Research on voltage fluctuation control based on Analytic Hierarchy Process

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Abstract. In recent years, more and more distributed photovoltaic power generation is connected to poverty alleviation areas. When the proportion of household photovoltaic power generation is too large, the voltage limit problem may appear. Therefore, this paper proposes a dual objective voltage control method based on analytic hierarchy process (AHP) to adapt to regional differences. Taking power quality and cost as the voltage control objectives of photovoltaic poverty alleviation areas, combining photovoltaic inverter with plug and play equipment, according to the differences of poverty alleviation areas, adjusting the weight can switch in different control modes, and using particle swarm optimization algorithm to solve the problem, It not only solves the problem of voltage overrun, but also saves the construction cost. Finally, the effectiveness of AHP is verified by simulation experiments.

1. Introduction
At present, the way of obtaining electric energy mainly depends on fossil energy. In order to solve the source shortage and environmental pollution caused by burning fossil energy, energy reform must be carried out to get rid of the dependence on fossil energy. Therefore, all over the world are trying to find new power generation energy [1]. Among them, distributed photovoltaic power generation has the advantages of abundant resources and inexhaustible use, which has been widely concerned all over the world. Therefore, distributed generation with new energy as the core has been more widely developed and applied, and has become the most potential new energy [2-3].

With the development and utilization of photovoltaic in various countries, its grid connected installed capacity is growing at a very fast speed. In the low-voltage distribution network in some parts of Europe, the installed photovoltaic capacity has exceeded 70% [4]. According to China's 13th five year plan for power development (2016-2020), the installed capacity of grid connected solar power generation has reached 170 million kilowatts by the end of 2018[5]. Distributed photovoltaic power generation is a clean energy, but it will cause harmonic pollution, overvoltage, three-phase imbalance and other problems when entering the grid. When the proportion of distributed photovoltaic power generation in the grid is too large, these problems will have adverse effects on the stability of the power system [6]. Therefore, we have to limit the proportion of distributed generation connected to the power grid, and the most important reason is the voltage overrun. If distributed generation is not installed, the power flow of distribution network always flows from the source side to the load side, and the voltage will decrease with the increase of transmission distance. The addition of distributed generation changes this state. The distribution network changes from a single source to a multi source network, which can
change the distribution and flow direction of power flow. For example, the power flow may flow from the user side to the power side, thus affecting the voltage distribution [7]. If used reasonably, distributed generation can raise the grid voltage and improve the under voltage problem, but beyond the reasonable range, it will lead to over-voltage, damage grid equipment and threaten life safety [8].

At present, some scholars have proposed to use photovoltaic inverter for reactive power voltage regulation, in reference [9], a voltage control strategy based on optimal power flow algorithm is proposed. By comparing with Q (U) method, a method is proposed to determine the minimum reactive power required for voltage regulation, which solves the above overvoltage problem and minimizes the reactive power exchange and network loss. Reference [10] studies the method of suppressing active power, and proposes a new type of inverter. The goal is to minimize the reactive power output and active power reduction. It adopts the centralized control strategy with the constraints of system power flow, inverter capacity and voltage, and uses the complex algorithm to solve the problem of voltage overrun. The research content of literature [11-12] is to use genetic algorithm to solve the output reactive power of each inverter, so as to achieve the minimum loss of distribution network, and to carry out simulation verification in different network structures. The purpose of reference [13] is to minimize the voltage deviation of each node in the power grid from the rated voltage of the system, call the residual capacity of generator and inverter, reactive power compensation device, and propose an intelligent immune algorithm based on competition and clustering clone mechanism to calculate reactive power output, which not only solves the problem of overvoltage, but also greatly reduces the reactive power loss of the system. In reference[14], considering that the reactive power output of distributed photovoltaic system may be accompanied by cost penalty in the future, a multi-objective optimization design is proposed to adjust the characteristic parameters of Q(U) curve, which not only minimizes the grid loss, but also makes the reactive power output of each photovoltaic system equal. However, this method has small capacity, considerable limitations and low economic benefits, it is difficult to use in large quantities.

Similarly, in order to solve the energy problem, some experts proposed to combine information, communication technology and traditional energy technology. The concept mainly aims at the demand of plug and play, two-way interaction of energy and information brought by the large-scale grid connection of distributed renewable energy, electric vehicles, energy storage systems and other intelligent energy supply and consumption equipment. The "plug and play" of smart devices means that when a new device is physically connected to the power grid, the power grid management platform can automatically identify and manage the new device. But plug and play equipment is mainly used in the field of computer, to be widely used in the power system, we need to deal with the technical difficulties, high construction cost, high maintenance cost and other problems.

In this paper, a voltage control method is proposed to adapt to the differences of photovoltaic poverty alleviation areas. Analytic hierarchy process is adopted to establish the expression of objective function and related constraints. Each weight K in the objective function is calculated, and the voltage can be regulated according to the actual situation of photovoltaic poverty alleviation areas. This paper first describes the differential voltage control method of photovoltaic poverty alleviation area, analyzes its advantages and disadvantages, and then puts forward the analytic hierarchy process based on AHP to adapt to regional differences, and establishes a simulation model to demonstrate the rationality of the method.

2. Differential voltage regulation methods in photovoltaic poverty alleviation areas

2.1. control mode of photovoltaic inverter

The common voltage regulation methods in the actual operation of power system are as follows:

1. Increase or decrease reactive power for voltage regulation.
2. Adjust the voltage by changing the network parameters.
3. The distribution of active power and reactive power can be changed to adjust the voltage. In special cases, the voltage can be adjusted by adjusting the power load or limiting the power supply [15].
When the power is transmitted in the power grid, the load current produces voltage loss on the transmission lines and transformers $\Delta U$. The relationship is as follows:

$$\Delta U = \frac{(PR + QX)}{U_N}$$  \hspace{1cm} (1)

After installing the reactive power compensation device, the line voltage loss will decrease $\Delta U'$ is:

$$\Delta U' = \frac{(PR + (Q - \Delta Q)X)}{U_N}$$  \hspace{1cm} (2)

Where, P and Q are the active and reactive power of the load respectively, $\Delta Q$ is reactive power compensation, $R$ and $X$ are resistance and reactance of load respectively. $U_N$ is the bus voltage.

The main module of photovoltaic power generation is grid connected inverter. At present, the most widely used structure in power grid is two-stage photovoltaic inverter, which has the advantages of high reliability, wide voltage input range and simple control. The structure and control principle of two-stage photovoltaic grid connected circuit are shown in Figure 1.

![Figure 1. Structure and control principle of two-stage photovoltaic grid connected circuit.](image)

Photovoltaic output is random and affected by the light intensity. When the light radiation intensity changes, the photovoltaic active power output changes. The reactive power of the PV inverter is regulated by using the partial residual capacity generated when the active power output is low.

$$\max_{PV} Q = \pm \sqrt{S^2 - P_{PV}^2}$$  \hspace{1cm} (3)

Where $Q_{PV\ max}$ is the maximum available reactive power capacity of the inverter, the positive sign represents the output reactive power and the negative sign represents the absorbed reactive power; $S$ is the rated capacity of the inverter and $P_{PV}$ is the current active output of the photovoltaic cell.

The functional expression of the relationship between the absorbed reactive power and voltage of the inverter is as follows:

$$Q = \begin{cases} 
0 & U_a < U < U_b \\
\max_{Q} (U - U_b) & U_b < U < U_{max} \\
\max_{Q} U_{max} - U_b & U_{max} \leq U
\end{cases}$$  \hspace{1cm} (4)

Where, $U_{max}$ represents the upper limit of the parallel point voltage; $U_a$ and $U_b$ respectively represent the upper and lower limits of the set target range. Through this setting, the PV inverter can effectively reduce the situation that the voltage exceeds the upper limit.
The local voltage control can only dispatch the inverter with voltage overrun node, which can not solve the problem of voltage overrun when the residual capacity is insufficient. If we take the whole grid voltage as the control objective and control the residual capacity of the whole grid inverter cooperatively, we can effectively improve the active power reduction and improve the power quality. With the progress of power grid technology, this idea is gradually becoming possible. The optimal coordinated control strategy of feeder voltage of multi-point photovoltaic inverter proposed in this paper can call the residual capacity of all inverters on the feeder. To achieve the purpose of voltage regulation. It is difficult to collect the voltage, load and other electrical parameters of each node in real time due to the large and complex load of distribution network users. The method proposed in this paper only collects the parameters of each power supply (including grid power supply and photovoltaic power supply) node, appropriately simplifies the distribution network model with multiple photovoltaic power supply, greatly reduces the installation number of monitoring terminals and the amount of communication data. The structure and control principle of two-stage photovoltaic power generation grid connected circuit are shown in Figure 2, and the dotted line indicates the communication connection.

![Figure 2 structure and control principle of two-stage photovoltaic grid connected circuit.](image)

In this paper, the reactive power required by inverter voltage regulation is used \( \Delta Q \) as an instruction, and it is allocated to each inverter according to the capacity to describe the correlation model of V regulation and inverter voltage regulation in power grid once, as shown in Figure 3. It can be seen from equation (2) that the size of \( \Delta Q \) is:

\[
\Delta Q = \frac{PR - \Delta U^U_i}{X} + Q
\]  

(5)

Reactive power to be regulated by each inverter \( \Delta Q_i \) is:

\[
\Delta Q_i = \frac{Q_{pv,i}}{\sum_{i=1} Q_{pv,i}}
\]  

(6)

Where, \( i \) is the node on the bus, \( Q_{pv,i} \) is the residual reactive capacity of the inverter on node \( i \).
Figure 3. Schematic diagram of correlation model for primary voltage regulation of power grid

Further research is needed for its optimal coordinated control. In order to make the output reactive power and minimum simultaneous voltage of each grid connected inverter as close to the grid voltage rating as possible, this paper mainly studies its control strategy from two aspects of objective function and constraints.

It is only the basic goal to adjust the voltage to the set voltage limit by dispatching all inverters on the feeder. The control strategy in this paper can also call more residual capacity and reduce the reactive power output of the inverter as much as possible. According to the above analysis, the target of optimal coordinated control is determined as follows:

\[
\begin{align*}
    f_1 &= \min \left( \sum_{i=1}^{n} Q_{PV,i} \right) \\
    f_2 &= \min \left( \sum_{i=1}^{n} \left( \frac{U_i - U_N}{U_{\max} - U_{\min}} \right)^2 \right)
\end{align*}
\]  

(7)

Where, \(f_1\) and \(f_2\) represent objective functions 1 and 2, which require the sum of reactive power output by grid connected inverters and the voltage of PV node of distribution network to be close to the rated value of grid voltage respectively. The value of \(i\) is the value of PV node, \(Q_{PV,i}\) is the output reactive power of each inverter, \(U_i\) is the voltage of current PV node, \(U_N\) is the rated voltage of power grid. \(U_{\max}\) and \(U_{\min}\) are the upper and lower limits of allowable voltage of power grid.

The constraint conditions are as follows:

a. Voltage constraint:

\[
U_{\min,i} \leq U \leq U_{\max,i}
\]

(8)

Where, \(U_{\max}\) is the upper limit value of node voltage and \(U_{\min}\) is the lower limit value.

b. Inverter capacity constraints:

\[
-S_{PV,i}^2 - P_{PV,i}^2 \leq Q_{PV,i} \leq S_{PV,i}^2 - P_{PV,i}^2
\]

(9)

The two objective functions can be simplified by weighting method, the simplification is as follows:

\[
\min f = w_1 f_1 + w_2 f_2
\]

(10)

\[
w_1 + w_2 = 1
\]

(11)

Where \(w_1\) is the weighting coefficient of objective function 1, \(w_2\) is the weighting coefficient of objective function 2, and the specific value is determined by the actual requirements of the system.

2.2. Control mode of plug and play equipment in normal operation

In order to change the existing energy consumption and production mode and reduce the dependence on traditional energy, some experts proposed to combine information and communication technology with energy technology to build a global energy Internet. The object of this concept is distributed renewable energy, electric vehicles and other intelligent energy supply and consumption devices, which are connected to the power grid on a large scale, resulting in the demand of plug and play, two-way interaction of energy and information [16]. This concept has changed the traditional operation mode of power grid. The customer side can meet the power demand through power generation devices. When the customer side has excess power, it can also sell the power to the power grid, changing from the power consumer to the production consumer [17].

Plug and play equipment in the electrical field refers to that when new equipment is physically connected to the power grid, the power grid management platform can automatically identify the new equipment and manage and control the equipment [18]. At present, plug and play technology is widely used in the field of computer and network, which is used to configure the motherboard and peripherals.
Through plug and play technology, users can complete a series of operations of the device without manually configuring hardware or operating system [19]. But in the field of electrical plug and play equipment research is not in-depth, it is worth further development.

In order to ensure that the energy storage plug and play equipment in rural power grid area has the ability of active and reactive power support and good power quality, the appropriate control method of energy storage converter is needed. The energy storage converter is composed of AC-DC controlled rectifier circuit and isolated Bidirectional DC-DC circuit, which has bidirectional converter ability. The energy storage coordination controller should have the functions of real-time monitoring and statistical analysis to monitor and analyze the operation status, load and environment of the equipment, and display the results visually.

The system contains voltage autonomous device, which can collect and node voltage. When the parallel node voltage is abnormal, judge the operation status of distributed photovoltaic and energy storage, adjust the reactive power output on the AC side according to the actual situation, and set its upper limit, which can ensure safe and stable operation and support grid connected voltage. After a period of operation, it gradually returns to the previous state. Judging whether the self-made device is working according to the voltage of the parallel dot, the voltage of the parallel dot is divided into three areas. As shown in Figure 4. When \( U < U_1 \), the voltage is low, when \( U > U_4 \), the voltage is high, when \( U \in [U_2, U_3] \), the voltage of the parallel node returns to the normal area. In the out of limit and normal direct hysteresis region, frequent switching is prevented.

![Figure 4. Voltage division of parallel point.](image)

The grid connected voltage \( U_{DG} \) of distributed generation is as follows:

\[
U_{DG} = U_s + \frac{(P_{DG} - P_{load})R + (Q_{DG} - Q_{load})X}{U_s} \tag{12}
\]

Where \( U_{DG} \) is the voltage of the parallel node; \( U_s \) is the grid bus voltage; \( P_{DG} \) and \( Q_{DG} \) are the active power and reactive power respectively; \( P_{load} \) and \( Q_{load} \) are active power and reactive power of load side respectively; \( R \), \( X \) are the resistance and reactance of the line in the distribution network respectively. The average voltage offset is as follows:

\[
f_{ave} = \frac{1}{n} \sum_{n=1}^{n} \frac{U_{ref} - U_{DG}}{U_{ref}} \times 100\% \tag{13}
\]

Where, \( n \) is the number of users and \( U_{ref} \) is the reference voltage of the parallel node.
The voltage autonomous device of distributed generation synthesizes the information of the voltage, SOC state of energy storage and current operation state of the device to output reactive power coordination control. The flow chart of coordination control is shown in Figure 5.

![Flow Chart](image)

**Figure 5.** Control flow of voltage active support in parallel node.

The plug and play system constructed in this paper can not only meet the current demand, but also predict the photovoltaic output in the next 24 hours, and optimize the control strategy to make the next 24 hours home users run at the minimum cost, the objective function of the optimization model is as follows:

$$
\min F = \sum_{t=1}^{T} (P_{EV}(t) + P_{ES}(t) + P_{load}(t) - P_{PV}(t)) \cdot \delta(t)
$$

(14)

Where, $F$ is the daily electricity charge of household users (yuan); $T$ is the optimization time (h), taken as 24h; $P_{EV}(t)$ represents the charging power of electric vehicle at time $t$ (kW); $P_{ES}(t)$ represents the charging and discharging power of the energy storage system at time $t$ (kW); $P_{load}(t)$ represents other load power at time $t$ (kW); $P_{PV}(t)$ is the predicted power of photovoltaic power generation system at time $t$ (kW); $\delta(t)$ represents time/electricity price (yuan /kWh).

The power balance constraints are shown in (15):

$$
P_{in} + P_{PV} = P_{ES} + P_{EV} + P_{load}
$$

(15)

Where, $P_{in}$ is the power purchased from the grid (kW).

3. Analytic Hierarchy Process

Photovoltaic inverters are small in capacity and have considerable limitations. At the same time, the economic benefits are not high and it is difficult to use them in large quantities. Plug-and-play equipment is currently mainly used in the computer field. To be widely used in power systems, it is necessary to deal with technical difficulties and construction problems such as high cost and high maintenance cost. The two need to be combined to obtain optimal control. However, some photovoltaic poverty alleviation areas do not have plug-and-play equipment or photovoltaic inverters are not suitable for voltage regulation. This paper proposes a dual-target voltage fluctuation control study that adapts to the differences in photovoltaic poverty alleviation areas, that is, dual-target voltage control that adapts to regional differences method.

This article takes voltage quality and cost as the dual goals of voltage regulation. On the one hand, the voltage quality is the objective function as the minimum difference between the voltage and the safety limit; on the other hand, the reactive power regulation of the inverter and the active power output of the plug-and-play equipment require costs, and both costs are directly proportional to the power output. Relations, and the cost coefficients of the unit adjustment amount are different, so the cost needs
to be divided into two sub-functions: the smallest reactive power adjustment amount and the smallest active power adjustment amount. Therefore, the control objectives of cost and voltage quality can actually be divided into three sub-functions. In order to obtain the respective weights of the sub-functions, this paper adopts the analytic hierarchy process to establish a weight distribution plan.

To use the analytic hierarchy process to judge the value of $k$, we must first construct a judgment matrix. The content of the matrix is the ratio between all factors. Then obtain the largest eigenvalue of the judgment matrix and the eigenvector corresponding to the eigenvalue, and the normalized result is the weight $k$ of each influencing factor. The construction of the judgment matrix needs to use the 1-9 scale method, that is, the value of the influencing factors is selected according to the importance, the most important is 9, and so on. Name the third-order judgment matrix constructed according to this method as matrix $B$. In matrix $B$, the indicators in each row from top to bottom are the reactive power output of the photovoltaic inverter, the active power output of the plug-and-play equipment, and the electrical energy quality.

After obtaining the matrix $B$, the next step is the arithmetic average method to obtain the weight coefficients. The steps for obtaining the weight coefficients are as follows: First, the judgment matrix $B$ is normalized by column, then the columns are added, and the added vector is divided by $z$ obtains the weight vector, $z$ is the matrix order.

Finally, use matrix $B$ to check the consistency of the obtained results. When the consistency ratio $CR=CI/RI<0.1$, the representative result is reasonable. The consistency ratio $CI=(\lambda_{\text{max}}-n)/(z-1)$, where $\lambda_{\text{max}}$ is the maximum characteristic value of $B$. The consistency index $RI$ is related to the order of the judgment matrix $B$, and the index shown in Table 1 can usually be directly used for calculation. Finally, the weight coefficients $k_1$, $k_2$ and $k_3$ are obtained.

| $n$ | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|-----|----|----|----|----|----|----|----|----|----|
| RI  | 0  | 0  | 0.52 | 0.89 | 1.12 | 1.24 | 1.36 | 1.41 | 1.46 |

The comprehensive optimization of this article includes two aspects, cost and power quality. The cost includes the cost of regulating the reactive power of the inverter and regulating the active power of the plug-and-play equipment. The power quality is represented by the average voltage offset in this article.

According to the above research, only need to set the weight coefficients of different objective functions, it can be between the inverter control mode of photovoltaic reactive power control technology, the plug-and-play equipment control mode, and the dual-objective comprehensive optimization control mode. Switching significantly improves power supply reliability and power quality.

In the correlation model of the inverter control mode, minimizing the required output of reactive power is the first objective function to achieve comprehensive optimal control, namely:

$$f_Q = \sum_{i=1}^{n} |Q_{PV,i}|$$  \hspace{1cm} (16)

In the formula, $i$ is the PV node number, and $Q_{PV,i}$ are the reactive power output by each inverter.

In the bias control mode of normal operation of plug-and-play equipment, minimizing the charging and discharging power of the plug-and-play equipment, that is, the energy storage system, is the second objective function of the comprehensive optimization control mode, as shown in formula (17).

$$f_P = \sum_{i=1}^{n} |P_{EV,i} + P_{ES,i} + P_{\text{load},i} - P_{PV,i}|$$  \hspace{1cm} (17)
In the formula, \( i \) is the PV node number, \( P_{EV,i} \) are the charging power; \( P_{ES,i} \) are the charging and discharging power of the energy storage system; \( P_{load,i} \) is the power of other loads; \( P_{PV,i} \) is the predicted power of the photovoltaic power generation system.

Combining formula (10) and formula (14), set the voltage safety range of the poverty alleviation area as \([U_x, U_y]\), and express the power quality, that is, the voltage deviation as the sum of the difference between the line voltage and the safe voltage limit:

\[
f_U = \sum_{i=1}^{m} \left[ x_i (U_x - U_i) + y_i (U_i - U_y) \right]
\]  

In the formula, \( m \) is the total number of nodes, and \( U_{ref} \) is the reference voltage of the grid-connected point. \( x_i \) and \( y_i \) are judgment coefficients. When the voltage is lower than \( U_x \), \( x_i \) is 1 and \( y_i \) is 0; when the voltage is higher than \( U_y \), \( x_i \) is 0 and \( y_i \) is 1.

In summary, combined with the actual conditions of poverty alleviation areas, the weights of the three objective functions \( k_1, k_2, \) and \( k_3 \) can be obtained, and then the objective function of comprehensive optimization control can be written as:

\[
f = k_1 \cdot f_Q + k_2 \cdot f_P + k_3 \cdot f_U
\]  

By changing the weights of \( k_1, k_2, \) and \( k_3, \) a control mode that conforms to the actual conditions of poverty alleviation areas can be obtained. When the value of \( k_1 \) is 0, the area is in a plug-and-play device active power adjustment state. When the value of \( k_2 \) is 0, the area is in the reactive power regulation state of the photovoltaic inverter. When the ownership value is not 0, the region is in a dual-objective comprehensive optimization control mode.

In order to solve the objective function 19, the particle swarm algorithm can be used to solve the problem. This is a cluster intelligence algorithm. Its advantages are easy implementation, rapid convergence, and high accuracy. Therefore, this paper uses particle swarm optimization to solve the problem. The steps to apply it to the method proposed in this article are:

1) Initialization of particle swarm position and velocity.
2) Calculate the \( f \) value corresponding to each particle (formula 19).
3) According to the value of \( f \), update the individual optimal position of each particle.
4) On the premise of constraint conditions, update the global optimal position of the particle swarm according to the value of \( f \).
5) Output the optimal solution.

4. Case analysis

4.1. Simulation system
The simulation power distribution system of photovoltaic poverty alleviation area is shown in Figure 6. The simulation model is established in matlab. The power distribution node uses a small system in IEEE. There are 13 buses in total, among which buses 2, 3, 4, 6, 7, 10 and The home on 12 is equipped with a household optical storage system, and the simulation time is 24 hours.
4.2. Case study
In different time periods of the day, the light intensity is different. The photovoltaic output curve is shown in Figure 7, reaching a peak of 38kW at about 12 noon, and the photovoltaic output at night is 0.

Figure 7. Photovoltaic output curve.

Figure 8 is the load curve of the poverty alleviation area, showing the electricity consumption of residents in a day, with a time scale of 1h.

Figure 8. Load curve of poverty alleviation areas.
It can be seen from Figure 6 that the user 10 is the furthest away from the transformer, and is the user with the most serious voltage limit violation. The simulated power distribution system in the photovoltaic poverty alleviation area proposed above is simulated and the terminal node voltage is measured, as shown in Figure 9. Due to the mismatch between the photovoltaic output power and the load demand in the poverty alleviation area, the power flows along the feeder line, and there will be a significant voltage rise or drop at the end of the line, and even exceed the limit. Therefore, by measuring the terminal node voltage, the overvoltage and undervoltage status of the photovoltaic system can be obtained.

![Figure 9. Terminal node voltage.](image)

It can be seen from Figure 9 that the system has over-voltage problems when the photovoltaic output is large at noon, and under-voltage problems occur in the evening when the photovoltaic output is greatly reduced but the electricity demand is still high. It can be seen that the over-voltage and under-voltage problems of the system are very serious when the voltage control method is not used.

The analytic hierarchy process that adapts to regional differences is used to simulate the system, and different control methods can be switched by changing the weights. When the inverter bias control mode is used for adjustment, that is, $k_2=0$, the simulation result is shown in Figure 10(a). When the plug-and-play equipment is used for adjustment or the analytic hierarchy process is adopted, that is, when $k_1=0$ or $k_1$ and $k_2$ are not 0, the simulation result is shown in Figure 10(b).

![Figure 10. Voltage control results.](image)
It can be seen from Figure 10 that when the photovoltaic inverter control mode is used for regulation, the system still has overvoltage. This is because the capacity of the photovoltaic inverter is limited, which is not enough to solve the overvoltage problem during the peak period of photovoltaic output. When the plug-and-play equipment is used for adjustment or the analytic hierarchy process proposed in this article is used for adjustment, the over-voltage and under-voltage problems are solved.

In terms of control results, the use of plug-and-play equipment and analytic hierarchy process for adjustment are the same, but considering the construction cost, the cost of plug-and-play equipment is significantly higher than that of photovoltaic inverters. The analytic hierarchy process proposed in this article guarantees under the premise of the regulation effect, a photovoltaic inverter is added, which reduces the construction cost.

The analytic hierarchy process proposed in this paper fully adapts to the differences in poverty alleviation areas. If only photovoltaic inverters are installed in the poverty alleviation areas without plug-and-play equipment, the value of $k_2$ is set to 0. Similarly, if the light intensity in the area is very high if the PV inverter has no remaining capacity to adjust, the value of $k_1$ is set to 0. Having two devices at the same time adopts comprehensive voltage regulation.

5. Conclusion
This article first introduces the respective advantages and disadvantages of the photovoltaic inverter control mode and plug-and-play equipment, and proposes an analytic hierarchy process based on the analytic hierarchy process to adapt to regional differences.

Secondly, the regulation mode of photovoltaic inverter and the plug-and-play equipment were deeply studied, and their voltage regulation principles, methods, objective functions, and constraint conditions were analyzed. Then the analytic hierarchy process is adopted, and an analytic hierarchy process that combines the photovoltaic inverter control mode and plug-and-play equipment is proposed to adapt to regional differences.

Finally, the proposed strategy was simulated, a simulation model of the simulated power distribution system in photovoltaic poverty alleviation areas was established, and different voltage control methods were simulated. The results showed that the analytic hierarchy process not only achieved the expected effect but also saved the cost.

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