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Optimal Distributed Generation and Capacitor Placement for Loss Minimization and Voltage Profile Improvement using Symbiotic Organisms Search Algorithm

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Abstract

In the present day power systems, Distributed generation (DG) technologies are becoming more significant due to the increased demand for electrical power. Integration of DG affects the performance of distribution network significantly. DG placement key benefits are power loss reduction and improved voltage profiles which are the objectives in this problem. This paper presents a new efficient technique called Symbiotic Organisms Search (SOS) which is based on the symbiotic interactions of the ecosystem living organisms for optimal location and sizing of DG and capacitor to achieve the objectives. IEEE 33-bus, 69-bus test systems are considered to validate the results of proposed technique and the simulation is carried out in MATLAB.

Keywords: Symbiotic Organisms Search (SOS), Real power loss, optimal location, optimal size, Distributed generation (DG)

1. INTRODUCTION

The interest of distributed generation (DG) for power systems is growing rapidly. Integration of DG's in the distribution systems is increasing from the last few years due to their technical, economical and environmental benefits. The most important is the power loss minimization [1], which improves the quality of the power distributed; also the increased load demand can be met. DG acts as alternative for residential, industrial and commercial application. Several definitions are defined for DG based on plant rating, technology used, generated voltage levels, point of connection, etc. Conclusion can be made that DG's are small scale power generators generally embedded in the distribution systems to get the advantage of rapid load demand meeting and power loss reduction [2-3]. The Electric Power Research Institute (EPRI) defined distributed generation as the generation from "a few kilo-watts to 50 MW". Distributed generation generally consists of different types of renewable energy sources. Some technologies like photovoltaic, wind turbines, fuel cells, micro-turbines, gas turbines, reciprocating engines etc are used as DG technologies. Also depending upon the type of power they deliver, DG's are classified into following types

Type 1: DG's that produce only active power (e.g. PV, micro turbines, fuel cells)

Type 2: DG's that produce only reactive power (e.g. capacitors, synchronous compensators)

Type 3: DG's that produce both active and reactive power (e.g. synchronous generators)

Type 4: DG's that produce active power by consuming reactive power (e.g. induction generators)

The major reasons for a customer to install a DG are: they are used generate a customer's entire power supply for peak shaving or for standby or emergency generation, as a green power source or for increased reliability. Their placement affects the power flow and voltage conditions of the distribution systems. Their impact may be positive or negative. Positive impacts like loss reduction, voltage profile improvement, power quality improvement, improved reliability can be obtained by placing them at optimal locations and with optimal sizes. If they are placed at non optimal locations and sizes they will lead to negative impacts like increased loss, bad voltage profile and increased capital. IEEE std. 1547 defines the technical requirements for interconnecting the DG's in the power systems. In practice, in the distribution network, load pattern is varying with time. The optimal location and size of DG determined under invariant loads may not be optimal under time-varying loads and the optimal DG size may vary with varying load demand. But in practice, it is not economically feasible to change the DG size with changing load demand. Therefore, for planning purpose, an optimal size and location of DGs can be determined by considering peak, average, or combination of the two loading conditions to get the maximum benefit of DGs

In literature there are many techniques for determining optimal location and size of DG's to be connected in the distribution systems. An analytical approach was used for determining the optimal allocation of DG's [4]. An improved multi-objective

harmony search algorithm was employed for optimal placement of DG's [5]. Kalman filter approach was used in [6]. Bacteria foraging optimization [7], a hybrid modified shuffled frog algorithm and differential evolution algorithm were employed for determining the optimal location and sizes of DG's with respect to power loss minimization [8]. Another research work included a hybrid of genetic algorithm (GA) and particle swarm optimization method for multi-objective sizing and locations of DG's [9]. Authors [10] implemented artificial bee colony (ABC) algorithm for solving optimal DG placement problem. Embedded Meta Evolutionary-Firefly Algorithm (EMEFA) [11] was applied for DG sizing and allocation.
In this paper a new meta-heuristic optimization technique, Symbiotic Organisms Search (SOS) algorithm is implemented for finding optimal locations and sizes of DG's of Type 1 and Type 2 to get the real power loss minimization and voltage profile improvement.

The objectives considered are the Real power loss minimization and voltage profile improvement. Here both locations and sizes are obtained simultaneously rather than a two stage methodology in which first optimal location is found out and follows the size. The proposed algorithm is implemented on standard IEEE 33 and 69 bus distribution systems.

2. PROBLEM FORMULATION

2.1 Objective function:

The main goal is to find out the optimal locations and sizes of DG to be placed in distribution systems by which maximum real power loss reduction and voltage profile improvement are obtained.
The objective function is formulated as

$$OF = \min\left(f_1 + f_2\right) \tag{1}$$

Where, f_1 is the objective of minimizing real power loss and f_2 is the objective of improving the voltage profile i.e. minimization of voltage deviations, and they are formulated as below

$$f_1 = \sum_{i=1}^{n} I_i^2 R_i \tag{2}$$

$$f_2 = \left|V_1 - V_i\right| \tag{3}$$

Where 'n' is the total number of branches, I_i and R_i are the current and resistance of the ith branch. The current I_i will comprises of two components, active (I_a) and reactive (I_r) components of the branch current.

2.2 Constraints:

The operating constraints are as follows

- Voltage constraint

$$V_{\min} \le V_i \le V_{\max} \tag{4}$$

Where V_i is the voltage magnitude at i[th] bus, V_{min} and V_{max} are the minimum and maximum voltages.

- Power balance constraint

$$P_s + \sum_{k=1}^{ndgs} P_{DG} = P_d + P_{loss} \tag{5}$$

Where, Ps and P_{DG} are the powers from substation and DG. P_d is the total load demand and P_{loss} is the Total loss, '*ndgs*' are the number of DG's placed.

- Distributed generation capacity limits

$$P_{DG}^{\min} \le P_{DG} \le P_{Dg}^{\max} \tag{6}$$

$$Q_{DG}^{\min} \le Q_{DG} \le Q_{Dg}^{\max} \tag{7}$$

3. SYMBIOTIC ORGANISMS SEARCH (SOS) ALGORITHM

3.1. Introduction

A robust meta-heuristic algorithm known as symbiotic organisms search (SOS) algorithm was developed by Min-Yuan Cheng and Doddy Prayogo in the year 2014, to solve various numerical optimization and engineering design problems [12]. The algorithm is inspired by the symbiotic relationships that take place between two organisms in the ecosystem for their survival. In ecosystem, organisms rarely live in separation due to dependence on others for their survival. The word symbiosis is a Greek word which means 'living together'.

There exist three types of symbiotic relations between the organisms in the nature. They are mutualism, commensalism and parasitism. SOS algorithm uses all these phases for searching an optimal solution in a given search space.

Mutualism is a relation in which two organisms are benefited by their mutual interaction. In commensalism between the two organisms, one organism is benefited by the other and the later is neither benefited nor affected by the benefited one. In parasitic relation between two organisms, one is benefited and the second is harmed effectively.

SOS algorithm starts with an initial population called Ecosystem. The algorithm performs all the above three phases on the ecosystem and the operation continues till the termination criteria are met. The phases are explained clearly below.

3.2. Mutualism

In mutualism phase two random organisms from the ecosystem, X_i and X_j are made to interact with each other with the idea of increasing their survival. As a result of their interaction new candidate solutions are formed from X_i and X_j, which are modeled in equations (8) and (9).

$$X_{inew} = X_i + rand(0,1) * (X_{best} - Mutual\_Vector * BF1) \tag{8}$$

$$X_{jnew} = X_j + rand(0,1) * (X_{best} - Mutual\_Vector * BF2) \tag{9}$$

$$\text{Where } Mutual - Vector = \frac{X_i + X_j}{2} \tag{10}$$

rand (0, 1) in equations (8) and (9) is a vector of random numbers. Here benefit factors *BF1*, *BF2* are usually 1 or 2. These factors give the level of benefit to each organism which determines whether an organism is partially or fully benefitted from the interaction. Equation (10) shows a vector called Mutual- Vector which represents the relationship characteristic between organisms X_i and X_j. The part of equation (X_{best} -*Mutual_Vector*), reflects the mutual effort to achieve the goal of increasing survival advantage. If the new candidate solutions have better values than the original solutions, they replace the original solutions in the ecosystem.

3.3 Commensalism

Similar to mutualism phase two random organisms X_i and X_j from the ecosystem are allowed to interact in commensalism phase. In this interaction organism X_i benefits by the interaction, but organism X_j neither benefit nor suffers from the relationship. New candidate solution for X_i is calculated as shown by equation (11)

$$X_{inew} = X_i + rand(-1,1) * (X_{best} - X_j) \tag{11}$$

The benefit advantage in this case is provided by (X_{best} –X_j) in which the organism X_j provides maximum benefit to organism X_i in terms of survival.

3.4 Parasitism

In parasitism phase, one of the randomly selected organisms from the ecosystem X_i acts as a "Parasite-Vector". Parasite-Vector is created in the search space by duplicating organism X_i, then modifying the randomly selected dimensions using a random number. The newly formed parasite fights for survival with the organism X_j. If X_j has lesser fitness than the parasite, then the parasite kills the organism X_j and takes its place in the ecosystem.

The flow chart of the SOS algorithm for DG placement is shown below Fig. 1. Here it is shown only for DG sizes, for locations the same follows simultaneously.

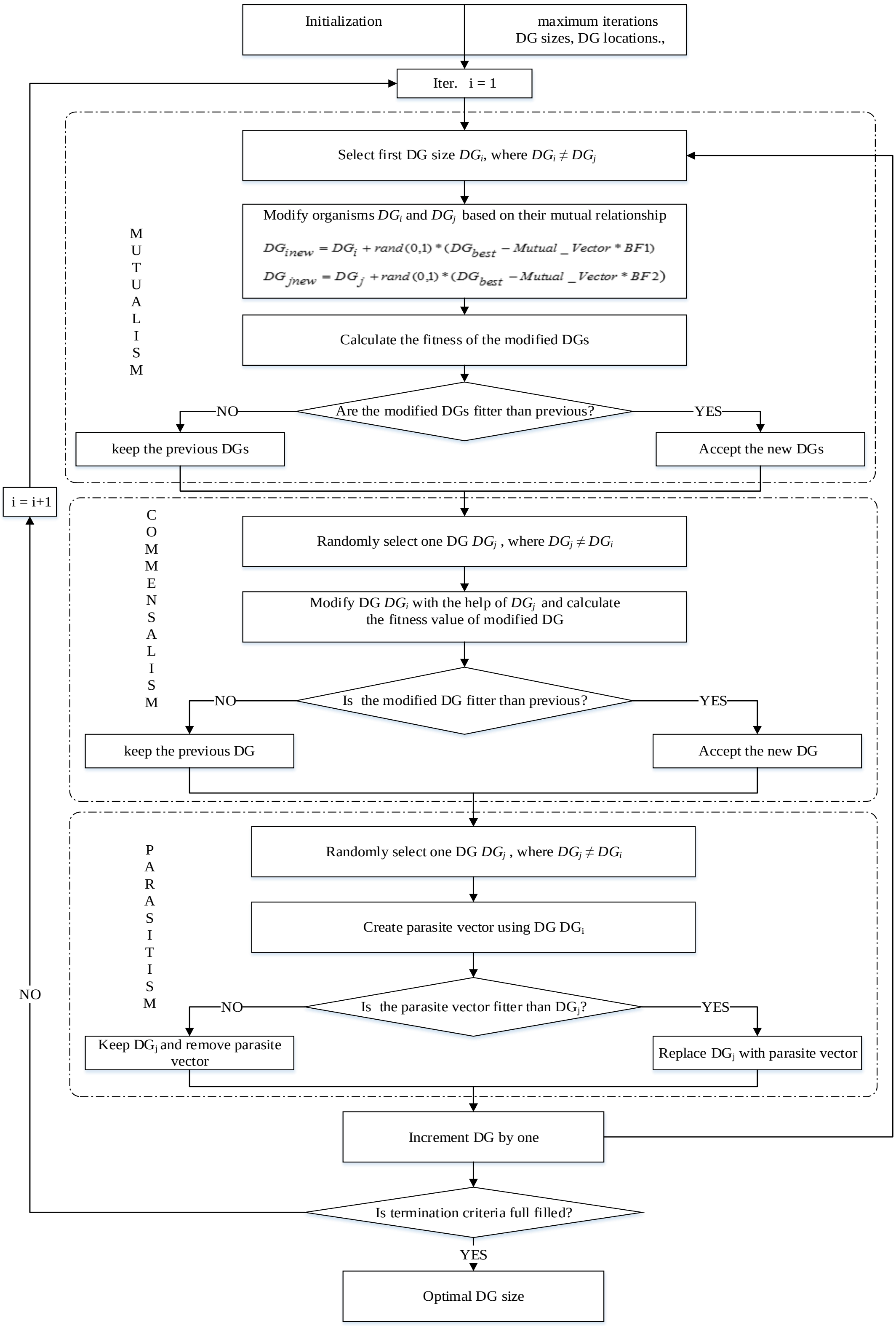

Figure 1. Flow chart of SOS algorithm for DG placement

4. TEST SYSTEMS AND SIMULATION RESULTS

First load flows are carried out to get power losses before placing DG's. Due to the high R/X ratio and distributed nature of the distribution systems, conventional Newton-Raphson (N-R) and Gauss-Seidel (G-S) methods do not converge. In this paper, distribution power flow method [13], which uses Bus injection to branch current matrix (BIBC) and Branch currents to bus voltages (BCBV) matrix is used for power flows to get the losses. After getting losses, optimal DG placement is done by SOS algorithm to minimize them. The simulation is done for different types of DG's. The simulation is carried out in Matlab R2013a software.
Parameters taken for simulation in this paper are

Eco size=50
Beneficial factors= 1 or 2
DG min= 50 KW and 50 KVAr
DG max=5000 KW and 5000 KVAr

4.1 IEEE 33 bus distribution system

This is a radial distribution system; its single line diagram is shown in Fig. 2. and the corresponding data is given below

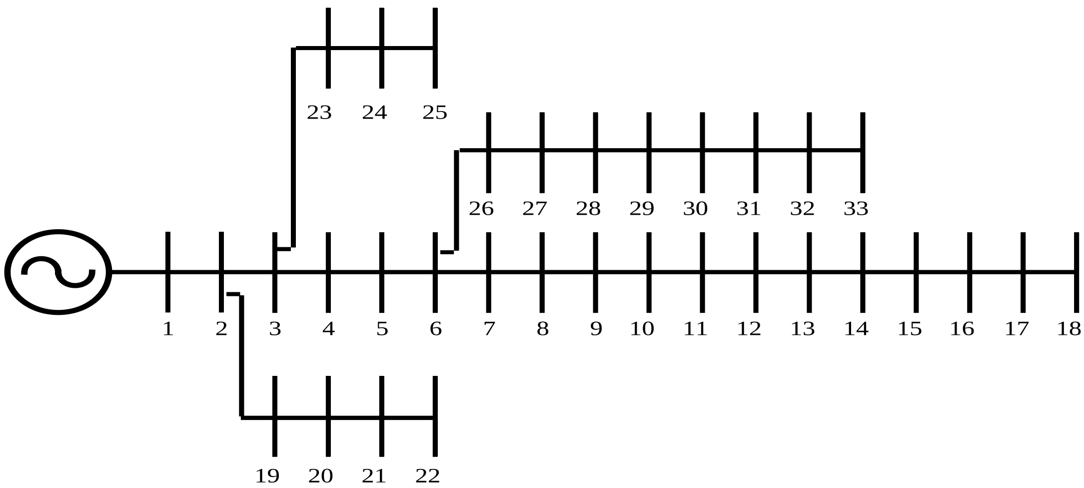

Figure 2. IEEE 33-bus distribution test system.

This 33 bus test system has the following data [14]:

Buses : 33
Branches: 32
Base voltage: 12.66 KV
Base MVA: 100
Total Load connected: 3.715 MW and 2.3 MVAr.

Load flows are done in Matlab and the results are shown in Table 1

4.2 IEEE 69 bus distribution system

The single line diagram of the system is shown in Fig. 3. and the corresponding data is given below [15]

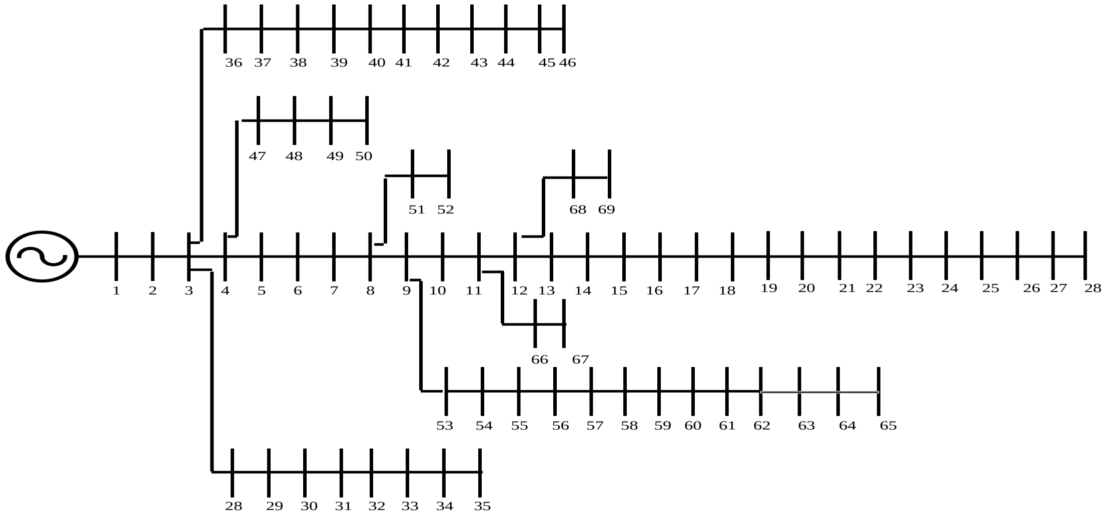

Figure 3. IEEE 69-bus distribution test system

System data: Buses : 69

Branches: 68

Base voltage: 12.66 KV

Base MVA: 100

Total Load connected: 3.80 MW and 2.694 MVAr

Load flows are done in the Matlab and the results are shown in Table 1

Table 1. Load flow results

Bus system	Active current component loss P_{La}(KW)	Reactive current component loss P_{Lr}(KW)	Total real power loss P_{Lt} (KW)
33	135.942	66.724	202.666
69	152.826	71.715	224.541

4.3 DG placement results

4.3.1 DG and capacitor placement in IEEE 33 bus system

As already discussed, by placing Type 1 DG the active currents flowing in the lines are compensated and by placing Type 2 DG the reactive currents flowing in the lines are compensated. The local active and reactive loads connected at the buses can be compensated. As a result, the real power loss associated with active and reactive components of the branch currents can be reduced. Here by the proposed algorithm

both optimal locations and sizes of DG are obtained simultaneously rather than a two stage methodology. Here one DG placed represents the simultaneous placement of one DG of Type 1 and Type 2 (capacitor).
The DG placement results are shown in Table 2

Table 2. Results of 33 bus system with DG's of Type 1 and Type 2 (capacitor)

<table>
<tr><th rowspan="2">Number of DG's placed</th><th rowspan="2">optimal Type1 location</th><th rowspan="2">optimal Size (MW)</th><th rowspan="2">Optimal Type2 (capacitor) location</th><th rowspan="2">Optimal Size (MVAr)</th><th colspan="3">Loss with DG's (KW)</th><th rowspan="2">Loss Without DG (P_{Lt}) (KW)</th><th rowspan="2">% reduction in loss P_{Lt}</th></tr>
<tr><th>Active P_{La}</th><th>Reactive P_{Lr}</th><th>Total P_{Lt}</th></tr>
<tr><td>1</td><td>6</td><td>2.5174</td><td>30</td><td>1.2508</td><td>40.079</td><td>11.715</td><td>51.795</td><td rowspan="10">202.666</td><td>74.443</td></tr>
<tr><td rowspan="2">2</td><td>13</td><td>0.8399</td><td>12</td><td>0.4524</td><td rowspan="2">23.164</td><td rowspan="2">5.311</td><td rowspan="2">28.475</td><td rowspan="2">85.949</td></tr>
<tr><td>30</td><td>1.1402</td><td>30</td><td>1.0411</td></tr>
<tr><td rowspan="3">3</td><td>6</td><td>1.1736</td><td>3</td><td>0.8079</td><td rowspan="3">15.223</td><td rowspan="3">3.348</td><td rowspan="3">18.572</td><td rowspan="3">90.836</td></tr>
<tr><td>14</td><td>0.6033</td><td>14</td><td>0.3351</td></tr>
<tr><td>31</td><td>0.6798</td><td>30</td><td>0.9923</td></tr>
<tr><td rowspan="4">4</td><td>3</td><td>1.2687</td><td>7</td><td>0.3776</td><td rowspan="4">10.989</td><td rowspan="4">1.174</td><td rowspan="4">12.164</td><td rowspan="4">93.998</td></tr>
<tr><td>7</td><td>0.8005</td><td>14</td><td>0.2720</td></tr>
<tr><td>14</td><td>0.5859</td><td>24</td><td>0.4715</td></tr>
<tr><td>31</td><td>0.6944</td><td>30</td><td>0.8947</td></tr>
</table>

In the above table, PLa is the active component loss of real power loss and PLr is the reactive component loss of real power loss. PLt is the total real power loss. From the results, it is observed that, the active component current loss of real power loss is getting reduced from 135.942 KW to nearly 10 KW , and the reactive current loss of real power loss getting reduced from 66.724 KW to nearly 1 KW by placing DG's and capacitors simultaneously. The total real power loss reduction of above 90 % can be obtained by this placement. The voltage profile of this 33 bus system without placing and after placing of DG's of Type 1 and Type 2 (capacitor) is shown in figure 3.

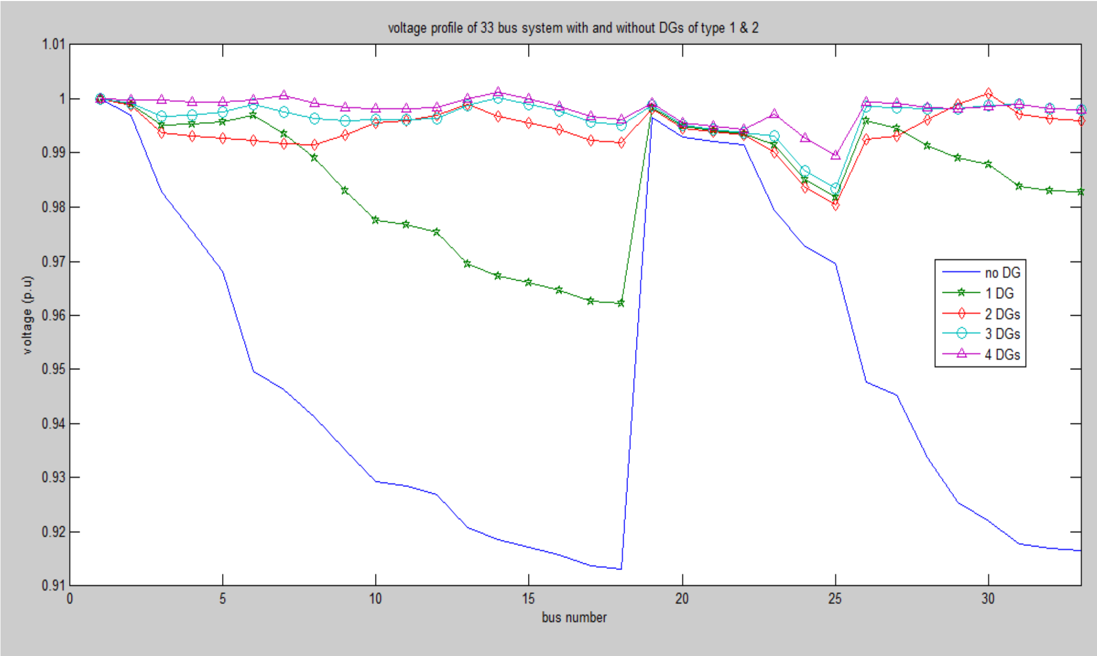

Figure 4. Voltage profile of 33 bus system with and without DG's of Type 1 and Type 2

The minimum voltages at the buses obtained by this placement are shown in Table 3.

Table 3. Buses with minimum voltages after DG placement

Number of DG's placed	Min voltage p.u	Bus number
1	0.9622	18
2	0.9804	25
3	0.9834	25
4	0.9895	25

4.3.2 DG and capacitor placement in IEEE 69 bus system

The theory is similar to that of in section 4.3.1. The DG placement results are shown in Table 4.

Table 4. Results of 69 bus system with DG's of Type 1 and Type 2 (capacitor)

Number of DG's placed	optimal Type1 location	optimal Size (MW)	Optimal Type2 (capacitor) location	Optimal Size (MVAr)	Loss with DG's (KW)			Loss Without DG (P_{Lt}) (KW)	% reduction in loss P_{Lt}
					Active P_{La}	Reactive P_{Lr}	Total P_{Lt}		
1	61	1.8283	61	1.3005	15.506	7.257	22.763	224.541	89.862
2	17	0.5158	17	0.3487	4.767	2.438	7.206		96.790
	61	1.7357	61	1.2392					
3	9	0.7159	17	0.2762	3.461	1.531	4.992		97.776
	17	0.4833	61	1.1900					
	61	1.6263	67	0.2696					

From the results, it is observed that, the active component current loss of real power loss is getting reduced from 152.826 KW to nearly 3 KW , and the reactive current loss of real power loss getting reduced from 71.715 KW to nearly 1 KW by placing DG's and capacitors simultaneously. The total real power loss reduction of nearly 98 % can be obtained by this placement. The voltage profile of this 69 bus system without placing and after placing of DG's of Type 1 and Type 2 (capacitor) is shown in figure 4.

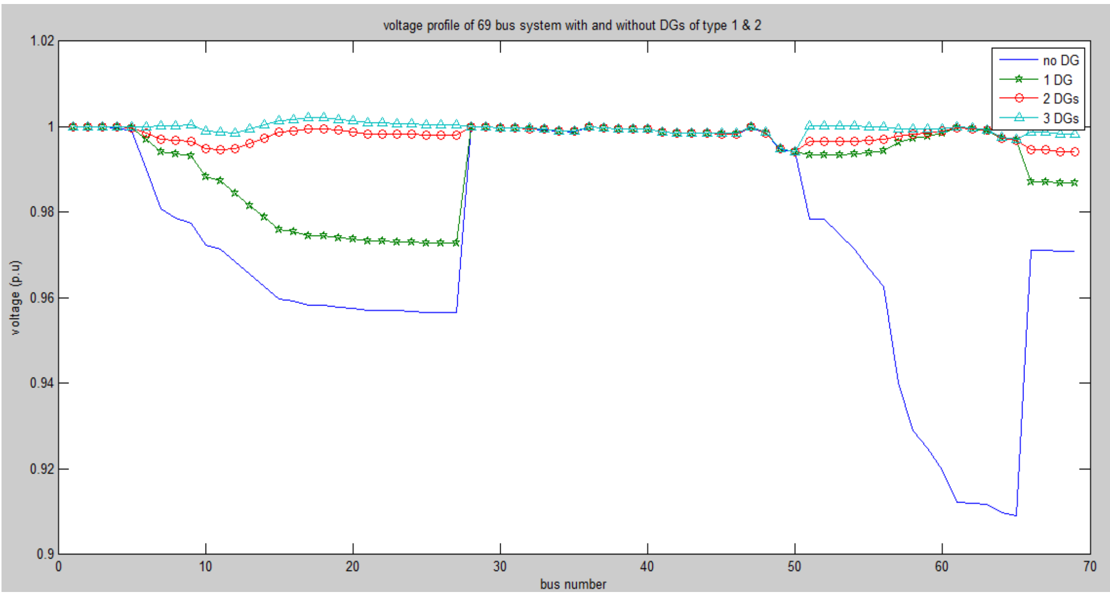

Figure 5. Voltage profile of 69 bus system with and without DG's of Type 1 and Type 2

The minimum voltages at the buses obtained by this placement are shown in Table 5.

Table 5. Buses with minimum voltages after DG placement

Number of DG’s placed	Min voltage p.u	Bus number
1	0.9728	27
2	0.9943	50
3	0.9943	50

CONCLUSION

This paper presented a new meta-heuristic approach called Symbiotic Organisms Search (SOS) for placement and sizing of DG’s. The objective considered is minimizing the real power loss and to improve the voltage profile. The SOS takes the greatest advantage that; it does not require any algorithm controlling parameters and it is easy to implement. In this paper both optimal locations and sizes are determined simultaneously rather than a two stage methodology. The proposed SOS technique is applied on IEEE 33 and 69 bus test systems. The simulation is carried out in MATLAB programming environment. The simulation results obtained shows the effectiveness of the proposed technique in minimizing the losses and obtaining the objectives. The methodology presented can be easily implemented in the practical distribution systems for planning and operational studies.

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