Диференціальний еволюційний алгоритм для розгляду розміщення розподільного компенсатора при змінних режимах навантаження

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Більшість навантажень в мережі споживає реактивну потужність, яку вони повинні потім якомога краще використати. У системах розподілу, конденсаторні батареї є кращим варіантом для виробництва реактивної потужності. Для з'ясування проблеми оптимального розміщення конденсатора в розподільних мережах, запропоновано декілька методів і підходів, між іншими, диференціальний еволюційний алгоритм (DE). Для вирішення проблеми оптимального розміщення конденсатора (рівняння (1)) слід врахувати п'ять обмежень (рівняння (2-6)). Загальноприйнята цільова функція включає вартість винаходу і *кВАр* конденсатора, а критерій втрат енергії використовується для оптимізації процесу. Алгоритм DE складається з п'яти етапів. На етапі ініціалізації утворюється початкове населення, яке піддається дії оператора мутації для його зміни. Для вираження оптимального місцевого рішення, застосовується оператор схрещення. Вкінці, за допомогою оператора селекції вибирається найкраще з доступних рішень. У цьому процесі число повторення становить критерій його закінчення.

Для застосування методу DE змодельовано 34-шинну систему з трьома рівнями навантаження, а саме, 0.5 *pu* впродовж періоду 1000 h, 0.8 *pu* впродовж періоду 6760 h і 1 *pu* впродовж періоду 1000 h через рік [7]. Рис. 1 представляє діаграму 34-шинної мережі IEEE. Результати застосування цієї техніки наведено в таблиці 2. Вони порівнювалися з результатами дослідження без конденсатора і на основі цього запропоновано метод наведений у списку літератури [7]. Новий алгоритм, який там наведено, заснований на комбінації нечіткого алгоритму (FUZ), алгоритму форвардного оновлення (FWD) і генетичного алгоритму (GA) з розміщенням конденсатора у розподільних фідерах, що запропоновано в 2009.

Для порівняння методів використано п'ять критеріїв, тобто вартість в дол. США, максимальну напругу в системних одиницях *(pu)*, мінімальну напругу в *pu*, енергетичну втрату в *кВт*, повну встановлену потужність в *кВАр*. Результати дослідження наведено в таблиці 2 і на рис. 3-5. Зокрема, на вказаних рисунках представлено порівнювальну діаграму трьох головних параметрів (вартості, мінімальної напруги і енергетичної втрати).

Обчислювальні дослідження, які були проведені на 34-шинній випробувальній системі IEEE, показали оптимальні результати застосування DE-методу. У роботі розглядалися три рівні навантаження. При використанні запропонованого методу, вартість і енергетичні втрати значно зменшилися, а діапазон варіювання напруги шин є меншим, ніж у випадку інших підходів, які представлено у літературі.

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Differential Evolutionary Algorithm for distribution Capacitor Allocation Considering Varying Load Conditions

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Many loads in power systems are inductive loads then consume reactive power, this fact lead to drop voltage and in worst case blackout and collapse voltage. Best option in distribution networks for avoid of this problem is installation of capacitor bank. In capacitor installation, finding optimal location and size of capacitor have special importance. In this paper, Differential Evolutionary (DE) algorithm is proposed for optimal placement and sizing of capacitor. Our objective function includes the minimization of investment costs and energy losses. Load of network has been considered in three levels. The proposal method has been tested on 34-bus radial distribution system and results of simulation have been compared with several valid reference.

Keywords – Differential Evolutionary (DE) Algorithm, Optimal Capacitor Placement, Radial Distribution Network, Varying Loads.

I. Introduction

Power network consisting of three main parts: generation, transmission, and distribution. Due to increase population in rural and urban areas and growth of demand for energy in industry, consumption of distribution network has been increased. Majority of loads in network consume reactive power, then must satisfied these by best way. In distribution systems, capacitor banks are superior option for generating of reactive power. Also, it used to reduce power losses, improve voltage profile and power factor correction. Many approach applied to optimal placement capacitor problem, such as loop-analysis based method [1], fuzzy-GA method [2], fuzzy EP algorithm and dynamic data structure [3], artificial immune systems [4], genetically optimized fuzzy [5], heuristic constructive algorithm [6]. In this paper, Differential Evolutionary (DE) algorithm is proposed for optimal placement and sizing of capacitor. Our objective function includes the minimization of investment costs and energy losses. The proposal method is tested on 34-bus radial distribution system and results of simulation have been compared with several valid references.

II. Problem Formulation

The objective function of varying loads has three terms. First term is cost of installation, C_{inst}, in *$* and capacitor bank capacity, Q_i, in *kVAr* is multiplied to corresponding cost, C_{kVAr}. in *$/kVAr*. Second term is total active power loss, $P_{loss(i,i+1)}$, in *kW* is multiplied Cost per energy loss, K_E, in *$/kWh/year* and during of any load

[*] This paper has been extracted from M.Sc thesis.

level, T_k, in *h*. Also third term, Λ^{Tpeak}, is added for considering cost of produced power in peak load.

$$Min\left[\left(\sum_{i=1}^{N_c} C_{inst} + C_{kVAr} \times Q_i\right) + \sum_{k=1}^{NLL}\left(K_E \times \left(\sum_{i=0}^{N-1} P_{loss(i,i+1)}^{T_k} \times T_k\right)\right) + \Lambda^{T_{peak}}\right] \quad (1)$$

where N_c and N are total number of capacitors and buses, respectively, *NLL* is total number of load levels in a year.

To solve these problems we must observe several constraints, we has sorted these in three category. First category is load flow restrictions of active and reactive power (equations (2) and (3)), latter is inequality of voltage profile and loading margin that have been showed in equations (4) and (5). Finally, equation (6) that denotes number of available capacitor sizes for installing [7].

$$P_{gi} - P_{di} - V_i \sum_{j=1}^{N} V_j Y_{ij} \cos\left(d_i - d_j - q_{ij}\right) = 0 \quad (2)$$

$$Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N} V_j Y_{ij} \sin\left(d_i - d_j - q_{ij}\right) = 0 \quad (3)$$

$$V_i^{\min} \le V_i \le V_i^{max}, i = 1,\dots,N \quad (4)$$

$$P_i^{\min} \le P_{ij} \le P_i^{max}, i = 1,\dots,N \quad (5)$$

$$Q_c^{Total} \le Q_L, Q_c^{Total}, Q_c^{Total} = \sum_{i=1}^{N_c} Q_i \quad (6)$$

III. Differential Evolutionary Algorithm (DE)

Evolutionary algorithm is a kind of global optimization techniques which uses selection and recombination as their primary operators to solve optimization problems. It is a branch of evolutionary algorithms developed for optimization problems over continuous domain[8-9].

1. Initialization: Initial population with uniform distribution function as following:

$$x_{i,k}^{G} = x_{k\min} + rand[0,1] \times (x_{k\max} - x_{k\min}),$$
$$k \in [1, D] \quad i \in [1, N_p] \quad (8)$$

where, N_p and D are population and number of variables, respectively. Any variable, *k*, is initialized in chromosome *i*, at generation, *G*, into range of x_{kmin} and x_{kmax}.

2. **Mutation:** Mutation operator, generates mutation vectors, X_i' ,by Eq.(8) at generation *G*:

$$X_i'^{(G)} = X_a^{(G)} + F(X_b^{(G)} - X_c^{(G)}), \quad i = 1,\dots,N_p \quad (9)$$

where, *a*, *b* and *c* are randomly selected from the set *{1,…,N_p}*, that $a \neq b \neq c \neq i$, and also *F* is mutation constant in range [0,2].

3. Crossover: Cross over, X_i'', is generated by components of mutation vector, X_i', and corresponding objective vector, X_i, considering following Eq.(10):

$$X_{j,i}''^{(G)} = \begin{cases} X_{j,i}'^{(G)} & if \ r_j \le CR \ \text{or j = q} \\ X_{j,i}^{(G)} & \text{otherwise}, \end{cases} \quad (10)$$

$i = 1,\dots,N_p$, $j = 1,\dots,D$ where, ρ_j and *q* is chosen randomly from the interval [1,…,*D*], crossover rate, *CR*, and is a user defined parameter within range [0,1].

4. **Selection:** This function is importantest step in DE and play significant role. This operator for generate new generation, decides between generated vectors from initialization (step 1) and cross over (step 3):

$$X_i^{(G+1)} = \begin{cases} X_i''^{(G)} & if \ f(X_i''^{(G)}) \le f(X_i^{(G)}) \\ X_i^{(G)} & \text{otherwise}, \end{cases},$$
$$i = 1,\dots,N_p \quad (11)$$

5. **Termination Criteria:** The iterative process terminates when one of following two criteria is met, (1) an acceptable solution has been obtained, (2) number of iteration reach to predetermined iteration number. We used second criteria for Termination of algorithm.

III. Case Study

A radial distribution network, as shown in Fig.1 with 34 load bus is used to illustrate effectiveness of the proposed DE method. The system voltage is 11 *kV* [10]. Before compensation, the cost is *US$* 37 212, and the voltage limits in per unit are 0.9417 and 1.0.

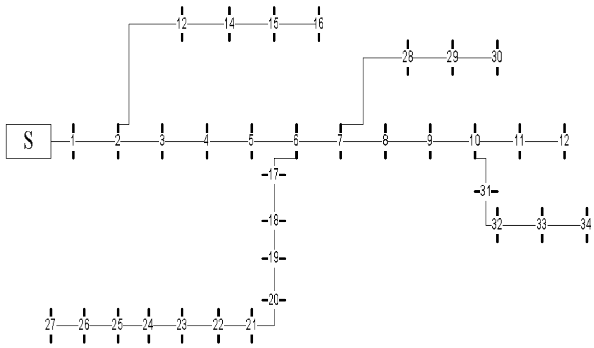


Fig. 1. 34-bus distribution network

Three load levels has used in this study that values of durations and load levels of the scenario have been presented in table 1 and Fig.2 The scenario has been applied on 34-bus radial distribution network.

Table 1

Durations and load levels in varying load

Case	Load levels(*pu*)	Duration(h)
1	1.0	1000
2	0.8	6760
3	0.5	1000

Results of DE algorithm for solving capacitor placement problem have been listed in table 2. In this table, resuls simulation of have been compared with without capacitor and approach of Ref. [7]. In this paper, Cost per energy loss Cost per energy loss, K_E, *is 0.06 $/kWh/year.* For determining capacity, Q_i, and cost, C_{kVAr}, of capacitor, proposed capacitor banks in Ref.[11] have used. Also in equation (7), x_{kmin} and x_{kmax} are zero and number of capacitor types. For solve load flow problem, a direct load flow (DLF) approach used in this study [12]. Simulation is carried out on 10-bus and 34-bus IEEE systems. The crossover rate, *CR*, is chosen 0.1.

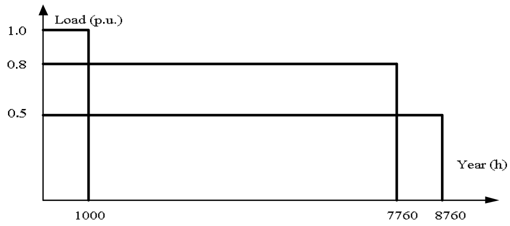
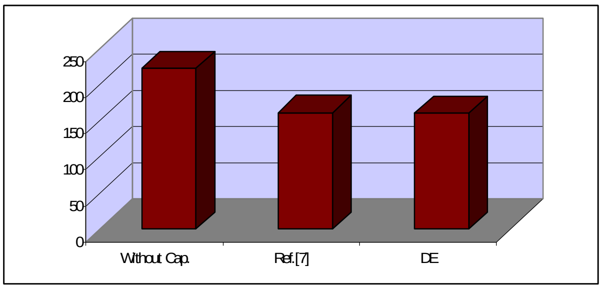
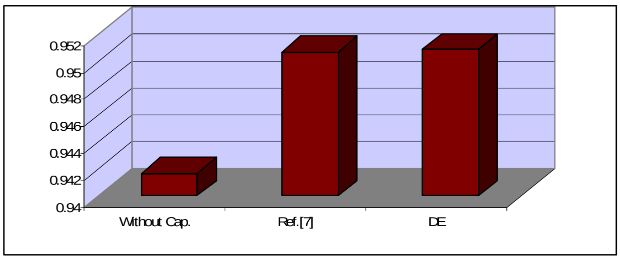


Fig. 2. Diagram of load-hour of three load levels

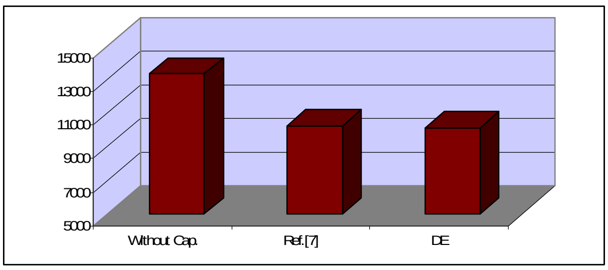
In case 1, power loss from DE is 61.78 and 0.56 *kW* lesser of without capacitor state and approach of Ref.[7], respectively. This reduction in case 2 is 39.05 *kW*, but in case 3, power loss of Ref.[7] is 1.03 more than DE. In worst case, minimum voltage of 0.94169 and 0.05068 *pu* from without capacitor case and approach of Ref.[7] has raised to 0.95007 *pu.* Total installed capacity on network have been reduced by DE. The reduction in case 1 are 150 *kVAr* and in case 3 are 300 *kVar* but in case 2 total installed capacity of DE and approach of Ref.[7] are 900 *kVAr.* In case 1, annual cost from DE is 3182 and 120 *$* lesser than without capacitor case and approach of Ref.[7], respectively. The reduction in case 2 is 15148 and 243 *$* and in case 3 is 525 and 31 $. The results of table 2 have been illustrateed in Figs.1-3. The maximum voltage is 1.0 *pu.*



(a) power loss (kVAr)

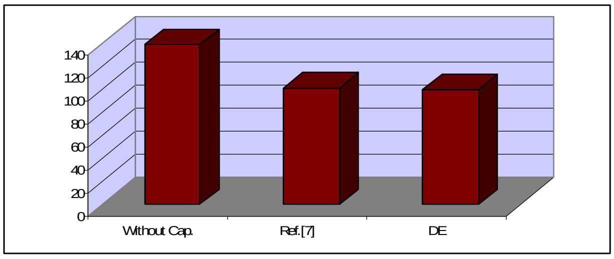


(b) minimum voltage (*pu*)

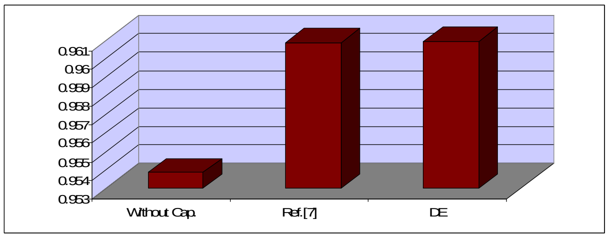


(c) cost ($)

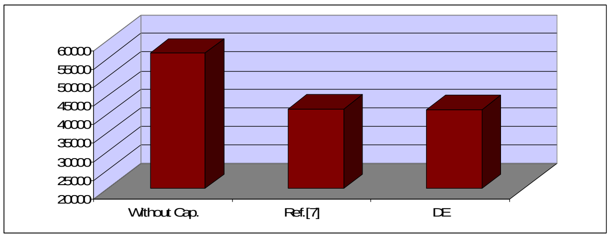
Fig. 3. Results of Capacitor Placement in case 1



(a) power loss (*kVAr*

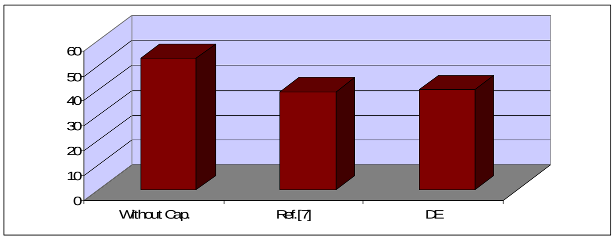


(b) minimum voltage (*pu*)

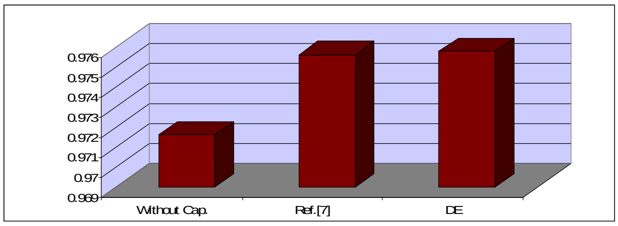


(c) cost ($)

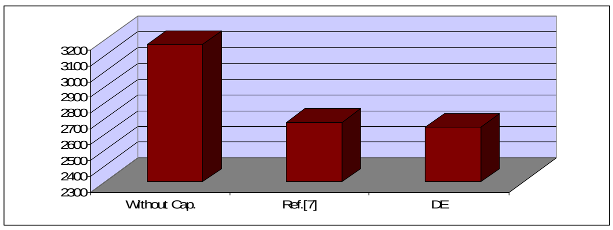
Fig. 4. Results of Capacitor Placement in case 2



(a) power loss (*kVAr*)



(b) minimum voltage (*pu*)



(c) cost ($)

Fig. 5. Results of Capacitor Placement in case 3

Table 2

Results of capacitor placement IN 34-bus with varying load

Cost($)	Total Cap (kVAr)	Min.Voltg. (*pu*)	Power Loss (kW)	Optimal size (kVAr)-Optimal Location (Bus No.)							Case	Method
13303	-	0.94169	221.72	-	-	-	-	-	-	-	1	Without Cap.
56443	-	0.95385	139.16	-	-	-	-	-	-	-	2	
3171	-	0.9716	82.855	-	-	-	-	-	-	-	3	
10241	2250	0.95068	160.5	-	-	450-34	300-32	450-30	450-24	900-9	1	Ref.[7]
41583	2100	0.96087	101.185	-	-	-	450-34	300-30	450-27	900-9	2	
2677	1200	0.97563	39.276	-	-	-	-	450-34	150-30	600-9	3	
10121	2400	0.59087	159.94	-	-	-	450-25	900-21	600-10	450-6	1	DE
41295	2100	0.96091	100.11	150-26	300-24	450-21	300-17	150-11	300-9	450-6	2	
2646.2	900	0.97577	40.308	-	-	-	-	-	450-31	450-27	3	

Conclusion

Reducing of reactive power in radial distribution networks by capacitor is main focus of this study. In this paper, DE algorithm has been used for optimal capacitor placement and sizing in radial distribution networks. From of results, in 1.0 *pu* load level, power loss from DE is %38 and % 0.38 less than before compensation and approach of Ref.[7], respectively. This reduction in 0.8 *pu* load level is %39 and %1.08 and in 0.5 *pu* load level 31 and %2.56. In worst case, 1.0 *pu* load level, the minimum voltage of without capacitor state and approach of Ref.[7] from 0.94169 and 0.95068 pu ,respectively, has raised to 0.59087 *pu* in DE. Finally, The cost of DE method is %31 and %1.2 in 1.0 *pu* load level, %36.7 and %0.7 in 0.8 *pu* load level and %19.8 and %0.72 in 0.5 *pu* load level, less than before compensation and method of Ref.[7], respectively.

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