REVIEW OF COMPUTER ENGINEERING STUDIES

A publication of IIETA

ISSN: 2369-0755 (Print), 2369-0763 (Online)
Vol. 3, No. 2, June 2016, pp. 39-42
DOI: 10.18280/rces.030203

International Information and Engineering Technology Association
Advancing the World of Information and Engineering
http://www. iieta. org/Journals/RCES

Application of GIS and Improved PSO Algorithm in Site Selection of Transformer Substation

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ABSTRACT

According to the existing substation locating and sizing method due to the neglect of geographic factors which affect the accuracy of practical application, this article puts forward a method of substation locating and sizing based on geographic information system, the method combining the characteristics of county power grid and the geographical environment of substation, but also considering the effect of geographical factors such as terrain, landform, and density of population on investment cost, so that the results can play the biggest role in the practical application. Moreover, the application of the improved particle swarm algorithm in substation locating and sizing, taking into account the relationship between the individual and the overall situation, to further improve the location accuracy. The application of this method in a county in Shaanxi Province of substation location, confirmed that the method can effectively reduce the infeasible solutions, and eventually converges to the global optimal solution and make the substation planning results consistent with the actual requirements.

Keywords: GIS, PSO, Site selection of transformer substation, Economical capacity of transformer substation.

1. INTRODUCTION

Substations are an important part of power network, making substation siting a crucial link in rural power network planning. Whether the final location is superior or not will have an enormous impact on power supply safety and quality of the entire rural power network [1-2], so experts and scholars at home and abroad have conducted considerable research on substation siting. Among such research, substation sizing and siting, with many merits, has attracted broad attention [3-4]. There has been a lot of research on substation sizing and siting planning algorithms, the crux of the work, including Simulate Anneal Arithmetic (SAA), Tabu Search (TS), Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm [5-6]. However, such algorithms fail to consider the coordination between individual and overall situations. In this context, this paper presents an improved algorithm which is to select extremums of optimal individual and global positions to update particle velocity based on basic PSO. Relying only on multiple algorithms to cope with substation planning, nonetheless, fails to meet actual application needs. Also, there is a need to consider such geographic factors as terrain, physiognomy and population density. Consequently, this paper integrates GIS data with optimization algorithm before the sizing and siting of substations.

2. MATHEMATICAL MODEL FOR SUBSTATION SIZING AND SITING

Suppose a substation satisfies such conditions as a circular power supply region and known annual load distribution of planning, the substation siting is optimized to minimize investment and annual operating costs (including substation investment costs, investment and operating costs of circuits), which can be expressed mathematically as:

$$C(a_1, b_1, a_2, b_2, \lambda) = C_1 + C_2 + \lambda\phi \qquad (1)$$

where C_1 is annual investment costs of both substation and circuits; C_2 is annual costs of line loss as well as depreciation and maintenance, the latter of which is proportional to total investment). C_1 and C_2 can be formulated as:

$$C_1 = \frac{(a_1 + b_1 S) + DR(\frac{a_2 S\lambda}{p_L} + \frac{b_2 S}{\sqrt{3}U_N J})}{T} \tag{2}$$

$$C_2 = H(a_1 + b_1 S) + HDR(\frac{a_2 S\theta}{p_L} + \frac{b_2 S}{\sqrt{3}U_N J}) + 0.924\frac{\rho J\tau C_0}{U_N} \times \frac{\sqrt{\theta}S^{3/2}}{\sqrt{\pi\sigma}K_e^{5/2}} \times 10^{-3} \tag{3}$$

Here, a_1 is the part of substation investment irrelevant to substation capacity (Unit: RMB); b_1 is the coefficient of substation investment that has a linear relationship with substation capacity (Unit: RMB/ kVA); D represents topographic correction coefficient; a_2 is the part of circuit investment irrelevant to conductor cross-section (Unit: RMB); b_2 is the coefficient of circuit investment that has a linear relationship with conductor cross-section (Unit: RMB/ km*mm^2); L_P represents the average circuit load (Unit: kW); N_U is the rated voltage (kV); θ is the average power factor per load (RMB/kWh); H represents the coefficient concerning the proportion of depreciation and maintenance costs in total investment; T is the investment term (Unit: year); λ is geographic information constraints; and φ is the costs regarding geographic factors in investment.

It is thus evident that the model considers geographic information factors in substation sizing and siting with geographic factors serving as investment constraints. The Lagrangian function is established to calculate the minimum value, i. e. , the minimum investment, hence fulfilling economical investment.

3. IMPROVED POS ALGORITHM

With such advantages as simple operation, easy to use and fast convergence rate, PSO algorithms have been widely applied in engineering practice. There exist, however, the following problems in application.

1) Each particle moves to the optimal solution based on the search experience of itself and other particles. Under the influence of larger inertia factors, particles may be subject to less precise search for lack of fine search of the optimal solution;

2) All particles move to the optimal solution. The closer each particle is to the optimal particle, the slower the velocity is. As a result, all particle swarms tend to be the same and lose solution diversity, thus easily converging local optimization.

To this end, there is a need to improve the traditional algorithms in the optimization of substation sizing and siting using PSO algorithm. With regard to MPSO algorithm, used in this paper, when each particle moves in the same velocity direction at different velocity amplitudes, high-velocity particles go through global optimization and regular particles conduct local optimization. At first, particle velocity is updated by selecting the extremums of individual and global optimal positions from known positions. High-velocity particles are defined as global search particles, which can avoid local optimum and prematurity. Low-velocity particles satisfy the requirements of fine search, which can avoid moving to the space of the optimal solution and quickly search local optimal solution. It can be formulated as:

$$\begin{cases} v_{id}^{(k+1)} = \omega v_{id}^{(k)} + c_1\gamma_1(P_{id}^{(k)} - x_{id}^{(k)}) + c_2\gamma_2(P_{gd}^{(k)} - x_{id}^{(k)}) \\ x_{id}^{(k+1)} = x_{id}^{(k)} + v_{id}^{(k+1)} \\ v_{id}^{(1)} = a(1)v_{id}^{(0)}, \cdots, v_{id}^{(m)} = a(m)v_{id}^{(0)}, \cdots, v_{id}^{(j)} = a(j)v_{id}^{(0)}; m = 1, 2, \cdots, j \\ x_{id}^{(1)} = x_{id}^{(0)} + x_{id}^{(1)}, \cdots x_{id}^{(m)} = x_{id}^{(0)} + x_{id}^{(m)}, \cdots, x_{id}^{(j)} = x_{id}^{(0)} + x_{id}^{(j)}; m = 1, 2, \cdots, j \end{cases} \tag{4}$$

where r1 and r2 is a random number between [0, 1]; c1 and c2 represents accelerated velocity coefficient; ω is inertia factor; $v_{id}^{(0)}$ and $v_{id}^{(m)}$ are reference and search velocity components of particle i in d dimension respectively; Pid is the best position component of particle i at different velocities in d dimension; Pgd is the best position of current particle swarm at different velocities in solution space; a(m) is variable coefficient of velocity to determine the relation of search velocity to reference velocity. Suppose Mi1 is the fast velocity and Mi2 is the slowest velocity, if $v_{id}^{(0)}$ >Mi1, a(m) slows down search velocity; if $v_{id}^{(0)}$ <Mi2, a(m) speeds up the search velocity; and if Mi1< $v_{id}^{(0)}$ <Mi2, a(m) increases and decreases search velocity on both sides of $v_{id}^{(0)}$. Only in this way can particles search enough solution space.

Besides, this paper uses neighborhood particle swarm optimization, i. e. , stipulating that each particle in the particle swarm can recognize (or observe) and utilize a certain amount of other particle information or such information in a given area around itself, which is defined as ‘neighborhood of particle swarms’. In this way, the PSO algorithm can be simplified as:

$$\begin{cases} v_{id}^{(k+1)} = \omega v_{id}^{(k)} + r(P_{id}^{(k)} - x_{id}^{(k)}) \\ x_{id}^{(k+1)} = x_{id}^{(k)} + v_{id}^{(k+1)} \\ v_{id}^{(1)} = a(1)v_{id}^{(0)}, \cdots, v_{id}^{(m)} = a(m)v_{id}^{(0)}, \cdots, v_{id}^{(j)} = a(j)v_{id}^{(0)}; m = 1, 2, \cdots, j \\ x_{id}^{(1)} = x_{id}^{(0)} + x_{id}^{(1)}, \cdots x_{id}^{(m)} = x_{id}^{(0)} + x_{id}^{(m)}, \cdots, x_{id}^{(j)} = x_{id}^{(0)} + x_{id}^{(j)}; m = 1, 2, \cdots, j \end{cases} \tag{5}$$

where $P_{id}^{(k)}$ is the best particle position for $x_{id}^{(k)}$ in the neighborhood, also known as neighborhood extremum and r is a random number within [0, 1]. As to retention policy of new particles in Equation (5), survival of the fittest prevails. Only when is $v_{id}^{(k+1)}$ better than $x_{id}^{(k)}$, can it be retained. Based on the merits of new particles, particle velocities in PSO algorithm can be divided into two categories: one is superior particle velocity which generates new particles that superior to previous particles; the other is called as inferior particle velocity. The updating strategy for particle velocities is illustrated as follows: superior particle velocity improving particle quality is retained to go for a global search, while inferior particle velocity is to search finely.

A fix ω value is employed in the traditional PSO algorithms and thus there is a poor balance between global search capability and local fine search capability. Therefore, at the initial stage of algorithm, particles can quickly move to the best global position at present, but they fail to conduct a fine search as a result of constant movement inertia when closing the best global position, hence giving rise to poor convergence precision. In this paper, we propose the MPSO algorithm which uses a ω value gradually changing with the number iterations to flexibly strive the particle balance between the global and local search capability, for the purpose of fulfilling a higher convergence rate early on and a higher convergence precision later. At the same time, the MPSO algorithm introduces variable coefficient of velocity and neighborhood selection algorithm based on the traditional PSO algorithms, which keeps particle swarm diversity and improves the algorithm traversal in solution search space, contributing to a greater possibility of global optimum.

4. APPLICATION OF GIS IN SUBSTATION SIZING AND SITING

4. 1 Geographic information processing in GIS

Generally, substations are seen as dotted entities, while their locations are counted as a closed region. Parcel attributes includes such geographic information as load density, parcel area, land usage, traffic, construction condition and terrain, which plays a decisive role in substation location[7]. County power systems featuring long power supply distance, scattered loads and single power supply are mostly distributed in a scattering and divergent manner. Such features lead to the complex geographic positions of substations in county power systems, but locations have consistent parcel attributes. In this context, township (town) with load density can be abstracted to a single point for processing and the number of iterative operations is determined based on the comparison of circumcircle radius of all abstract location points with supply radius of the substation.

4. 2 Economic capacity and number of substations

(1) Economic capacity of substations is determined based on Equation (6).

$$S_j = K^3\sqrt{\sigma} \tag{6}$$

Here, S_j is the corresponding economic capacity of a substation (Unit: KVA); K is the coefficient of medium-voltage lines relating to substation construction and generally K=40; and σ represents load density (Unit: kw/km^2).

(2) Determination of the number of substations:

The planned annual substation capacities are determined based on the requirements of local power sector to saturated annual substation capacities, including 4×40MVA, 4×50MVA and 4×63MVA. Considering unbalanced substation loads resulting from unbalanced space distribution, the number of newly-built substations is determined according to Equation (7):

$$n = a \cdot \left[\frac{S_x}{4 \times 50} \right] \tag{7}$$

where n is the number of newly-built substations, [·] is rounding and α is redundancy factors (generally 1. 0≤α≤1. 4).

5. APPLICATION EXAMPLE

Based on the above analysis, the presented method considers geographic information features to optimize siting algorithms, which is more in line with actual demands and can be applied to specific examples. County –level substation siting in Shaanxi Province is of great significance to the local power development, but conventional siting methods make it difficult to satisfy local demands in a particular geographic environment. For this reason, the presented method can be used to acquire the basic data on power consumption features of a substation in a part of Townships and towns in a county in Shaanxi Province, as shown in Table 1.

Table 1. Some basic data on a county in Shaanxi Province

No.	Township (town) name	Area (km^2)	Population in 2007 (person)	Power supply in 2007 (kw)	Power supply in 2009 (kw)	Predicted power in 2019 (kw)	Load density in 1019 (kw/Km^2)
7	Shangwang Township	75. 75	23209	3421252	3397764	7498327	98987. 8
13	Baonan Township	47. 5	15526	6839682	4635662	12618518	265653. 0
18	Jiaqu Township	52. 5	29000	8119287	11363777	21423966	408075. 5
24	Jingyao Town	103. 2	61000	5421720	7485471	14193005	137529. 1
32	Linger Township	31. 5	14695	5914650	7166013	14383759	456627. 2
33				3581310	4411846	8789434	

Note: 33 is load point.

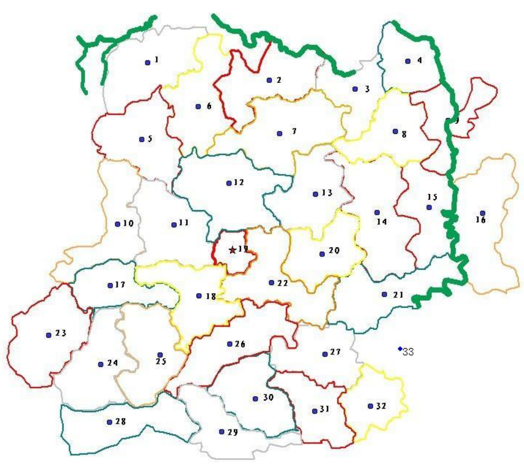

Figure 1. Geographic information features of power consumption in a county of Shaanxi Province

Figure 1 shows geographic information features of power consumption in a county of Shaanxi Province.

Substation locations based on the above geographic features can take an assigned load point as the starting point, to which the closest unselected load point is searched. It can thus be seen that the load point at the upper left is selected as a starting point. Load area is overlaid in search before solving the load density, and then Equation (6) is not to be calculated until economic capacities of the substation indicate a threshold level which is determined based on the principle that when adds a load point, economic capacities are greater than the overall loads. Upon the determination of economic capacities of the substation, equivalent load center is selected as the position for the to-be-built substation and substation capacity can be calculated by multiplying the overall selected loads by capacity-load ratio. In case a satisfying load point cannot be found, the load point is selected as a starting point for loop searches till all load points finish searching. Table 2 demonstrates substation capacity and coverage area.

Table 2. Substation capacity and coverage area

Substation	Covered load points	Overall loads (kw)	Capacity-load ratio	Substation capacity (kw)
No. 1	1, 2, 5, 6, 7, 10, 11, 12, 13, 19, 20, 22	216130989	1. 8	389035780. 2
No. 2	3, 4, 8, 9, 14, 15, 16, 21, 33	70675457	1. 8	127215822. 6
No. 3	17, 18, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32		1. 8	305878465. 8

Note: Load point 33 is added to No. 2 substation for which has a smaller capacity.

Substation locations of a county in Shaanxi Province are distributed as shown in Figure 2.

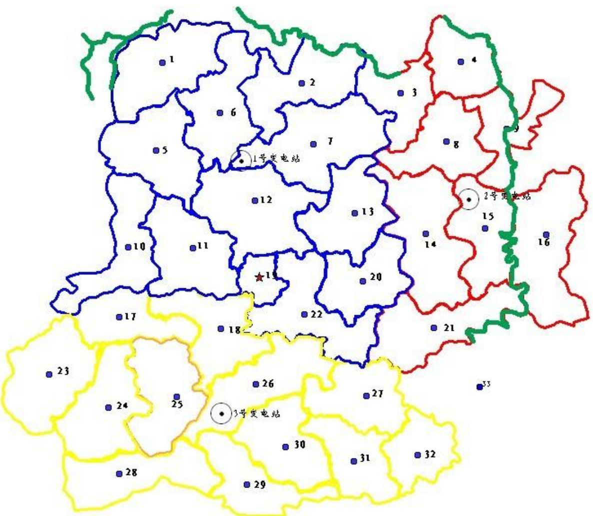

Figure 2. Substation locations and coverage area

In Figure 2, blue area is the coverage area for No. 1 substation containing 12 load points, red area is that for No. 2 substation covering 9 load points and yellow area is that for No. 3 substation covering 12 load points. It follows that substation distribution and coverage area are not only consistent with geographic information, but meet the actual demands for substation capacity.

6. CONCLUSIONS

Traditional methods are difficult to meet the actual demands in research on county-level substation sizing and siting. Therefore, this paper has gained good effects in practice by combining GIS platforms with the improved PSO algorithm. The research has come to the following conclusions:

(1) GIS platforms are introduced to the siting of county-level substations, because GIS can assist planners in avoiding geographic environments, including rivers, mountain lands and lakes, which are inconvenient to select substation locations;

(2) The improved PSO algorithm, with rapid computing speed, good global optimization capability and better comprehensive optimization capability than the traditional PSO algorithms, is applied to substation location. (3) GIS is used to manage special and attribute data needed for substation location planning, so that such data can be intuitively displayed to planners and the planning is more realistic.

This paper fully considers the effects of geographic factors on substation location by combining PSO algorithm and GIS database, which visualizes the planned locations, realizes a more scientific location and improves the location quality.

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