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Design and Typical Application of Solar-storage Integrated System for Tailings Ecological Restoration

Rende Dai [1], Tangfeng Lv [2], Zhiyong Li [2*], Chunsheng Wang [2], Xiaolei Jiao[3]

1 Hunan Zhongda Design Institute Co., Ltd, Changsha 410205

2 School of Automation, Central South University, Changsha 410083
3 Linyuan Holding Group Co.,Ltd, Nanjing 210000
(*Corresponding Author: Lizy@csu.edu.cn)

ABSTRACT

In order to solve the problem of huge electricity demand in the tailings ecological restoration process, according to the natural conditions of the tailings area, combined with the rich characteristics of renewable natural resources, the integrated system of solar energy and storage is designed and analyzed with examples. Considering the complex terrain characteristics of the mining area, the multi-channel MPPT photovoltaic array is selected to adapt to the complex terrain environment for power generation, and the energy storage unit is added for peak shaving. While solving the problem of power shortage in local ecological restoration, the impact of the system on the fluctuation of the grid voltage is alleviated. Finally, a typical application analysis of a tailing mine in Chuxiong City, Yunnan Province was carried out to discuss the rationality of the designed system. The results show that the designed system can effectively alleviate the power consumption problem in the ecological restoration of mining areas, which provides an important reference value for the ecological restoration of similar tailings areas and has certain popularization.

Keywords: Ecological restoration of tailings, Integrated photovoltaic storage, Multiplex MPPT, Energy storage for peaking

NONMENCLATURE

Abbreviations	
MPPT	Maximum Power Point Tracking
Symbols	
α	The absorption conversion efficiency ofthe east-facing PV arrays
β	The absorption conversion efficiency ofthe west-facing PV arrays
I_T	The solar irradiance of the tilted plane

1. INTRODUCTION

China's tailings emissions are huge, and the high content of heavy metals in tailings causes serious regional environmental pollution and forms a safety hazard[1]. In the process of ecological restoration of tailing areas, a large amount of electricity is consumed[2]. Tailings are mainly distributed in areas far away from towns and cities, far away from the main network, at the end of the power grid, poor power transmission capacity, voltage fluctuations. A large number of ecological restoration of electricity will increase the peaks and valleys of the power system load, which in turn will increase the scheduling pressure of the power system, which is not conducive to the stable operation of the power system[3].

Du Yulong's team[4] proposed the use of pit water for power generation to reduce operating costs, but it lacks feasibility in water-scarce areas. Xu Fuli[5] proposed to use gas for power generation, but it lacks safety and has safety risks. Wu Haijun[6] proposed the use of agricultural and optical complementary restoration technology for the restoration of damaged land in mining areas, which is of some reference significance to the design of optical storage integration system in this paper.

In this article, for the electricity consumption in the ecological restoration process of the legacy tailings area, the optical storage integration system design is adopted and feasibility analyses are carried out, and finally a

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tailings ecological restoration of a tailings in Chuxiong, Yunnan Province, is carried out for typical application analyses to demonstrate the reasonableness.

2. OVERALL SYSTEM PROGRAMME DESIGN

2.1 Overall system design based on source-grid-load-storage integration

The solar-storage integrated system applied in the tailings ecological restoration processincludes two parts: a photovoltaic generatorset and an energy storage unit. The input energy issolar power generation and public grid power. The operating principle of the system is to generate electricity through solar power generation equipment to meet the electrical load demand of tailings ecological restoration. The energy flow of the system is shown in Figure 1.

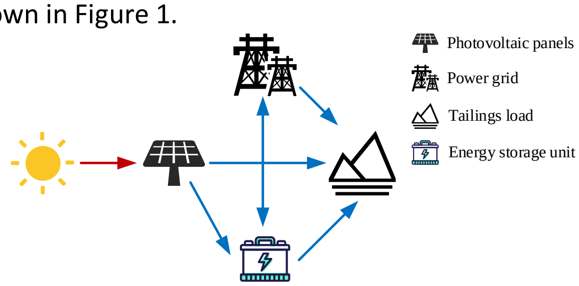

Fig. 1. System energy flow

Figure 2 shows the structure of the integrated photovoltaic storage system applied to the ecological rehabilitation of tailings. The DC side is the PV power generation unit, which consists of multi-way combined PV modules, and the PV modules are boosted by the Boost converter, which is controlled by the maximum power point tracking (MPPT) to maximise the use of solar energy[7]. The two PV modules are combined to generate power, and work in synergy with the energy storage unit, so that the power generated on the DC side is compatible with the power used by the loads, thus reducing the impact on the power quality of the public grid due to the direct grid connection of photovoltaic power generation.

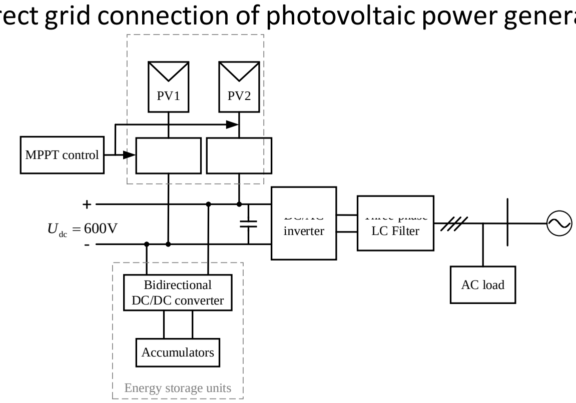

Fig. 2. System energy flow

The AC side adopts a three-level grid-connected inverter to convert the DC voltage to AC voltage and connect it to the grid. Through a reasonable control strategy, the three-level grid-connected inverter[8] achieves the functions of regulating the output voltage, limiting the grid current and harmonic suppression. The main purpose is to feed the excess power from PV generation into the public grid under the condition of meeting the load power demand, as well as to transmit power from the public grid to supply AC loads at night.

2.2 Combined power generation of multiple photovoltaic arrays based on DEM

The terrain of the tailings is undulating, which makes it difficult to lay PV arrays. If PV arrays are laid on the east and west sides of the sunny side of the pit, due to changes in the angle of solar irradiation, one side of the PV array is irradiated by sunlight during the day, and the other side of the PV array is in the state of no solarirradiation for a long period of time, which resultsin the uneven exposure of PV arrays to light. The topography of the mining area can be reconstructed based on Digital Elevation Models[9] (DEM) to provide reference for the laying of PV arrays.

The sunny side of the east side of the light is not enough light means that the west side of the light is sufficient to consider the east and west side of the photovoltaic array for the combination of power generation to the respective photovoltaic array issued the maximum power as the goal, in the daytime light is sufficient to make the photovoltaic power generation to the external output of the total power of the equilibrium. Let S is the main irradiation area state of sunlight, S is 1 that light is concentrated in the east, S is 0 that light is concentrated in the west. At this time, the total irradiation received by the PV arrays on the east and west sides of the sunny face

$$E=\alpha SE_t+\beta(1-S)E_t \tag{1}$$

Where α, β represent the absorption conversion efficiency ofthe east- and west-facing PV arrays, which is related to the sunlight and the tilt angle between the PV modules, E_t represents the amount of solar irradiation in the environment at moment t, which is influenced by weather conditions.

The use of a two-way PV array combination for power generation can equalise the total irradiance absorbed by the PV array. For a single specific PV array, the currently commonly used PV module modelling approach generally uses solar irradiance and temperature as model inputs and PV module power as output for modelling. The solar irradiance of the tilted surface is mainly determined[10] by equations (2) to (5)

$$I_T=I_{b,T}+I_{d,T}+I_{g,T} \tag{2}$$

$$I_{b,T} = I_b \frac{\cos\vartheta}{\cos\vartheta_x} \tag{3}$$

$$I_{g,T} = \frac{(I_b + I_d)\rho(1-\cos\beta)}{2} \tag{4}$$

$$I_{d,T} = \frac{I_d(1-F_1)(1+\cos\beta)}{2} + I_d F_1 \frac{a}{b} + I_d F_2 \sin\beta \tag{5}$$

Where I_T represents the solar irradiance of the tilted plane. $I_{b,T}$, $I_{d,T}$, $I_{g,T}$ represents direct, scattered and reflected irradiance. I_b, I_d represent the horizontal plane direct radiation and scattering irradiation. ϑ, ϑ_x represent the angles of incidence and zenith of the sun. ρ represents the ground reflectance. β represents tilt angle for component installation. F_1 and F_2 represent the number of encircling solar systems and the horizontal brightness factor. a, b represent the correction factor for the angle of solar incidence.

The stronger the light intensity, the lower the operating temperature, the higher its output power, and the output voltage increases, the output power first rises and then decreases. In order to ensure that the photovoltaic array in different operating conditions are obtained under the maximum operating efficiency, the current often use the maximum power tracking control, such as conductivity incremental method, so that the output voltage is stable in the maximum power point near.

2.3 NPC three-level inverter grid-connected control strategy

The traditional two-level inverter topology is simple, with only two IGBTs on each phase bridge arm. To improve the output waveform quality, when considering the comprehensive performance index, the neutral point clamped (NPC) three-level inverter can be used.

For a three-phase balanced system there is

$$U_{AN} + U_{BN} + U_{CN} = 0 \tag{6}$$

A three-level circuit has only three level outputs $U_{dc}/2$, 0, $-U_{dc}/2$ for each phase of the bridge arm. According to Kirchhoff's voltage law, the three-phase current differential equation is given by:

$$\begin{bmatrix} U_{AN} \\ U_{BN} \\ U_{CN} \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \begin{bmatrix} \frac{di_a}{dt} \\ \frac{di_b}{dt} \\ \frac{di_c}{dt} \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \tag{7}$$

As shown in Fig. 3, a double closed-loop control structure[12] is used, and the DC voltage outer loop is designed to regulate the DC-side voltage U_{dc} to ensure that the bus voltage remains constant, and U_{dc} can be controlled by the current i_d.

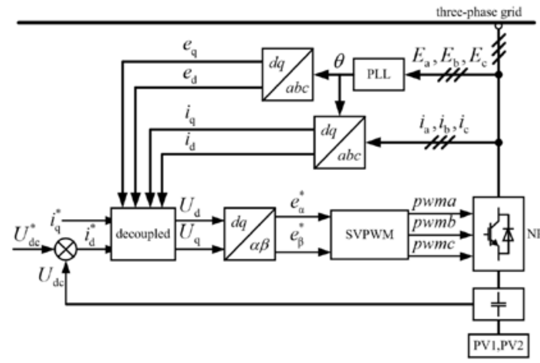

Fig. 3. NPC three-level inverter double closed-loop control structure

After comparing the DC reference voltage U_{dc}^* of the outer ring with the actual DC voltage U_{dc}, the deviation ΔU is controlled by the PI regulator, and the output of the PI regulator is the current reference value i_d^* of the inner ring of active current. The reference value i_q^* of the reactive current inner loop current is determined according to the reference value Q^* of the reactive power to be delivered to the grid.

The reactive current inner loop is realised in the dq synchronous rotating coordinate system. The inverter output currents i_a, i_b, i_c are converted into the dc components i_d and i_q in the dq synchronous rotating coordinate system by *abc/αβ/dq* coordinate transformation, which are compared with the reference values i_d^*, i_q^* respectively, and then controlled by a PI regulator, the outputs are then inverted by the dq/αβ inverse transformation, and the corresponding switching drive signals of the inverter, pwma, pwmb, and pwmc can be obtained by the spatial voltage vector pulse-width modulation to realise the grid-connecting control of the system, of which the phase angles ϑ can be obtained by the phase-locked-loop control.

2.4 Constant power plant output strategy considering energy storage

The power generated by PV arrays fluctuates with light intensity during the day, while the user-side load power also fluctuates periodically with time during the day. If the PV power can be matched with the user-side load power, the impact on the grid can be minimised.

Set the photovoltaic array in a day time power generation for P_{pvi}, this time the user side load power for P_{loadi} , in order to make the grid voltage to maintain a stable state, the need to maintain a relatively stable grid power, grid power P_{gridi} need to be kept constant, that is, $P_{gridi} = P + \Delta P$ (P is a constant, ΔP is a small fluctuations), then the energy storage unit P_{bati} in the moment of the i time should be out of power power for $P_{bati} = P_{loadi} - P_{gridi} - P_{pvi}$.

$$\begin{cases} P_{bati} = 0, \text{ if } P_{loadi} = P_{pvi} + P_{gridi} \\ P_{bati} < 0, \text{ if } P_{loadi} < P_{pvi} + P_{gridi} \\ P_{bati} > 0, \text{ if } P_{loadi} > P_{pvi} + P_{gridi} \end{cases} \quad (8)$$

3. TYPICAL SCENARIO APPLICATION ANALYSIS

Taking a mining area in Chuxiong City, Yunnan Province as an example, which is rich in renewable energy and abundant in solar energy resources, it is suitable to use the optical storage integration design scheme designed in this paper to alleviate the problem of electricity tension when carrying out ecological restoration of tailings.

3.1 Results Electricity load analysis

The specifics of the power consumption of the main loads of the tailings ecological restoration activities are shown in Table 1, which mainly include land levelling, land improvement, water irrigation in vegetation restoration, environmental protection facilities, monitoring and surveying, as well as the consumption of power in the living area.

Table. 1. Main load power consumption

Main load	Electricity consumption ($kW \cdot h^{-1}$)
sewage treatment	56
irrigate	23
Tailings processing	129
Monitoring Measurement	8
living area	87

3.2 Analysis of multiplexed photovoltaic arrays for complementary power generation

The topography of the tailings area makes it difficult to directly lay PV arrays over a large area, and the combination of multi-way PV arrays is selected for power generation based on the characteristics of the east and west sides of the sunny side of the undulating terrain. As shown in Fig. 4, for the two-way PV array combination power curve, the PV array group each using nine 7×9 PV modulesfor power generation.

When the sunlight irradiates the PV arrays on different sides, the PV array output can be balanced by controlling the output of the PV arrays and selecting the one with the largest power generation in the PV arrays as the output in real time.

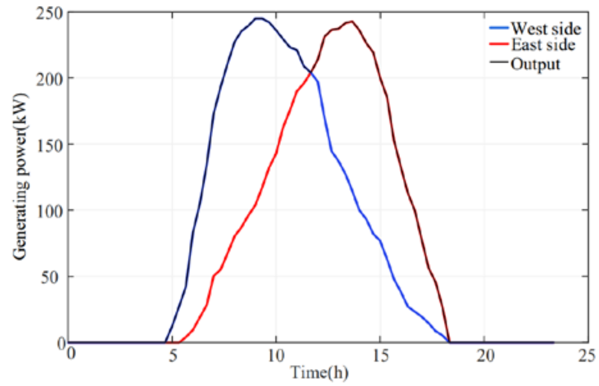

Fig. 4. PV output power

3.3 System simulation and analysis

In order to verify the reasonableness of the designed system, the simulation is carried out in Matlab/Simulink, and Fig. 5 shows the DC bus voltage change when the simulated light radiation received by the PV array changes. It can be seen that by adopting a suitable control strategy, it can be ensured that the DC bus voltage remains stable when the light intensity changes.

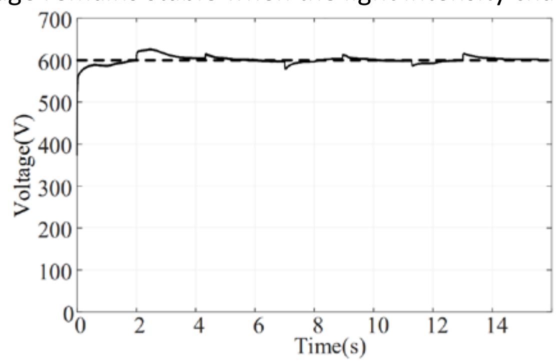

Fig. 5. DC bus voltage variation

Taking phase A as an example, Fig. 6 shows the waveform of phase A grid - connected voltage. From the simulated waveforms, it can be seen that the whole system can work stably and normally, and the quality of the grid - connected voltage waveform is high, which proves the feasibility and effectiveness of the designed control strategy.

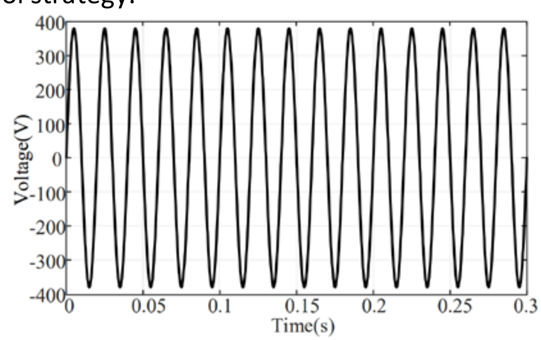

Fig. 6. A-phase grid-connected voltage waveform

3.4 Analysis of the Friendliness of the Internet

In the process of ecological restoration of tailings, to mitigate the voltage fluctuations and scheduling pressure on the grid due to excessive demand for electricity, and to ensure the stability of grid output power as much as possible, it is necessary to utilise energy storage unitsfor peak shaving and valley filling.

Fig. 7 shows the variation of the output power of each part of the unit, the sum of the grid output power and the real-time PV generation power is matched with the load consumption power, and the shaded part indicates the variation of the power of the energy storage unit.

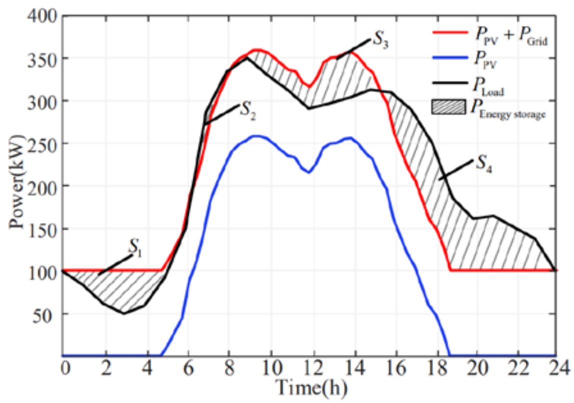

Fig. 7. Unit output power of each part

In order to slow down the impact of fluctuations on the power grid as much as possible, assuming that the power output of the grid is stable at about 100 kW, when the sum of the output power of the PV and the grid is higher than the load consumption power, the energy storage unit will be not consumed energy storage, such as the region S_1, S_3, the sum of the output power of the PV and the grid is lower than the load consumption power, the storage unit will be before the part of the energy storage to supply the load to consume, such as the region S_2, S_4. Through the peak shifting effect of energy storage, when the power fluctuation occurs at the load side, the energy storage unit can consume the power in time to ensure the stability of the grid output power.

4. SUMMARY

In this paper, a solar-storage integrated system is designed for the huge power consumption of tailings ecological restoration.

Analyse the composition of each part of the system and its mechanism, using two - way photovoltaic array combination power generation, the output voltage through the NPC three - level grid-connected inverter for grid connection, and join the energy storage unit for peak shifting, and analysed with a tailings mine in Chuxiong. The results prove that the system can alleviate the problem of electricity tension in the ecological restoration of mining areas, while reducing the impact on the grid voltage and power quality, and the designed system scheme provides an important reference value for the ecological restoration of similar tailings areas, and has the popularity.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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