placement of substation and DG. In order to show the effectiveness of the proposed method, the model was implemented and optimized on a realistic network and the obtained results were given.

Table 4. Objective function components obtained from test implementation on standard network

Value ($)	Parameter
450000	(AC_{ss}) Cost access to substation
3000000	(IC_{SS}) Cost of substation installation
12840000	Cost of DG installation
10^10(1.8485, 1.7267, 1.6786)	(OC_{SS}) Operation cost of substation
10^10(6.0389, 6.03331, 6.0287)	(OC_{DG}) Operation cost of Distribution generation
2570425	(AC_{LP}) Cost access to load point

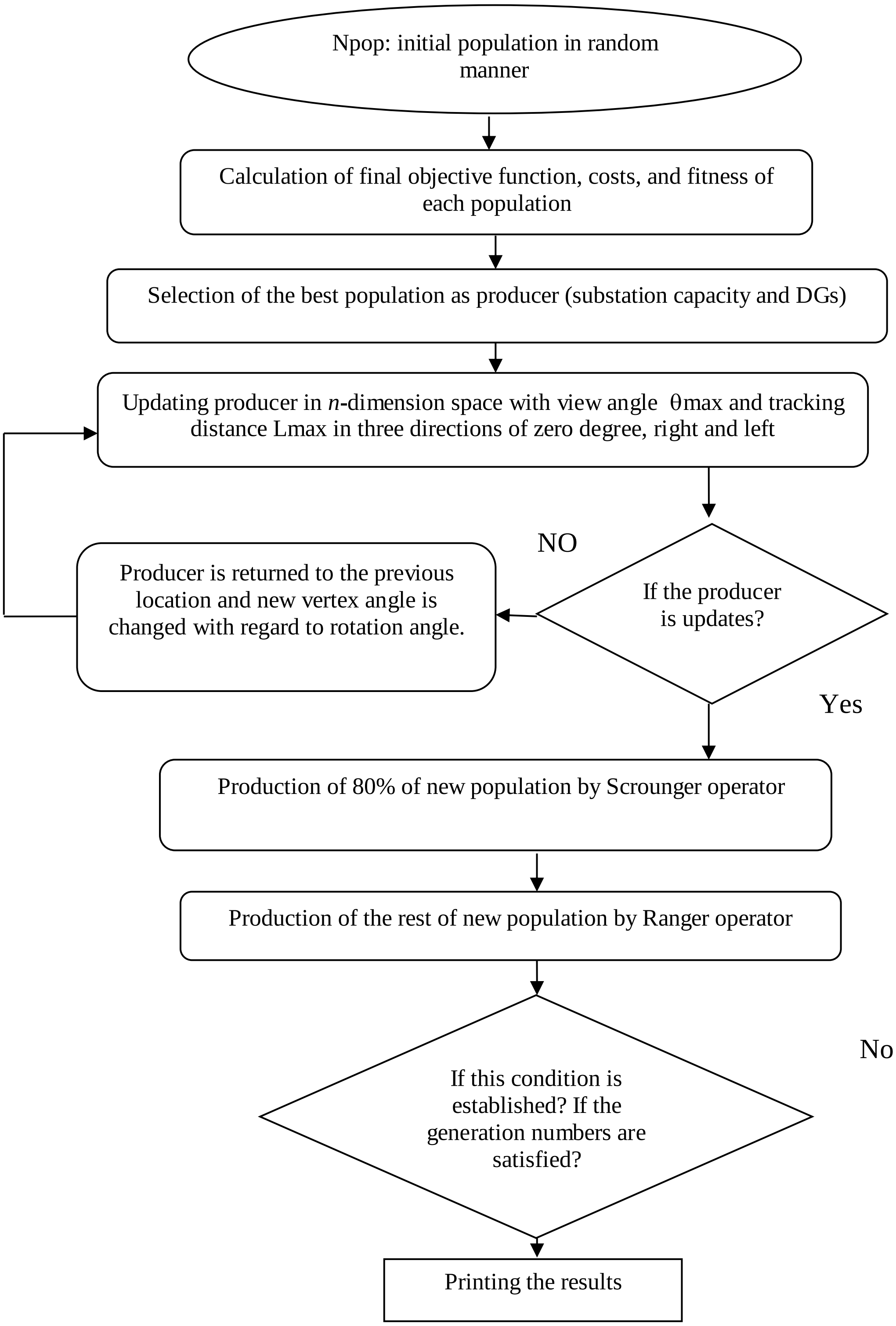

Figure 8. GSO Algorithm flowchart for this problem

Appendices

Table A1. Load forecast data for real zanjan network

	Power (MVA)		
Load point	Maximum possible value	Highest possible value	Lowest Possible value
1	13	8	4
2	13	8	4
3	13	8	4
4	13	8	4
5	9	6	3
6	9	6	3
7	9	6	3
8	10	7	4
9	9	6	3
10	13	8	4
11	9	6	3
12	10	7	4
13	6	3	1
14	9	6	3
15	13	8	4
16	5	3	1
17	5	2	1
18	4	2	1
19	9	6	3
20	8	5	3
21	13	8	4
22	9	6	3
23	4	2	1
24	10	7	4
25	14	9	5
26	13	8	4

Table A2. The required technical and economical data for Zanjan real network

Parameter	Value
The Maximum Cost possible of energy in substations	50
The highest Cost possible of energy in substations	30
The lowest Cost possible of energy in substations	20
Construction cost of DG ($/MWH)	280000
Operation cost of DG ($/MWH)	27
Resistance of medium voltage network (Ω/Km)	0.125
Reactance of medium voltage network (Ω/Km)	0.127
Nominal Voltage(KV)	20
construction cost of medium voltage network($/KM)	5000
construction cost of Hybrid DGs($/MW)	510000
Authorized capacity of building substations in the candidate location 10 to 20	30,45,60,75
Authorized capacity of building substations in the candidate location 1,2,4,7	30,45,60,75
Authorized capacity of building substations in the candidate location 3,5,6,8,9	45,60,75
Cost of accessibility to candidate substation	150000
Cost of accessibility to existing substation	0
Effective functioning period of equipments. (per year)	15
Annual inflation rate	0.07
Annual interest rate	0.12
maximum possible voltage drop (%)	5
production cost of Hybrid DGs($/MWh)	5

References

[1] M.R. Haghifam, M. Shahabi, Optimal location and sizing of HV/MV substations in uncertainly load environment using genetic algorithm, Electric Power Systems Research 63 (2002) 37–50.

[2] T.F. da Silva, A. Nunes de Souza, P. da Costa Junior, Developing an optimization tool for evaluating the transmission system expansion, Latin America Transactions, IEEE (Revista IEEE America Latina) 13 (2015) 998–1004.

[3] A. Rastgou, J. Moshtagh, Improved harmony search algorithm for transmission expansion planning with adequacy–security considerations in the deregulated power system, International Journal of Electrical Power & Energy Systems 60 (2014) 153–164.

[4] H. Shayeghi, A. Bagher, Dynamic sub-transmission system expansion planning incorporating distributed generation using hybrid DCGA and LP technique, International Journal of Electrical Power & Energy Systems 48 (2013) 111–122.

[5] M. Jalali, K. Zare, M. Tarafdar Hagh, A multi-stage MINLP-based model for sub-transmission system expansion planning considering the placement of DG units, International Journal of Electrical Power & Energy Systems 63 (2014) 8–16.

[6] H.M. Khodr, J.A. Melian, A.J. Quiroz, D.C. Picado, J.M. Yusta, J. Urdaneta, A probabilistic methodology for distribution substation location, IEEE Transactions on Power Systems 18 (2003) 388–93.

[7] S. Najafi, S.H. Hosseinian, M. Abedi, A. Vahidnia, S. Abachezadeh, A framework for optimal planning in large distribution networks, IEEE Transactions on Power Systems 24 (2009) 1019–1028.

[8] R. Ragan, B. Venkatesh, D. Das, A new algorithm for power distribution system planning, Electric Power System Research 62 (2002) 55–65.

[9] S.P. Torres, C.A. Castro, Specialized differential evolution technique to solve the alternating current model based transmission expansion planning problem, International Journal of Electrical Power & Energy Systems 68 (2015) 243–251.

[10] B. Alizadeh, S. Jadid, A dynamic model for coordination of generation and transmission expansion planning in power systems, International Journal of Electrical Power & Energy Systems 65 (2015) 408–418.

[11] E.G. Carrano, R.H.C. Taka, E.P. Cardoso, R.R. Saldanha, O.M. Neto, Optimal substation location and energy distribution network design using a hybrid GA-BFG-s algorithm, IEEE proceedings. Generation, Transmission and Distribution 152 (6) 919–926.

[12] H.k. Temraz, M.M.A. Satama, A planning model for siting, sizing and timing of distiribation substations and defining the associated service Area, Electic Power systems Planning Research 2 (2002) 145–151

[13] F. Liu, X.T. Xu, L.J. Li, Q.H Wu, The Group Search Optimizer and its Application on Truss Structure Design, Fourth International Conference on Natural Computation (ICNC), (2008).