MODELLING AND SIMULATION OF WIND TURBINE HEAT RECYCLING SYSTEM

by

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The paper aims to discuss the power supply and heat supply system of wind turbine, promote the development of wind energy in heat recycling, and expand the application of renewable energy resources in replacing fossil energy. Starting from the construction of wind power heat storage system model, first, molten salt was selected as the fluid heat storage material. Based on the realization process of two-pot molten salt electrothermal transformation, the model of two-pot molten salt heat storage (MSHS) system was established. Second, based on the model of heat storage system, the high temperature MSHS wind power heating system was simulated by using the numerical simulation analysis method. The results showed that the simulation results of the thermal storage system model were highly consistent with the actual results, and the model was accurate and reliable, which was suitable for the simulation analysis of the thermal storage system. After a day of operation, the utilization rate of wind energy of the MSHS wind power heating system could reach more than 94%. The combination of the MSHS wind power system and regional heating had obvious effect on absorbing wind power, saving resources, and solving the problems of wind curtailment. In the MSHS wind power supply heating system, the configuration of MSHS significantly improved the utilization ratio of wind energy in the wind power generation system, even up to 100% at maximum. To sum up, the configuration of MSHS can absorb most of the wind energy generated on that day, thus improving the energy utilization ratio of the wind power generation system.

Key words: *wind power generation, molten salt heat storage, simulation analysis, wind energy utilization*

Introduction

As an important renewable energy, wind energy is widely distributed and rich in resources, mainly including offshore and onshore [1, 2]. The solar energy radiates on the earth's surface, the temperature changes unevenly on the earth's surface, and the pressure distribution in the atmosphere is unbalanced through the synergistic effect of the solar energy and the landform, which causes a continuous air-flow, thus forming the wind energy [3]. Wind energy has

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great application potential in energy structure transformation, global climate change, fossil fuel shortage, and power demand. It will be an inevitable energy development trend in the future to continue to expand the application of wind energy and connect it with the energy network [4, 5]. As a kind of renewable energy technology, wind power generation technology is one of the main forms of wind energy utilization. However, due to the features of wind energy change, wind power resource itself is characterized by volatility, intermittence, seasonality, randomness, and reverse distribution. At last, it causes a series of difficulties and challenges in the connection between wind power generation and power grid under the condition of regional concentration [6-8]. Hence, various mitigation or solution strategies have been put forward. For example, in some parts of Europe, by vigorously building transmission grid, the wind power will be transmitted from the enriched area to the power load area, thus achieving the optimal allocation of energy resources in a large range. Additionally, Denmark can also achieve the goal of absorbing wind power and saving energy through heat production and heating of wind power and electric boiler. Facing the development trend of renewable energy resources and the demand for energy conservation and emission reduction, energy storage technology is focused on in terms of energy structure transformation and industrial sustainable development. It is of great significance to seek a kind of energy storage technology with large capacity and low cost and construct the corresponding system, no matter in improving the flexibility of power system, or in improving the utilization ratio of wind energy, thus solving the problem of wind power curtailment.

At present, the technologies applied to energy storage of renewable energy resources mainly include electric energy storage technology and thermal energy storage (TES) technology, corresponding to mechanical energy storage, TES, chemical energy storage, electrochemical energy storage, and many other energy storage forms [9-11]. The heat storage technology has realized the mature application in the field of solar energy concentration, and has become one of the most advantageous technologies in renewable energy storage due to its good economy, wide applicability, and long service life [12]. Aided by the sensible heat property of the thermal storage material, the thermal energy can be stored by changing the temperature of the thermal storage material. Among them, the more commonly used solid sensible heat storage materials are mainly high temperature ceramics and concrete, while the more commonly used liquid sensible heat storage materials are mainly molten salt and mineral oil [13, 14]. Among them, molten salt refers to the inorganic salt in the melting state, which has good heat transfer and storage performance and wide temperature application range. In addition, high temperature molten salt has all the conditions required for heat transfer and storage process. Hence, it has become the most advantageous fluid sensible heat storage material, which has great potential in heat transfer and heat storage of large-scale solar energy and other renewable energy resources [15]. The TES technology has achieved large-scale design and application in solar thermal power generation and other fields. Similarly, in the fields of improving the output quality of wind power and utilizing wind energy resources, TES technology is still feasible.

In this paper, based on the energy recycling of wind turbine, the high temperature molten salt thermal storage (MSTS) wind power system is taken as the research object. Based on the realization process of the electric heat conversion of the two-pot molten salt, the two-pot MSTS module system is constructed. According to the numerical simulation analysis and combined with the regional heating, the high temperature MSTS wind power supply and heating system are simulated to provide some reference for the development of heat recycling in the process of wind power generation.

Methods

Construction of two-pot MSHS model

The two-pot MSHS module mainly includes pot module, electric heater module, and heat exchanger module. The process of electric heat conversion by using two-pot molten salt is molten salt flows out through the low temperature energy storage tank and the electric heater, and then rises to the high temperature, so that the energy can be stored in the high temperature energy storage pot after the electric heat conversion. The indirect-two-pot heat storage system is composed of two circuits: indirect heat transfer circuit and high temperature molten salt storage and heat release circuit. Its heat transfer mode includes forward flow and reverse flow heat transfer. There are many components in the molten salt storage pot module, of which the cold and hot molten salt storage pot and molten salt pump are the most important. In the heat storage system module, the heater module is mainly used to heat the low temperature molten salt to the high temperature. Generally, the heat exchange equipment of high temperature molten salt mainly includes shell and tube molten salt and one-way heat exchanger, with relatively simple structure. Relying on this module, the heat exchange process between molten salt and water can be realized. Among them, the corresponding mathematical expression of heater module is shown in eq. (1). The mathematical expression of heat exchanger module is shown in eq. (2):

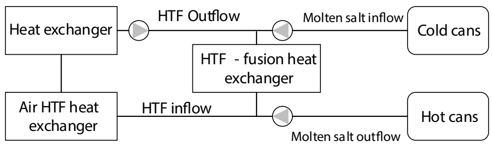

Figure 1. Indirect-two-pot MSHS module system

$$W_{\mathrm{s}} = \dot{f}_{\mathrm{s}} c_{\mathrm{ps}} \left(T_{\mathrm{s\_out}} - T_{\mathrm{s\_in}}\right) \tag{1}$$

where W_s is the heat exchange power, $\dot{f}_s$ – the indicates fluid-flow, c_p – the isobaric heat capacity, and T – the suggests temperature, in – the inlet, out – the outlet, and s – the – molten salt;

$$W_{\mathrm{s}}\eta_{\mathrm{h}} = \dot{f}_{\mathrm{w}} c_{\mathrm{pw}} \left(T_{\mathrm{w\_out}} - T_{\mathrm{w\_in}}\right) = W_{\mathrm{w}} \tag{2}$$

where η is the corresponding efficiency of the heat exchanger, w – the suggests water and h – the heat exchanger.

The operation of the indirect dual tank MSHS module system is shown in fig. 1.

Heating system of MSHS wind power

The energy storage of high temperature molten salt system is completed by converting electric energy into thermal energy. If the thermal energy can be reused in the form of electric energy to realize the recycling and reuse of heat, the secondary conversion of energy needs to be carried out aided by thermoelectric conversion system, in which the energy loss caused cannot be ignored. To save energy resources, replace coal resources with renewable energy and optimize energy structure, thermal energy is used directly in district heating. The corresponding high temperature MSHS wind power heating system is shown in fig. (2). The calculation of wind energy utilization rate of the system is shown in eq. (3):

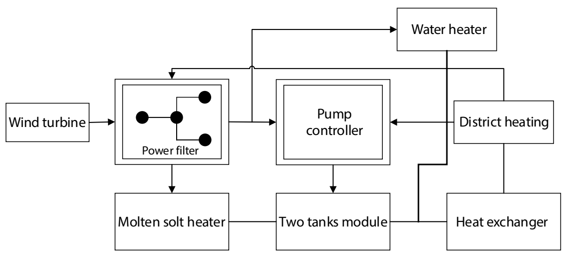

Figure 2. Heating system with high temperature MSHS wind power

$$\eta_E = \frac{E_\mu}{E_{\mathrm{w}}} \cdot 100\% \tag{3}$$

where E_μ is the total energy used by the system and E_{w} – the total wind energy generated in the system.

Heating and power supply system of MSHS wind power

For the construction of the heating and power supply system of MSHS wind power, all the stored energy in the MSHS system is taken as the reserve energy in the district heating. When the electric energy generated in the wind farm passes through the power controller, on the one hand, the energy flow process of all the generated electric energy is controlled. According to the regulation of the fluctuation between the wind power output value and the power load, the heating and power supply of the wind power system is realized. On the other hand, the flow of power energy restricted by the power controller is regulated. The corresponding high temperature MSHS wind power supply heating system is shown in fig. 3.

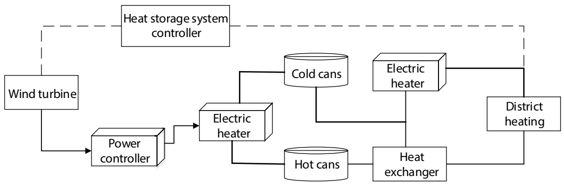

Figure 3. Power supply heating system of high temperature MSHS wind power

Results and discussion

Design of high temperature two-pot MSHS wind power system

To verify the realization of the function between the charging and discharging process and the heat exchanger of the two-pot heat storage system constructed, based on the aforementioned two-pot MSHS model, combined with the countercurrent heat transfer mode, the synthetic heat transfer oil is selected as the heat transfer process fluid. Additionally, the solar salt is selected as the heat storage medium to complete the verification of the practicality and accuracy of the construction module. Under the two operation modes of heat storage and heat release, the temperature change of synthetic heat transfer oil and molten salt at the heat exchanger is shown in figs. 4(a) and 4(b).

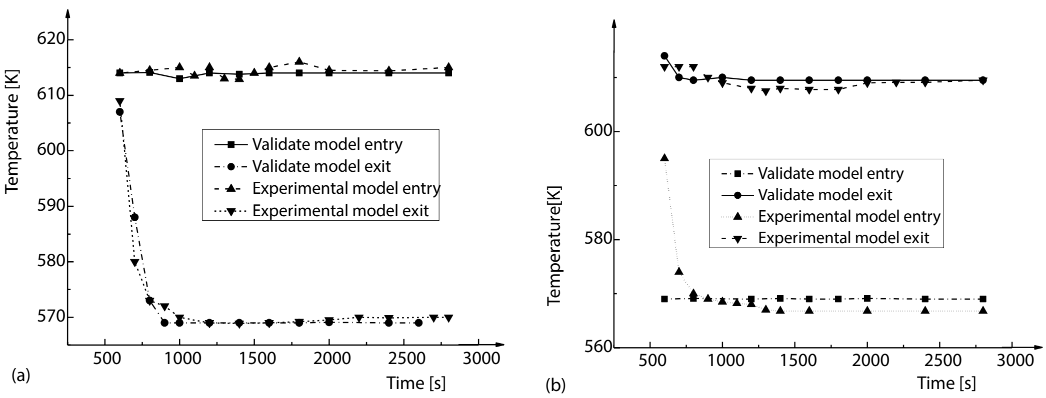

Figure 4. Temperature change at heat exchanger of MSTS wind power system; (a) synthetic heat transfer oil, (b) molten salt

The change of temperature data shows that the change trend of the actual temperature curve is basically the same as that of the simulation temperature curve. Meanwhile, in the change of the actual temperature curve of the system, there is a transition in the initial temperature at the entrance of the high temperature molten salt changing from the high temperature to the set temperature. The actual initial temperature at the outlet of the molten salt side of the heat exchanger first tends to the temperature at the inlet of the synthetic heat transfer oil side, and then gradually changes to the set temperature value, and there is a deviation between the simulated temperature and the actual temperature.

In the verification of the two-pot MSHS system, to ensure the safety of the system, the molten salt in the system pipe-line must always be kept in the molten state. Thus, a temperature tracking device is installed, so the temperature value in the system pipe-line can be higher than the set temperature in the low temperature molten salt energy storage tank. This device will interfere with the temperature at the outlet, so the actual verification result is inconsistent with the numerical simulation result. Under the heat exchange mode of countercurrent exchange, the outlet of one side of molten salt is at the same end as the inlet of synthetic heat transfer oil, so once started, synthetic heat transfer oil and molten salt enter the heat exchanger from the inlet of both ends. In this process, the heat exchange occurs, so that the temperature at the outlet will be affected by the temperature at the other side of the same end. Therefore, the temperature value at the outlet of the molten salt side is close to that at the inlet of the synthetic heat transfer oil side. In addition, in the heat storage system, one side of the synthetic heat transfer oil dominates the heat transfer process. Because the pressure value set on one side of the synthetic heat transfer oil is higher than that on the molten salt side. In fact, the flow speed of the synthetic heat transfer oil itself is faster. Hence, in the start-up stage of the system, the influence of one side of the synthetic heat transfer oil on the temperature of the molten salt side is greater. On the whole, when the thermal storage system reaches the dynamic balance, the consistency between the simulation results and the actual results is quite good. It can be seen that the wind power thermal storage system model based on high temperature two-pot molten salt built is accurate and reliable, and it is applicable to the modelling and simulation analysis of the thermal storage system.

Modelling and simulation of wind power heating system

The realization of the heating system needs to go through the whole-day operation process. If the hot water can circulate stably, the design of the wind power heating system is in line with the demand. From the point of view of system heating, the heat exchange situation of heating cycle is judged on the macro level. In the whole simulation process, for the convenience of calculation and analysis, it is assumed that the operation time of the system is 24 hours, the outdoor environment temperature of the wind power heating client is within the range of 270-280 K. It is also supposed that the wind source input of each wind turbine in the unit is the same model, the rated power rate is 3.45 MW, and there are ten corresponding units. For the whole dynamic simulation calculation of high temperature MSHS wind power heating system, DYMOLA software, a multidisciplinary system modelling and simulationol, is used. The corresponding wind power flow and the temperature change of the user room for regional wind power heating, as well as the molten salt level change in the energy storage pot of the high temperature MSHS wind power heating system, are shown in figs. 5(a)-5(c), respectively.

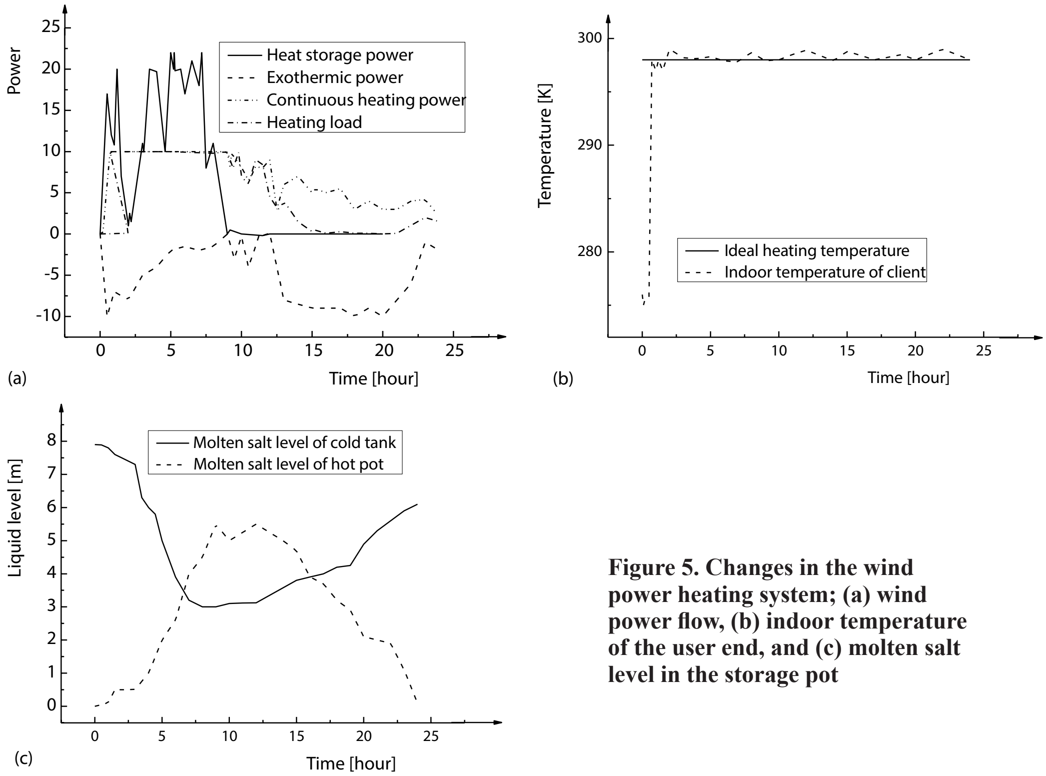

Figure 5. Changes in the wind power heating system; (a) wind power flow, (b) indoor temperature of the user end, and (c) molten salt level in the storage pot

The power flow of the regenerative wind power system suggests that in the earlier stage (within 10 hours) with lower temperature, the demand for thermal power load of the district heating users of the regenerative wind power system is relatively high, while in the later stage (within 14 hours) with higher temperature, the demand for load is relatively low. In addition, the heat release power in the thermal storage system is in a continuous fluctuation state, and it is calculated that the fluctuation range of molten salt in the thermal storage pot is less than 3 kg/s, so this fluctuation state is only relative. In the change of the indoor temperature curve of the user end, it is found that the indoor temperature is basically stable at the ideal heating temperature level from the initial 0.5 hour to 24 hours. The liquid level in the MSTS pot changes with the variation of the heat storage and release behavior in the thermal storage wind power heating system. As a whole, the total amount of molten salt remains unchanged. After 24 hours of operation, the utilization rate of wind energy of the heat storage heating system can reach over 94%.

Taking the heat load curve as the boundary line, the wind power can be divided into two parts: heat storage power and continuous heating power. The output power of wind power is not less than the specific period of heating load, and the heating can be realized by continuous heating power. When the output power of wind power is lower than the heating load due to the influence of wind speed, the continuous heating power is equal to the output power of wind turbine, and the heating system of heat storage wind power is in the exothermic mode. The reason for the continuous fluctuation of the heat release power in the heat storage system is that the control of the process is actually the control of the molten salt outflow rate in the heat storage tank, but it does not affect the operation safety of the loop. It can be seen that the heating system of heat storage wind power can effectively regulate the output power of the system, and the system can meet the regional demand for heat supply. By using simulation analysis, the wind power system with MSHS is applied to district heating, which has significant effect in absorbing wind power, saving resources, solving wind curtailment and other problems.

Modelling and simulation of wind power supply-heating system

The simulation and analysis of high temperature MSTS wind power supply heating system is also realized by using DYMOLA software. To facilitate the study and analysis of the system parameters, the operation time of the system is assumed to be seven days, and the corresponding maximum load is 35 MW. The outdoor environment temperature of the wind power supply-heating user side is stable within the range of 270-280 K, and the wind power supply system is repeated. The wind source of each wind turbine is assumed to be the same model, the rated power is 3.45 MW, and there are ten corresponding units. The change of corresponding high temperature MSTS wind power supply, the thermal storage and release power of the heating system and the molten salt level in the energy storage pot, as well as the utilization of wind energy before and after the heating with or without thermal storage, are shown in figs. 6(a)-6(c), respectively.

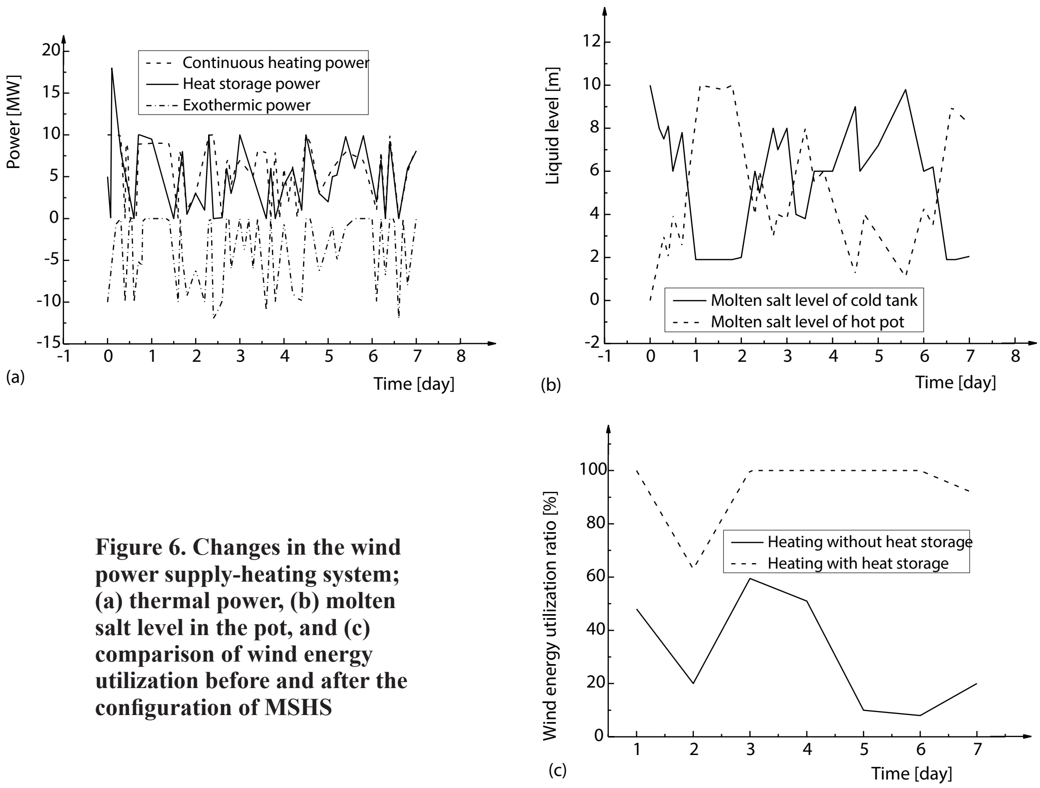

Figure 6. Changes in the wind power supply-heating system; (a) thermal power, (b) molten salt level in the pot, and (c) comparison of wind energy utilization before and after the configuration of MSHS

After analyzing the simulation results, it is found that in the power storage and heat release changes of the power supply-heating system, when the continuous heating power is not higher than the heating load, the heat storage system starts to release heat. The change of molten salt level in the energy storage pot is analyzed, and it is found that the molten salt level reaches

9 m during 1.2-1.6 days, 1.65-1.8 days, 6-6.5 days, and 6.6-6.8 days. When there is no MSHS, the utilization rate of wind power generation system for wind energy is low, only ranged 8-58%. By contrast, when MSHS is configured, the utilization rate is significantly improved, especially on the fifth day, the utilization rate of wind energy is even as high as 100%.

By taking the heating load value as the dividing line, in fact, it makes the storage of heat and the wind curtailment before heating present two trends, so that the continuous heating and the storage of heat can be realized, respectively. The change of molten salt level in the energy storage pot is related to the size of the molten salt energy storage pot. Whereas, the limitation of the size of the energy storage pot is closely related to the capacity of the heat storage system for the size of the wind curtailment power. If the size of the heat storage pot is not large enough, the heat storage system for the wind energy will be limited, thus affecting the utilization of energy. It should be noted that the corresponding heating scale in the hot area will also affect the effective utilization of wind energy. The results of wind energy utilization before and after MSHS show that MSHS can absorb most of the wind energy generated on that day, so it can significantly improve the wind energy utilization of wind power generation system.

Conclusions

Starting from the application of wind energy in the field of electric power, the modelling and simulation of the energy reuse system of wind turbine are discussed. The molten salt with excellent sensible heat performance is selected as the heat storage material. Based on the principle of two-pot molten salt electrothermal transformation, a high temperature MSHS model is constructed. Then, the numerical simulation analysis method is selected to analyze the high temperature MSHS wind power heating system and the power supply-heating system is simulated and analyzed.

The results show that: in the temperature change of MSTS wind power system model, when the system is in dynamic balance, the consistency between the actual results and simulation results is high, the model is accurate and reliable, and the applicability is high in system modelling and simulation analysis. The heat release power of the high temperature MSHS wind power heating system fluctuates, the indoor temperature is stable at an ideal level, and the total amount of molten salt remains unchanged. Moreover, the wind energy utilization rate of the 24 hours heat storage wind power heating system is more than 94%, which has a significant effect in eliminating wind power, saving resources, solving wind curtailment. When the MSHS is not configured, the high temperature MSHS wind power heating power supply system shows a low utilization rate of wind energy. When MSHS is configured, the maximum utilization rate of wind energy can reach 100%. Obviously, the configuration of MSHS can absorb most of the wind energy generated, significantly improve the energy utilization rate of the wind power generation system, which has a positive effect on recycling the power.

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