Research on optimal layout of Video Surveillance in the Smart Grid based on Multi-dimensional Evaluation Objectives

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Abstract. The video surveillance is a key technology, which is one of the design technology for the ubiquitous perception and acquisition of panoramic information in the smart grid. The remote video surveillance technology and power automation systems such as remote control, telemetry, remote sensing and remote signal, which ensure the normal operation of the whole smart grid, can greatly improve the security of important substations or unmanned substations. At present, there is not a unified standard for video surveillance layout of the smart grid. The video surveillance system in each area is often arranged with reference to the requirements and habits of the operation and maintenance in the region. But, other important factors are not taken into account. In this paper, by constructing the objective function of multi-dimensional evaluation, the optimal layout scheme of video surveillance in the smart grid is obtained. Finally, the effectiveness of the proposed method is proved by the analysis of the cases.

1. Introduction
In recent years, the video surveillance technology in the smart grid has made great progress. A large number of new technologies are applied to the field, such as high-definition camera, infrared camera, image recognition. However, there is not much research on the layout of video surveillance. At present, there are mainly the following problems in the layout of video surveillance in the smart grid:

1) There are too many cameras. Too much attention is paid to the overall monitoring of the scene. There are too many cameras and too dense cameras in many substations, which leads to an increase in the cost of video surveillance equipment.

2) The arrangement of video surveillance is complex. Due to too many cameras and unreasonable arrangement, the layout of the video surveillance system is complex and redundant.

3) The anti-interference of network topology is poor. From the network topology of the whole video surveillance system, there are a small number of highly important nodes and edges in many network topologies.

Under the background of the rapid development of the smart grid, how to arrange video surveillance equipment reasonably from the stability of the network and the economy of equipment is an urgent problem to be solved.

2. The objective function
In the smart grid, the video surveillance system of large substations can be regarded as a complex network. A switch can be regarded as a node of a complex network. The connections between camera and switch, switch and switch, switch and video surveillance system server are regarded as connections in the complex network.
Based on the complex network theory, this section constructs the objective function for the evaluation of the network stability, so that the optimal layout scheme of video surveillance system can be obtained in the later optimization results.

2.1 Node importance
The node importance, which is used to describe the direct influence of nodes in the network, is a basic parameter for the study of complex network topology. Its value is the number of nodes which the important node is directly connected to.

The node importance is defined as follows:

\[
\alpha = \frac{1}{n} \\
I = \sum_{i,j \in V} \frac{d_{\text{min},ij}}{(n(n-1)/2)}
\]

In the formula, \( n \) is the number of nodes in the network. \( l \) is the average shortest path between nodes. \( d_{\text{min},ij} \) is the shortest distance between any two nodes \( i \) and \( j \) in a network expressed by the number of edges. \( V \) is a collection of all nodes in the network. From the definition, we can see that if the node is in the hub position of the network, it is the very important node.

Taking the network shown in figure 1 (a) as an example, the node importance of node 12 is 3. The importance of node 9 in figure (b) is 8.

![Figure 1. The demonstration of node](image)

2.2 The intermediate number of the Connecting edge
The intermediate number of the Connecting edge is also a basic parameter for the study of complex network topology. It refers to the number of times that the edge is passed by the shortest path between all nodes in the network, which can reflect the importance of the influence of the edge on the network. The intermediate number of the Connecting edge is defined as follows:

\[
G_k = \frac{\sum_{i \neq j \in V} N_{ij}(k)}{\sum_{i \neq j \in V} N_{ij}}
\]

\( k \) is the number of the Connecting edge, \( \sum_{i \neq j \in V} N_{ij} \) is the shortest number of paths between any two nodes in the network, \( \sum_{i \neq j \in V} N_{ij}(k) \) is the number of times which the shortest path between any two nodes in the network passes through edge \( k \).
2.3 the objective function of multi-dimensional evaluation

When we build the smart grid video surveillance network, we approximate it to a complex network. In the pursuit of optimal layout, the importance of nodes in the network is not supposed to be much higher than that of other nodes, so that once a key node is damaged, it will bring inestimable consequences to the whole network.

Therefore, we construct the objective function of network stability evaluation as follows:

\[
\begin{align*}
\Delta \alpha_1 &= (\alpha_{MAX} - \bar{\alpha}) / \bar{\alpha} \\
\Delta \alpha_2 &= (\alpha_{MIN} - \bar{\alpha}) / \bar{\alpha} \\
\Delta G_1 &= (G_{MAX} - \bar{G}) / \bar{G} \\
\Delta G_2 &= (G_{MIN} - \bar{G}) / \bar{G}
\end{align*}
\]

\[
f(\Delta \alpha, \Delta G) = \left( |\Delta \alpha_1| + |\Delta \alpha_2| + |G_3| + |\Delta G_4| \right) / 4 \times 100% \quad (4)
\]

The smaller the value \( f(\Delta \alpha, \Delta G) \) is, the more average importance of nodes and edges in the network is, and the more stable the network is.

3. constrain conditions

In this section, constraint relations are constructed from different analysis angles in order to make the optimization result converge to get the optimal solution.

3.1 The constraint relationship between the configuration of video surveillance system and the annual power failure time in the smart grid

Through the investigation of the historical statistical data which recorded the operation and maintenance conditions of the smart grid, it is found that with the increase of video surveillance equipment, the state of the smart grid can be more comprehensively grasped, the probability of equipment failure can be reduced, the reliability can be improved, and the power supply interruption time can be reduced. According to the statistical data, the curve of the relationship between the annual failure time of power equipment (T) and the number of cameras (n) is as follows:

\[
T = T_0 + \frac{T_1}{n + 1} \quad (5)
\]

![Figure 2. The relation curve between T and n](image)

![Figure 3. The schematic diagram of camera view coverage](image)
and $T_1$ are based on the historical statistical data which recorded the operation and maintenance conditions of power companies. The layout of the Video Surveillance is constrained by the constraint function of formula (5).

### 3.2 The constraint function which describes the camera coverage angle

The camera layout scheme is constrained by the constraint function which describes the camera coverage angle in order to get the optimal solution. The geometric structure of the whole distribution room is discretized horizontally and longitudinally as shown in the figure. The $m \times n$ grid points are get.

To judge whether the grid point is covered by the camera, the following conditions should be met at the same time.

- $P_i \{x_i, y_i\}$ is the position of the grid point;
- $O_j \{X_j, Y_j\}$ is the position of the camera location;
- $|PO|$ is the distance between the position of the grid point and the position of the camera location;
- $R$ is the detection radius of the camera;
- $PO$ is the vector from the position of the grid point to the position of the camera location.

If the position of the grid point is inside the range of the detection radius of the camera, the following formula must be satisfied.

$$|PO_j| = \sqrt{(x_j - X_j)^2 + (y_j - Y_j)^2} \leq R$$

$$|w_j - w_{j0}| |w_j - (w_{j0} + p)| \leq 0$$

In the formula (7): $w_j$ is the azimuth of $PO_j$, $w_{j0}$ is the starting azimuth of the detection range of the j-th camera. At the initial stage of using the rand function of Matlab software, $w_{j0}$ is randomly obtained.

When $x_i - X_j \geq 0$ and $y_i - Y_j \geq 0$, $w_j = acr \tan \left( \frac{y_j - Y_j}{x_i - X_j} \right)$; 

When $x_i - X_j < 0$, $w_j = acr \tan \left( \frac{y_j - Y_j}{x_i - X_j} \right) + \pi$;

When $x_i - X_j \geq 0$ and $y_i - Y_j < 0$, $w_j = acr \tan \left( \frac{y_j - Y_j}{x_i - X_j} \right) + 2\pi$.

$P_i O_j$ and $Q_i Q_j$ do not intersect.

$$\left( Q_i \times Q_i Q_j \times Q_j Q_i \right) \geq 0 \left( P_i O_j \times P_i O_j \times P_i O_j \right) \geq 0$$

Camera coverage constraint function

$$\text{cov} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} U(i, j)}{m \times n} \times 100\%$$

$\text{cov}$ is the optimal function of camera coverage;

$m$ is the number of transverse grid points after discretization of the total region;

$n$ is the number of longitudinal grid points after discretization of the total region.

When $P_i \{x_i, y_i\}$ is covered by the camera, $U(i, j) = 0$.
When \( P_{i,j} \) is not covered by the camera, \( U(i,j) = 1 \).

4. Case study
In this section, a case, which is a new 220kV substation in Xiamen City, Fujian Province, is taken as an example. Based on the above objective function and constraint conditions, the particle swarm optimization algorithm of MatLab software is used for optimization. The calculation process is shown in the figure:

The effectiveness of the optimization method is verified by the analysis of the results.

4.1 Case
This case is a 220kV substation newly built in Xiamen City, Fujian Province. The different layout schemes are obtained by using the traditional equipment layout method (Scheme 1) and the optimal layout method in this paper (Scheme 2), and the two schemes are compared. The layout of the substation is shown in the figure:
The site is arranged in accordance with the A2-9 plan, including three buildings: Power distribution building, operation and maintenance building, guard room. The total floor area is 6405 $m^2$. The main areas that need to be equipped with video surveillance in the substation area are the substation gate, the building foyer, the perimeter of the wall, each equipment room, each equipment area and so on.

Through the comparison of the two schemes, we get the following comparative analysis table.

### Table 1. Comparative analysis table

| Scheme | Video surveillance equipment switches | Monitoring host | Video processing unit | Local cabinet | Network stability | The cost of equipment (yuan) |
|--------|--------------------------------------|----------------|----------------------|---------------|------------------|----------------------------|
| Scheme 1 | 138 | 3 | 1 | 5 | 3 | 30% | 1344000 |
| Scheme 2 | 118 | 7 | 1 | 5 | 3 | 60% | 1206000 |

#### 4.2 Results analysis

Different samples are continuously taken from the sampling area for calculation and analysis, and the following results are obtained.

### Table 2. Comparative analysis table for different samples

| Sample | General design scheme adopted in substation | Built-up area (m2) | The cost savings of Scheme 2 is better than that of Scheme 1. | The network stability of scheme 2 is higher than that of scheme 1. |
|--------|---------------------------------------------|-------------------|---------------------------------------------------------------|----------------------------------------------------------------|
| Sample 1 | A1-1 | 602 | 2% | 18% |
| Sample 2 | A1-2 | 704 | 2% | 22% |
| Sample 3 | A3-3 | 2588 | 6% | 55% |
| Sample 4 | A3-4 | 3770 | 7% | 70% |
In the Figure 6, $x$ is built-up area of the substation. $f_1$ is the function of the cost savings of Scheme 2, $f_2$ is the network stability of scheme 2. From the statistical results, it can be concluded that with the increase of the total building area of the sample, the $F_1$ and $F_2$ of the layout scheme obtained by using the method described in this paper continue to increase. The improvement of network stability is the most obvious. It shows that the scheme 2 is better for the more complex cases.

5. Conclusion
In this paper, according to the current situation of the smart grid video surveillance configuration, the optimization objective function of multi-dimensional evaluation is constructed, and the optimal layout scheme of the smart grid video surveillance is obtained. Finally, the effectiveness of the proposed method is proved by the analysis of the cases. Under the background of improving quality and efficiency proposed by State Grid, this method has certain application value and promotion prospect in the research field of the design technology for the ubiquitous perception and acquisition of panoramic information in the smart grid.

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