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The Design and Implementation of Blockchain Smart Contract in Hybrid Energy Storage Management of Photovoltaic System

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Abstract. As the main power supply mode of new energy, photovoltaic system has the characteristics of wide distribution and scattered energy collection Traditional management methods cannot realize the effective processing of distributed energy storage. Therefore, finding an effective intelligent method is the focus of current research, and the design of blockchain smart contracts can theoretically realize the centralized processing of photovoltaic energy storage systems. In this paper, the blockchain smart contract system is taken as the research object, and the energy storage management of the photovoltaic system is quantified through mapping, so as to realize the massive quantitative processing of data. Then, the reduction function is used to differentially reduce the distributed functional energy storage system, complete the centralized management of energy storage, and simplify the unnecessary data. Finally, combined with the hybrid energy storage situation, the key indicators in the data are mined, and the completion rate of the contract and the stability analysis of energy storage management are calculated. The results show that blockchain can mine the characteristics of hybrid energy storage, reduce the impact of distributed features on energy storage, improve the energy storage efficiency by 20%, and make the energy storage stability reach more than 90%. At the same time, the completion rate of smart energy storage contracts can be enhanced, the fitting degree can reach 90%, and the grid connection with the thermal grid can be effectively connected, the utilization rate of distributed energy resources will reach 85%, and the cost saving rate will be increased by 10%. Therefore, blockchain can solve the problem of hybrid energy storage in integrated systems, improve the completion rate of smart contracts, and promote the development of new energy.

Key words. Blockchain, Nodes, Intrusion Signals, Early Warning Methods.

1. Introduction

Today, blockchain technology can realize the real-time control, management, and maintenance of physical equipment such as wind turbines and solar photovoltaic panels, and plays a key role in new energy [1]. However, the substantial increase of photovoltaic energy equipment has enhanced the distribution of photovoltaic energy storage systems, and also provided difficulties for the implementation of intelligent energy storage. From another perspective, the introduction of photovoltaic equipment such as wind turbines has greatly optimized the traditional thermal power grid and improved the efficiency of power generation [2], [3]. On the other hand, since distributed devices need to have different computing power and processing requirements, they must rely on decentralized optimization strategies to achieve effective management. Blockchain technology uses its own Gossip, network offset and other algorithms to complete the energy accounting between different regional points, which can provide support for distributed energy storage in theory. Some scholars believe that the blockchain algorithm is based on the online operation of intelligent entities, as well as the interaction with other entities, and gradually handles the complex and limited optimization tasks of the photovoltaic system [4], [5]. However, the possible risk of implementing distributed management is the instability of power flow and voltage, in order to ensure the stability of power supply of thermal power grids and the continuous output of energy storage equipment. Blockchain should implement smart contract design to strengthen the distributed management of photovoltaic energy storage equipment, and determine the output of abnormal power flow and voltage in the photovoltaic system, and eliminate them from the distributed grid in time [3]. Blockchain technology utilizes its firewall for power flow and voltage management of PV generators, and is based on Gossip's distributed computing [6], [7] Collect the light energy signal and light energy intensity in the photovoltaic matrix, and make a comprehensive judgment on the natural environment in which the photovoltaic system is located, especially the light intensity, and complete the comprehensive allocation of power flow and voltage of the photovoltaic system. Some scholars believe that there are differences in blockchain technology in the process of glorious hybrid energy storage, and only the centralized management of the functions in it cannot eliminate the differences between the two. Some scholars believe that the application of blockchain technology in photovoltaic management should be combined with mathematical methods or smart contracts to ensure the balance between photovoltaic output and input, but there is a lack of relevant case studies for the design and softening effect of smart contracts. Some scholars believe that hybrid energy storage has disadvantages in voltage stability and tidal balance in photovoltaic systems, and cannot reduce the influence of natural factors such as weather on the voltage stability after mixing [8], [9]. Therefore, the integration of smart contract blockchain technology and photovoltaic energy storage has always been controversial. Although some scholars have constructed hybrid energy storage in photovoltaic systems in theory, there is a lack of specific practical cases, and the stability, cost, and implementation effect of hybrid energy storage in photovoltaic systems lack case support. On the whole, there is a theoretical rationality between blockchain technology, intelligent hybrid, contract technology, and energy storage management of photovoltaic systems. However, in the process of practical application and case analysis, there is a lack of practicality. Therefore, this paper is based on blockchain smart contract technology and relies on photovoltaic systems to manage hybrid energy storage. Among them, the voltage and power flow and current balance, especially the balance after grid connection, are analyzed to find and verify the abnormality of current and power flow, and provide support for related research. Photovoltaic energy storage and thermal power grids are used for grid integration, and are balanced by the difference function. The difference between the distributed generation energy storage management system is balanced by the reduction function, and the power flow voltage change is detected in real time, the key points and outliers are found, and the feasibility of blockchain intelligent mixing is verified through actual cases, and the specific calculation process is as follows.

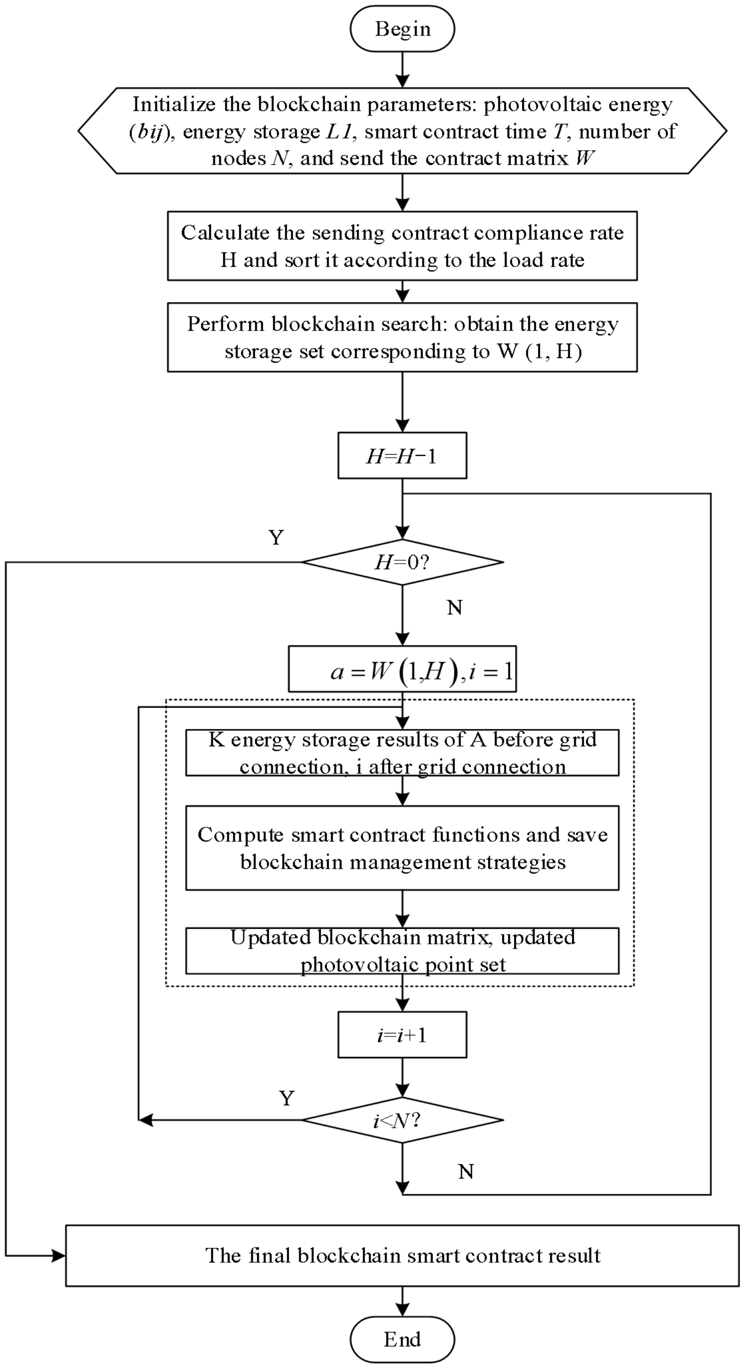


Figure 1. Hybrid Energy Storage Management Process of Photovoltaic System

2. Problem Description of Hybrid Energy Storage Management in Photovoltaic System

A. Global Balance of Photovoltaic Matrix

In the process of collecting the PV matrix area, CA is used to distribute the power flow of the PV system [10], in this process, the power flow sum caused by voltage and current is introduced, and all the data C_1 C_2 are normalized by using the mapping function Hash, which is calculated as follows:

$$M : C_i \times C_j \to C_{i\times j} \qquad (1)$$

$$H = \{0,1\}^* \to C_i \qquad (2)$$

Among them, M is the relationship between blockchains; H is a Hash function, which is mainly used to shorten the relationship between different photovoltaic matrices. The final hybrid storage energy can be expressed as $Cout = \{c, C_1, C_2, H\}$ a c C_i generating element. The power flow Cout of a PV system affects AA the local and overall power flow of the storage system, and AA generates random adjustment factors for all power flow, current, and voltage images. Any power flow in the hybrid energy storage management of a photovoltaic system AA can be expressed as:

$$APK_i = \left(M\left(c_i, c_i\right)^{a_i} \mid c^{b_i}\right) \qquad (3)$$

$$ASK_i = \left(a_i, b_i\right) \qquad (4)$$

where a_i b_i are for the properties of the power flow of the randomly selected PV matrix, as shown in Figure 1.

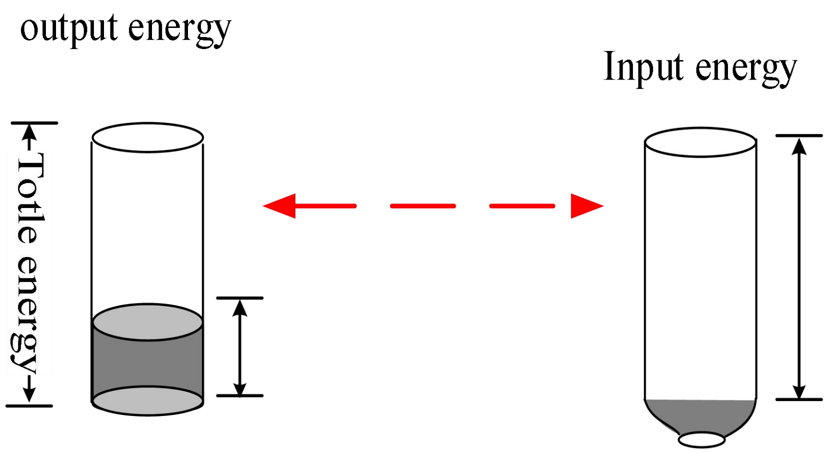


Figure 2. Relationship between Regional Energy Storage and PV Matrix

The smart contract process is implemented based on DM and adopts a contract mapping mechanism. Assuming that there is a total m_i photovoltaic matrix, the solar energy obtained by the photovoltaic matrix can be expressed as P a = $m_i \times n_i$ order matrix, and any solar energy P will generate a power flow. Describing the power flow change as a function map, the relationship between the PV matrix and the power flow is expressed as (P, map), and the design process of the smart contract DM is as follows

$$C_{it} = \left(\begin{array}{l} C_i = \overline{pt}\left(\sum m\left(c_i, c_j\right)^i\right)^j, C_{i,x} = r_i \times c_j, \\ C_{j,x} = r_i \times c_j, C_{j,x} \in H\left(map\left(x_i\right) \mid c_{ij}\right)^z \end{array} \right) \qquad (5)$$

Among them, pt represents lithium battery storage energy; d represents random output energy; z represents energy (weather, geography) for random.

When a blockchain smart contract is required, the (P, map) contract fulfillment rate is determined according to the overall flow of the PV system and the PV matrix. If (P, map) is a positive value, then the description of the blockchain can be carried out, which is described as follows

$$D_t = \frac{s_t \cdot \sum m\left(c_i, c_j\right)^z}{n \cdot \sum m\left(c_i, c_j\right)} \qquad (6)$$

Among them, s_t represents the current of any photovoltaic matrix.

B. Optimization of Hybrid Energy Storage Management

The data scale of the hybrid energy storage management center is huge, and if the voltage, power flow and current data in the photovoltaic matrix are directly stored, it will occupy database resources. Therefore, for the dynamic data collection of the blockchain, the time series database is established by using the reduction function to record the correlation between the data. Compress storage space and improve query efficiency by associating attributes. The data of the photovoltaic matrix is multi-dimensional and multi-floating-point, so it is necessary to transform the floating-point data, quantify the data through vectors, and complete the storage management of hybrid energy storage management. Assumption: The constant value of the energy storage data is D_i, and the variable part is D_j. The process of vectorization is as follows:

$$D_i = \begin{cases} k \cdot D_i + \Delta D_i \\ k_i \cdot D_i + l_{i+1} \cdot \Delta D_{i+1} \end{cases} \quad (7)$$

Among them, k_i represents the grid-connection coefficient of photovoltaic energy; l_i Indicates the default coefficient of the smart contract, reflecting the correlation between the PV matrices. If the value l is larger, the D_i D_j approximation of and will be higher, and the final optimization result will be

$$D_{i \times j} = D_i + D_j \quad (8)$$

For the continuous monitoring of the optimized hybrid storage management, the monitoring data are processed by the Hash function, and formed to ensure the effectiveness and irreversibility of the hybrid storage management data, and the smart contract constraints are as follows.

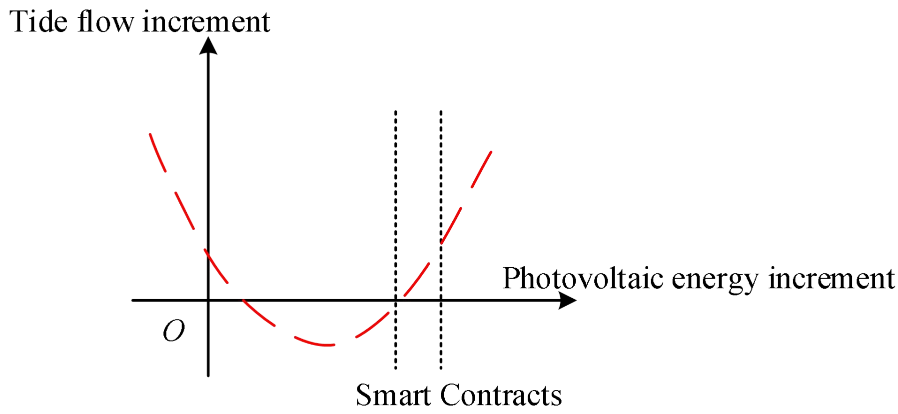


Figure 3. Scope of Fulfillment of Smart Contracts

3. Adjustments to Blockchain Smart Contracts

The functions of blockchain smart contract design are divided into three categories, mainly for hybrid energy storage management, energy storage invocation and energy storage allocation, and different photovoltaic matrices are checked and adjusted according to their light intensity. Suppose the result of the smart contract is $Z = \{z_1, z_2, \cdots, z_n\}$, indicating a n default at this time. In addition, they share the same list of energy storage because the same points in the PV matrix are to be replaced in parallel $List$. $List$ It includes the location point ID and light intensity of energy storage Hr, and judges the correlation of the blockchain by this, so as to improve the rationality of matrix energy call. The energy call of any photovoltaic matrix is set by the signature of the smart contract to ensure that it can be legally retrieved during data analysis. Assuming that each energy call is denoted as h_i, the energy call of any PV matrix i can be expressed as

$$\sum h_i = \begin{cases} h_i - \Delta h, hight \\ h_i + \Delta h,_i, low \end{cases} \quad (9)$$

Among them, indicates the $hight$ lowest point of energy harvesting of the PV matrix, i.e., the energy harvesting of any PV matrix should not be lower $\sum h_{\min}$. When the energy collection of the photovoltaic matrix is lower $\sum h_{\min}$, the photovoltaic matrix is eliminated, and the nearby points are searched for energy retrieval.

For the photovoltaic matrix, the photovoltaic matrix with a high frequency of energy transmission can be weighted, and the energy storage amount can be compared, and a smart contract design scale can be formed, and the blockchain will give priority to the all-use small and high photovoltaic matrix when making energy calls, and feedback the voltage, current and power flow changes of the photovoltaic matrix, and the specific results are as follows

$$h_i = h_{i+1} + \Delta h + h_j \quad (10)$$

Among them, h_j represents the contract level of the PV matrix, which is calculated as follows:

$$h_j = \frac{\sum rep\left(z^f\right)}{N\left(z^i\right) \times n \cdot \left(node_{sig}\right)} + n \cdot \frac{\sum h_i}{N\left(node_{sig}\right)} \quad (11)$$

wherein, the z^f effective photovoltaic energy output area is described; z^i Indicates a reasonable smart contract signing area; current z^f and voltage information represented by rep; The photovoltaic matrix $node_{sig}$ represents the successful call of the blockchain; $N(\cdot)$ indicates the number of photovoltaic matrices in the effective area of photovoltaic energy output.

In the process of blockchain smart contract design, the invalid photovoltaic matrix should be eliminated, and the specific content is as follows

$$h_i = \begin{cases} h_i, h_i \le h_{\min} \\ h_i - N\left(node_{sig}^f\right) \times \Delta h_i, h_i > h_{\min} \end{cases} \quad (12)$$

In the process of signing and invoking a smart contract, the power and current voltage of its output determine whether it performs the smart contract. Otherwise, it will be included in the default list, reducing the frequency of energy calls for this PV matrix. At the same time, the proportion of effective PV matrices in the area where smart contracts are evaluated should be greater than 2/3, that is, $\frac{2}{3} N\left(z^f\right) + \Delta\lambda$, otherwise the area will be re-evaluated and its smart contract signing level will be reduced, as follows.

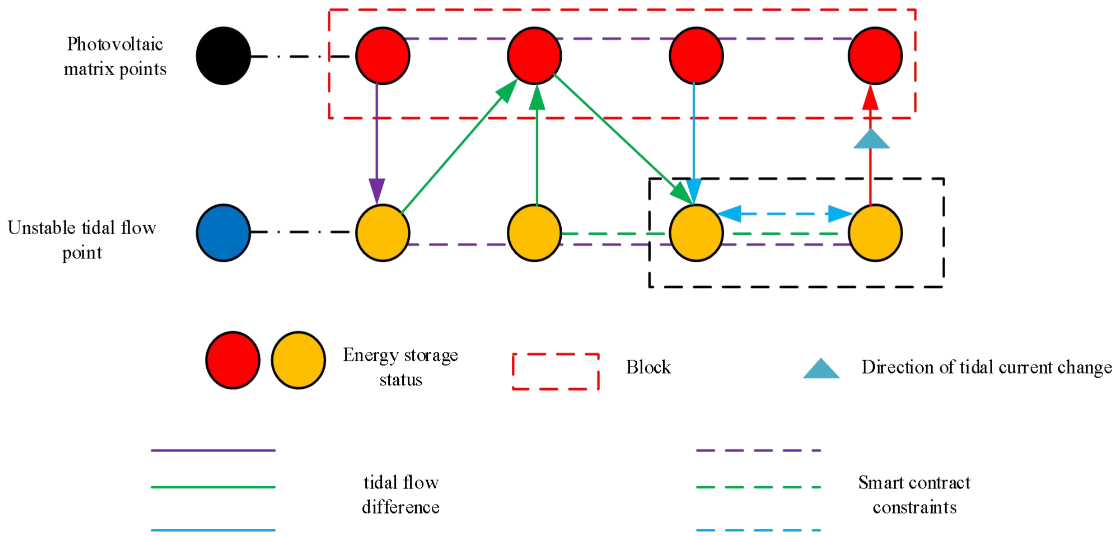


Figure 4. The Smart Contract Fulfillment Process of the PV Matrix

From the analysis in Figure 4, it can be seen that the smart contract performance of the PV matrix changes from the best to the lowest point, and the selection and elimination of the PV matrix are carried out by the degree of the performance of the smart contract. As the management method of the hybrid system of the photovoltaic matrix, the blockchain can evaluate the energy of any point in the photovoltaic matrix through smart contract technology, and realize the stability of energy output and input through value assignment. Among them, it is necessary to comprehensively evaluate the power flow, voltage and current of each photovoltaic matrix to ensure the stability of the power flow after grid connection and the stability of the output energy of each photovoltaic matrix. Due to the interference of natural factors such as light and other factors on the output of the photovoltaic matrix, and the energy reserve of lithium batteries is also quite different, it should be completed with the help of smart contract design. Through the smart contract design, the energy evaluation of each photovoltaic matrix, the evaluation and analysis of the success rate of its contract performance, the formation of a hash-based energy storage list to help the hybrid energy storage center for energy mobilization and distribution, in the calculation process, the blockchain to iteratively evaluate each photovoltaic matrix, real-time judgment of its output power and voltage stability, for the photovoltaic matrix that does not meet the requirements and constraints to reject, to achieve the dynamic management of hybrid energy storage. In addition, the blockchain records the excluded photovoltaic matrix, and comprehensively judges it based on historical data, and feeds back the judgment results to the hybrid energy storage management center. Based on the difference between the expected and actual values, it is determined whether the energy supply or maintenance is carried out. Therefore, the blockchain smart contract design can be judged according to the success rate of its energy supply, reduce the process of hybrid energy storage management center, and improve its management level.

4. Case Study of Hybrid Energy Storage Management in Photovoltaic Systems

A. Description of Photovoltaic Hybrid Energy Storage Conditions

In the case of photovoltaic energy storage devices with solar polysilicon, the gap of polysilicon is 0.01 nanometers, and the angle adjustment is carried out by phototropic detectors. The light energy intensity in the study area was 100mh~120mh, the average was 106mh, the illumination time was 16h, and the monitoring time was 6 months. The number of PV matrices is 1,023 with an area of 102 hectares. The blockchain is based on the cloud platform, the network communication is 500M optical fiber, and the transmission mode is WIFI. The criteria for smart fulfillment contracts are power flow, voltage, and current balance, with 20% fulfillment being rejection conditions, 50% re-evaluation conditions, and 90% being premium conditions. The management area of the blockchain is 14 photovoltaic matrices/photovoltaic matrices, which are analyzed by hybrid transmission. The distribution of test points is as follows.

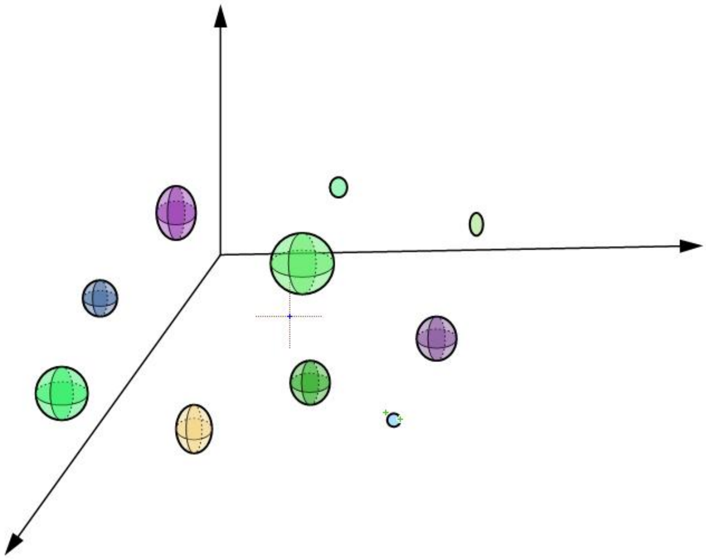


Figure 5. Spatial Distribution of Photovoltaic Systems

From the analysis in Figure 5, it can be seen that the intermediate distribution of the photovoltaic system is relatively scattered, which can be used as the analysis object of the blockchain photovoltaic matrix.

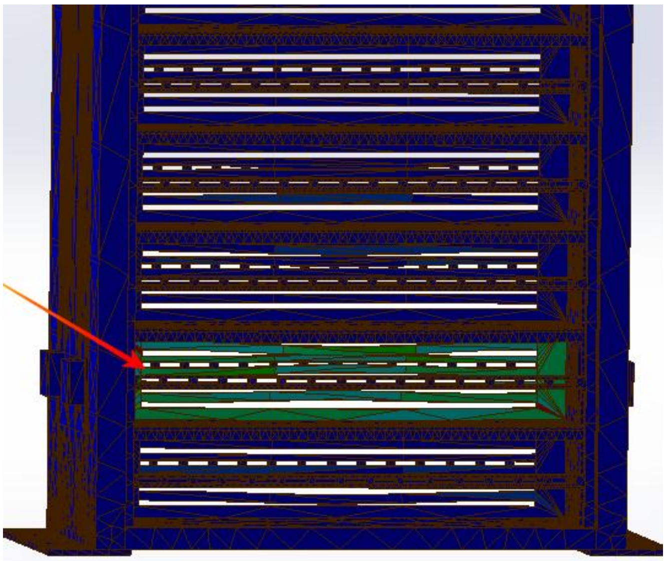
B. Contract Fulfillment Rate for Hybrid Energy Storage Management of PV Systems

Essentially, the blockchain system is a power flow-driven state machine, in which each state transition originates from a power flow equilibrium result, so smart contract performance is also a performance judgment of adjacent PV matrices. Therefore, the contract fulfillment rate of hybrid energy storage management is the result of blockchain management and the goal of energy storage management optimization, and the specific results are as follows.

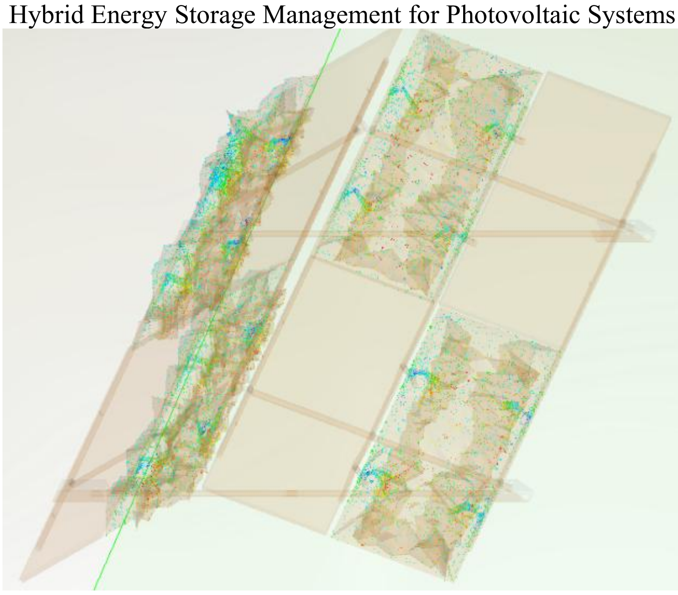
Table 1. Input Data Parameters

	Fulfillment Outcome (mean ± standard deviation).		**T (smart contract).**	**P**
	Non-fulfillment (n = 2).	**Fulfillment (n = 2).**		
Tidal Current	9.00 ± 0.00	91.00 ± 0.00	null	null
Voltage	7.37 ± 1.94	93.36 ± 0.53	0.697	0.600
Current	7.46 ± 0.29	92.74 ± 0.29	4.447	0.047*
Power	7.09 ± 1.37	93.98 ± 1.24	1.454	0.284
Load	7.17 ± 1.48	92.96 ± 1.20	1.331	0.315
* p < 0.05 ** p < 0.01				

From the data analysis in Table 1, it can be seen that the results of blockchain smart travel are relatively good, the overall results are greater than 90%, and the proportion of unfulfilled accounts for 10%, indicating that the design of blockchain smart contract is reasonable, which can realize the hybrid energy storage management of photovoltaic system and balance the trend of photovoltaic matrix. Blockchain smart contracts perform the following key steps: 1) In the blockchain environment, the energy storage management center needs to make a power flow call request to generate the corresponding power flow translation, and then use point-to-point transmission of photovoltaic energy through lithium batteries. In a hybrid grid, the individual PV matrices create authorizations through power flow contracts. 3) The licensed PV matrix will integrate the current energy sources in the hybrid grid that have not yet been delivered to form a new block. 4) The authorized PV matrix initiates a point-to-point energy storage transmission and balances all the PV matrices in the block, the energy storage management other PV matrices will be checked, and once the check is passed, the best PV matrix will be added to the entire blockchain, and then the next energy storage transfer will begin. When executing a blockchain smart contract, all PV matrices that fulfill the contract are distributed through a list, which means that each PV matrix has its own energy storage results. Although part of the PV matrix in the PV grid has stopped energy transmission, it still accepts light energy normally, so as to balance the stability of the power flow, as shown in Figure 6.



Hybrid Energy Storage Management for Photovoltaic Systems



Photon Intensity of the PV Matrix

Figure 6. Energy Storage Management of Photovoltaic System and the Corresponding Photovoltaic Matrix

As shown from the image analysis in Figure 6, when more than 50% of the photovoltaic matrix absorbs sunlight, the corresponding energy storage management system will increase the call frequency. This shows that the blockchain intelligent management system can make intelligent calls according to the light energy collection of the photovoltaic matrix and perform the corresponding contracts. When the PV matrix is running, all power flows, voltages, and currents are in the blockchain's state database. When the light energy conversion rate of the PV matrix increases, the PV matrix will store the electrical energy in the lithium battery, and use Json-rpc to call the interface provided by Geth to realize the light energy transmission at different stages. Among them, the interaction between the energy storage management system and the smart photovoltaic matrix tries to adjust the power flow according to the state to complete the performance of the contract.

C. Stability of Voltage and Current after the Performance of the Contract

Since the blockchain smart contract will adjust the entire power flow when traveling, and then cause the difference in voltage, current and power flow, finding and judging the stability of the power flow after it is connected to the grid is the auxiliary goal of hybrid energy storage management of the solar energy system, so judging the stability of voltage and current after the contract is fulfilled is also the standard for verifying the application effect of the blockchain, the specific content is as follows.

Table 2. Current and Voltage Changes after Contract Fulfillment

Indicators of Change	Change Value (V).	Relating to the Total Score of Contract Fulfillment	P-value (In relation to the weight of the PV matrix).
Current	0.425	0.185	0.633
Voltage	0.697	0.487	0.183
Instantaneous Current	4.447*	0.323	0.397
Instantaneous Voltage	1.454	0.494	0.177
Overall Change	1.331	0.401	0.285

From the data analysis in Table 2, it can be seen that the current and voltage changes after the contract is performed, while the instantaneous current changes are relatively large, the overall current changes are relatively small, and the current and voltage changes are correlated with the contract performance, and the higher the score and the weight value of the photovoltaic matrix are also relatively high. It shows that the performance of the contract will have an impact on the power flow and voltage of the PV matrix, and the weight coefficient can balance the impact of the contract performance, so as to maintain the stability of the hybrid system of the entire PV system. When the PV matrix increases in the blockchain, it usually needs to be properly configured for a limited number of power flows, and the power flow distribution process requires the participation of all PV matrices. When dispatching solar energy resources, all PV matrices exchange energy with other PV matrices and continuously replenish their own energy. During each state change, factors such as weather and light lead to differences in the energy conversion of photovoltaic panels, so the weight coefficient can balance the above problems. Table 2 preliminarily demonstrates the performance of the integration, time difference and spatial difference of the photovoltaic matrix, and uses the control module and the photovoltaic matrix detection module to carry out the power flow distribution. Once the blockchain detects a matrix with a power flow of less than 50% and interrupts the AC link, the PV matrix will be excluded from the management of the energy storage system, and the specific current and voltage oscillations are as follows.

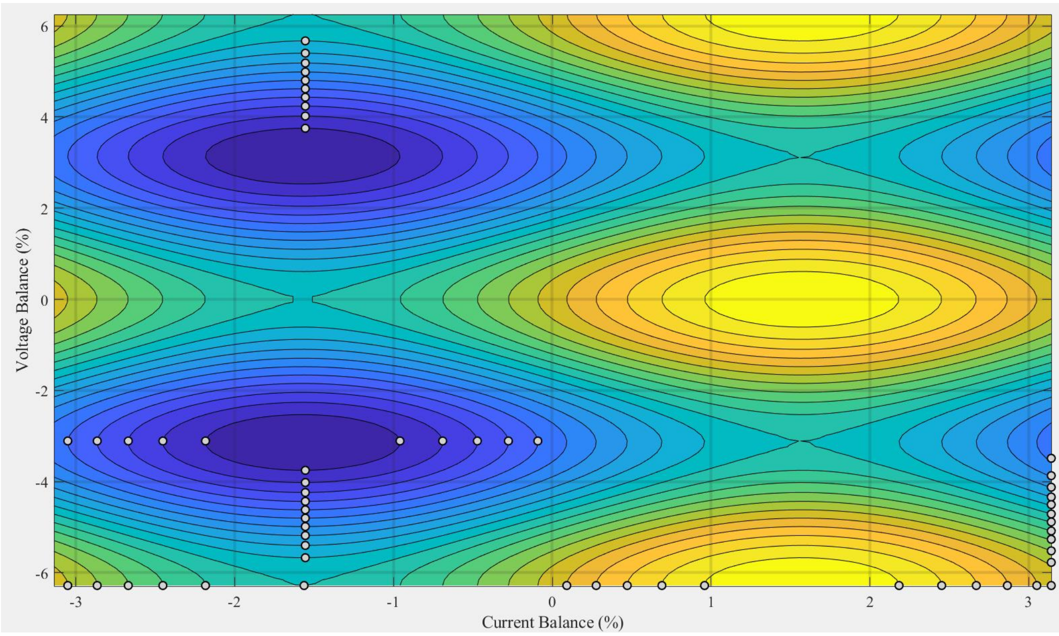


Figure 7. Oscillation Results of Current and Voltage

As shown in the analysis in Figure 7, the current and voltage show sinusoidal fluctuations in the process of oscillation, and the various symmetries between the two indicate that the oscillation of current and voltage is relatively stable and meets the normal processing requirements.

D. *Costs after the Fulfillment of Blockchain Smart Contracts*

The purpose of blockchain smart contract fulfillment is to increase the proportion of photovoltaic energy storage and maintain the stability of thermal power generation operation, so as to save power generation costs. Therefore, the ultimate purpose of studying the energy storage management of photovoltaic system is to reduce the cost of power generation and improve the sustainability of power generation, so the cost saving rate of blockchain smart contract fulfillment should be analyzed to verify the effectiveness of the model, and the specific results are as follows.

Table 3. Cost Savings Effect

Time	Cost (100 million)			Photovoltaic Power Generation Consistency	Power Generation Efficiency	Cost-saving Energy Levels
	Transport	Energy	Manage			
6:00~19:00	4.24	3.24	0.42	0.016	90.12	Outstanding
20:00~6:00	3.24	2.64	0.33	0.016	92.32	Outstanding
30d	105.24	30.23	9.31	0.016	93.2	Outstanding

From the analysis in Table 3, it can be seen that there are relative differences in the balance ratio of power generation costs at different times, and the transportation costs, energy costs and management costs increase significantly at 6:00~19:00, while the costs are relatively small between 20:00~6:00. Over the course of an average of 30 days of power generation, the cost savings are substantial. Through the consistency analysis of photovoltaic power generation, it is found that the cost saving at different times has a high consistency, and the power generation efficiency is almost 100%, and the cost saving level is excellent. This shows that the blockchain smart contract design can meet the hybrid energy storage management of photovoltaic systems, save the corresponding costs, balance the power flow analysis through the adjustment of coefficients, reduce the proportion of thermal power in the entire power grid power supply, and improve the depth of new energy application.

5. Conclusion

The hybrid energy storage management of photovoltaic system involves the power generation of thermal power and photovoltaic energy, so there is a problem of wide power distribution in the process of energy storage management, and it is difficult to carry out centralized management. Blockchain smart contract technology completes the stability of power flow and voltage through the remote regulation of blockchain and the fulfillment of smart contracts, and maintains the balance of the entire power grid. The research results of this paper show that in the hybrid energy storage management of photovoltaic systems, blockchain can realize the adjustment of different photovoltaic matrices, schedule the energy storage effects of different photovoltaics, and rationally distribute the energy output of photovoltaic energy. Among them, the smart contract realizes the retrieval and input of photovoltaic energy storage through weight analysis, completes the energy supply of the entire photovoltaic module, and maintains the balance of the power grid. Among them, the level of photovoltaic energy storage management is increased by 10%~20%, the accuracy reaches 90%, and the cost saving rate is about 10%, which indicates that the hybrid matrix management of photovoltaic system can effectively carry out distributed management in the later stage. There are also some limitations in this round of research, mainly because the amount of data in hybrid energy storage management itself is large, and it is difficult to conduct short-term analysis.

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