Membrane Technology
ISSN (online): 1873-4049

Research on Active Vibration Control and Environmental Performance Evaluation of Large Mechanical Grid Connected Systems

ZANG Ji -song[1,*], LIU Kai-hua[2], LI Zhe[1]

[1]*Mechanical Engineering Department, North China Institute Of Aerospace Engineering, Langfang ,China;*
[2]*Coal Science (Beijing) Test Technology Co., Ltd. ,China*

Abstract:

Introduction: After the mechanical grid connected system is connected to the power grid, it may cause significant grid vibrations, which will have a certain impact on the environment and the stable operation of the mechanical system.

Objectives: In order to improve the stability of the power grid and the operational efficiency of machinery, this paper explores an active vibration control strategy for large-scale mechanical grid connected systems.

Methods: We provides an in-depth analysis of the characteristics of large-scale mechanical grid connected systems and constructs corresponding mathematical models to calculate system parameters accurately. Furthermore, we constructed mechanical vibration models under various modes based on the operating status, load conditions, and environmental factors such as temperature and humidity of the machinery. Based on this, we have designed a vibration control algorithm and its criteria for mechanical grid connected systems.

Results: The experimental results show that the vibration of the power grid is effectively controlled and does not exceed the safe range in these modes.

Conclusions: It can be seen that this control strategy enhances the stability of the power grid, and helps to improve the operational efficiency and environmental performance of mechanical systems.

Keywords: mechanical grid-connected system, active vibration control strategy, mechanical vibration

INTRODUCTION

As an important component of modern power grids, the role of mechanical grid connected systems is becoming increasingly prominent[1]. By connecting the large mechanical equipment to the power grid, the energy utilization efficiency can be improved, but diversified energy supply can be achieved at the same time. However, with the widespread application of mechanical grid connected systems, the potential vibration problems that may arise after their integration into the power grid are gradually becoming apparent[2-6]. Its unique operating characteristics and energy exchange mode may have a certain impact on the stable operation of the power grid. Especially when mechanical equipment is started, operated or stopped, the impact and vibration generated may spread through the power grid, causing fluctuations or even vibrations in the power grid, thereby threatening the safe and stable operation of the power grid[7].

OBJECTIVES

Researchers have conducted in-depth research on the vibration problem of the power grid caused by mechanical grid connected systems, and various improvement methods have been proposed and applied in practice. Among them, active vibration control strategy is one of the important methods. This method analyzes the characteristics of mechanical grid connected systems in depth and constructs corresponding mathematical models to accurately calculate system parameters.

METHODS

OVERVIEW OF POWER FLUCTUATION RESEARCH AND SIMULATION MODELING OF MECHANICAL GRID CONNECTED SYSTEMS

In the mechanical grid connected systems, energy storage equipment or components(ESEC) are connected in series and parallel to form a mechanical array. M mechanical modules are connected in series, and N mechanical modules are connected in parallel to form a mechanical array. The working state of mechanical module with bypass equipment or components is determined by the current of the string where the module is located and the short circuit current of the module under the received light intensity and temperature. When the current flowing through the equipment or components string is less than its short circuit current, the mechanical array works normally, and the bypass equipment or components is under reverse voltage at both ends and in the off state. At this time, the mathematical model of the mechanical ESEC is the same as that of the single equipment or components module. Its mathematical model is shown in Formula (1).

$$I_{PV}=I_{SC}-A\left(e^{\frac{(U_{PV}+I_{PV}R_S)}{B}}-1\right)-\frac{(U_{PV}+I_{PV}R_S)}{R_{SH}} \tag{1}$$

Where: ISC - short circuit current of mechanical ESEC;

A. B -- Parameters related to light intensity and component temperature.

$$I_{SC}=I_{STC}\frac{R_{PV}}{R_{STC}}(1+\alpha_1(T_{PV}-T_{STC})) \tag{2}$$

$$A=\frac{I_{STC}+\alpha_1(T_{PV}-T_{STC})}{e^{(U_{OC}+\alpha_V(T_{PV}-T_{STC}))/B}-1} \tag{3}$$

$$B=\frac{aN_S kT_{PV}}{q} \tag{4}$$

Where: ISTC, UOC short circuit current and open circuit voltage of mechanical ESEC under standard test conditions (RSTC=1000w/m2, ESEC temperature TSTC=298.15K);

αI, αV - temperature coefficient of current and voltage of mechanical ESEC;

TPV - mechanical ESEC temperature;

NS - number of mechanical ESEC in series;

k - Boltzmann constant, k=1.3806503 × 10-23J / K;

q - electronic charge, g=1.60217646 × 10-19C;

a - Ideal coefficient of equipment or components (value range: 1~1.5).

When the current flowing through the mechanical ESEC string is greater than its short circuit current, the voltage UPV at both ends of the mechanical ESEC is negative. When the - U is greater than the positive conduction voltage of the bypass equipment or components, the bypass equipment or components is positive conduction. At this time, the mechanical module is in a short circuit state, and its current is short circuit current. The excess current is dredged by the bypass equipment or components, which can avoid the generation of hot spot effect. At this time, the I-U characteristics of mechanical modules with bypass equipment or components are mainly determined by the bypass equipment or components. In this paper, the equipment or components are described by a linear model, that is, the voltage and current at both ends of the mechanical modules meet the formula (5):

$$I_{PV}=I_{SC}-(U_{PV}+U_{th})/R_d \tag{5}$$

Where: Uth - threshold voltage of bypass equipment or components;

Rd - equivalent resistance when the bypass equipment or components are on.

Based on the above two operating conditions of mechanical ESEC, the mathematical model of mechanical modules with bypass equipment or components can be expressed as:

$$I_{PV}=\begin{cases} I_{SC}-A\left(e^{\frac{(U_{PV}+I_{PV}R_S)}{B}}-1\right)-\frac{(U_{PV}+I_{PV}R_S)}{R_{SH}} & U_{PV}>\text{-}U_{th} \\ I_{SC}-(U_{PV}+U_{th})/R_d & U_{PV}<\text{-}U_{th} \end{cases} \tag{6}$$

The above formula can be abbreviated as:

$$\begin{aligned} f_1(I_{PV},U_{PV})=0 \quad U_{PV}>-U_{th} \\ f_2(I_{PV},U_{PV})=0 \quad U_{PV}<-U_{th} \end{aligned} \tag{7}$$

Due to the large floor area of the mechanical array, cloudy weather or building occlusion may cause the mechanical array to be partially shaded, resulting in distortion of the I-U characteristic curve of the mechanical array. The output of mechanical array varies with the position of the sheltered mechanical array and the number of components in the sheltered array. Therefore, as the shadow moves, the output of the mechanical array fluctuates for a period of time. Therefore, it is necessary to simulate the mechanical array output in cloudy weather, design a moving shadow model, and obtain the mechanical output fluctuation curve.

In cloudy and breezy weather, the cloud moves along the wind direction at a constant speed, and the shadow generated by sunlight on the cloud will gradually cover the mechanical array, causing the decline of light intensity and temperature received by the mechanical array; After a period of time, the clouds drift away, the shadow no longer covers the mechanical array, and the mechanical array recovers the light intensity and temperature in sunny days.

In order to get the output fluctuation curve of mechanical array under moving shadow for a period of time, a moving shadow model is designed. Simulate the cloud moving path and occlusion effect under the fixed wind direction as the moving shadow model of the occlusion mechanical array, which can simulate the light intensity and temperature changes under the joint occlusion of two clouds.

A METHOD FOR SUPPRESSING POWER FLUCTUATION OF MECHANICAL ARRAY

In the traditional grid connected mechanical system, the mechanical array tracks the peak point of the P-U characteristic curve of the mechanical array through the maximum power point tracking algorithm, and outputs the voltage value corresponding to the peak point of the power, so as to ensure that the mechanical array outputs with the highest working efficiency. The disadvantage of this method is that the maximum power point tracking algorithm makes the output of the mechanical array non adjustable. When the output of the mechanical array fluctuates sharply due to weather changes, the mechanical array cannot control the output of the mechanical array through its own adjustment.

For the first type of fluctuation classification, due to its large fluctuation amplitude, the regulation of grid connected inverter alone cannot achieve the purpose of suppressing power fluctuation and bearing power imbalance. Therefore, this paper proposes a mechanical frequency feedback active power frequency modulation control strategy to suppress the negative impact of the first type of power fluctuation on the power grid. The core of the control strategy is the reserve capacity of mechanical array and the feedback power regulation. By tracking the offset between the actual frequency and the frequency reference value when the mechanical array is inverter connected to the grid, the frequency offset is fed back to the MOSFET switch control link of the DC/DC voltage rise circuit, and the output power of the mechanical array is adjusted accordingly according to the feedback frequency offset. By controlling the duty cycle of the MOSFET, the output power of the mechanical array is smooth and stable before the inverter is connected to the grid. The block diagram of mechanical frequency feedback active frequency modulation control strategy is shown in Figure 1.

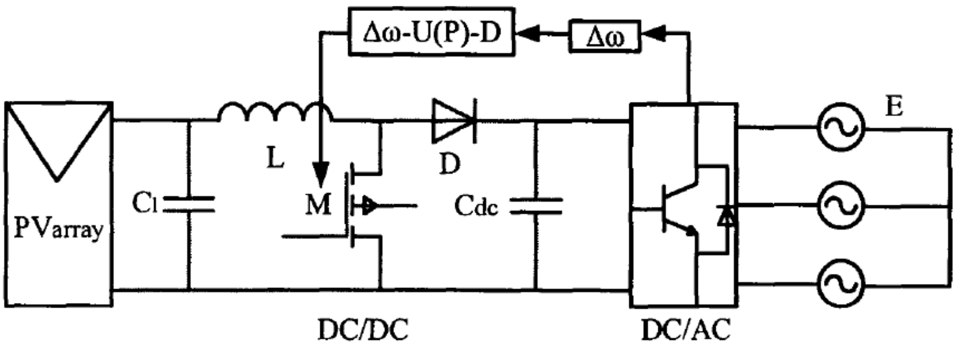

Fig. 1. Photovoltaic array direct to direct voltage boosting circuit topology

The mechanical array is composed of multiple mechanical modules in series and parallel connection. During the shadow movement, the mechanical array is exposed to uneven sunlight. The light intensity and temperature of each mechanical module in the mechanical array are different and change in real time. After the series and parallel connection, the output current curve of the mechanical array will fluctuate slightly, which is the second fluctuation classification. Although the amplitude of the small amplitude oscillation of the active power output of the mechanical array is between 1 and 10kW, for the mechanical power station composed of a large number of mechanical arrays, the fluctuation of the active power output of the mechanical power station after the confluence cannot be ignored.

For the second kind of fluctuation classification with small fluctuation amplitude, this paper proposes the design of active power frequency modulation control strategy for mechanical energy storage system. By adding energy storage equipment to the mechanical array, set the reference value of the active power of the mechanical array DC bus, take the offset of the two adjacent sampling points of the mechanical array active output as the control value of the energy storage system, design the charging and discharging control link of the energy storage system, control the energy storage system to discharge when the offset is negative, and charge when the offset is positive, so as to suppress small amplitude power fluctuations, and achieve smooth and stable grid connected active power of the mechanical array inverter.

RESULTS

OVERVIEW OF POWER REGULATION OF MECHANICAL ENERGY STORAGE SYSTEM

In recent years, with the large-scale development and utilization of mechanical power generation, mechanical energy storage system as a necessary link, related control technologies have been developed rapidly. Due to the volatility and randomness of solar energy, the output power of mechanical array is not constant. Large mechanical arrays cover a large area, and cloud shadows will be blocked in cloudy weather. Mechanical arrays are exposed to uneven sunlight, resulting in different light intensity and temperature of each mechanical ESEC in an array, which will change with the movement of clouds. Therefore, the output power of the mechanical array fluctuates continuously during the shadow movement. The change of meteorological conditions makes the output of mechanical array fluctuate. This adds difficulty to the control of energy storage system and the selection of energy storage capacity.

SELECTION OF MECHANICAL ENERGY STORAGE COMPONENTS

For large mechanical power generation systems, the energy storage elements required should have the characteristics of high energy storage density, fast response, low investment cost, long service life, simple and convenient maintenance, etc. At present, lead-acid batteries and supercapacitors are widely used as energy storage components.

(1) Lead acid batteries: At present, most mechanical power stations use lead acid batteries as energy storage components. The advantages of lead-acid battery are: low price, low cost of large capacity input, simple and convenient maintenance; Disadvantages: less charging and discharging times, slow response speed, large volume and weight, lead and lead oxide will pollute the environment, and it is difficult to recycle.

(2) Supercapacitor: Supercapacitor is a newly developed energy storage component in recent years, which has just been put into the market. The advantages of supercapacitors are: large capacitance, many times of charging and discharging, long service life, wide working temperature range, convenient and adjustable capacity, and fast green, environment-friendly and pollution-free response; Disadvantages: improper use will cause electrolyte leakage.

Based on the advantages and disadvantages of the above energy components, the three components are compared in terms of energy storage capacity, service life, operating temperature, environmental protection, response speed and input cost. The results are shown in Table 1.

Table 1. Characteristic comparison of energy storage elements

Component Properties	Lead acid battery	Supercapacitor
Energy density	75-100 Wh/kg	Thousands of Farad
Service life (charging and discharging times)	Four hundred and fifty	One hundred thousand
Charging and discharging time	10-14 hours	1-25 seconds
Working temperature	-30-65°	-40-65°
Input cost	Low	Higher
Response speed	Slower	Extremely fast
Environment protection	Heavy metal pollution	Pollution-free

For the second type of fluctuation classification with small amplitude and frequent fluctuation in this paper, energy storage components are required to have fast response speed, many times of charging and discharging, and little demand for energy storage capacity. Based on various factors in Table 1, this paper uses supercapacitor as the energy storage element of mechanical energy storage system.

The internal structure of SC is composed of positive electrode and negative electrode. Its working principle is to store energy by using the double-layer electrolyte interface formed between electrode and electrolyte. When the applied voltage acts on the two plates of the SC, the positive charge moves to the positive plate and the negative charge moves to the negative plate. The two plates generate potential difference due to the rapid accumulation of positive and negative charges, and the gap between the plates forms an electric field. In order to balance the effect of electric field, the contact surface of electrode and electrolyte will produce a stable and opposite polarity charge layer, which is the interface double electric layer, that is, the two positive and negative electrodes of the capacitor. When the two electrode plates of sC are connected in the circuit to form a loop, the positive and negative charges transfer to release electric energy.

SC is a complex high internal resistance capacitor network. Each path contains resistors and capacitors of different capacities, and the corresponding time characteristic constants are different. Due to the complexity of the internal network of supercapacitor, the equivalent model of supercapacitor is often used for characteristic analysis and simulation in practical engineering applications. The SC is discharged after the external resistance R is connected. The discharge current is Ni, and the voltage at the sC terminal is the target. According to Ohm's law, the following can be obtained:

$$U_2 = U_C - I_2 R_{ES} \tag{8}$$

Wherein, the initial discharge voltage of UC is the equivalent terminal voltage U1, and the calculation formula of ESR can be obtained by introducing formula (8):

$$R_{ES} = \frac{U_1 - U_2}{I_2} \tag{9}$$

The leakage current of SC is closely related to EPR, and the leakage current affects the self discharge ability of SC. Because the leakage current is very small and the resistance of ESR is also very small, the influence of ESR is ignored

The formula for calculating the leakage current IL is:

$$I_L = \frac{U_R}{R} \tag{10}$$

Due to the role of the leakage current IL in the circuit, the size of EPR will determine the terminal voltage of C, that is, the voltage value of SC, so the calculation formula of EPR can be obtained as follows:

$$R_{EP} = \frac{E - U_R}{I_L} = \frac{E - U_R}{U_R} R \tag{11}$$

The mechanical array is connected to the DC bus through the boost boost circuit. The SC is connected in parallel with the DC bus through the non isolated bidirectional boost buck voltage raising and dropping circuit. The super capacitor energy storage inductor LSC, MOSFET tubes M1, M2 and Cdc form a boost buck voltage rise/drop circuit, which is only a resistive load, while Csc is a super capacitor.

(1) Super capacitor energy storage inductance k: inductance k is also selected under continuous inductance current state,

(2) MOSFET controllable switches M1 and M2: MOSFET tubes M1 and M2 in boost buck voltage rise and drop circuit control duty cycle through power regulation control strategy of energy storage system,

(3) Supercapacitor CSC: analyze the second type of fluctuation of the mechanical array output power curve, stabilize the power fluctuation through the power regulation control strategy of the energy storage system, obtain the power difference △Pmax when the two adjacent sampling points fluctuate most violently in the second type of fluctuation, and calculate the required SC capacity through Formula (12).

$$C_{SC} = \frac{\Delta Q}{U_{SC}} = \frac{I * t}{U_{SC}} = \frac{\Delta P_{\max} * t}{U_{SC}^2} \tag{12}$$

DISCUSSION

With large-scale large-scale mechanical power stations connected to the distribution network, the output active power of mechanical arrays fluctuates due to weather and other uncertain factors, which will have a negative impact on the frequency stability of the grid after mechanical power stations are connected to the distribution network. Therefore, for large grid connected mechanical power plants, it is particularly important to design effective active power/frequency control strategies to reduce the fluctuation of active power output of mechanical arrays.

REFRENCES

[1] BEHNAMFAR, M. R. , and M. ABASI . Uncertainty Management in Short-Term Self-Scheduling Unit Commitment Using Harris Hawks Optimization Algorithm. Journal of Operation & Automation in Power Engineering 12.4(2024).

[2] LIN, M. , J. SHEN , and C. L. Q. W. Y. CHENG . Long-term multi-objective optimal scheduling for large cascaded hydro-wind-photovoltaic complementary systems considering short-term peak-shaving demands. Energy conversion & management 301.Feb.(2024):1.1-1.19.

[3] DONKOR, LETICIA , E. ESSIEN , and N. S. AFFRIFAH . "A Systematic Review of Linear Programming Techniques as Applied to Diet Optimisation and Opportunities for Improvement." Journal of Optimization (2023).

[4] E. J. OLIVEIRA, L. M. HONÓRIO, A. H. ANZAI et al. Optimum Transient Droop Compensator and PID Tuning for Load Frequency Control in Hydro Power Systems. Int J Elec Power, 68, 345 (2015).

[5] A. HELSETH, M. FODSTAD, B. MO. Optimum Medium-Term Hydropower Scheduling Considering Energy and Reserve Capacity Markets. IEEE T Sust Energ, 7, 934 (2016).

[6] R. O. C. SCARESECI, M. S. ZAMBELLI, S. SOARES et al. Ensemble of Markovian Stochastic Dynamic Programming Models in Different Time Scales for Long Term Hydropower Scheduling. Elec Power Syst Res, 150, 129 (2017).

[7] A. HELSETH, H. BRAATEN. Efficient Parallelization of the Stochastic Dual Dynamic Programming Algorithm Applied to Hydropower Scheduling. Energies, 8, 14287 (2015).

[8] L. YUAN, J. ZHOU, C. LI et al. Benefit and Risk Balance Optimisation for Stochastic Hydropower Scheduling. Water Resour Manag, 30, 3347 (2016).

[9] X. ZHANG, X. YU, H. QIN. Optimum Operation of Multi-Reservoir Hydropower Systems Using Enhanced Comprehensive Learning Particle Swarm Optimisation. J Hydro-environ Res, 10, 50 (2016).

[10] A. RASOULZADEH-AKHIJAHANI, B. MOHAMMADI-IVATLOO. Short-Term Hydrothermal Generation Scheduling by A Modified Dynamic Neighborhood Learning Based Particle Swarm Optimisation. Int J Elec Power, 67, 350 (2015).