



APPLICATION OF SLIME MOULD ALGORITHM FOR OPTIMAL ALLOCATION OF DATACOM AND PV SYSTEM IN REAL EGYPTIAN RADIAL NETWORK

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Abstract

The aim of this paper to assess the optimal site and size of photovoltaic (PV) generation-based DG along with Distribution Static Synchronous Compensator (DSTATCOM) in the real distribution network East Delta Network (EDN). In this paper, a new optimization method called Slime Mold Algorithm (SMA) simulates the oscillation mode of a slime mold in nature. DSTATCOMs and PV modules are applied to reduce losses, voltage profile and enhance stability while meeting the limitations of equality and inequality in the system. Evaluation is provided with only PV modules installed, DSTATCOMs installed only and PV modules installed with DSTATCOM. The simulations verified that the optimization of PV modules combined with DSTATCOMs can significantly enhance system performance compared to PV only modules or DSTATCOMs and the effectiveness of the proposed algorithm for allocating PVs and DSTATCOMs in terms of objective functions.

© 2021 Published by Faculty of Engineering – Sohag University. DOI: 10.21608/SEJ.2021.155557.

Keywords: PV; DSTATCOM; Slime Mould Algorithm; Power losses; Real Distribution system.

1. INTRODUCTION

Integration of renewable distributed generators (RDGs) has more attention for researchers, and decision makers in electrical sectors for many technical, economic, environmental aspects as well is to cover the increasing load growth [1-3]. To maximize utilization of RDGs such as solar wind turbines, PV (photovoltaic), Hydro, and biomass etc. Numerous researchers focus on the techniques for enhancement of current network and its topology [4, 5] It worth mentioning that distribution networks (RDNs) has a high R/X ratio compared with transmission system. Thus, RDNs suffer from poor power quality [6-8]. Inclusion the reactive power compensators paly important to solve the poor power quality problem of the RDNs. The reactive power compensator includes several distributed Flexible AC transmission systems (DFACTS) such as DSTATCOM, unified power quality conditioner and, Distribution Static Var Compensator (D-SVC),etc. [9-12].

DSTATCOM is a powerful device that is included in RDNs to control bus voltage. Moreover, DSTSTCOM has been integrated into RDNs for many tasks such as mitigating harmonics, reducing loss, improving stability, power factor correction, and reducing voltage deviations. [13]. All these tasks have been accomplished due to

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the DSTATCOM ability for injecting and absorbing reactive power to system very fast, dynamical responses made its application very wide within the field [14]. A comprehensive review has been presented in [15-17] to indicate the applications of the D-STATCOM in electrical system for performance enhancement.

Nowadays, the PV based DGs have been widely embedded in RDNs compared to the other renewable resources to supply the system of the required power instead of the conventional sources [18, 19]. The integration of PV based DGs in electrical networks can provide peak shaving, reduce overloading of transmission lines, and reduce the greenhouse emissions. However, inclusion the PV system in an improper locations will affect the power quality of the RDNs [20, 21]. Several efforts have been introduced for optimal inclusion the PV based DGs where the authors in applied for inclusion the PV and DSATCOM using Modified Ant Lion Optimizer under uncertainties of load and solar radiation [22]. An improved ecosystem algorithm has been implemented for optimal sizing PV, wind turbine (WI) and fuel cell [23]. Equilibrium optimizer (EO) has been employed for optimal size and site of the PV and WT in a Micro-grid [24]. The authors in [25] applied the Pathfinder Algorithm (PFA) to assign the PV units in multi-lateral RDNs. DSTATCOM is an efficient controller and it plays a significant role for improving the system performance. Several efforts have been presented for optimal sizing and placement the DSTATCOM in RDNs such as immune algorithm [26], Particle Swarm Optimization algorithm [27], JAYA optimization [28], bat algorithm [29], harmony search algorithm [30], improved sine cosine algorithm [31] and grey wolf optimizer [32]

SMA is an efficient algorithm that simulates the behavior and morphological changes of a slime mold. Meanwhile, the use of weights in SMA is to simulate the positive and negative reactions produced by slime mold during foraging, thus forming three different types of morphs. [33]. In this paper, SMA is used to find the best locations and volumes of PV and DSTATCOMs in the true Egyptian distribution network. The paper's organization is listed as follows: Section 2 illustrates the formulation of the problem. Section 2 describes the steps for the SMA technique. Section 3 explains the simulation results. Section 4 depicts the final conclusions.

2. Problem Formulation

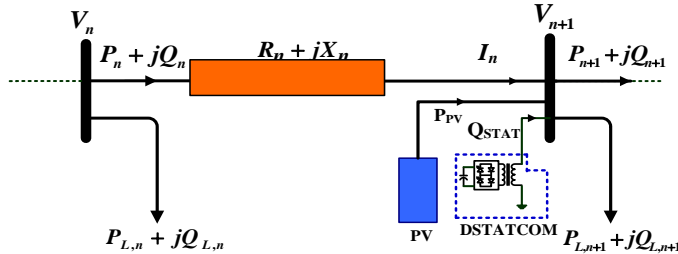


Fig.1. A simple RDNs with units and DSTATCOMs.

The RDNs consist of a set of branches, balanced power nodes, and constant loads. Equations (1) and (2) are used to describe the power flow solution with the integration of DSTATCOM and PV modules and are illustrated in Fig.1.

$$P_{n+1} = P_n - P_{L,n+1} - R_{n,n+1} \left(\frac{P_n^2 + jQ_n^2}{|V_n|^2} \right) + P_{PV} \quad (1)$$

$$Q_{n+1} = Q_n - Q_{L,n+1} - X_{n,n+1} \left(\frac{P_n^2 + jQ_n^2}{|V_n|^2} \right) + Q_{DSTAT} \quad (2)$$

where, $X_{n,n+1}$ is the reactance of the line while $R_{n,n+1}$ denotes its resistance of the line, respectively. Q_n and P_n denote the flows of active and reactive capabilities, respectively. Real power losses are formulated as follows:

$$P_{loss(n,n+1)} = R_{n,n+1} \left(\frac{P_n^2 + jQ_n^2}{|V_n|^2} \right) \quad (3)$$

The stability index is given using (4)

$$VSI_{(n+1)} = |V_n|^4 - 4(P_{m+1}X_n - Q_{n+1}R_n)^2 - 4(P_{n+1}X_n + Q_{n+1}R_n)|V_n|^2 \quad (4)$$

The voltage deviations of RDN is given using (5)

$$VD = \sum_{h=1}^n |V_n - 1| \quad (5)$$

where, n represents number of buses.

2.1. Objective function

The purpose of installation the DSTATCOMs along with PV system is reducing the loss as well as the voltage profile and stability boosting. Therefore, the fitness function is is considered as follows:

$$k = L_1k_1 + L_2k_2 + L_3k_3 \quad (6)$$

where, L_1 , L_2 and L_3 denotes the weighting factors which can be formulated using (7):

$$|L_1| + |L_2| + |L_3| = 1 \quad (7)$$

where k_1 denotes the first fitness function of the power losses of the multi-target function which represents the total reduction of active energy losses and can be found as follows:

$$k_1 = \frac{(P_{T,loss})_{PV\&DSTATCOM}}{(P_{T,loss})_{base}} \quad (8)$$

where, $(P_{T,loss})_{PV\&DSTATCOM}$ is the power losses with optimal integration of PV or DSTATCOM. $(P_{T,loss})_{base}$ denotes the power loss with at base case. k_2 represents the of the boosting voltage profile which has been formulated as:

$$k_2 = \frac{(VD)_{PV\&DSTATCOM}}{(VD)_{base}} \quad (9)$$

where, $(VD)_{PV\&DSTATCOM}$ is the VD with optimal integration of PV or DSTATCOM. $(VD)_{base}$ denotes the VD at base case.

k_3 is the voltage stability boosting which can be given using (10) as follows:

$$k_3 = \frac{1}{\sum_{i=1}^{nb} |VSI(i)|_{PV\&DSTATCOM}} \quad (10)$$

2.2. The System constraints

The system limitations are classified as follows:

2.2.1. Equality constraints

$$P_s + \sum_{i=1}^{np} P_{PV} = \sum_{h=1}^n P_D(h) + \sum_{j=1}^{nl} P_{loss}(j) \quad (11)$$

$$Q_s + \sum_{i=1}^{nc} Q_{DSTATcom}(i) = \sum_{h=1}^n Q_D(h) + \sum_{j=1}^{nl} Q_{loss}(j) \quad (12)$$

where, P_s is the active injected power at slack bus while Q_s the reactive power. P_D the active demand while Q_D is the reactive load, respectively. nc denotes number of DSTATCOMs. np represents number of PV units.

2.2.2. Inequality constraints

$$V_{min} \leq V_i \leq V_{max} \quad (13)$$

$$\sum_{i=1}^{nc} Q_{DSTATCOM}(i) \leq \sum_{i=1}^n Q_D(i) \quad (14)$$

$$\sum_{i=1}^{np} P_{PV}(i) \leq \sum_{i=1}^n P_D(i) \quad (15)$$

$$I_n \leq I_{max,n}, \quad n = 1,2,3 \dots, N_b \quad (16)$$

where, V_{min} and V_{max} are the lower limit and upper voltage limit. $Q_{DSTATCOM}$ is injected with reactive power by DSATACOM. P_{PV} is injected with reactive power by PV units.

2.3. Slime Mould Algorithm (SMA)

This algorithm simulates a method for finding multiple heads in a vesarium that inhabits cold and wet places. In this technique, weights approach to negative and positive feedbacks created by sticky mold during the foraging process. During this stage, the slurry can determine the best food-gathering path in a superior way. The organic matter in the slime mold searches for food. Then it encircles it and releases enzymes for its consumption. In the migration stage, the anterior end expands into a fan shape along with a venous network that allows the cytoplasm to slide inward. An intravenous network consists of using multiple food sources simultaneously to form to connect them. In this mechanism, a reproductive wave is formed when a vein approaches a food source. The mathematical representation of MSA is formulated as follows:

2.3.1. Approach food

The shrinkage mode of a slime mold can be represented as follows [34]:

$$X(t+1) = \begin{cases} X_b(t) + vb \cdot (W \cdot X_A(t) - X_B(t)), & r < p \\ v_c \cdot X(t), & r \geq p \end{cases} \quad (17)$$

where v_b denotes a parameter with a range of $[-a, a]$, v_c is reduced from one to zero. t denotes the current iteration, X_b is the location of slime mould with the highest odor concentration currently assigned, X denotes the location of slime mould, X_A and X_B are two individuals randomly selected from the swarm, W represents the weight of slime mould. The p is a parameter which can be obtained as follows:

$$p = \tanh|S(i) - DF| \quad (18)$$

where $i \in 1, 2, \dots, n$, $S(i)$ denotes the objective function of \vec{X} , DF is the best objective function obtained in all iterations. vb is calculated as follows:

$$v_b = [-a, a] \quad (19)$$

$$a = \operatorname{arctanh} \left(- \left(\frac{t}{\max_t} \right) + 1 \right) \quad (20)$$

The W is depicted using (21) as follows:

$$W = \begin{cases} 1 + r \cdot \log \left(\frac{b^F - S(i)}{b^F - w^F} + 1 \right), & \text{condition} \\ 1 - r \cdot \log \left(\frac{b^F - S(i)}{b^F - w^F} + 1 \right), & \text{others} \end{cases} \quad (21)$$

$$\text{SmellIndex} = \text{sort}(S) \quad (22)$$

where *condition* indicates that $S(i)$ classifies the first half of the population, r represents a random parameter in rang $[0,1]$, bF represents the optimal objective function, wF represents the worst objective function.

2.4. Wrap food

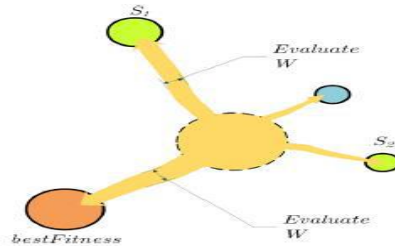


Fig. 2. Evaluation of fitness.

The case simulates a slime mold to control research patterns related to food quality. If the food concentration is contained, the weight near the area is greater; when the concentration of food is low, the weight of the area will decrease, and thus it will turn to explore other areas. Fig. 2 illustrates the process of evaluating the fit values of a slime mold. Based on the principle above, the mathematical formula for updating a slime mold site is as follows:

$$X^* = \begin{cases} \text{rand} \cdot (UB - LB) + LB, & \text{rand} < z \\ X_b(t) + v_b \cdot (W \cdot X_A(t) - X_B(t)), & r < p \\ vc \cdot X(t), & r \geq p \end{cases} \quad (23)$$

where LB is the lower bound of control variable while UB is its maximum, rand and r are random variables which equal to $1 \geq r, \text{rand} \geq 0$.

2.5. Grabble food

The v_b varied randomly within rang $[-a, a]$ and gradually go to zero with as increasing the iterations number. The value of vc varied between $[-1, 1]$ and reached to zero eventually.

Algorithm 1 Pseudo-code of SMA

Define the parameters of SMA the maximum number of iterations.

Generate initial locations of slime mould $X_i (i = 1, 2, \dots, n)$;

While ($t \leq \text{Max_iteration}$)

evaluate the objective function for each slime mould;

Update *bestFitness*, X_b

Obtain the W using Eq. (21);

For each search portion

Update p, v_b, v_c ;

Update locations by Eq. (23);

End For

$t = t + 1$;

End While

Return *bestFitness*, X_b ;

3. Simulation Results

TABLE.1. PARAMETERS OF SYSTEM

Specification	Value
Max iteration	100
slime moulds	25
Voltage bounds	$0.90 \leq V_i \leq 1.05 \text{ p.u}$
PV sizing bounds	$0 \leq P_{DG} \leq 23 \text{ MW}$
DSTATCOM sizing bounds	$0 \leq Q_{STATCOM} \leq 14 \text{ MVar}$

The numerical results are shown in this part where the positioning and evaluation of PV modules and DSTATCOMs are made using SMA distribution in the East Delta Network (EDN) as part of the Unified Egyptian Network (UEN) network. System constraints and SMA parameters are tabulated in Table 1. EDN system data are provided in [34].

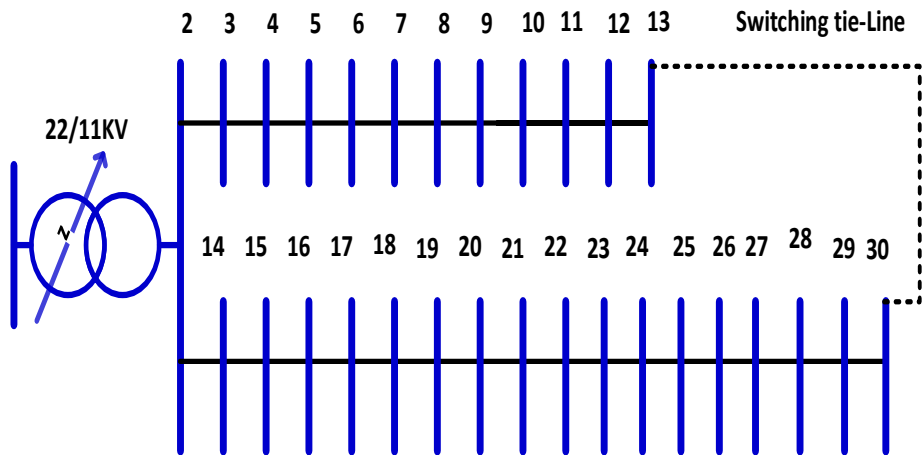


Fig. 3. Single line diagram of the (EDN)

Fig. 3. Shows the single EDN schematic diagram. The system load demand is 11 kV, the system load is 22,441,259 kW +j 14,162,265 kV. The minimum voltage value is 0.94626 p.u on bus 30. The total active loss is 805.733 kW. Three case studies were presented including optimized assignment of DSTATCOMs only, optimized allocation of PV only modules and optimized assignment of DSTATCOM along with PV modules. All simulations are listed in Table 2. Judging from Table 2, it is clear that the active power loss has decreased from 805.733 (base case) to 790.5877 kW, 339.7244 kW, and 123.0589 kW with optimal integration of DSTATCOMs only, and installation of PV modules only and PV modules were installed with DSTATCOMs, respectively. Improved voltage profile from 1.0669 p.u. (Base case) to 0.6698 (using DSTATCOM only) p.u, 0.1496 p.u (with PV only) and 0.0652 p.u (with PV and DSTATCOM). The voltage stability indicator has also been improved. Improved voltage profile from 24.9867 p.u. (Base case) to 26.4203 (with DSTATCOM only) 28.4080 pu (with PV only) and 28.8183 p.u (with PV and DSTATCOM). From the results obtained, the system is greatly improved with optimized allocation of PV and DSTATCOM simultaneously) Compared with the optimized assignment of PV only or DSTATCOM. The voltage profile has been depicted in Fig 4; it can be evident that PV modulation with DSTATCOM can enhance the voltage profile greatly. Referring to Table 2, voltage stability also enhanced PV modulation with DSTATCOM. Fig. 5 that the proposed algorithm has excellent and stable convergence characteristics as no fluctuation appears.

TABLE.2. SIMULATION RESULTS WITH OR WITHOUT PV UNITS AND DSTATCOM.

Values	Basic	DSTATCOM	PV	PV & DSTATCOM
Optimal PV Location (Size kW)	—	—	11 (4894.5) (14627)19	20 (11927) 7 (6676)
Optimal DSTATCOM Location (Size kVar)	—	19 (13924) 6(8327)	—	16 (9878.9) 12 (1400)
Total P_{PV} (kW)	—	—	19,521.5	18,603
Total $Q_{DSTATCOM}$ (KVar)	—	22251	—	11,278.9
$V_{min}(p.u)$ @ bus no.	0.94626 @ bus 30	0.96422 @ bus 30	0.99038 @ bus 30	0.99437 @ bus 30
Total P_{losses} (kW)	805.733	790.5877	339.7244	123.0589
Total Q_{loss} (kVar)	61.184	347.708	143.005	46.890
$VD(p.u)$	1.0669	0.6698	0.1496	0.0652
$\sum VSI$	24.9867	26.4203	28.4080	28.8183

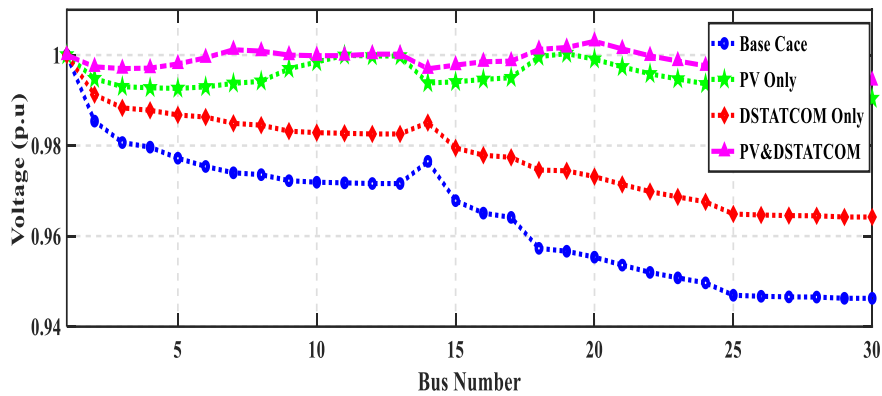


Fig .4. The system voltage profile.

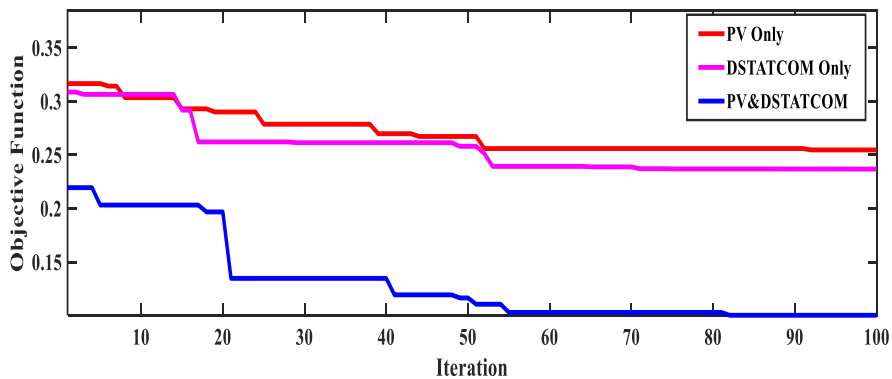


Fig .5. The convergence characteristic of the SMA for power losses minimization.

4. Conclusion

This paper has presented an efficient method for optimal sizes and locations of DSTATCOMs and PV system in a true distribution network (East Delta Network). A new optimization technique called Slime Mold Algorithm (SMA) has been applied to set the best locations and sizes of PV and DSTATCOMs to reduce power loss, voltage stability, and improve the voltage profile. Outcomes confirmed that SMA is an effective algorithm to solve the presented problem. In addition, the optimized allocation of PV modules and DSTATCOM can greatly improve performance by reducing active system losses, improving system voltage profile and system stability.

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