IMPROVED HYBRID TS/PSO ALGORITHM FOR MULTISTAGE DISTRIBUTION NETWORK EXPANSION PLANNING

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ABSTRACT

Optimal multistage expansion of medium-voltage power network because of load growth is a common issue in electrical distribution planning. Minimizing total cost of the objective function with technical constraints, make it a combinatorial problem which should be solved by optimization algorithms. In this paper, a new improved hybrid Tabu Search/ Particle Swarm Optimization algorithm is proposed for multistage distribution network expansion planning. The proposed algorithm is executed in two phases but it is not limited by some optimal solutions of each stage of the planning. It contains adequate adjustment between intensification and diversification. To show the ability of the proposed algorithm, it is applied to a 71-bus 20 kV distribution network as a test case. The numerical results and comparisons show the proposed algorithm can efficiently improve the total cost of distribution network.

INTRODUCTION

Optimal multistage expansion of medium-voltage power network because of load growth is a common issue in electrical distribution planning. Minimizing total cost of the objective function with technical constraints, make it a combinatorial problem which should be solved by optimization algorithms. The problem consists of optimal HV/MV substations placement and sizing as well as medium-voltage feeders routing and design using complex cost objective function and technical constraints. The objective function usually includes facilities installation and operation cost and the reliability cost. In recent years, a lot of mathematical models and algorithms have been developed for solving this problem in different conditions. However, multistage planning of large network because of dynamic load growth makes the problem more complex. At the end of each stage, an intermediate system should be determined. So each selected facility will have a construction date as a decision parameter. Facilities installed in each stage have no construction cost associated with them in the next stages, but they have associated power loss and operation costs in the next stages. The cost objective function of each stage should be calculated in the base year. The optimal solution may not minimize the objective function of each stage, but it should minimize the total resultant objective function of all stages.

In this paper, a new improved hybrid Tabu Search/ Particle Swarm Optimization (TS/PSO) algorithm is proposed to solve the multistage distribution network expansion problem.

PROBLEM STATEMENT

It results in the problem that optimizes the location, type and installation date of new feeders as well as the location, capacity and installation date of new substations and/or the capacity increment and the upgrade date of existing substations while minimizing the cost objective function of the network under technical constraints. The objective function usually includes facilities installation and operation cost and the reliability cost. Consider the following notation:

OF_s Objective function of *s*-th stage ($)
C_s^{INS} Installation cost of facilities in *s*-th stage ($)
C_s^{OPR} Operation cost of the network in *s*-th stage ($)
C_s^{RLB} Reliability cost of the network in *s*-th stage ($)

The total objective function (OF) is as follows.

$$OF = \sum_s OF_s \tag{1}$$

$$OF_s = C_s^{INS} + C_s^{OPR} + C_s^{RLB} \tag{2}$$

where the cost functions are calculated for the base year of study regarding to the interest rate and inflation rate. If the interest rate is more than the inflation rate, delay in facilities installation date, can improve the installation cost function. In this paper, the reliability cost is calculated by costumer outage cost. The expected outage cost is evaluated for all load points during failure events. The optimal distribution system must normally supply the required loads and keep the load node voltages in the acceptable boundary. In addition, capacity of facilities can not be exceeded and the configuration of the network must be radial because of protection system constraints.

IMPROVED HYBRID TS/PSO ALGORITHM

Particle Swarm Optimization (PSO) is a swarm intelligence algorithm which is based on the movement of some groups of particles which share their explorations among themselves. This technique is motivated by simulation of social behavior. Each individual in PSO called particle flies in the searching space with a velocity. Assuming that the searching space is *n*-dimensional, the *i*-th particle of the swarm is presented by the vector

$\boldsymbol{x}_i = (x_{i,1},...,x_{i,n})$ with a flying velocity $\boldsymbol{v}_i = (v_{i,1},...,v_{i,n})$. The particles move in the searching space regarding their velocities. The velocity vector is updated in each iteration with respect to the best previous positions of the particles and the global best position of the swarm. More details can be found in [2].

In the proposed improved PSO algorithm for multistage planning, the population is divided into some groups of particles. The position vector of the *j*-th particle of *i*-th group is presented by $\boldsymbol{x}_{ij}$. Each group of particles optimizes the intermediate network of one stage during iterations. So the number of groups is equal to the number of planning stages. The particles of different groups (i.e. different stages) fly consecutively. In each iteration, *j*-th particle of the first group starts to move from its own last position, but for $i > 1$ the *j*-th particle of *i*-th group starts to move from the last position of *j*-th particle of ($i-1$)-th group. In *i*-th group, objective function of each particle for *i*-th stage is calculated using Eq. (2). The best position of *i*-th group which minimizes OF_s (where $s = i$) is presented by $\boldsymbol{x}_i^{LB}$ as a local best position. The complete solutions are obtained from serial particles positions of all groups. In each iteration, the number of new generated complete solutions is equal to the number of particles of each group. The objective function of each complete solution (i.e. *OF*) is calculated using Eq. (1). Then the best complete solution is found. The intermediate solution of *i*-th group, which belongs to the best complete solution, is presented by $\boldsymbol{x}_i^{GB}$ as a global best position.

The velocity vector is updated respecting not only to the global best particles, but also to the local best particles. The velocity vector is updated as follows:

$$v_{ij,k} = w \times v_{ij,k} + c_1 \times \mathrm{r} \times (x_{ij,k} - x_{i,k}^{LB}) + c_2 \times \mathrm{r} \times (x_{ij,k} - x_{i,k}^{GB}) \quad (3)$$

where $c_1 < c_2$, $i = 1,2,...,N_g$, $j = 1,2,...,N_{pg}$, $k = 1,2,...,n$ and the following notation is used:

w	Inertia weight
c_1, c_2	Positive constants as learning factors
r	Random function generating random numbers uniformly distributed within the range [0,1]
N_g	number of all groups
N_{pg}	number of particles in each group

The second term in right part of Eq. (3) prevents the particles moving to ineffective regions; however the third part leads the particles to move into the global optimum.

In the proposed improved PSO, the particles are manipulated regarding not only to the velocity vector, but also to the local best particles, the global best particles and a new controller parameter (q) as follows:

$$x_{ij,k} = \begin{cases} 1 & \text{if } \{[\mathrm{r} < [1/(1+\exp(-v_{ij,k}))] \text{ AND} \\ & \quad [(x_{i,k}^{LB} = 1)\,\mathrm{OR}\,(x_{i,k}^{GB} = 1)\,\mathrm{OR}\,(q < \mathrm{r})]\} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

where $0 < q < 1$. It is a constant parameter that increases the intensification which is seriously needed in high-dimension optimization. The particles minimize the objective function of each stage as a local objective function and the final objective function of all stages as a global objective function. Local objective function leads to a local optimum. So the best solution is selected finally regarding only to the global objective function.

Particles of PSO algorithm simultaneously search in several regions of solutions space. So PSO can successfully pass the local optimum points. However, it may not consider the regions in details. Local search of Tabu Search (TS) algorithm can eliminate this weakness.

TS is a local-search-based algorithm. The algorithm starts from an initial solution. In each iteration, the best neighbor solution is selected to move, although it may lead to a less adequate solution compared with the current solution. Moreover a tabu list, as a memory, is used to prevent cycling. In practice, evaluation of all neighbor solutions of the current solution is infeasible. So probability local search is used in TS. As a result, there is no guarantee to achieve a global optimum.

In this paper it is proposed to use an improved TS algorithm, as an auxiliary algorithm, in combination with the modified PSO algorithm for multistage distribution network expansion. The improved TS includes an intelligent local search algorithm which is proposed in [5]. In this algorithm, the branch exchange method is used for local transformations, in which added branch selection is performed randomly but selecting the removed branch is controlled. At the initial iterations, branches which are directly connected to the substations, have more chance to be removed from the network. At the later iterations, branches which have less electrical current in the created loop and more impedance, have more chance to be removed. The procedure is controlled by two lists of branches. More details can be found in [5]. The improved TS algorithm is originally used in static distribution network planning to decrease the number of HV/MV substations. Using such algorithm in multistage expansion planning is proposed here to postpone the installation of new HV/MV substations to the later stages. Moreover, using the improved TS decreases the local search size needed in both single stage and multistage planning.

To combine the improved TS algorithm with PSO in proposed hybrid algorithm, after moving the particles of PSO in each stage, local search algorithm is applied to N_n particles randomly (that $N_n < N_{pg}$). In this algorithm, unlike the conventional TS, the current solution of the stage will be replaced by the best neighbor solution if the best neighbor solution is more adequate than the current solution regarding to the local objective function. This strategy adapts both diversification and intensification and efficiently improves the convergence of the algorithm. The improved hybrid algorithm can be stated as follows:

1. Generate initial positions randomly and initialize the velocity vectors.
2. Set $i \leftarrow 1$ and move the particles of the first group from their last positions, using Eq. (4).
3. If $i > 1$, move the particles of i-th group from last positions of particles of ($i-1$)-th group using Eq. (4).
4. Set $s \leftarrow i$ and calculate local objective function of particles for s-th stage using Eq. (2).
5. Set $c \leftarrow 1$.
6. Set $j \leftarrow \{\text{integerpart}(r \times N_{pg}) + 1\}$.
7. Generate N neighbors for $\boldsymbol{x}_{ij}$, using the improved local search algorithm.
8. Calculate local objective functions of the neighbors for s-th stage, using Eq. (2).
9. Find the best neighbor ($\boldsymbol{x}_{ij}^{NB}$) among N neighbor solutions and if $OF_s(\boldsymbol{x}_{ij}^{NB}) < OF_s(\boldsymbol{x}_{ij})$, then set $\boldsymbol{x}_{ij} \leftarrow \boldsymbol{x}_{ij}^{NB}$.
10. Set $c \leftarrow c+1$, if $c < N_n$ then go to step 6.
11. Find the best particle of i-th group ($\boldsymbol{x}_i^{LB}$).
12. Set $i \leftarrow i+1$ and if $i \leq N_g$, then go to step 3.
13. Calculate global objective function of the particles.
14. Find the best complete solution of the current iteration
15. Update the global best solutions.
16. Update velocity vector using Eq. (3).
17. If termination criterion is not satisfied go to step 2, otherwise output the global best solutions.

It is proposed to run the improved hybrid TS/PSO algorithm in two serial phases. In the first phase, the algorithm is executed for a static model in a single stage to obtain a solution which can meet the demand requirements of the final year of the study. This single stage model describes the location of HV/MV substations which can be considered in the second phase as the main multistage phase. Only substations which belong to the optimal solution of the first phase can appear in the second phase. The date of the selected substations installation or upgrade is specified in the second phase. However, other facilities are selected in the second phase, neglecting the optimal solution of the first phase.

NUMERICAL RESULTS

In order to show the ability of the proposed algorithm for solving multistage distribution network expansion planning problem, the following example is presented. It is a 71-bus 20 kV distribution network which consists of an existing HV/MV substation and 13 existing feeders. 52 new load points are added to the network during 4 stages. Each stage includes 4 years. Five candidate HV/MV substations are considered to be added to meet the new loads. The existing distribution network, new load points and candidate

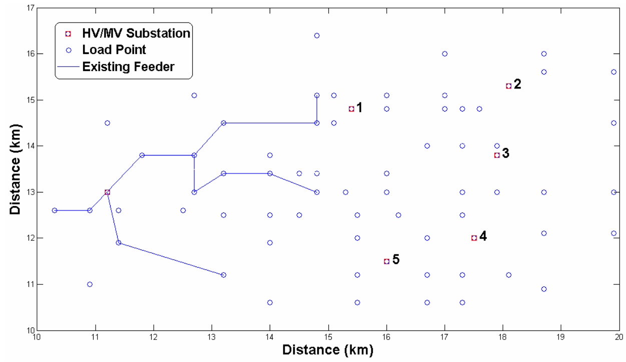


Fig. 1. The configuration of the existing network, new load points and candidate substations

Table 1. Parameters of the test distribution network

Parameter of the test case	Value
Total candidate feeders number	155
Capacity of existing HV/MV substation (MVA)	10
Average load per node (kW)	400
Power factor	0.9
Annual increment load rate	0.03
Failure rate of feeder ($km^{-1}.yr^{-1}$)	0.062
Failure rate of HV/MV transformer (yr^{-1})	0.025
Inflation rate	0.05
Interest rate	0.14

substations are presented in Fig. 1. More details are given in Table 1.

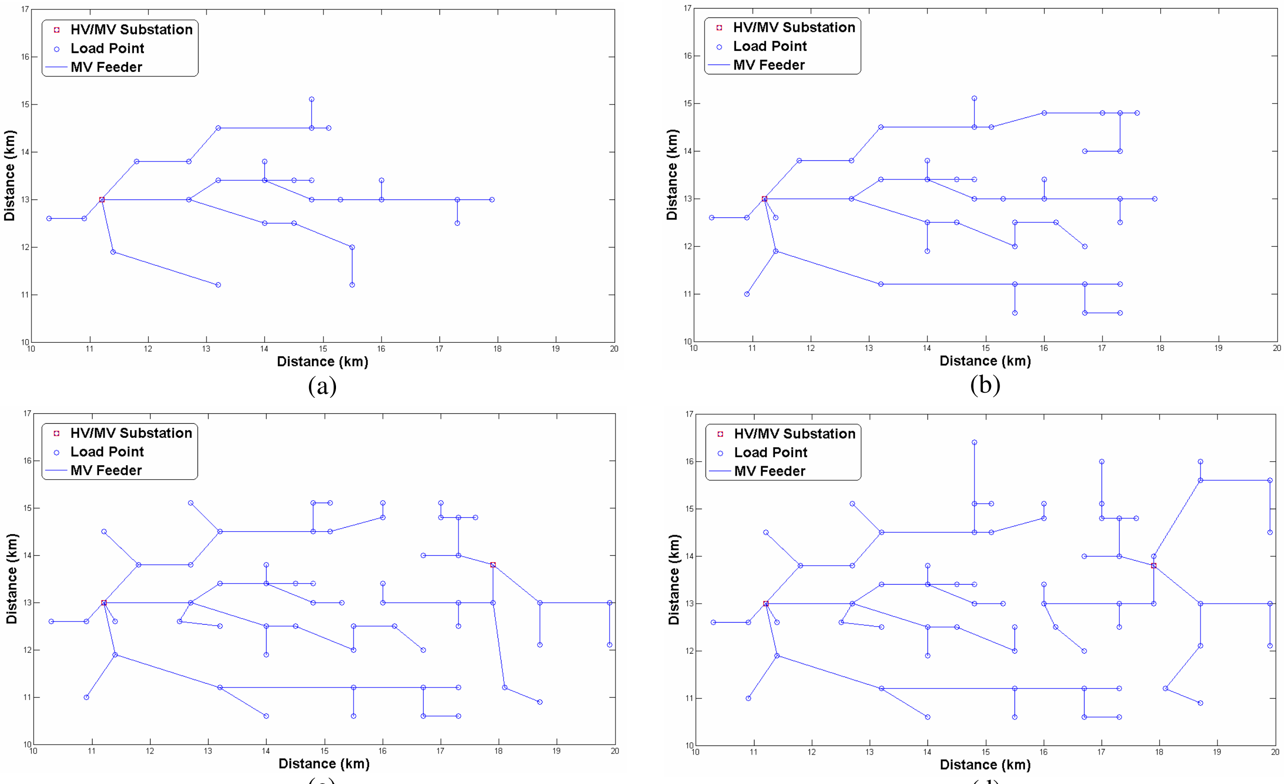
The proposed improved hybrid TS/PSO algorithm is applied to the test case in two phases. The outcome of the first phase specifies that the 3rd candidate HV/MV substation is the optimal choice to feed all the new load points in the 16th year of the study. Then the second phase obtains the optimal intermediate distribution network for each stage of planning. Fig. 2 presents the optimal networks of 4 stages which minimize the total cost function during 16 years. The results show the candidate substation should be added to the network at the beginning of the 3rd stage. As a result, installation of the new substation is delayed for 8 years which can improve the total objective function.

To specify the advantages of the proposed algorithm, the following algorithms are applied to the same test case:

1. The conventional PSO without improvement and hybridization (PSO).
2. The improved PSO without combining to TS (IPSO).
3. The hybrid conventional PSO and improved TS (ITS/PSO).
4. The hybrid improved PSO and conventional TS (TS/IPSO).

The results compared with the results of the proposed algorithm (ITS/IPSO) are given in Table 2.

The results show the proposed algorithm obtains the best total objective function among all. The proposed modifications and hybridization techniques can successfully improve the procedure of multistage



(a) (b) (c) (d)

Fig. 2. Configuration of the optimal networks in four stages of the expansion planning: a) 1st stage, b) 2nd stage, c) 3rd stage and d) 4th stage.

Table 2. Results of the four other algorithms applied to the test system, are compared with the proposed algorithm

Algorithm	Total objective function (M$)	Stage of new substation installation	Capacity of new substation (MVA)
PSO	2.9653	2	10
IPSO	2.0486	2	11
ITS/PSO	1.8915	2	8
TS/IPSO	1.8801	2	7
ITS/IPSO	1.7909	3	7

distribution network expansion planning.

CONCLUSION

In this paper a new improved hybrid PSO-based TS/PSO algorithm is proposed for multistage distribution network expansion planning. The improved PSO traces both the local best particle of each stage and the global best particle of all stages as a quasi-multi-objective search. As a result, the main global search is more efficient and realistic. Local search concept of TS algorithm with special strategy is added to the improved PSO to search the space in more details. Moreover, the local searches are modified to search more intelligently and delay the installation of new substations. As a result, the algorithm contains adequate adjustment between intensification and diversification. Numerical results of a 71-bus test case and comparisons show the ability of the proposed algorithm for multistage distribution network expansion planning. The algorithm can be adapted and implemented to the modern distribution networks as future work.

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