Scholar Publishing Group
Academic Journal of Energy
https://doi.org/10.38007/RE.2021.020405
ISSN 2790-2714 Vol. 2, Issue 4: 35-43

Transformation and Application of Sustainable Renewable Energy based on Energy Storage Principle

Hongrong Hou*

Philippine Christian University, Philippine

1353243163@qq.com

**corresponding author*

Keywords: Energy Storage System, Sustainable Energy, Renewable Energy, Transformation and Application

Abstract: The efficient utilization of renewable energy has been a research hotspot in recent years, but the characteristics of instability and intermittence limit the large-scale and efficient utilization of variable renewable energy such as solar energy and wind energy. This paper mainly studies the transformation and application of sustainable renewable energy based on the principle of energy storage. Firstly, this paper analyzes the necessity and economics of energy storage system in detail, and constructs a large-scale hybrid energy storage system composed of gravitational potential energy storage, battery and super capacitor. Taking IEEE-39 bus test system as an example, the proposed method is simulated by MATLAB simulation software to verify the correctness and efficiency of the proposed method. The simulation results show that the method proposed in this paper meets the economic rationality, and can realize peak shaving and valley filling.

1. Introduction

Renewable energy is abundant in China, and its power generation process does not produce emissions of harmful gases such as carbon dioxide, sulfur dioxide and carbon monoxide [1]. Compared with traditional fossil energy power generation technology, it has the advantages of "inexhaustible", green, clean and sustainable. Among them, wind power generation and photovoltaic power generation technologies have gradually matured in recent decades, and have developed rapidly in China. However, the primary energy supply of wind and photovoltaic power generation technology fluctuates with natural conditions, its controllability is weak, and it is difficult to accurately predict, so its grid connected power has volatility and uncertainty. The energy storage system has the advantages of bidirectional power regulation, fast response rate, flexible charging and discharging, which can not only assist the active power control of wind power, but also improve the frequency characteristics of the system. Therefore, it has a good application prospect in improving the frequency stability of power systems with high proportion of renewable energy. Compared with other equipment currently used in the power grid, energy storage technology can give play to its technical advantages in some application scenarios to meet the new needs of the power system under the background of large-scale renewable energy grid connection [2]. At the same time, affected by its technical characteristics, cost and other factors, energy storage is difficult to fully meet the high-capacity demand of the system at present, but with the rapid development of energy storage technology, it has great potential in the future [3]. Therefore, in the power system planning, it is necessary to combine the technical advantages of energy storage and other equipment, and plan reasonably according to the system requirements.

With the continuous improvement of renewable energy penetration, the research of integrating energy storage into the power system has gradually attracted more and more attention. How to optimally allocate the capacity of energy storage is an important problem [4]. At present, in the research on energy storage planning for large-scale wind power grid connection, some literatures have separately configured or planned energy storage [5]. A small part of these literatures use the method based on empirical formula. Some scholars put forward the concept of peak load regulation capacity ratio according to the proportion of adjustable capacity in the installed capacity, based on which the installed capacity of pumped storage units is determined [6]. Empirical methods usually get the corresponding capacity allocation formula based on the understanding of the physical meaning of peak shaving. However, these methods usually consider the part of the net load curve beyond the installed capacity of the system from the perspective of power, which is difficult to deal with complex system operation conditions such as strong fluctuation events of renewable energy [7]. Therefore, most of the research on energy storage planning is based on mathematical programming method. Other scholars have proposed an optimal planning method of battery energy storage for power grid peak shaving to deal with the inverse peak shaving characteristics of large-scale wind power output, and believe that the price of battery energy storage has an important impact on its revenue and system planning results.

This paper takes large-scale energy storage technology as a technical option of power system planning, and realizes the coordinated planning of power grid and energy storage by combining the technical characteristics of various equipment.

2. Modeling of Renewable Energy Storage System

2.1. Value Analysis of Energy Storage System

(1) Necessity

There have been many studies on the role of energy storage systems in enhancing the capacity of renewable energy consumption. There are mainly two aspects:

On the one hand, energy storage devices (pumped storage, compressed air storage, etc.) can realize peak shaving and valley filling of net load. The energy storage system discharges at the peak of the net load curve (i.e. the output of the regenerative power supply is small), and plays the role of "power supply", which can assist the thermal power unit in peak load regulation, reduce the climbing pressure of the thermal power unit, and avoid load shedding during the peak period of net load; At the low point of the net load curve (i.e. the output of renewable power supply is large), the energy storage system will charge and assume the role of "load". When the thermal power unit cannot give way to renewable energy due to the limitation of minimum technical output, it will help to accept excess renewable energy and avoid the phenomenon of wind and light abandonment during the low point of net load [8].

On the other hand, power energy storage devices (all kinds of batteries, super capacitors, etc.) can increase system backup to cope with the intermittent renewable energy. In order to cope with the uncertainty of renewable energy, the system needs to reserve a certain amount of up and down reserves. When the proportion of renewable energy becomes higher and higher, the capacity proportion of thermal power units decreases, and the ability to provide auxiliary services decreases. At the same time, the uncertainty of system power generation increases with the increase of the proportion of renewable energy. Due to the short-term increase of charge and discharge power of power type energy storage, the reserve release capacity is strong, Therefore, the energy storage system can assist the thermal power unit to provide backup to reduce the risk of wind, light and load loss caused by insufficient reserve capacity or insufficient reserve release speed [9].

When the renewable energy access ratio is low, the power structure is "active power supply + passive power supply" mode. After the active power supply is reduced, the system regulation ability decreases, and the system uncertainty increases with the increase of the proportion of passive power supply. Therefore, after the high proportion of res is connected to the grid, the flexible resources represented by energy storage become an indispensable part of the power structure, and the power structure becomes the mode of "active power supply + passive power supply + flexible resources" [10].

(2) Economy

The construction cost per unit capacity of different types of energy storage varies greatly. Research shows that the investment cost of battery energy storage of the same scale, including the cost of equipment and the cost of construction land, is 5-8 times higher than that of pumped storage power stations. However, with the continuous development of technology, the cost of battery energy storage continues to decline, which is expected to be applied in large-scale power systems [11-12].

The energy storage device is put into the power system, so that the power system can obtain a certain operating income. And the income is reflected differently in different time scales:

If only the intra day dispatching operation is studied, the energy storage system can reduce the regulation burden of thermal power units and reduce the coal consumption of thermal power units through charging and discharging; If the unit combination before the day is studied, the energy storage system "cuts the peak and fills the valley" for the net load, reduces the startup and shutdown times of thermal power units, at the same time, undertakes part of the standby, and increases the utilization hours of thermal power units; If we study the energy storage configuration in the long-term planning, we can reduce the investment of thermal power units and accept more renewable energy power generation with limited thermal power units. Therefore, the value of energy storage system participating in the long-term planning is more obvious [13].

2.2.Modeling of Energy Storage System

(1) Gravitational potential energy storage model

In order to achieve flexible and efficient renewable energy consumption, a large-scale physical energy storage technology with low cost coefficient is proposed in this paper. The operating condition of gravitational potential energy storage is relatively simple, with strong robustness and energy storage and release capacity [14]. Taking advantage of the environmental advantages of Northwest China, its construction cost is low, and its dependence on and impact on the environment is weak, which can effectively improve the economy and technology of the energy storage system. The structure diagram of gravitational potential energy storage system is shown in Figure 1 [15]. On the mountain with a slope of, the motor interacts with the weight through ropes, and the weight m moves up and down to store and release energy. Build a track on the mountain to reduce friction and reduce the energy loss of the energy storage system.

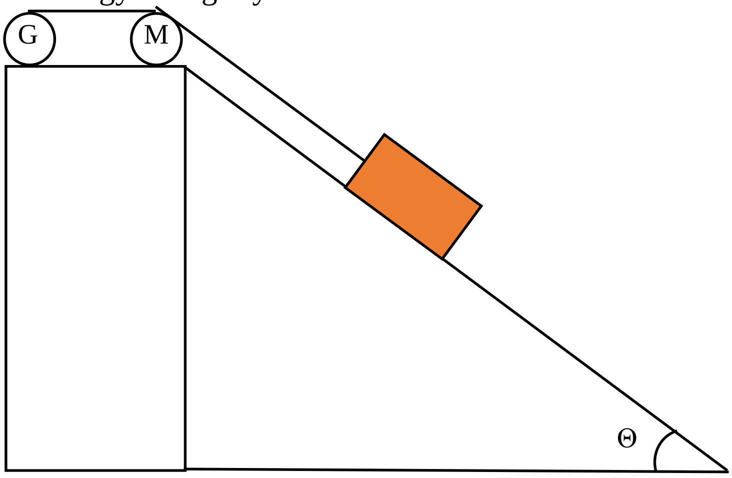

Figure 1. Structure diagram of gravitational potential energy storage system

During energy storage, the motor M pulls the weight upward to convert the electric energy into the gravitational potential energy of the weight and store it. At this time, the stress analysis of stones includes:

$$F_{up} = mg\sin\theta + F_f - a_{up}m \tag{1}$$

Power of motor:

$$P_{up} = F_{up} \cdot v_{up} \tag{2}$$

At this time, the energy conversion efficiency between the gravitational potential energy and the work done by the motor is:

$$\eta_2 = \frac{\sin\theta}{\sin\theta + \mu\cos\theta - a/g} \tag{3}$$

When the acceleration =0, the energy conversion efficiency reaches the maximum value. Among them, FUP is the traction force of the upward movement of the weight; FF is the friction force on the weight; VuP is the lifting speed of the weight; Pg0 is the reference power signal of the gravitational potential energy storage system; 1 is the motor power loss factor; U is the friction coefficient.

During energy release, the weight m moves downward to pull the generator g to generate power, and at the same time, the motor M is used to brake the weight to drop at a uniform speed, converting the gravitational potential energy into electric energy. This process is divided into the following two stages:

Preparation stage: the weight will not be pulled by the generator and will move downward in acceleration.

Energy release stage: when the descending speed reaches V1, the weight will change and accelerate to drive the generator to generate electricity. The weight is balanced by the traction force of the motor.

The height of the weight in the gravitational potential energy storage system reflects the real-time energy storage and release capacity of the system.

(2) Battery energy storage model

The third-order dynamic model describing the characteristics of lead-acid batteries is equivalent to a single port network with parallel main reaction branches and parasitic branches [16]. The model accurately simulates the dynamic characteristics of the battery, and is convenient for the analysis of battery states such as voltage, current, state of charge, depth of charge and discharge, and electrolyte temperature.

The simulation model of battery equivalent circuit is used to analyze the charging and discharging characteristics. Take the battery charging and discharging current as the input and observe the change trend of its terminal voltage [17].

(3) Supercapacitor energy storage model

Supercapacitor is actually a complex resistance capacitance network that integrates multiple RC series branches with characteristic time constants. The mathematical models of supercapacitors mainly include classical equivalent model, grid connected second-order model and dynamic model. The influencing factors of storage capacity mainly include voltage level, placement time, charge state and discharge current [18].

The classical equivalent model of super capacitor mainly includes a series resistor and an RC network composed of parallel resistor and parallel capacitor. This model is relatively simple and widely used, and can accurately analyze the charge and discharge characteristics of super capacitor. In the process of charging and discharging, the equivalent series impedance res will cause energy loss, reduce the effective energy storage rate of the super capacitor, and cause its heating.

3. Simulation Experiment

In this paper, IEEE 39 node test system is used for simulation analysis, and on this basis, light and hydropower are connected at node 32 and wind power is connected at node 34. The typical daily output curves of photovoltaic, hydropower and wind power are shown in Figure 2. The time of use tariff is shown in Table 1. The investment cycle of energy storage is 20 years.

According to the characteristics of load curve, the TOU price is shown in Table 1. The investment cycle of energy storage is 20 years.

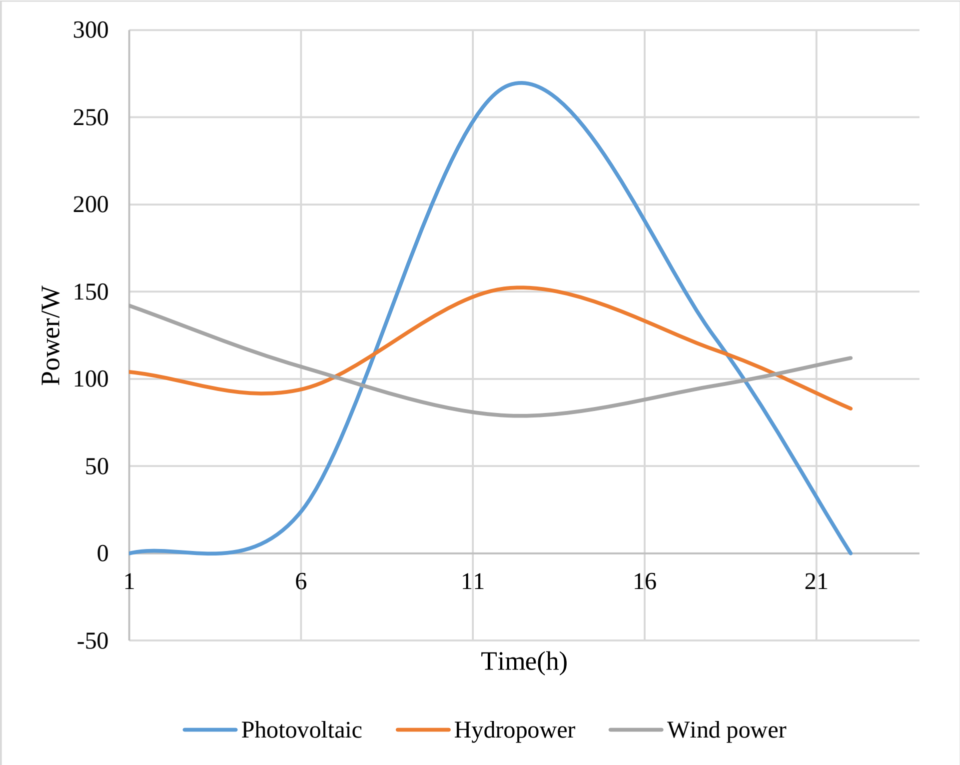

Figure 2. Typical daily characteristic curve of photovoltaic, hydropower and wind power

Table 1. Time-of-use electricity price

Number	Load period	Time/h	Electricity price (10000 yuan /mw.h)
1	Trough	0-6	0.052
2	Flat	13-7,23-0	0.117
3	Peak	7-12,18-22	0.153

4. Simulation Experiment Results

The simulation results show that when the energy storage system is connected to node 21 and node 39, the energy storage capacity is 200mw H, the power grid loss and operation cost of the whole system are minimal. Within 20 years of energy storage investment cycle, the energy storage system can make a profit of 164.275 million yuan and the network loss cost is 6921.68 million yuan through peak load discharge and low load charging. The network loss cost caused by not connecting the power grid to the energy storage system is 7024.61 million yuan, indicating that connecting the energy storage system to the power grid can reduce the network loss to a certain extent, and the total profit that the energy storage system can bring is 1094.14 million yuan within the investment cycle of 20 years.

Taking the 39 node results as an example, the comparison between the load curve before adding energy storage system and the load curve after adding energy storage is shown in Table 2 and figure

3.

Table 2. Original load and load statistics after energy storage

	1	6	12	18	22
Original 39 node load	1072	1106	1304	1412	1276
39 node equivalent load	1072	1113	1397	1387	1243

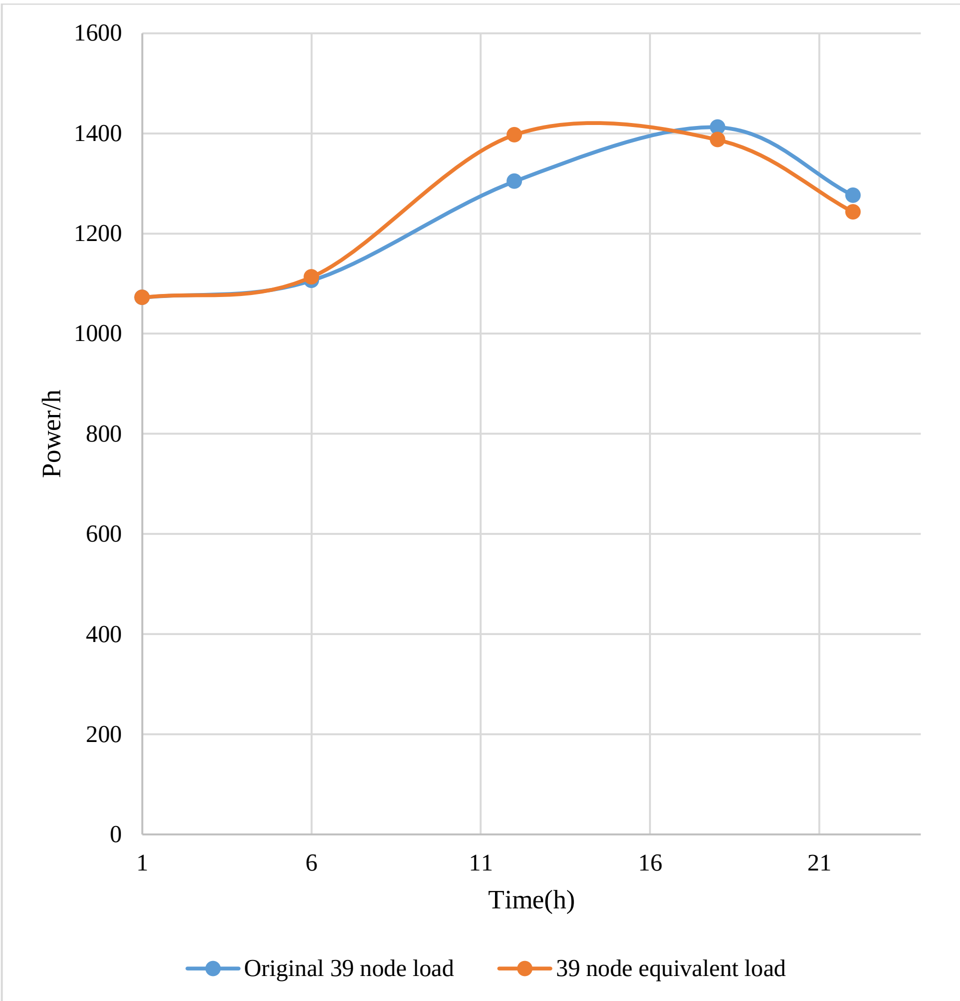

Figure 3. Comparison diagram of 39 node original load curve and load curve after energy storage

It can be seen that the system has a certain peak shaving and valley filling effect on the load after it is added to the energy storage power station, but the effect is not obvious.

5. Conclusion

Firstly, this paper carefully studies the current research status of energy storage and the reliability and economic planning of energy storage connected to the power grid, analyzes the various needs of the power grid for energy storage, and summarizes various economic models and methods of energy storage connected to the power grid. In this paper, a hybrid energy storage system composed of gravitational potential energy storage, storage battery and super capacitor is constructed according to the electricity demand of users and renewable energy power generation. IEEE-39 bus test system and MATLAB simulation software are used to verify the proposed method. Due to the limitation of my ability and research time, some problems need further in-depth study: This paper only studies the two scenarios of energy storage to smooth the output fluctuation of renewable energy and load peak shaving and valley filling, but in practice, there are many other application scenarios of energy storage, which is worthy of further study.

Funding

This article is not supported by any foundation.

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

References

[1] Priecel P , Lopez-Sanchez J A . Advantages and Limitations of Microwave Reactors: From Chemical Synthesis to the Catalytic Valorization of Biobased Chemicals. ACS Sustainable Chemistry And Engineering, 2019, 7(1):3-21. https://doi.org/10.1021/acssuschemeng.8b03286

[2] Kamdar I , Taweekun J . Assessment of wind energy potential of Hat Yai (Songkhla), Thailand. IOP Conference Series: Materials Science and Engineering, 2021, 1163(1):012001 (14pp).

[3] Navarro J C , Centeno M A , Laguna O H , et al. Policies and Motivations for the CO2 Valorization through the Sabatier Reaction Using Structured Catalysts. A Review of the Most Recent Advances. Catalysts, 2018, 8(12):578. https://doi.org/10.3390/catal8120578

[4] Carpinelli G , Rizzo R , Caramia P , et al. Taguchi's method for probabi1istic three-phase power flow of unbalanced distribution systems with correlated Wind and Photovoltaic Generation Systems. Renewable energy, 2018, 117(MAR.):227-241.

[5] Vasquez V , Mauro Ortega L , Romero D , et al. Comparison of methods for controllers design of single phase inverter operating in island mode in a microgrid: Review. Renewable & Sustainable Energy Reviews, 2017, 76(SEP.):256-267. https://doi.org/10.1016/j.rser.2017.03.060

[6] Abdulkhani, Alizadeh, Hedjazi, et al. Potential of Soya as a raw material for a whole crop biorefinery. Renew Sust Energ Rev, 2017, 2017,75(-):1269-1280. https://doi.org/10.1016/j.rser.2016.10.082

[7] Cortes-Vega D , Alazki H . Robust maximum power point tracking scheme for PV systems based on attractive ellipsoid method. Sustainable Energy Grids and Networks, 2021, 25(1):100410. https://doi.org/10.1016/j.segan.2020.100410

[8] Rao\T A . future and scope of wind energy in india. Renewable & Sustainable Energy Reviews, 2019, 13(2):285-317.

[9] Apostolou D , Enevoldsen P . The past, present and potential of hydrogen as a multifunctional storage application for wind power. Renewable and Sustainable Energy Reviews, 2019, 112(SEP.):917-929. https://doi.org/10.1016/j.rser.2019.06.049

[10] Fedorova V A , Kadzhaeva E T , Vovkodav K V . Transformation of the energy sector in the Arctic in the context of sustainable development of the region. IOP Conference Series: Materials Science and Engineering, 2021, 1201(1):012069.

[11] Siwal S S , Zhang Q , Devi N , et al. Recovery processes of sustainable energy using different biomass and wastes. Renewable and Sustainable Energy Reviews, 2021, 150(1):111483. https://doi.org/10.1016/j.rser.2021.111483

[12] Sulzer M , Orehounig K , Knoeri C , et al. Concept for next generation of technical energy regulations in buildings. IOP Conference Series Earth and Environmental Science, 2020, 588(2020):1.01-1.05.

[13] Middleton P . Sustainable living education: Techniques to help advance the renewable energy transformation. Solar Energy, 2018, 174(NOV.):1016-1018. https://doi.org/10.1016/j.solener.2018.08.009

[14] Sperling K . How does a pioneer community energy project succeed in practice? The case of the Samso Renewable Energy Island. Renewable & Sustainable Energy Reviews, 2017, 71(MAY):884-897. https://doi.org/10.1016/j.rser.2016.12.116

[15] Erdiwansyah, Mamat R , Sani M , et al. Renewable energy in Southeast Asia: Policies and recommendations. The Science of the Total Environment, 2019, 670(JUN.20):1095-1102.

[16] Syed-Hassan S S A , Wang Y , Hu S , et al. Thermochemical processing of sewage sludge to energy and fuel: Fundamentals, challenges and considerations. Renewable & Sustainable Energy Reviews, 2017, 80(dec.):888-913. https://doi.org/10.1016/j.rser.2017.05.262

[17] Signe E , Kanmogne A , Emmanuel G D , et al. Comparison of seven numerical methods for determining Weibull parameters of wind for sustainable energy in Douala, Cameroon. International Journal of Energy Sector Management, 2019, 13(4):903-915.

[18] Isa N M , Tan C W , Yatim A . A comprehensive review of cogeneration system in a microgrid: A perspective from architecture and operating system. Renewable and Sustainable Energy Reviews, 2017, 81(pt.2):2236-2263. https://doi.org/10.1016/j.rser.2017.06.034