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Determining Optimal Location and Size of Diesel Generator and Wind Turbine in Simultaneous Mode

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***Abstract*— In this paper, Group Search Optimization (GSO) algorithm has been proposed to determine optimal location and size of diesel generator and wind turbine. For this propose, a novel multiobjective function has been suggested based on power loss cost and Cost of Energy Not Supplied (CENS) as well as costs of installation and operating resource. Case study has been performed on 37 bus test system and four scenarios and four cases introduced in this system. The studied parameters are: total system cost, installation cost, CENS, power loss cost and location and size of the placed units.**

Keywords*— Hybrid system, Diesel Generator, Wind Turbine, GSO algorithm.

I. INTRODUCTION

A wind/diesel or hybrid power system presents an opportunity to combine the conventional attributes of autonomous diesel electric generators with the advantages of renewable energy resources [1]. Economical electric generation with wind energy in remote areas has been under investigation for many years. For example, small battery charging wind plants were often used to provide electricity in many parts of the United States in the 1930s. In most cases, these units were replaced by electricity from a central grid. In other cases, diesel generators, which could provide power more reliably, in greater quantity and at reasonable cost, displaced the wind machines. With the rising cost and uncertainty of supply of oil in the mid-1970s, attention turned again to using wind machines to reduce fuel costs [2].

Detailed studies has been performed on hybrid system. In this section, the published works of hybrid system have been categorized in three groups; which are: diesel/other renewable sources, wind turbine/other renewable sources and wind/diesel.

In [3-5], researchers have designed hybrid system by considering diesel and other renewable sources. Ref.[3] presents an optimal design of a solar PV-diesel hybrid mini-grid system for a fishing community in an isolated island-Sandwip in Bangladesh using genetic algorithm. Ref.[4] reports on the investigating economic feasibility of a PV/diesel hybrid power systems in various climatic zones within South Africa. Ref.[5] is devoted to a renewable hybrid PV–diesel generator developed to supply power to a designated remote controlled FM transmitters located in remote locations.

In [6-9], placement of wind turbine and other renewable sources have been performed. The objective of Ref.[6] is to propose a series-parallel resonant high frequency inverter for stand-alone hybrid photovoltaic (PV)/wind power system in order to simplify the power system and reduce the cost. In [7], a laboratory study has been performed by combining wind and solar energies to generate electrical energy in the climate in Jordan. Ref.[8] presents the results of a wind/PV/Battery Energy Storage System (BESS) hybrid power system simulation analysis undertaken to improve the smoothing performance of wind and PhotoVoltaic (PV) power generation. In [9], a pre-feasibility of wind-PV-battery hybrid system has been performed for a small community in the east-southern part of Bangladesh.

In [10-13], the studies have been performed based on allocation of diesel generator and wind turbine. Ref.[10] presents a comparative study of reactive power control for isolated wind-diesel hybrid power system in three different cases with wind power generation by induction generator (IG), permanent-magnet induction generator (PMIG) and permanent-magnet synchronous generator. A dynamic programming method is used in [11] to generate the optimum operational option by maximizing the net cash flow of the plant. Results show that operational options can provide additional value to the hybrid power system when this operational flexibility is correctly utilized. The collection and analysis of 6 months of continuously recorded field data from a small remote wind-diesel power system at a coastal farm site has been reported in [12].

In this paper, designing hybrid system have been done based on diesel and wind energies by Group Search Optimization (GSO) algorithm. This context has been organized in five sections. The multiobjective function has been formulated in Section 2. Concept of GSO algorithm has been discussed in Section 3. Simulation results have been listed in several tables in Section 4. This work has been concluded in Section 5.

II. OBJECTIVE FUNCTION

Improving reliability and reduce power loss are the main challenges of distribution system designers. Thus in this paper, the multiobjective function has been formulated based on maximizing reliability and minimizing power loss cost (*CLOSS*). For this, the Cost of Energy Not Supplied (CENS) has been used index as reliability index. Unit installation are applied cost of installation and operation (CDG) to system. Then the proposed multiobjective function is as following,

$$OF = CENS + CLOSS + CDG \quad (1)$$

To calculate reliability indices, SAIDI and CENS, analytical method based on error modes and their effects (FMEA) is used [13]. Accordingly the mentioned parameters are calculated using Eqs. (2) to (3).

$$CENS_i = \left(C_{ns}\lambda_{sys}\frac{l_i}{l_t}\right)\left[\left(r_{loc}\frac{l_{loc,i}}{l_t}\right)\left(P_{loc,i}\right)+r_{rep}P_{rep,i}\right] \quad (2)$$

$$CENS_{sys} = \sum_{I=1}^{K} CENS_i \quad (3)$$

where:
CENSi: Cost of Energy Not Supplied due to an error in the *i*th region
λsys: Annual failure rate of system
l_i: Length of the *i*th region
l_t: Total length of feeder
r_{loc}: Average time for locating the fault
$l_{loc,i}$: The length of region which is de-energized for locating the fault due to an error in the *i*th region
$N_{loc,i}$: Total number of customers who are de-energized for locating the fault due to an error in the *i*th region
N_t: Total number of system customers
r_{rep}: Average time to repair a fault
$N_{rep,i}$: The number of customers who are de-energized for repairing the fault due to an error in the *i*th region
C_{ns}: The average cost of a 1 *KWh* outage
$P_{loc,i}$: The average outage active power for repairing the fault due to an error in the *i*th region
$P_{rep,i}$: The average outage reactive power for repairing the fault due to an error in the *i*th region.

III. GROUP SEARCH OPTIMIZATION ALGORITHM [14-15]

The population of the GSO algorithm is called a group and each individual in the population is called a member. In an *n*-dimensional search space, the *i*th member at the *k*th searching bout (iteration) has a current position $X_i^k \in R^n$, a head angle $\Phi_i^k = (\Phi_{i1}^k, \ldots, \Phi_{i(n-1)}^k) \in R^{n-1}$. The search direction of the *i*th member, which is a unit vector $\boldsymbol{D}_i^k(\Phi_i^k) = (d_{i1}^k, \ldots, d_{i(n-1)}^k) \in R^n$ that can be calculated from ϕ_i^k via a polar to Cartesian coordinate transformation.

$$d_{i_1}^k = \prod_{q=1} \cos\left(\phi_{i_q}^k\right) \quad (4)$$

$$d_{i_1}^k = \sin\left(\phi_{i_{(j-1)}}^k\right).\prod_{q=1} \cos\left(\phi_{i_q}^k\right) \qquad \left(j = 2,\ldots,n-1\right) \quad (5)$$

$$d_{i_1}^k = \sin\left(\phi_{i_{(j-1)}}^k\right) \quad (6)$$

In GSO, a group consists of three types of members: producers and scroungers whose behaviors are based on the PS model; and dispersed members who perform random walk motions. For convenience of computation, we simplify the PS model by assuming that there is only one producer at each searching bout and the remaining members are scroungers and dispersed members. The simplest joining policy, which assumes all scroungers will join the resource found by the producer, is used. In optimization problems, unknown optima can be regarded as open patches randomly distributed in a search space. Group members therefore search for the patches by moving over the search space. It is also assumed that the producer and the scroungers do not differ in their relevant phenotypic characteristics. Therefore, they can switch between the two roles.

A. Producer

At the kth iteration, let the producer's position denoted by $X_p^k = (x_{p1}^k, \ldots, x_{pn}^k)$. It scans three points around it to find a better position. First, the producer scans a point in front of it:

$$X_F = X_P^k + r_1 l_{\max} D_p^k\left(\phi^k\right) \quad (7)$$

Second, it scans a point on its right-hand side:

$$X_F = X_P^k + r_1 l_{\max} D_p^k\left(\phi^k + r_2\,\theta_{\max}/2\right) \quad (8)$$

Third, it scans a point on its left-hand side:

$$X_F = X_P^k + r_1 l_{\max} D_p^k\left(\phi^k - r_2\,\theta_{\max}/2\right) \quad (9)$$

where, r_1 is a random number normally distributed with mean 0 and standard deviation 1, r_2 is a random number uniformly distributed in[0,1].The y_{max} is max-pursuit angle, and the l_{max} is max-pursuit distance:

$$l_{\max} = \left\|U - L\right\| = \sqrt{\sum_{j=1}^{n}\left(U_j - L_j\right)^2} \quad (10)$$

where, U_j and L_j are the upper bound and lower bound of the search range.

If the producer finds that the best position in the three points is better than its current position, it moves to the best position and change its head angle as Eq.(9),where α_{max} is the max-turning angle. Otherwise, it stays at original position. If the producer fails to find a better point in a iterations, it scans front again as Eq.(12):

$$\phi^{k+1} = \phi^k + r_2\alpha_{\max} \quad (11)$$

$$\phi^{k+a} = \phi^k \quad (12)$$

B. Scrounger

In the computation, most of the members are chosen as scroungers. If the *i*th member is chosen as a scrounger at the *k*th iteration, it moves toward the producer with a random distance,

$$X_i^{k+1} = X_i^k + r_3.\left(X_p^k - X_i^k\right) \quad (13)$$

where, r_3 is a random sequence uniformly distribution in [0,1].

C. Ranger

The rest members in the group are rangers. If the *i*th member is chosen as a ranger at the *k*th iteration, it turns its head to a random angle as Eq.(9), and calculates the search direction using Eqs. (4-5), then moves to that direction with a random distance as the following:

$$l_i = a.r_1 l_{\max} \tag{14}$$

D. Solving the problem by the GSO algorithm

In Sections II-III, concepts of optimal diesel generator and wind turbine placement problem and GSO algorithm has been presented. In this section, the problem solution by GSO algorithm is discussed. The capacitor placement problem solution by GSO algorithm has been performed in nine steps:

Step 1. Generating initial members
Step 2. Randomly generated feasible discrete particles with position vectors
Step 3. Running load flow program
Step 4. Choosing a member as producer
Step 5. Performing the producer
Step 6. Choosing scroungers
Step 7. Performing the scroungers scrounging
Step 8. Dispersing the rest members to perform ranging
Step 9. Evaluating members

Fig.1 shows flowchart of optimal capacitor placement solution by the GSO algorithm

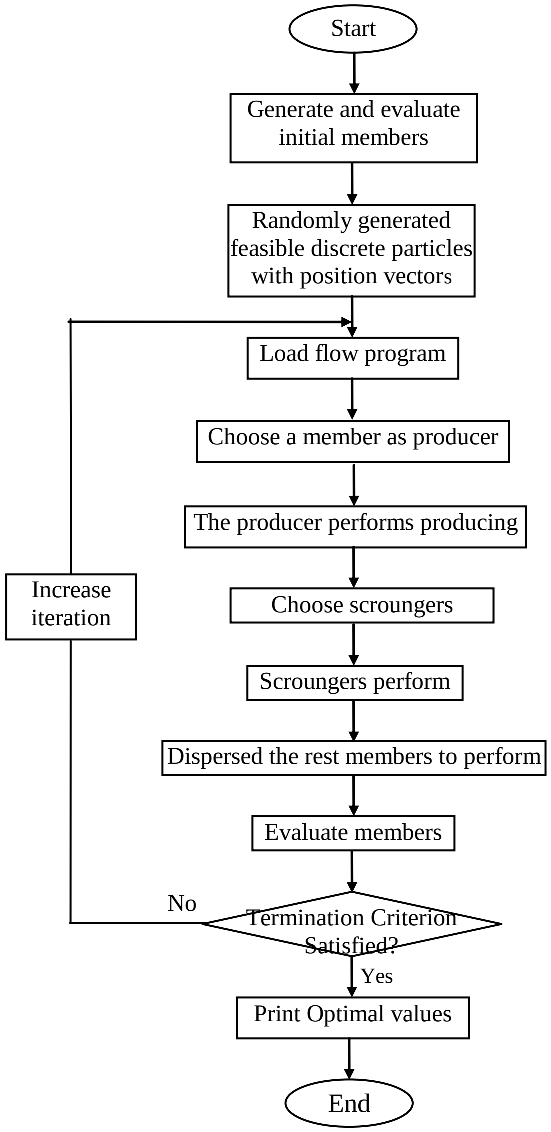

Fig. 1. Flowchart of the solving problem by the GSO algorithm

IV. CASE STUDY

IEEE 37-bus distribution network is selected as test system. Single line diagram of this system has been illustrated in Fig.2.

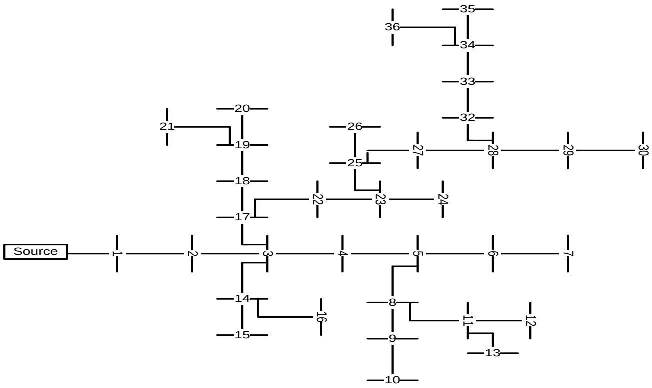

Fig. 2. Single line diagram of test system

Four scenarios have been introduced for the system:
Scenario I: Placement of one diesel generator
Scenario II: Placement of two diesel generators
Scenario III: Placement of three diesel generators
Scenario IV: Placement of four diesel generators
Four Cases have been defined for each scenario:
Case i: Placement of one wind turbine
Case ii: Placement of two wind turbines
Case iii: Placement of three wind turbines
Case iv: Placement of four wind turbines

A. Scenario I: Placement of one diesel generator

In first scenario, one diesel generator have been placed in the presence of one to four wind turbine. Results of first scenario have been listed in Table I.

TABLE I. RESULTS OF FIRST SCENARIO

Case	CENS	CDG	CLOSS	OF
i	27669232	1587608000	2394183800	4009461032
ii	27666419	1757182000	2194144724	3978993143
iii	27679056	1882546000	2074349995	3984575051
iv	27680491	1934319000	1974367759	3936367250

By considering results if Table I, it can be claimed that fourth case is the best solution. Table II ahows optimal location and size of the placed units.

TABLE II. OPTIMAL LOCATION AND SIZE OF UNITS IN FIRST SCENARIO

Case		1	2	3	4
DGen	Location	12	12	12	13
	Size	2000	2500	300	150
WT	Location	11	11 ،14	34 ،18 ،11	11 ،15 ،18 ،34
	Size	750	150 ،750	45،90 ،105	90 ،90 ،60 ،45

By considering results of above table, diesel generator is tendency to install in Bus 12 however is installed in bus 13 in fourth case. While usually wind turbine is placed in bus 11.

B. Scenario II: Placement of two diesel generators

In second scenario, two diesel generators are placed simultaneous with changing the number of wind turbine from one to four and their results have been presented in Table 3.

TABLE III. RESULTS OF SECOND SCENARIO

Case	CENS	CDG	CLOSS	OF
i	27678693	1775217000	2394257284	4446261221
ii	27677063	1969720000	2294336510	4291733573
iii	27680411	2082148000	2094367932	4204196343
iv	27675518	2204147000	1993966506	4225789024

By considering results of Table III, third and first cases present the best and worst solution, respectively. Cost of third case is 242064878, 87537230 and 21592681 *$* less than related value of first, second and fourth cases. Location and size of the installed diesel generator and wind turbine are visible in Table IV.

TABLE IV. OPTIMAL LOCATION AND SIZE OF UNITS IN SECOND SCENARIO

Case		1	2	3	4
DGen	Location	12 ،18	11 ، 12	13 ،12	13 ،35
	Size	50 ،100	50،50	100 ،50	250 ،2000
WT	Location	34	11 ، 12	11 ،12 ، 34	11 ،12 ،15 ، 34
	Size	750	90،750	75 ،15 ، 60	90 ،15 ،15 ، 300

In this scenario, diesel generator tends to install in bus 13 in more cases however in two cases are installed in bus 12. Wind turbine in more case (expect case i) tends to presence in bus 11.

C. Placement of three diesel generators

Table V consists of results of placement of three diesel generator for changing the number of wind turbine from one to four units.

TABLE V. RESULTS OF THIRD SCENARIO

Case	CENS	CDG	CLOSS	OF
i	27667501	2081285000	2394278112	4503230613
ii	27678228	2204147000	2194266740	4426091968
iii	27676662	2465654000	2094334289	4587664951
iv	27674835	2611441000	1894328667	4533444502

By considering results if Table V, second case presents the best solution for objective function while in none of the three studied parameters, this case do not offer the best solution. The cost of second case is 77138645, 161572983 and 107352534 $ less than related value of first, third and fourth cases, respectively. In this scenario, third case presents the best solution. Table VI illustrates the location and size of the placed units in third scenario.

TABLE VI. OPTIMAL LOCATION AND SIZE OF UNITS IN THIRD SCENARIO

Case		1	2	3	4
DGen	Loc.	11 ،12 ،13	31 ،13 ، 12	11 ،12 ،20	12 ،13 ،31
	Size	2000 ،400 ، 400	250 ، 500 ، 500	300 ،150 ، 200	100 ،50 ،150
WT	Loc.	11	34 ،15	11 ،12 ،15	11 ،12 ،15 ، 34
	Size	750	60 ،45	240 ،60 ، 300	60 ،105 ،240 ، 750

D. Scenario IV: Placement of four diesel generators

In the last scenario, allocation of four diesel generators and one to four wind turbines have been done and their results are visible in Table VII.

TABLE VII. RESULTS OF FOURTH SCENARIO

Case	CENS	CDG	CLOSS	OF
i	27678261	2022136000	2394257284	4444071545
ii	27677960	2389547000	2004328285	4421553245
iii	27680135	2411284000	1794392329	4233356464
iv	27677614	2612324000	1614243813	4254245427

By considering results of Table 7, third and first cases present the best and worst solution, respectively. Cost of third case is 210715081, 188196781 and 20888963 $ less than related value of first, second and fourth cases. Location and size of the installed diesel generator and wind turbine are visible in Table VIII.

TABLE VIII. OPTIMAL LOCATION AND SIZE OF UNITS IN FOURTH SCENARIO

Case		1	2	3	4
DGen	Loc.	11 ،13 ، 18 ،31	11 ، 12،20 ،34	11 ،15 ، 31 ،34	10 ،12 ،13 ،20
	Size	50،50 ،50 ، 100	100 ، 100 ، 250،200	100 ، 100،250 ، 200	50 ،600 ،300 ، 300
WT	Loc.	34	15 ،34	11 ،12 ،34	11 ،15 ،21 ،34
	Size	750	15 ،15	75 ،15 ،60	375 ،240 ،300 ، 90

V. CONCLUSION

In this paper, the placement of diesel generator and wind turbine has been performed by GSO algorithm. In case study, four scenarios and four cases have been introduced. From simulation results, we can be claimed:

Increase the number of units, technical feasibility, but may not necessarily be economically justified. Except in the first scenario in the rest scenarios, increasing the number of units may not be the best answer possible.

In three scenarios, first case has the worst solution. This fact indicates that the number of placement units is reasonably close relationship must exist and the number of diesel and wind are should not be statistically significant.

Third case in three scenarios present the best solution. The optimal solution obtains from simultaneous optimization of three objective function parameters.

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