Low power optimization method for contactless micro intelligent voltage sensor communication network

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Abstract—Aiming at the problems of high power consumption and low success rate in contactless micro voltage sensor communication network, a low power consumption optimization method of contactless micro voltage sensor communication network is proposed. By calculating the average power consumption of micro voltage sensor nodes in the communication network area, the energy balance degree of micro voltage sensor nodes is obtained. When the micro voltage sensor nodes meet the sleep probability of communication network area coverage factor, the power consumption of voltage sensor communication network is calculated. By defining the information entropy of communication network data set, the conditional entropy of data feature classification of communication network is obtained, and the high-power data is eliminated by using the validity kernel function of data features. Combined with the low-power optimization algorithm of micro voltage sensor communication network, the low-power optimization of micro voltage sensor communication network is realized. The experimental results show that the optimization method in this paper can not only reduce the power consumption of data transmission in contactless micro voltage sensor communication network, but also improve the success rate of data transmission, and has better optimization effect.

1. INTRODUCTION
Voltage measurement, often applied in the engineering field, is of great significance in the academic circle. However, in electrical system, voltage measurement is usually realized with micro voltage sensors\cite{1}. The main function of micro voltage sensors is isolating the electricity at the high-voltage side from that at the low-voltage side. When the electrical system is operating normally, micro voltage sensors could reduce its pressure, transforming high voltage into low voltage that is more supportive for the stable operation of the electrical system. However, micro voltage sensors have their limits in application. When the electrical system malfunctions, especially under extreme weather, it is very difficult to find the accurate malfunctioning area. To the contrary, in contactless micro voltage sensors, the communication network could accurately measure the breakdown signal. The principle is maintaining the smoothness of the communication network by taking advantage of the relationship...
between the intense magnetic field surrounding the semiconductor and the electric conductor, featuring simple structure and rapid response. By studying the method for low power consumption optimization of communication network of micro voltage sensors, this paper aims to provide strong theoretical support for future development of electric grid and sensor intelligence.

Li Bin et.al. [2] proposed a MEC-based method for low power consumption optimization of high-speed railway communication network, using traditional MEC technology to analyze wireless network of high-speed railway. The study offered an optimization scheme for wireless communication network, verified the performance of the optimization method with real cases under high-speed railway scenario and obtained the conclusion that the method would consume a relatively large amount of power, which provided strong theoretical support for the optimization of wireless network. Li Bin et.al. [3] proposed an electric power communication network optimization algorithm based on risk joint equalization. In his study, data about features of electric power communication network were extracted and existing resources of each network nodes were analyzed to build electric power communication network optimization model. The electric power communication network optimization algorithm based on risk joint equalization could effectively improve the operation efficiency of the network, with the power consumption still being relatively high.

To improve the optimization effect, this paper, focusing on the communication network of contactless micro voltage sensors, designed a low power consumption optimization method based on the aforesaid studies.

2. DESIGN OF LOW POWER CONSUMPTION OPTIMIZATION METHOD FOR VOLTAGE SENSOR COMMUNICATION NETWORK

2.1. Calculation of Power Consumption of Voltage Sensor Communication Network

First, set the energy consumption equilibrium index of each transmission node to obtain the average power consumption of different transmission modes. Then, calculate the power consumption of communication network at each node according to the coverage rate of transmission nodes in the communication network of micro voltage sensors based on the power consumption equilibrium index of voltage sensors. In this way, the calculation of power consumption of voltage sensor communication network is completed. Detailed steps are as follows:

It is assumed that the power consumption value of all network transmission nodes against neighbor nodes is $l_{sd}$, $D(E_r)$ is the variance of residual power consumption of each network transmission nodes, $E_r$ is the power consumption value of each transmission node where communication network data transmission does not occur, and $E_w$ is the power consumption of each transmission nodes where data transmission is performed through voltage sensors. Assuming that there are $N$ transmission nodes in any area of the voltage sensor communication network and $K$ transmission nodes are under operating mode, formula (1) can be used to calculate the average power consumption of each transmission node in voltage sensor communication network every $X$ period. The formula is:

$$E = \frac{E_r \times E_w \times \{1_{sd}\} \times K}{D(E_r) \times X \pm N}$$  \hspace{1cm} (1)

Within $X$ periods, $K$ transmission nodes are under the operating mode. $df_{xg}$ is the coverage rate of transmission nodes in the voltage sensor. $I_{ef}$ refers to one transmission node in voltage sensor communication network. $p_{sd}$ is the communication network transmission period of each transmission node. $\sigma_{xg}$ is the power consumption per bit of information of voltage sensor communication network. Formula (2) can be used to indicate the degree of balance of voltage sensor communication network at each transmission node:

$$d_{kh} = \frac{X \times K}{df_{xg} \times I_{ef} \times \sigma_{xg} \times p_{sd} \times \sigma_{xg}} \pm h_{kh}$$  \hspace{1cm} (2)
Where $g_{dfh}$ indicates the working state of each transmission node in the voltage sensor; $u_{djh}$ refers to the power consumption of each transmission node under operation; $h_{hjk}$ is the probability of any area being covered by transmission nodes in the communication network.

If the power consumption of each transmission node is $\mu_{j}$, $\omega_{j}$ is specific location of transmission node in the voltage sensor, $p_{ij}$ is all the power consumed to transmit communication information from node $i$ to node $j$, $t_{ij}$ is the time taken to transmit communication information from node $i$ to node $j$. Formula (3) can be used to calculate the power balance of voltage sensor communication network:

$$W_{\text{net}} = \sum_{i} t_{ij} p_{ij} \mu_{j} \omega_{j} \frac{(i,j)}{g_{dfh} \times r_{sh}}$$

In the formula, $g_{dfh}$ is the gross power consumed during the transmission process, $r_{sh}$ is the total transmission time of all transmission nodes.

In voltage sensor communication network, the number of bits transmitted between transmission node $i$ and $j$ by each signal is $\theta_{ev}$. The number of bits of communication information is $d_{ag}$. Formula (4) can be used to calculate the coverage rate of all transmission nodes of voltage sensor communication network:

$$p_{ag} = \frac{d_{sh} \times E}{\theta_{ev} \times d_{ag} W_{\text{net}}} \times f_{sh}$$

In the formula, $f_{sh}$ is the number of two neighbor transmission nodes. The power consumed to send information from voltage sensor communication network from level $i$ to level $j$ is $k_{sh}$. Formula (5) can be used to calculate the power consumption of voltage sensor communication network:

$$W_{\text{net}} = \frac{(i,j)}{k_{sh} \times e_{sh} \mu_{j} \omega_{j} \times W_{\text{net}}}$$

The calculation of power consumption of communication network of contactless micro voltage sensor is hereby completed.

### 2.2 Elimination of High Power Consumption Data in Voltage Sensor Communication Network

In the communication network of micro voltage sensor, the data sample can be mainly classified into $m$ categories $c_{i}$ ($i=1, 2, L, m$), and $|c_{1}|+|L|+|c_{m}|=S$. The probability of data sample transmitted through the communication network of any voltage sensor belonging to category $c_{i}$ is $P_{i} = c_{i} / S$. The information entropy of data sample set $S$ transmitted through voltage sensor communication network is hereby defined as:

$$\text{Info}(S) = \sum_{i} p_{i} \log_{2}(p_{i})$$

Assuming that the features value of data transmission of voltage sensor communication network is $t_{i}$, the training sample set of data transmission of voltage sensor communication network is divided as $S = \{S, S_{1}, L, S_{n}\}$, where the number of data sample contained in $S$ is $|S|$. After classifying the features of data transmitted through voltage sensor communication network [4], the condition entropy obtained can be expressed by formula (7):

$$\text{Info}_{i}(S) = \sum_{i} |S_{i}|/|S| \cdot \text{Info}(S)$$
The above result is used as the information gain $e^{Gain(t_i)}$ of features $t_i$ of data transmission of voltage sensor communication network:

$$Gain(t_i) = Info(S) - Info_i(S)$$  \hspace{1cm} (8)

In the formula, the feature vector of data transmission of voltage sensor communication network can be indicated as the vector value of each feature in the sample [5]. The feature vector of data transmission of voltage sensor communication network can be indicated with formula (9):

$$f_i = \left( \frac{Gain(t_i)}{\sum_{i=1}^{n} Gain(t_i)} \right)^{Gain_i()}$$ \hspace{1cm} (9)

In the formula, $e^{Gain_i()}$ is the feature vector of a certain transmission node sample. If the feature vector matrix in feature $t_i$ of data transmission of voltage sensor communication network can describe $n$ features, the validity of voltage sensor communication network can be obtained with the following formula:

$$P = \{f_i | P_f\}$$ \hspace{1cm} (10)

In the formula, $f'$ is the feature validity of the data transmission of the $i^{th}$ communication network. Set $K$ as transmission data matrix and $P$ as the validity matrix of features in data transmission of $n$-tier voltage sensor communication network, and the validity function is:

$$K(x, x') = K(x^P, x'^P)$$ \hspace{1cm} (11)

In the function, $x^P$ is the feature vector matrix of the $i^{th}$ data transmission of the voltage communication network; $x'^P$ is the feature vector matrix of the $j^{th}$ data transmission of the voltage communication network; $r$ is the power consumption value of the validity function. The power consumption function $K'$ of voltage sensor communication network can be expressed with formula (12):

$$K(x, x') = \exp \left[ -r \left( x - x' \right) P \cdot f' \right]$$ \hspace{1cm} (12)

The smaller power consumption of data transmission of voltage sensor communication network $f'$ is, the smaller the influence the $i^{th}$ feature in the data sample transmitted through voltage sensor communication network has on the calculation of power consumption of data transmission would be. [6] In this light, power consumption function of data transmission of voltage sensor communication network can be used to distinguish high power consumption data and low power consumption data and thereby eliminate the high power consumption data in voltage sensor communication network.

**2.3. Design of Low Power Consumption Optimization Algorithm for Micro Voltage Sensor Communication Network**

Set the transmission range of communication data of network transmission node $m$ as [0,T], the probability distribution function of transmission node can be expressed as:

$$P(m,a) = \begin{cases} 
0 & a < 0 \\
\frac{a}{T} & 0 < a < T \\
1 & a > T 
\end{cases}$$ \hspace{1cm} (13)
In the formula, the threshold of the probability distribution of transmission node \( m \) in micro voltage sensor communication network is \( a \). When the information between two nodes is being transmitted in voltage sensor communication network, assume the probability of communication network information transmission is \( 1 - P(T_x,0) \), the transmission model of voltage sensor communication network can be expressed as:

\[
F(t) = P(T_x, t) = \frac{P(T_x, t) - P(T,0)}{P(T,0)}
\]  
(14)

In the formula, the power consumption is \( e_r \) when the coverage probability of voltage sensor communication network is \( P_r \). \( a \) refers to the constraint function of actual data transmission of communication network. \( E_k \) refers to the residual power consumption after the transmission nodes complete transmission of communication information.

This paper has optimized the power consumption of the communication network of micro voltage sensors with residual power consumption optimization method, and obtained the final constraint equation of low power consumption optimization of voltage sensor communication network:

\[
e(L) = \frac{E_k + ae_r}{e_r}
\]  
(15)

In the equation, \( e_r(A) \) and \( e_r(B) \) refers to the power consumption value of transmission node \( A \) and \( B \) under micro voltage sensor communication network respectively. \( T_{ab} \) represents the time node \( A \) and \( B \) have to take to transmit communication data. \( r \) indicates the size of communication network data. \( p \) refers to the transmission rate of communication network data. \( T_r \) is the transmission time after communication network data is compressed.

To this end, a low power consumption optimization algorithm for micro voltage sensor communication network is designed to realize the low power consumption optimization of communication network.

\[
G\left( \frac{e_r(A)}{e_r(A)} - \frac{e_r(B)}{e_r(B)} \right) - \frac{T_{ab} - r}{p} = T_r
\]  
(16)

In the formula, the time interval of communication network information transmission at node \( x \) is \( T_x \). \( t \) is the time constraint threshold of the communication network. Calculate the above formula, obtain the duration \( T_f [7] \) of the data transmission of micro voltage sensor communication network, and thereby construct a data transmission model for voltage sensor communication network. Compress the low power consumption data of voltage sensor communication network with data compression algorithm [8], the following formula is obtained:

3. Test and Analysis

3.1. Preparation

Verify the effectiveness of the optimization method proposed in the paper through simulation analysis. Select an area of 150m*150m in the communication network of contactless micro voltage sensor, and put 150 voltage sensor nodes in the area randomly, with the initial power consumption of each node being 10W (as shown in Figure 1).
In Figure 1, the optimization method based on MEC (the method in Literature [2]) is compared with the optimization method based on load and risk joint equilibrium (the method in Literature [3]). The two methods are both applied to lower the power consumption of micro voltage sensor communication network. The following test results are obtained.

3.2. Analysis of Test Results

For the communication network of micro voltage sensors, low power consumption optimization aims to lower the transmission power consumption of the communication network. In the study, three optimization methods were applied to lower the power consumption of voltage sensor communication network with data transmission time being the independent variable. The power consumption of data transmission of voltage sensor communication network was as shown in Figure 2.

From Figure 2, it can be concluded that the longer the transmission time is, the power consumption of communication network of the three optimization methods would all increase, with the power consumption of MEC-based optimization method and the optimization method based on load and risk joint equilibrium being relatively high within specific transmission time. The MEC-based optimization
The method can keep the power consumption of communication network within the range of 2.65W~2.95W, while the optimization method based on load and risk joint equilibrium can keep the power consumption of communication network within the range of 2.5W~2.8W, almost the same. In contrast, when optimizing the communication network of micro voltage sensors with the method proposed in the paper, the transmission power consumption is relatively stable, between 2.15W~2.35W, smaller than the power consumption range of the other two methods, which indicates that the method proposed in the paper performs better in lowering the power consumption of micro voltage sensor communication network.

In order to further verify the effect of the optimization method proposed in the paper, success rate of data transmission is used as an indicator of the optimization effect of micro voltage sensor communication network. Success rate of data transmission refers to the proportion of data successfully transmitted in the network. The result is shown in Figure 3.

![Data Transmission Success Rate](image)

**FIGURE 3 TEST RESULT OF DATA TRANSMISSION SUCCESS RATE**

From Figure 3, it can be concluded that when MEC-based optimization method is applied, the success rate of data transmission in micro voltage sensor communication network is close to that before optimization; before the 2nd -3rd test and 6th -7th test, the success rate of data transmission after the optimization method is applied is lower than that before optimization. When the optimization method based on load and risk joint equilibrium, the success rate of data transmission is higher than that before optimization (fluctuation between 75% and 85%), fluctuating quite significantly, which is not as stable as the data transmission in network. When the optimization method proposed in the paper is adopted, the success rate of data transmission can be raised to over 95%, and the fluctuation of the success rate of data transmission is relatively stable, realizing better low power consumption optimization effect for micro voltage sensor communication network.

### 4. CONCLUSION

The paper proposed a low power consumption optimization method for contactless micro voltage sensor communication network. Tests have shown that the optimization method could achieve better effect in the communication network of micro voltage sensors and thereby lower the power consumption of traditional method in communication network. However, the method proposed still needs to be improved. In the future, studies should, while ensuring the optimization effect of the power consumption and data transmission success rate of the communication network, increase the speed of data transmission in micro voltage sensor communication network to avoid network congestion.
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