

# Research on Power Smoothing Control of Grid-Connected High Proportion New Energy Power Systems

Shunxi Guo

School of Automation, Beijing Institute of Technology, Beijing, 100080, China

1120201090@bit.edu.cn

**Abstract.** With the increasing share of renewable energy in power systems, the construction of an integrated "source-grid-load-storage" system in regions rich in renewable energy and areas with concentrated loads has become an effective way to promote large-scale local consumption of renewable energy. However, under scenarios of high renewable energy integration, the lack of synchronous inertia support in the integrated system poses severe challenges to system frequency stability. Therefore, it is crucial to deeply explore the frequency regulation potential of each component in the "source-grid-load-storage" system. This paper studies the frequency response characteristics of new energy power stations and the demand-side response mechanism. Based on the actual operating conditions of the system and expected fault scenarios, reasonable virtual inertia time constants are set, and a frequency response model of the "source-grid-load-storage" integrated system is established. Furthermore, a new optimized power command is proposed, which combines a moving average filtering algorithm to smooth wind power output fluctuations. Finally, an optimized energy storage configuration method considering resource coordinated operation is studied. The research in this paper provides theoretical support and reference for improving system frequency stability and promoting renewable energy consumption under high renewable energy integration scenarios.

**Keywords:** Integrated System, New Energy, Smoothing Control, Energy Storage.

## 1. Introduction

Under the background of the development of the 21st century, the pollution problem brought by the development of science and technology is becoming more and more serious, especially the daily electricity consumption based on fossil energy [1]. Traditional coal-fired and gas-fired synchronous generators can provide inertia support and voltage and frequency regulation for the power grid. However, with the increase of the penetration rate of new energy power and power electronic equipment, the power system is changing to a weak power grid with low inertia and low damping. The integrated system with new energy as the main body came into being [2]. Different from the general power supply mode of strong power grid, the integrated system realizes the flow of electric energy between power supply, power grid, load and energy storage. However, at the same time, the access of high proportion of renewable energy has led to the low inertia characteristics of the new power system, and the problem of frequency stability has become increasingly prominent [3]. In addition, it is worth noting that the energy storage power station has the characteristics of bidirectional power regulation and strong regulation ability, and has significant advantages in providing fast frequency regulation and inertia support.

Thus, the rational allocation of energy storage; the selection of the source-side network construction strategy; the frequency regulation measures coordinated by the demand side response are of great significance in improving the new energy power generation capacity, enhancing the frequency stability of the integrated system and maintaining the safe operation of the system. This paper mainly studies the frequency modulation capability of the integrated system from three aspects. The source-side grid-forming control strategy, by applying the grid-connected control strategy to the grid-connected inverter of the new energy unit, makes it have active support capability.

## 2. System modeling

The high-proportion new energy power system examined in this study operates under two distinct states: (1) Steady-state operation in a single-infeed mode, and (2) During periods of high load demand, power is procured from the grid via tie lines. However, due to the limited presence of conventional energy sources, systems with a high proportion of new energy generation are particularly vulnerable to frequency instability in the face of disturbance fluctuations. To address this challenge, this paper develops a grid control strategy for the grid-connected inverter of wind farms. Additionally, leveraging the rapid frequency response characteristic of energy storage power stations, the study integrates demand-side response into the frequency regulation process. The coordinated response of the source, storage, and load significantly enhances the frequency stability of the system. This section provides an in-depth analysis of the virtual inertia and demand-side frequency support capabilities of new energy stations, and it proposes the construction of an appropriate virtual inertia time constant for new energy stations, tailored to the system's actual operating conditions and anticipated fault scenarios.

### 2.1. Inertia support

#### 2.1.1 Inertia support of wind farm

The virtual inertia of the wind turbine is determined by the auxiliary frequency control strategy of the rotor kinetic energy of the wind turbine [4]. The model of the wind turbine can be expressed as.

$$\begin{cases} T_m = \frac{\rho \pi R^2 V_w^3 C_p(\lambda, \beta)}{2 P_{nom} \omega_r} \\ C_p = c_1 \left( \frac{c_2}{\lambda_i} - c_3 \beta - c_4 \right) e^{-c_5/\lambda_i} + c_6 \lambda \\ \frac{1}{\lambda_i} = \frac{1}{\lambda + c_7 \beta} - \frac{c_8}{\beta^3 + 1} \\ \lambda = \frac{\omega_r R}{v_w} \end{cases} \quad (1)$$

In the formula:  $\rho$  is the air density;  $r$  is the radius of the wind wheel;  $v_w$  is the current wind speed;  $c_p$  is the wind energy capture coefficient; and are called tip speed ratio and pitch angle respectively;  $c_1$ - $c_8$  represents the coefficients related to the characteristics of the fan;  $p_{nom}$  represents the rated capacity of the wind turbine.

Ignoring the mechanical energy loss caused by the change of fan speed, the energy supporting the inertia of the wind turbine comes from the kinetic energy stored in the fan blade during overspeed operation. The allowable speed range of the fan is  $0.7 \sim 1.2 p.u$  [4]. According to the wind speed, the operating state of the fan is divided into three intervals:  $d1 [v_{min}, v_{d1}]$ ,  $d2 [v_{d1}, v_{d2}]$ ,  $d3 [v_{d2}, v_{wn}]$ .

$$\begin{cases} v_{min} = \frac{\omega_{wmin} R_w}{\lambda_d} \\ v_{d1} = \frac{\omega_{wmin} R_w}{\lambda_{opt}} \\ v_{d2} = \frac{\omega_{wmax} R_w}{\lambda_d} \end{cases} \quad (2)$$

In the formula:  $w_{min}$  and  $w_{max}$  are the upper and lower limits of the speed of the wind turbine respectively;  $v_{min}$  is the initial wind speed of the wind turbine under load shedding operation;  $v_{d1}$  is the wind speed corresponding to the wind turbine reaching the MPPT point;  $v_{d2}$  is the maximum wind speed of the wind turbine under load shedding operation;  $v_{wn}$  is the rated wind speed;  $\lambda_{opt}$  is the optimal tip speed ratio of wind turbine. When the wind speed is located in the interval  $d1$  and  $d2$ , the wind turbine adopts overspeed control to slow down, thereby releasing the rotor kinetic energy;

when the wind speed is located in the interval d3, the wind turbine adopts overspeed control and pitch control to slow down, and further releases kinetic energy until the rated wind speed. According to different wind speed ranges, the kinetic energy that can be released by wind turbines is:

$$E_k = \frac{1}{2} J \Delta \omega^2 = \begin{cases} \frac{1}{2} J \left( \frac{\lambda_d^2}{R_w^2} v_w^2 - \omega_{\min}^2 \right) & v_{\min} \leq v_w < v_{d1} \\ \frac{1}{2} J \left( \frac{\lambda_d^2 - \lambda_{opt}^2}{R_w^2} \right) v_w^2 & v_{d1} \leq v_w < v_{d2} \\ \frac{1}{2} J \left( \omega_{\max}^2 - \frac{\lambda_{opt}^2}{R_w^2} v_w^2 \right) & v_{d2} \leq v_w < v_{wn} \end{cases} \quad (3)$$

In the formula, the kinetic energy stored for the wind turbine is the inherent inertia of the wind turbine rotor. By analogy with the definition of the inertia time constant of the synchronous machine, the equivalent model is used to calculate the virtual inertia time constant of the wind farm in the integrated system, as follows:

$$\begin{cases} H_{k,t} = \frac{E_k(t)}{P_N} \\ H_{w,t} = \sum \frac{H_{k,t} \cdot P_N}{P_{wN}}, k \in K \end{cases} \quad (4)$$

Where  $H_{k,t}$  is the virtual inertia time constant of fan  $k$  at time  $t$ .  $P_{wN}$  is the installed capacity of the wind farm.  $H_{w,t}$  is the virtual inertia time constant of the wind farm at time  $t$ .

### 2.1.2 Inertia support of storage

The output power of photovoltaic power station is not stable due to the influence of light, temperature and so on. The equivalent inertia of the fixed photovoltaic power generation plate is zero. In order to make it also participate in frequency regulation, additional energy storage modules need to be configured. Considering the operating cost, the photovoltaic power station uses the maximum power output (MPPT) and adopts the integrated operation mode of light-storage to provide inertia support, and its inertia support ability can be equivalent to the energy storage power station. The inertia time constant of energy storage is 4s ~ 12s [5]. In the peak load period of the integrated system studied in this paper, the power shortage caused by the disconnection of the tie line has a great influence on the frequency stability of the system. Therefore, this paper regards the unplanned off-grid operation of the integrated system as the expected fault scenario, and sets the virtual inertia time constant of the energy storage to be proportional to the tie-line power, as shown in Equation:

$$H_{e,t} = H_{\min} + \frac{P_{tran,t}}{P_{\max tran}} (H_{\max} - H_{\min}) \quad (5)$$

In the formula:  $H_{e,t}$  is the virtual inertia time constant of the energy storage power station in  $t$  period;  $p_{tran,t}$  is the transmission power of tie line in  $t$  period;  $p_{\max tran}$  is the maximum transmission power of tie line;  $h_{\max}$  and  $H_{\min}$  are the upper and lower limits of the virtual inertia time constant of the energy storage station, respectively.

### 2.1.3 Demand side response

For the system demand side, this paper considers the load demand response (DR) operation characteristics when the interruptible load is connected. As shown in Figure 2, the dispatching center monitors the system frequency information in real time and uses the DR control module to set the threshold. If the load frequency reaches the threshold, the dispatch center issues an instruction to interrupt the load to participate in the system frequency modulation and obtain power feedback. The load demand response is determined by the preset ratio, the frequency change rate at the action threshold and the system virtual inertia time constant [6]. The workflow of demand side response is shown in figure 1.

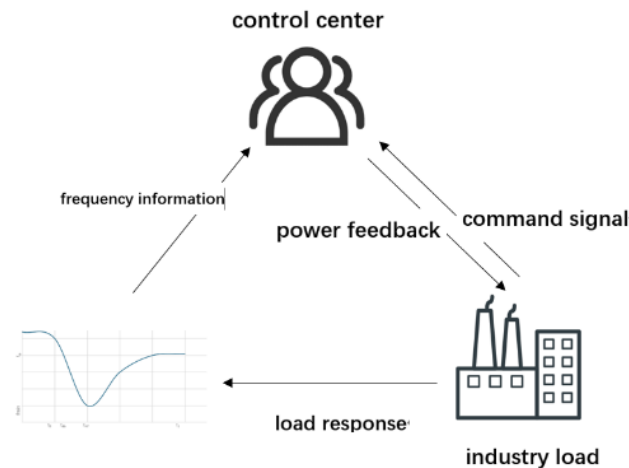


**Figure 1.** Workflow of demand side response

## 2.2. frequency response process

The frequency response process of the integrated system can be divided into two distinct phases, which are illustrated in the frequency response of the power system under disturbance conditions. Initially, when the power system experiences a loss of power due to external disturbances, it enters the inertia response phase during the  $t_0$  to  $t_{db}$  interval. During this phase, the inertia response alone contributes active power to the system. It is important to note that, due to the presence of a dead zone, the system's initial rate of frequency change is most pronounced at the moment the disturbance occurs. In the subsequent  $t_{db}$  to  $t_{NF}$  interval, the system receives active power through the combined effects of inertia response and primary frequency regulation. When the active power provided by primary frequency modulation equals the deficit caused by the disturbance, the system frequency reaches its lowest point, known as  $f_{nadir}$ . In the final phase,  $t_{NF}$  to  $t_1$ , the primary frequency modulation alone supports the system, gradually restoring the system frequency to a quasi-steady state, denoted as  $f_{ss}$ . Frequency response is shown in figure 2.

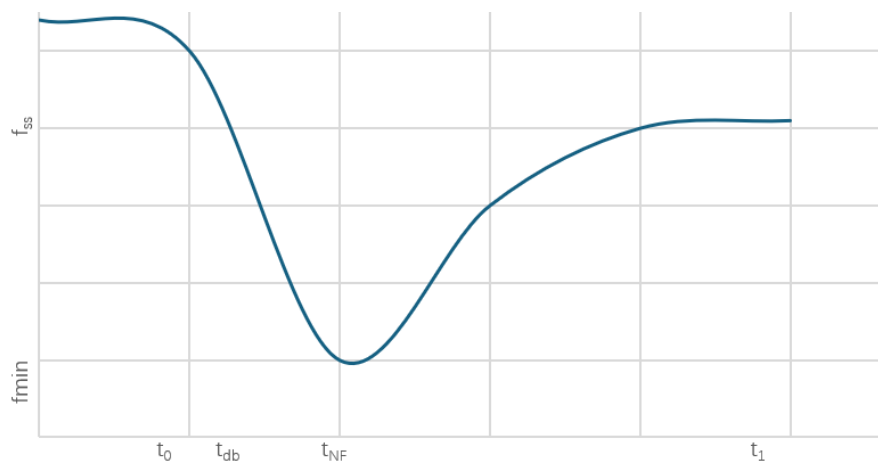


**Figure 2.** Frequency response

### 2.2.1 Grid-forming control strategy

Grid-connected technology is a new technology used to replace grid-connected technology in power system. Under the control of grid-connected inverter, distributed new energy systems such as solar energy and wind energy form local small power grids [7]. This ability to form an independent network represents that the grid-connected technology is essentially a voltage source. It can not only rely on the independent operation of new energy stations, but also be integrated into the main grid for grid-connected operation.

The frequency response of a power system can be categorized into three components: generation, storage, and load. For the 'generation' and 'storage' aspects, the output power of the grid inverter can

be modulated to react to system frequency variations by implementing specific control strategies within the inverter. Regarding 'load,' the primary considerations include load demand response and the implementation of active load shedding measures.

### 2.2.2 Inertia requirements of integrated system

Considering the maximum frequency change rate requirement that the system needs to meet, in order to avoid triggering the relay protection action to cause the system failure, the following formula needs to be satisfied:

$$E_{sys,t}^{\min} \geq \frac{|\Delta P_{loss,t}| f_0}{2RoCoF_{\max}} \quad (6)$$

In the formula:  $E_{min, sys, t}$  is the minimum inertia requirement of the system at time  $t$ ;  $p_{loss, t}$  is the expected disturbance at time  $t$ ;  $roCoF_{max}$  is the maximum frequency change rate that the system needs to meet [8].

## 2.3. Primary frequency modulation and limiting link

### 2.3.1 Grid-forming wind farm

In order to construct a grid-structured wind farm, we first need to obtain or simulate the motion equation of the approximate synchronous machine rotor. This can be achieved by applying virtual inertia control to the grid-connected inverter. The dynamic performance of the ideal virtual machine is exactly the same as that of the real unit.  $V_{sg}$  consists of three parts, which are the proportional link, the limiting link and the first-order inertia link [9]. The three are connected in series to form the frequency response model of the grid-connected wind farm.

The primary frequency modulation link composed of a proportional link and a first-order inertial link in series is:

$$\Delta P'_{F,i} = \begin{cases} 0 & \Delta f'_{F,i} < \Delta f_{db} \\ -\frac{K_{F,i}}{1+sT_{F,i}} (\Delta f'_{F,i} - \Delta f_{db}) & \Delta f'_{F,i} \geq \Delta f_{db} \end{cases} \quad (7)$$

Limiting link is:

$$\Delta P_{F,i} = \min(\Delta P'_{F,i}, P_{F,i,\max}) \quad (8)$$

### 2.3.2 Grid-forming power storage

The frequency response model of the grid-structured energy storage power station is also composed of the same three parts as the grid-structured wind farm station, namely the proportional link, the first-order inertia link and the limiting link. The proportional and first-order inertia are also connected in series to form a primary frequency modulation link expression as follows:

$$\Delta P'_E = \begin{cases} 0 & \Delta f < \Delta f_{db} \\ -\frac{K_{F,i}}{1+sT_{F,i}} (\Delta f - \Delta f_{db}) & \Delta f \geq \Delta f_{db} \end{cases} \quad (9)$$

Limiting link:

$$\Delta P_E = \min(\Delta P'_E, R_{ess}^{FFR}) \quad (10)$$

In the formula:  $P'_E$ ,  $K_E$  and  $T_E$  represent the output of the grid-structured energy storage power station through the first-order inertial link, the primary frequency modulation coefficient and the time constant of the first-order inertial link respectively;  $p_E$  and  $R_{FFR_{ess}}$  represent the actual output power and fast frequency response power of grid-structured energy storage participating in primary frequency modulation, respectively, which are determined by the steady-state output power and discharge rate of energy storage [10].

### 2.3.3 Load demand response

When the dispatching center monitors that the frequency reaches the action threshold, the system will automatically adjust the load according to the plan and participate in the system frequency modulation. The DR adjustment is as follows:

$$\Delta P_{DR,t} = \begin{cases} 0 & \Delta f < f_{DR} \\ K_{DR} \cdot R_O C_O F_t \cdot \frac{2H_t}{f_0} \big|_{t=t_{DR}} & \Delta f \geq f_{DR} \end{cases} \quad (11)$$

$$\Delta P_L = \min(\Delta P_{DR}, P_{L,\max}) \quad (12)$$

Active load shedding: When the frequency of the system is difficult to stabilize due to the large power of the tie line, the system can maintain the system frequency without exceeding the limit by removing a certain amount of load after the delay within the allowable range [11].

$$\Delta P_{cut,t} = \begin{cases} 0 & t < t_{cut} \\ \Delta P_{cut} & t \geq t_{cut}, P_{tran,t} > P_{cut} \end{cases} \quad (13)$$

### 2.4. Power smoothing control strategy

The motion equation of permanent magnet synchronous motor is:

$$T_w - T_e = J \frac{dw}{dt} + Dw \quad (14)$$

In the formula, J is the overall equivalent rotational inertia of the wind turbine and the permanent magnet synchronous motor, and D is the damping coefficient. The steady state operating point (SSOP) of the wind turbine is set as ( $\omega_0$ ,  $v_0$ ,  $P_{e0}$ ), and the small disturbance is adopted. In the dynamic analysis method, the equation is linearized at ( $\omega_0$ ,  $v_0$ ,  $P_{e0}$ ) and transformed by Laplace transform.

$$\Delta w = \frac{1}{Js + D} (\Delta T_w - \Delta T_e) = G_{w/\Delta T} (\Delta T_w - \Delta T_e) \quad (15)$$

The total differential of  $T_w$  and  $T_e$  at ( $\omega_0$ ,  $v_0$ ,  $P_{e0}$ ) can be obtained. Considering that the parameter optimization of the controller is not the focus of this paper, it is assumed that the parameters of each control link of the wind turbine are the optimal parameters, and the converter can respond to the change of the reference power in real time, that is, under the MPPT strategy, the electromagnetic power of the unit satisfies:

$$P_e = k_{opt} w^3 \quad (16)$$

The above equation is linearized to obtain the transfer function relationship between speed and power under MPPT strategy:

$$\Delta P_e = G_{P_e/w} \Delta w = k_{opt} w^3 - P_{e0} \quad (17)$$

In summary, the final wind turbine transfer function model is obtained. The smooth power command with real-time speed term is:

$$P_{hope} = (k_{opt} w_1^3 - P_{e0}) G_F(s) + P_{e0} \frac{1}{Ts + 1} \quad (18)$$

In this paper, the small disturbance modeling method is used to analyze the transmission power of the wind turbine. For the wind turbine, we usually need to determine the average wind speed  $v_0$  over a period of time. For the wind turbine, we define the angular velocity and electromagnetic power as  $\omega_0$  and  $P_{e0}$  during steady-state operation. In this paper, the above method is called AVG-SSOP (average of steady-state operating points) method [12]. However, due to the unpredictability of wind

speed in real life, it is unrealistic to predict the average wind speed of wind farm units for a period of time, so the application of AVG method will bring large errors to the system. In view of this, this paper proposes a method for selecting the steady-state operating point of wind turbines using the moving average algorithm, hereinafter referred to as the MAF-SSOP method.

### 3. Analysis and algorithm research

In this section, the detailed model and abstract transfer function model of wind turbine are established by using Simulink platform. Firstly, the sliding mean algorithm is introduced to smooth the real-time input wind speed, and the conclusion is proved under the MPPT control strategy:

The innovation of this method is as follows: Firstly, a new power instruction based on transfer function model is designed. The power instruction expression is simple and universal, and the decoupling adjustment of output power smoothness and power size is realized. The smoothing effect is further optimized by the selection method of steady-state operating point of wind turbine based on sliding mean filtering algorithm.

The mechanical power captured by the wind turbine is:

$$P_w = 0.5\rho\pi R^2 C_p v^3 \quad (19)$$

When the fan works at the steady-state operating point, the loss can be neglected. At this time, it can be considered that the captured wind power and the output electromagnetic power are equal, that is

$$P_w = P_e \quad (20)$$

From the relationship between pmsg electromagnetic torque and electromagnetic power:

$$P_e = \frac{T_e}{\omega} \quad (21)$$

The motion equation of permanent magnet synchronous motor is:

$$T_w - T_e = J \frac{d\omega}{dt} + D\omega \quad (22)$$

J is the overall equivalent moment of inertia of the wind turbine and permanent magnet synchronous motor, and D is the damping coefficient. The steady-state operating point of the wind turbine is  $(\omega_0, v_0, P_{e0})$ .

The small disturbance analysis method is used to linearize the motion equation at this point, and the Laplace transform is obtained:

$$\Delta\omega = \frac{1}{Js + D} (\Delta T_w - \Delta T_e) = G_{\omega/\Delta T} (\Delta T_w - \Delta T_e) \quad (23)$$

The total differential of  $T_w, T_e$  in  $(\omega_0, v_0, P_{e0})$  can be obtained:

$$\begin{cases} \Delta T_w = \frac{\partial T_w}{\partial \omega} \Big|_{(\omega_0, v_0)} \Delta\omega + \frac{\partial T_w}{\partial v} \Big|_{(\omega_0, v_0)} \Delta v \\ \quad = G_{T_w/\omega} \Delta\omega + G_{T_w/v} \Delta v \\ \Delta T_e = \frac{\partial T_e}{\partial \omega} \Big|_{(\omega_0, P_{e0})} \Delta\omega + \frac{\partial T_e}{\partial P_e} \Big|_{(\omega_0, P_{e0})} \Delta P_e \\ \quad = G_{T_e/\omega} \Delta\omega + G_{T_e/P_e} \Delta P_e \end{cases} \quad (24)$$

In this paper, the controller parameter optimization problem is not considered. All controller parameters are default to the optimal value. Under the MPPT control strategy, the pmsg output electromagnetic power can be expressed as:

$$P_e = k_{opt} \omega^3 \quad (25)$$

$$\Delta P_e = G_{P_e/\omega} \Delta \omega = k_{opt} \omega^3 - P_{e0} \quad (26)$$

Simultaneous transfer function model is obtained. Complement a transfer function is shown in figure 3.

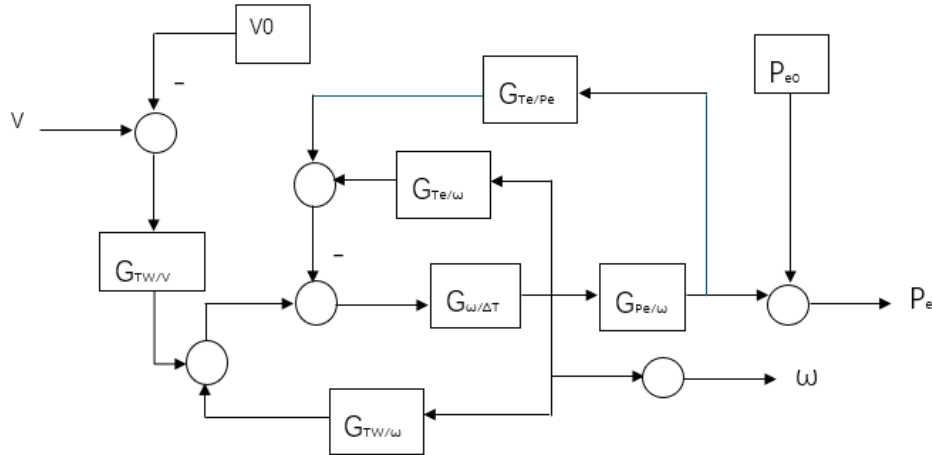


**Figure 3.** Complement a transfer function

The power smoothing strategy is to smooth the electromagnetic power output by Equation  $P_e = k_{opt} \omega^3$ , because the fan is in a stable operating state for a long time, the actual output electromagnetic power can be expressed as:  $P_{e0} = k_{opt} \omega_0^3$ , which is a constant. Without affecting the steady-state operating point  $(\omega_0, v_0, P_{e0})$  of the fan that needs to be satisfied in the previous derivation, a first-order filtering link  $\frac{1}{Ts + 1}$  is added to  $P_e$ . The power fluctuation after introducing GF (s) is as follow

$$\Delta P' = G_{P_e/\omega} G_F(s) \Delta \omega_1 \quad (27)$$

Let the ideal output power be

$$P_{hope} = P_e \frac{1}{Ts + 1} = \Delta P_e \frac{1}{Ts + 1} + P_{e0} \frac{1}{Ts + 1} \quad (28)$$

Smoothing with real-time speed terms the power instruction is

$$P_{hope} = (k_{opt} \omega_1^3 - P_{e0}) G_F(s) + P_{e0} \frac{1}{Ts + 1} \quad (29)$$

The above power instruction decomposes the output power into the characteristic power. The fluctuation of smoothness and the mean value of fluctuation representing the overall size of power. And realize the decoupling adjustment of the two, at the same time, compared with the direct to the most. The strong wind power is filtered as the power reference value, and the power command is with real-time speed feedback, the anti-disturbance ability is stronger.

## 4. Conclusion

Considering the growing prevalence of new energy transmission systems, this paper focuses on permanent magnet direct-drive wind turbines within the context of high-proportion new energy power systems. The study begins by analyzing and explaining the inertia support and primary frequency modulation processes in the frequency response of wind turbine systems, along with providing a method for calculating the inertia time constant. Addressing the coupling dynamics among power, speed, and wind speed transfer functions, the paper introduces a modeling and simulation approach

that combines an optimized power command with a sliding mean filter algorithm for wind turbines. The effectiveness of the proposed power smoothing strategy is validated through both simulation and experimental results. Additionally, the study explores the optimal configuration of energy storage systems, presenting an algorithm for their optimal configuration and demonstrating its effectiveness through practical examples.

## References

- [1] Li S, Zhu J, Dong H, et al. A novel rolling optimization strategy considering grid-connected power fluctuations smoothing for renewable energy microgrids. *Applied Energy*, 2022, 309: 118441.
- [2] Lunardi A, Normandia Lourenço L F, Munkhchuluun E, et al. Grid-connected power converters: An overview of control strategies for renewable energy. *Energies*, 2022, 15 (11): 4151.
- [3] Bharatee A, Ray P K, Ghosh A. A power management scheme for grid-connected PV integrated with hybrid energy storage system. *Journal of Modern Power Systems and Clean Energy*, 2021, 10 (4): 954-963.
- [4] Beltran H, Harrison S, Egea-Álvarez A, et al. Techno-economic assessment of energy storage technologies for inertia response and frequency support from wind farms. *Energies*, 2020, 13 (13): 3421.
- [5] Bera A, Chalamala B R, Byrne R H, et al. Sizing of energy storage for grid inertial support in presence of renewable energy. *IEEE Transactions on Power Systems*, 2021, 37 (5): 3769-3778.
- [6] Rinaldi A, Yilmaz S, Patel M K, et al. What adds more flexibility? An energy system analysis of storage, demand-side response, heating electrification, and distribution reinforcement. *Renewable and Sustainable Energy Reviews*, 2022, 167: 112696.
- [7] Zhang H, Xiang W, Lin W, et al. Grid forming converters in renewable energy sources dominated power grid: Control strategy, stability, application, and challenges. *Journal of modern power systems and clean energy*, 2021, 9 (6): 1239-1256.
- [8] Ratnam K S, Palanisamy K, Yang G. Future low-inertia power systems: Requirements, issues, and solutions-A review. *Renewable and Sustainable Energy Reviews*, 2020, 124: 109773.
- [9] Roscoe A, Knueppel T, Da Silva R, et al. Response of a grid forming wind farm to system events, and the impact of external and internal damping. *IET Renewable Power Generation*, 2020, 14 (19): 3908-3917.
- [10] Pishbahar H, Blaabjerg F, Saboori H. Emerging grid-forming power converters for renewable energy and storage resources integration—A review. *Sustainable Energy Technologies and Assessments*, 2023, 60: 103538.
- [11] Ma L, Li X, Kong X, et al. Optimal participation and cost allocation of shared energy storage considering customer directrix load demand response. *Journal of Energy Storage*, 2024, 81: 110404.
- [12] Tabosa da Silva P L, Rosas P A C, Castro J F C, et al. Power smoothing strategy for wind generation based on fuzzy control strategy with battery energy storage system. *Energies*, 2023, 16 (16): 6017.