Research on Frequency Control of Grid Connected Sodium-Sulfur Battery

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Abstract. Sodium sulfur battery is the only energy storage battery with large capacity and high energy density. It has a great application prospect in the peak load shifting of power grid，due to the lack of domestic research on it, it is urgent to evaluate the effect of grid-connection of sodium sulfur battery scientifically. According to the experimental data of the sodium sulfur battery project, the battery model is built. Compared with the real discharge curve, the error of the model simulation curve is small, so the battery model is effective. The AC / DC power grid model is built, and the rectifier and inverter control circuits are designed to simulate the scenario that the wind turbine and the battery are supplied to the passive load. The simulation results show that the grid-connected model of the sodium sulfur battery under the two control strategies can stabilize the larger frequency fluctuation.

1 Introduction

In recent years, the new type of energy storage battery has developed rapidly, and has been used more and more in the power grid. Energy storage battery not only can play the role of “peak load shifting”, but also may be used as a large scale long-term energy storage device in the power grid in the long term.

As an important factor of power quality, the frequency of power grid is an important index to evaluate the effect of peak load shifting of sodium sulfur battery. So it is very important to develop a reasonable and effective integration strategy. Based on AC / DC power transmission model, this paper simulates the grid connected effect of sodium sulfur battery, because the energy storage battery is always combined with the new energy[1], the wind power model is used in the model. Document [2] proposed to use reactive power and voltage control to solve the problem of lithium battery grid connection, and the key to study the problem of peak load shifting is the power balance between power and load. Therefore, this paper is based on reactive power control, at the same time, the current data are collected to achieve the "power control", and then directly control the frequency[3] of the system after grid connected.

2 Sodium sulfur battery model

2.1 Model establishment

The most important thing to study the grid-connection problem of sodium sulfur battery is to establish the correct battery model[4], which is the basis of the follow-up work. According to the nature and working characteristics of sodium sulfur battery, the equivalent circuit model of sodium sulfur battery is established. The model is shown in figure 1.

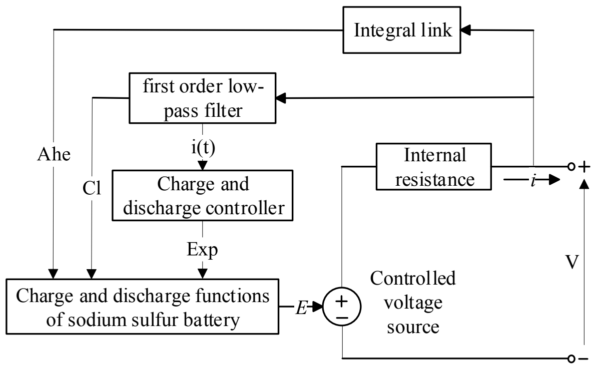

Figure 1. The circuit model of battery

In the above model, the charge and discharge functions of the source can best reflect the characteristics of the battery. According to the test data of sodium sulfur battery, the charging and discharging model[5] of the battery is established.

It is known that the electric potential of the battery during charging is E_c . The potential is related to a number of factors, which can be expressed by Formula (1).

$$E_c = E_0 - K\frac{Ah_m}{Ah_m - Ah_e}C_l - K\frac{Ah_m}{Ah_m - Ah_e}Ah_e + A\exp\left(-BAh_e\right) \tag{1}$$

In Formula (1), E_0 represents the constant voltage of the battery, K represents the polarization resistance, Ah_m and Ah_e represent the maximum capacity and extracted capacity of the battery respectively, and C_l represents low frequency current dynamics. In order to avoid the complexity of the formula, exponential voltage and exponential capacity are represented by A and B respectively.

Because of the nature of the battery, the charge and discharge curves of the battery are not coincident, and the potential functions of charging and discharging are also different. The expression of potential in the discharge process of sodium sulfur battery is shown as formula (2).

$$E_{dc}=E_0-K\frac{Ah_m}{Ah_e+0.1Q}C_l-K\frac{Ah_m}{Ah_m-Ah_e}Ah_e \\ +A\exp\left(-BAh_e\right) \quad (2)$$

In formula (2), E_{dc} is used to represent the potential of the battery in the discharge process. Sodium sulfur batteries operate at very high temperatures, usually between 300 and 400 degrees Celsius, so the battery model should take into account temperature factors. The temperature dependent parameters in the model are constant voltage E_0 , polarization resistance K and maximum capacity Ah_m . These parameters can be expressed with formula (3), (4) and (5).

$$E_0=E_0\left(T\right)=E_0\big|_{T_N}+\frac{\partial E}{\partial T}\left(T-T_N\right) \quad (3)$$

$$K=K\left(T\right)=K\big|_{T_N}+\exp\left(\alpha\left(\frac{1}{T}-\frac{1}{T_N}\right)\right) \quad (4)$$

$$Ah_m=Ah_m\left(T_e\right)=Ah_m\big|_{T_e}+\frac{\Delta Ah_m}{\Delta T}\left(T_e-T_N\right) \quad (5)$$

In the above formula, T_N represents the nominal ambient temperature, T represents the internal temperature, T_e represents the ambient temperature, and α represents the Arrhenius rate constant for the polarization resistance.

Then the expression of the output voltage V_o can be obtained.

$$V_o\left(T\right)=E_c-R\left(T\right)i \quad (6)$$

$$V_o\left(T\right)=E_{dc}-R\left(T\right)i \quad (7)$$

The formula (6) is the expression of output voltage during the charging process, the formula (7) is the expression of output voltage during the discharging process, and $R\left(T\right)$ represents the internal resistance of the battery, and its expression is shown in formula (8).

$$R\left(T\right)=R\big|_{T_N}\exp\left(\beta\left(\frac{1}{T}-\frac{1}{T_N}\right)\right) \quad (8)$$

In formula (8), β represents the Arrhenius rate constant for the internal resistance.

2.2 Model parameters and verification

According to the established model of sodium sulfur battery, the relevant parameters of the battery are set up. The parameters are all the experimental data in the test of sodium sulfur battery, which are shown in Table 1.

Table 1. Model parameter of single sodium sulfur battery.

Parameter	Value
Discharge voltage	2.076-1.9V
Charging voltage	1.9-2.2V
Rated current	40A
Limiting current	120A
Limiting voltage	35V
Internal resistance	2.1-10mΩ
Working temperature	345-355℃
Rated capacity	0.595kWh

In order to evaluate the accuracy of the battery model, the data in the parameter list is the data of the single cell.

According to the established battery equivalent circuit and model, the simulation model of is established based on the battery model in MATLAB/Simulink. In order to evaluate the accuracy of the model, the discharge curve of the single cell was simulated, and the discharge curve of the battery under different discharge current was obtained. In order to reflect the difference of curves under different currents, the discharge current values are set to 20A, 40A and 60A, as shown in Figure 2.

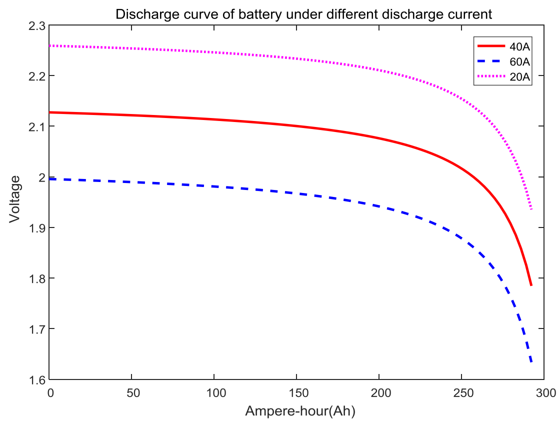

Figure 2. The discharge curves under different current.

The abscissa is the capacity of the cell, and the ordinate is the voltage of the battery. The three curves are obtained by the battery model built above, and verify the correctness of the model needs to be compared with the real discharge curve. The rated discharge current of the sodium sulfur battery in the actual project is 40A, so the real discharge curve of the battery with the discharge current of 40A is compared with the simulation curve to verify the correctness of the model, as shown in Figure 3.

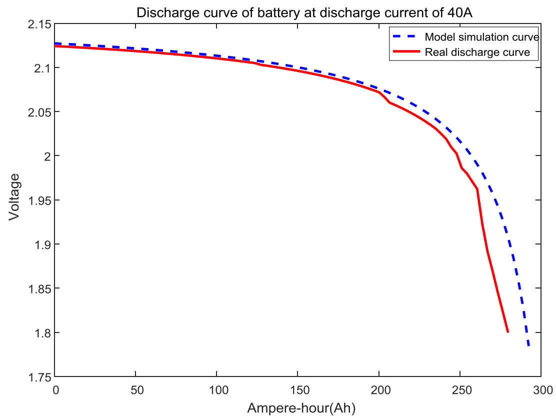

Figure 3. The discharge curves under 40A

It can be seen from the diagram that the discharge curve of the sodium sulfur battery model established in this paper has less error compared with the real curve, so it can be used for grid connected simulation experiment.

3 AC/DC power grid model

With the continuous development of new energy sources, sodium sulfur batteries are mainly used in the grid system composed of new energy sources. This paper selects the wind power and sodium sulfur battery connected to the grid, in order to test the effect of peak load shifting of batteries. In order to avoid excessive loss of electric energy in the transmission process causing the larger frequency fluctuation at the load side, the transmission process adopts the mode of direct current transmission.

AC/DC power grid model simulation based on MATLAB/Simulink. The transmission model is composed of a wind turbine model, a load model and a transmission and transformation model, the specific implementation methods of each model are described below.

3.1. Establishment of AC/DC power transmission model

The model simulates the situation of wind farm and battery supply power to passive load simultaneously. In order to test the effect of peak load shifting in sodium sulfur battery, step load is added to the model to investigate its transient[6] response.

The 3-phase source module is used to simulate a wind farm, and the Distributed Parameter Line function module is used to simulate the DC transmission line. The 3-phase parallel RLC load module is used to simulate the three-phase load.

The AC to DC rectifier consists of AC bus, transformer, filter circuit and bridge rectifier. The DC to AC part consists of filter, inverter, AC bus and transformer.

Because the simulation model is too complex, the basic components of the simulation model are described in block diagram, as shown in Figure 4.

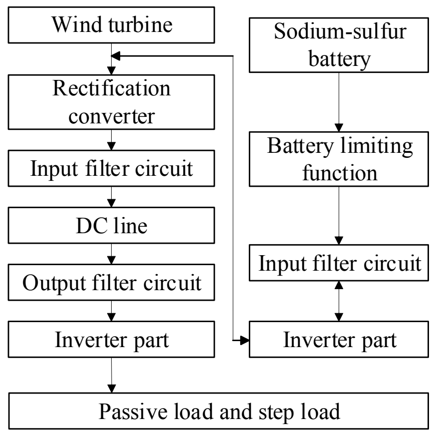

Figure 4. AC/DC power transmission model

In figure 4, the three-phase power generated by the wind turbine is transformed into a high voltage direct current through the rectifier bridge. After the filter circuit and the long distance transmission line, the power supply is supplied to the load through the inverter. When the battery is sufficient or the load is suddenly increased, the sodium sulfur battery supplies power to the load through the filter circuit and the inverter part, at the same time, the battery will absorb the electric energy from the grid when the battery capacity is insufficient or the load is suddenly reduced, so as to achieve the effect of peak load shifting.

3.2 Model of rectifier bridge control circuit

The control of rectifier is very important to DC transmission system. The power generated by the wind turbine needs to be converted into DC power by rectifier to be transmitted. In order to achieve the purpose of long distance transmission, it is necessary to boost the wind power. The DC voltage after transformation is easily disturbed by various disturbances, and the double closed-loop control strategy based on state feedback decoupling can solve this problem better. The simulation model is shown in Figure 5.

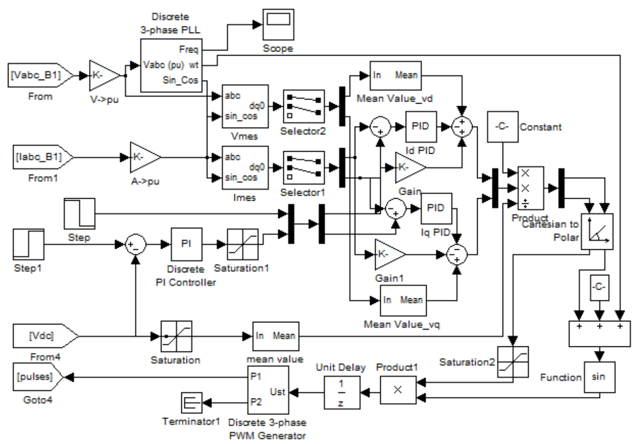

Figure 5. Rectifier bridge control circuit

In the above model, the reference value of DC voltage is 20Kv, and the reference value of reactive current is set to 0.

3.3 Model of inverter control circuit

The control circuit of the inverter is needed for the sodium sulfur battery grid-connected and the power supply circuit for the DC transmission line to load. The two inverter control circuits are described below.

The function of the inverter is converting high voltage direct current into low voltage alternating current in the transmission line. The control of the inverter is simpler than the control of the rectifier, the important role of DC transmission line to load power supply part is to ensure the stability of AC output voltage, therefore, only one AC voltage control loop is needed to achieve the control effect. The control model[7] is shown in figure 6.

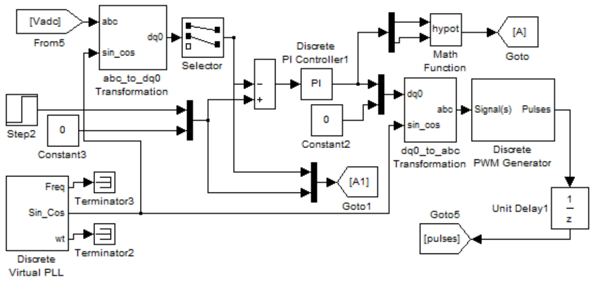

Figure 6. Inverter control circuit

The model can represent the inverter control model of sodium sulfur battery grid-connected. But the process of sodium sulfur battery grid-connected is more complex, and also need to consider some of the battery's own restrictions (battery voltage, capacity).

Fig. 7 is the control strategy with battery voltage as the standard in the control circuit of sodium sulfur battery.

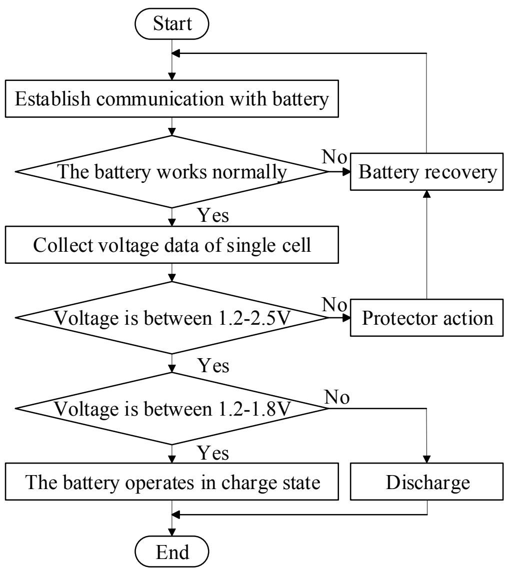

Figure 7. Control strategy with battery voltage as the standard

The diagram shows that the normal voltage range of single sodium sulfur battery is 1.2-2.5V, and the battery level is low between 1.2-1.8V, so the battery needs charging. In the 1.8-2.5V, the battery level is high, so the battery needs discharging. Similarly, the control strategy based on the battery capacity is also applicable to the block diagram shown in Figure 4, The normal capacity range of single sodium sulfur battery is 50-300Ah, and the battery level is low between 50-150Ah, so the battery needs charging. In the 150-300Ah, the battery level is high, so the battery needs discharging.

As one of the control indexes, the change of the frequency of the power grid affects the working state of the sodium sulfur battery. The experimental results show that the control strategy of sodium sulfur battery with its own limiting conditions can achieve the purpose of peak load shifting. So the application of the frequency is relatively simple, when the frequency drops, the battery should work in the discharge state. When the frequency rises, the battery should work in the charging state.

4 Grid connected simulation

Because the battery capacity and the battery voltage are two different control standards, the grid connected process of the sodium sulfur battery is simulated with these two control[8] standards respectively.

The capacity of the passive load in the simulation model is 5MW. In order to reflect the " peak load shifting " effect of sodium sulfur battery, the performance of sodium sulfur battery was simulated by increasing and reducing load. The simulation is divided into two stages. At the beginning of the simulation, the load capacity is reduced by 2MW, and then the load capacity is increased by 6MW at third seconds of simulation. Through the above settings to test the effect of two grid connected strategies on the frequency stabilization, the simulation results are shown in figure 8 and 9.

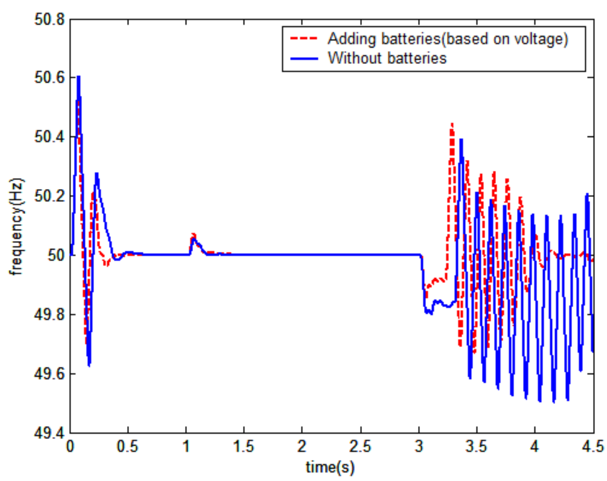

Figure 8. Frequency variation of power grid after adding sodium sulfur battery(based on voltage)

Figure 8 is the control strategy based on voltage as the standard, and the frequency fluctuation is obviously reduced in the diagram. Therefore, the peak load shifting effect of sodium sulfur battery is better.

The control strategy based on battery capacity as standard is shown in Figure 9.

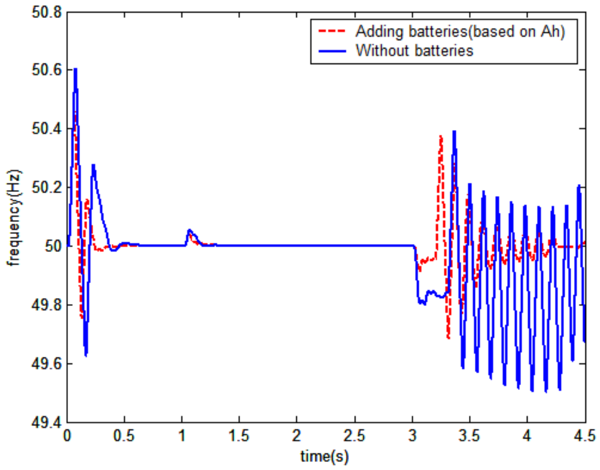

Figure 9. Frequency variation of power grid after adding sodium sulfur battery(based on Ah)

The capacity based control strategy has better control effect on frequency fluctuation, and the frequency fluctuation under the two control strategies is analyzed accurately. As shown in Table 2 and 3.

Table 2. Frequency fluctuation analysis(Load reduced by 2MW)

Index	Wind power	Adding batteries(V)	Adding batteries(Ah)
Maximum frequency	50.61	50.53	50.47
Minimum frequency	49.62	49.70	49.76
Fluctuation range	0.99	0.83	0.71
recovery time	0.3s	0.25s	0.16s

Table 3. Frequency fluctuation analysis (Load increased by 6MW)

Index	Wind power	Adding batteries(V)	Adding batteries(Ah)
Maximum frequency	50.41	50.43	50.39
Minimum frequency	49.53	49.71	49.73
Fluctuation range	0.88	0.72	0.66
recovery time	/	0.8s	0.62s

From the above analysis, it can be seen that when the sodium sulfur battery is connected to the grid, the battery capacity as the standard control strategy can better stabilize the frequency fluctuation. The frequency recovery time is short.

In order to verify the effect of sodium sulphide batteries, the follow-up work focused on the performance of the sodium sulfur battery in the actual operation.

5 Conclusion

The sodium sulfur battery model proposed in this paper can simulate the charging and discharging characteristics of the battery very well, and this model can provide a solid foundation for the follow-up study of sodium sulfur batteries. In the process of sodium sulfur battery grid connection, the control strategy with the battery capacity as the standard can better stabilize the grid frequency.

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