Convenient Power Supply Scheme Design for Remote Areas

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Abstract. At present, there are still a large number of people worldwide without electricity in remote villages. Electricity supply is one of the important conditions restricting the development of remote areas. In order to solve the power supply problem in these remote areas, this paper proposes a convenient power supply scheme. It adopts modular, flexibly configurable independent power supply based on renewable energy power generation technology, and is equipped with a backup power generation device based on human or animal power to ensure a certain degree of power supply reliability. Use easy-to-implement power supply equipment configuration and installation methods to achieve convenient layout of the power supply system. The above power supply scheme was evaluated in terms of technical feasibility, economy and social significance. Introduction

1. Introduction

In recent years, there are still many remote villages in the world without electricity, and the phenomenon of no electricity is more common. There are still about 1.3 billion people in the world without access to electricity [1]. Electricity problems have severely restricted the production methods and social life of these regions and populations, as well as the local social development. Areas without electricity are usually located in remote areas, far away from the large power grid, which makes it difficult to construct long-distance power transmission. According to the survey that it takes an average of 25 years to increase the power coverage rate from 20% to 80% by using traditional power supply schemes to power remote areas [2], with a long power construction period. The challenge of long-distance power transmission is far more than complicated terrain and construction. As the load increases, the original power construction needs to be expanded. The traditional expansion is usually limited by the natural environment, and the renovation fund and the investment efficiency are not mature, which lead to the delay of the renovation cycle [3].

Residents in remote areas are scattered, with irregular arrangement and limited traffic conditions. It takes a long time to construct power system for remote areas, resulting in higher costs in terms of investment, operation, and power supply equipment losses, which makes great burden for power grid companies and users. In fact, long-distance power transmission is not the only power supply mode, and the corresponding on-site development and consumption mode is more suitable for power supply in remote areas. The latter is based on an independent power generation system which disconnects with the large power grid and attains generation energy sources from natural resources such as water, wind, and sunlight, etc. to the large power grid. This mode can eliminate a series of problems caused by long distances. Remote areas have abundant resources to meet the conditions of the on-site mode.

Therefore, this article proposes a convenient solution for remote areas to provide a reference for solving the problem of no electricity in the future, and demonstrate the feasibility of the solution provided in this article through case studies.
2. Design principles and ideas

2.1 Design principles
According to the characteristics of the economic development and population education of remote areas, the power supply principles can be summarized as follows:

- Meet the basic load demand of the basic load;
- Modular design is beneficial for easy installation;
- Make sure the workload of implementation and maintenance is small;
- The electricity usage rules are convenient for the local residents, and users can use electricity at any time.
- Meet safety requirements in terms of the installation and connection of equipment.

2.2 Design ideas
On the basic of the characteristics of remote areas, the power supply scheme for this area will be explained from three aspects: module design, configuration method and safety measures.

2.2.1 Modular design. The main power source can be local renewable energy, and the backup power source can be human or animal power. The location of the power must not affect the lives of residents within the allowable power transmission range. Villagers in remote areas have weak awareness of safety. The layout of the wires should avoid misuse by villagers. The modules are connected by plug-in interfaces to improve installation efficiency. The power supply module should have portability and mobility for easy transportation and installation.

2.2.2 Configuration method. The area division should consider equipment cost and line cost. The configured capacity of the power generation part should meet the load demand with a safety margin. Lines can be divided into trunk lines and branch lines, and wires with corresponding carrying capacity can be selected. A non-type interface can be formed by a combination of basic type interfaces. Take the number of interfaces at the first place and then consider the economy.

2.2.3 Safety measures. The capacity selection of all power supply equipment is based on the load forecast with a margin. Switches of all modules must be off before and during the installations of modules. The construction safety should follow the "Code for Safety of Electricity Supply and Use at Construction Sites".

3. Modularization design

3.1 Power generation
Optional power modules include wind turbines (WT, 500W/unit and 1000W/unit, output voltage 24V), photovoltaic panels (PV, 50W/block and 200W/block, output voltage 24V), battery (nominal voltage 12V, nominal capacity 200Ah) and hand-cranked generator (200W).

3.2 Wire
Thin wires and thick wire are proposed. The thin wires use ordinary cables, which are suitable for households and branch lines. The thick wire adopts photovoltaic special cable, which is suitable for power generation part and main lines.

3.3 Wiring board
The wiring board has two functions: a) leading in power; b) distributing electric energy. The main switches correspond to the main and standby powers. When the main power source is insufficient, the residents can switch to the standby power source.

3.4 Interface
Interfaces include three types: a) male and female interfaces, suitable for the connection of lines and jacks; b) one-to-one interface, suitable for connection between line types; c) one-to-many interface, suitable for the connection of main trunk lines and branch trunk lines.

4. Installation and layout

4.1. Regional division

4.1.1 Economic division. Generally, the line loss rate $\Delta P_{\text{loss}}\%$ of 220/380V voltage level does not exceed 12% [4]. It is known that the power supply voltage is $U$, the power output power is $P$, the line loss power is $P_{\text{loss}}$, the wire resistivity is $\rho$, the wire section is $S$, and the maximum power transmission distance of the wire to be determined is $L_{\text{max}}$. The calculation is as follows:

$$\Delta P_{\text{loss}}\% = \frac{P_{\text{loss}}}{P} \times 100\% \leq 12\%$$

$$I = \frac{P}{U \cos \varphi} = \frac{P_{\text{loss}}}{\rho S} = I^2R$$

$$\Rightarrow L \leq 12\% \times \frac{U^2S \cos \varphi}{\rho P_{\text{loss}}}$$

In order to ensure safety, the power center is the center of the circle and the circle is $0.8L_{\text{max}}$ as the radius. The area inside the circle is regarded as the suppliable area, and other residents outside the circle need to consider separate power supply.

4.1.2 Security division

Literature [5] mentioned that when the voltage is 380V and the transmission capacity is below 100kW, the safe power supply range is within 600m, and the households beyond this range can be supplied separately.

4.2. Power supply location and configuration

4.2.1 Power supply location. The location of photovoltaic panels and wind turbines should be able to obtain energy to the greatest extent, such as high altitude or relatively open areas [6].

4.2.2 Power configuration. First, estimate the electric power $P_1$ of a single household, and the number of households in zone $i$ is $N_i$, and take the synchronization coefficient as 0.9, and calculate the total electricity consumption $P_{\Sigma i}$ of the village by formula (3).

$$P_{\Sigma i} = 0.9 \times N_i \times P_1$$

The main power source type corresponding to the large proportion of resources should shoulder 60% to 70% of the load, and the remaining load is attributed to another main power source type. The configuration method is as follows:

1) Calculate the module type with a small proportion first, find the load configuration closest to this part, and add the margin to the module type with a large proportion or deduct it from the latter.

2) When configuring modules of the same type, give priority to large-size modules.

3) The connection mode between the same kind of power modules is determined according to the system working voltage [7].

Considering that the longest continuous days without wind or light is 3 or 7 days, give the calculation method of the battery capacity $C$ and the series-parallel mode in these two cases [8], as shown in equation (4) and (5), where $N_s$ is the number of batteries in series, $N_p$ is the number of
batteries in parallel, \( U_s \) is the operating voltage of the system. One hand-cranked generator is configured for each household.

\[
C^{3d} = 5P_s / 12, \quad C^{7d} = 11P_s / 12
\]

\[
N_s = U_s / 12, \quad N_p = C^{3d} / 200, k = 3, 7
\]

4.3. Fast wiring

After determining the location of the power supply, design for the trunk lines and branch lines in turn.

The trunk line is laid along the main road. The branch line is the entry line, which is introduced into the users’ home. All outdoor cables are placed in wire troughs, laid flat on the ground or directly buried in the ground; indoor cables are laid out along the wall.

4.4. Interface

One-to-one interfaces are used in power in series and lines, and one-to-many interfaces are used in power in parallel and lines. The wiring terminal adopts male and female interfaces. The one-to-many interfaces in the power supply scheme are formed by the combination of basic interface types.

5. Scheme evaluation

5.1. Technical feasibility

The remote villages have abundant natural resources, which provide favorable conditions for new energy power generation such as wind and sunlight. The power supply system is an independent power generation system and does not need to rely on a large power grid to generate power. All the modules are regular components, and are connected through appropriate interfaces, which does not require high electrical expertise of the staff.

5.2. Economy

The traditional long-distance transmission mode needs to consider issues such as the construction and utilization of transmission corridors, and the difficulty of fault detection and maintenance. In contrast, the convenient power supply scheme has several advantages as follows:

1) The power generation system is an independent power generation system, and the power source is obtained locally and can be supplied infinitely;

2) There is no need to consider the problem of crossing complex terrain, and the detection and maintenance of power supply failures are relatively convenient;

3) The power supply range is small, the inspection and implementation project period are short, the installation efficiency is high.

5.3. Social significance

Power shortage has become a key factor restricting the development of developing countries. Utilizing natural resources in remote areas to provide power to local residents can not only save power supply costs, but also reduce pollutant emissions. It is environmentally friendly and in line with international renewable energy development policies.

6. Case study

6.1. Scenario description

The power supply area in this paper is an isolated village with rich sunlight and wind. The longest continuous rainfall days is 3 days. The village has 20 households (as shown in Figure 1.).
Figure 1. The distribution of villagers.

Villagers do not have high requirements for electricity, and they only need to meet basic electricity consumption. The daily routine of each household is similar, so the total daily power can refer to a household (3~4 people) which is shown in Table 1.

Table 1. Basic user load.

| Types           | Rated power (W) | Num | Sum (W) |
|-----------------|-----------------|-----|---------|
| Electric light  | 5               | 3   | 15      |
| Satellite receiver | 25           | 1   | 25      |
| TV              | 100             | 1   | 100     |
| Cell phone      | 0.6             | 1   | 0.6     |
| Electric fan    | 30              | 1   | 30      |
| **Total power (W)** | -           | **7** | **170.6** |

6.2. Power supply scheme

6.2.1 Power supply principle. The power supply scheme in this article uses the wind as the main power source, and batteries and hand-cranked generators as the backup power sources. The structure of the power supply system is shown in Figure 2.

Figure 2. The structure of power system.

6.2.2 Location and wiring. According the chapter 3.1, if the village is regarded as one power supply area, the power supply range does not meet the safety principle. There are three power supply schemes shown in Figure 3.

1) Scheme A: the number of districts is 2, and the number of households is 11 and 9 respectively.
2) Scheme B: the number of districts is 3, and the number of households is 3, 15, and 2 respectively.
3) Scheme C: the number of districts is 4, and the number of households is 3, 12, 4, and 1.
6.2.3 Module configuration. Since the rated voltage of most modules in this article is 24V, this value is set as the system operating voltage of this article. 70% of the total load of each district is classified as photovoltaic modules and 30% is classified as wind power modules, denoted by $P_{\Sigma i-pv}$ and $P_{\Sigma i-w}$ respectively.

According to the above scenario, the power consumption of a household is 170.6W, and the power is set to 200W for $P_1$. When there are multiple households in the area, the simultaneous coefficient should be considered as 0.9. After calculation, the configuration list of each program module is shown in Table 2.

6.3. Results and comparisons

The specific design of each power supply scheme is shown in Figure 4, and the estimated cost which refers to market price is shown in Table 2. This paper uses the load shortage rate as the power supply reliability index to quantitatively calculate the reliability of each scheme, that is, during the inspection period, the load shortage rate is equal to the system load shortage divided by the total load of the system \[10\]. The load shortage rates of each scheme without batteries are 0.1321, 0, and 0.01967, respectively, and option B has the highest reliability.

When the power supply target is the most economical, scheme A is selected; when the power supply target is the most reliable, option two is selected; when the power supply target needs to take into account economy and reliability, option two is the best option.

In the literature [11], a long-distance power transmission program was used to supply power to areas without electricity in Xinjiang. It took six months and 980 million yuan to solve 60,159 people without electricity. Calculated by 3 persons per household, the average cost is 48870.5 yuan per household, while the average cost of the scheme proposed in this paper is 885.26 yuan per household. The former has a longer construction period, which cannot quickly realize the user's desire to use electricity, and the cost is relatively high. By comparison, the latter has realized independent power generation in various regions, and the project implementation period is short, which can quickly and effectively solve the problem of no electricity for villagers.
Table 2. Module configurations and estimated costs of power supply schemes.

| Types                | Unit price (yuan) | Configuration quantities |
|----------------------|-------------------|--------------------------|
|                      |                   | A | B | C |
| WT 1000W (unit)      | 2000              | 0 | 1 | 0 |
| WT 500W (unit)       | 1000              | 1 | 0 | 1 |
| PV 200W (unit)       | 400               | 12|12|14 |
| PV 50W (unit)        | 100               | 5 | 5 | 5 |
| Battery (unit)       | 200               | 16|14|18 |
| HC generation (unit) | 100               | 20|20|20 |
| Wiring board (unit)  | 30                | 20|20|20 |
| Thick wire (m)       | 2.6               | 561.95|433.92|373.75|
| Thin wire (m)        | 1.8               | 314.87|360.66|215.94|
| Shared equipment (unit) | 750            | 4 | 4 | 5 |
| **Total costs(yuan)**|                   | 17127.85|17577.38|18410.44|

7. Conclusion

Aiming at the limitations of the extension of large power grids in remote areas, this paper proposes a convenient power supply scheme for remote areas, and the following results have been obtained.
1) The design principles and methods of power supply in remote areas are proposed, including the modularization of the power supply system and the configuration method of modules.

2) Considering the economy and safety of power supply, the division method of power supply area is proposed, and each district is supplied with power separately.

3) Utilize the wind and wind resources of the power supply area to generate electricity, which meets the requirements of renewable energy development and can significantly improve the living standards of residents.

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