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Sun, Peng; Teng, Yun; Leng, Ouyang; Chen, Zhe

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Stability Control Method for Hybrid AC-DC Transmission Systems Considering Cross-region Multi-energy Coordination

Peng Sun, Yun Teng, *Member, IEEE*, Ouyang Leng, and Zhe Chen, *Fellow, IEEE*

Abstract—China has built the largest hybrid AC-DC power systems with the highest voltage levels in the world. How to effectively guarantee the stable operation of the hybrid AC-DC power systems is a critical undertaking and technical demand. In view of the stability problems of hybrid AC-DC transmission systems with a high percentage of wind power, a hybrid AC-DC transmission system's stability control method that considers cross-region multi-energy coordination is established in this paper. Aiming at the uncertainty of a high percentage of wind power, the dynamic inversion method is used as the inner loop for robust control, and the battery energy storage and regenerative electric boiler are used as multiple energy sources to coordinate, and the outer loop robust control is used for uncertainty compensation. The hybrid AC-DC weak-sending terminal system with wind power is analyzed and designed by μ -synthesis based on the H_∞ control, and a stability control method for hybrid AC-DC transmission systems, considering cross-region multi-energy coordination, is established. Simulation results show that the model proposed in this paper can guarantee the robustness of the dynamic inversion method and improves the control performance of AC-DC transmission systems.

Index Terms—AC-DC transmission system, multi-energy coordination, robust control, uncertainty.

I. INTRODUCTION

HYBRID AC-DC power systems are a new form of power grid development, which have the characteristics of vulnerability, controllability, and cascading failures [1]–[3]. China has built the largest hybrid AC-DC power systems with the highest voltage levels in the world, and large-scale UHV (Ultra High Voltage) hybrid AC-DC power systems are in a period of rapid development [4]–[6]. However, the control nature of AC and DC systems is different, and the hybrid AC-DC power systems after fault have the characteristics of time-space non-linear and time-varying features [7]–[9]. The conventional AC system fault analysis method based on

Thevenin's equivalent circuit cannot effectively evaluate its transient process, and it's urgent to find a new method for transient stability control of hybrid AC-DC power systems.

Hybrid AC-DC power systems with a high percentage of renewable energy are accompanied by many uncertain parameter perturbations, such as wind power, load and other uncertainties. If transient faults occur at the same time, then the entire system may be unstable. This can cause severe challenges to the stability control of hybrid AC-DC transmission systems.

The stable control of hybrid AC-DC power systems is a crucial research field, and it is an effective requirement for the stable operation and sustainable use of energy [10]–[12]. Among them, the AC subsystem and the DC subsystem are interconnected through DC/AC converter stations, power electronic transformers and other types of equipment [13]. At present, scholars have made many researches on the stability control of AC subsystems or the stability control of DC subsystems [14]–[17]. Different from a single AC subsystem or a DC subsystem, the hybrid AC-DC power systems operate in a more complex mode, with strong non-linearity, time variability, and uncertainties [18], [19]. On the one hand, the interconnection of converter stations is critical when the system is grid-connected or isolated, and the equipment needs to keep the AC and DC subsystems working properly. On the other hand, under different operating modes, especially when the island is operating without the support of the distribution network, the converter station and the source network load and storage need to cooperate with each other to formulate an appropriate control strategy.

In recent years, scholars have gradually paid more attention to the safety and stability control of UHV power grids. A flexible voltage control strategy considering the high share of energy storage was proposed in [20] to improve the inertial response of the DC grid to the AC grid. The DC power modulation of a multi-machine hybrid AC-DC power system is designed in [21], [22] to improve the transient stability of the system. At present, research on the transient stability control of delivery systems with a high percentage of wind power access is in its infancy. The wind-fire power angle curve is used as the active crossover in [23], but the fast recovery characteristics of doubly-fed wind turbines are not conducive to the stability of the system's power angle. Wind power has advantages and disadvantages for AC-DC interconnection systems due to the uncertainty of wind-fire interaction [24],

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P. Sun, Y. Teng (corresponding author, e-mail: tengyun@sut.edu.cn) are with Shenyang University of Technology, Shenyang 110870, China.

O. Y Leng is with the State Grid East Inner Mongolia Economic Research Institute, Huhhot 010020, China.

Z. Chen is Department of Energy Technology, Aalborg University, Aalborg, Denmark.

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[25]. The current research rarely involves the transient stability optimization control of hybrid AC-DC power systems with weak transmitting end high power and high uncertainty wind power.

Hybrid AC-DC microgrids can meet both AC and DC load requirements, which are considered to be the preferred mode for future efficient development and utilization of distributed energy [26], [27]. A coordinated control strategy for bidirectional AC-DC converters in a hybrid microgrid in an island operational mode is proposed in [28], [29], but an energy management system was required to determine its operating mode based on the measured converter power value. To address the intrinsically stochastic availability of the high share of renewable energy in hybrid AC-DC microgrids, a novel power scheduling approach is introduced in [30], which involves the actual renewable energy as well as the energy traded with the main grid. A robust optimal power management system is developed in [31], [32] for a hybrid AC-DC micro-grid, where the power flow in the micro-grid is supervised based on solving an optimization problem.

This paper uses the actual project of hybrid AC-DC power systems to realize wind power transmission as an example, and then a stable control method of hybrid AC-DC power systems considering wind power uncertainty is proposed. In Section II, based on the structured and unstructured uncertainty characteristics of hybrid AC-DC transmission systems, a linear fractional transformation (LFT) model for uncertainty of hybrid AC-DC power systems is proposed. In Section III, the battery energy storage and regenerative electric boiler models are analyzed. In Section IV, the dynamic inversion method is used as the inner loop of robust control, the outer loop robust control compensation is performed for model uncertainty. Based on this, a hybrid AC-DC controller model based on dynamic inversion and H_∞ robust control is established. In Section V, the actual project of a weak transmission end of a hybrid AC-DC power system in Northeast China is taken as an example. Finally, Section VI summarizes the main conclusions of this paper.

II. UNCERTAINTY MODEL FOR AC-DC HYBRID SYSTEM

A. Structured Parameter Uncertainty

Errors in specific parameters in hybrid AC-DC power systems represent structured uncertainty. The parameters affecting the structural uncertainty for AC-DC hybrid systems are primarily manifested in wind power, load disturbance, AC line power oscillation, and DC line power oscillation. These four parameters are used as system uncertain parameters. In order to conduct μ -analysis, the standard of uncertain parameters δ is normalized into δ' :

$$\delta = \frac{\delta^+ + \delta^-}{2} + \frac{\delta^+ - \delta^-}{2} \delta' \quad (1)$$

where $\delta \in [\delta^-, \delta^+]$, $\delta' \in [-1, 1]$ are the uncertain parameters which are divided into two parts: the nominal part and the perturbed part.

B. Unstructured Uncertainty

The situation where the parameter perturbation and the actual structure between the systems are unknown is called unstructured uncertainty, and it can be divided into two types: additive and product. Assuming that the nominal parameter of the uncertainty variable is N and the error is Δ , and using the weighting terms W_1 , W_2 to measure the error term, then the uncertainty term can be expressed by $\Delta W_1 \Delta W_2$. In the new system, the additive uncertainty and product uncertainty are expressed as $\Pi = N + \Delta W_1 \Delta W_2$, $\Pi = (1 + \Delta W_1 \Delta W_2)N$, respectively.

C. LFT Uncertainty Modeling

Linear fractional transformation (LFT) of structural and non-structural uncertainties $\underline{\Delta}$ is performed in scalar and full form:

$$\underline{\Delta} = \text{diag}(\delta_1 I_{r_1}, \delta_2 I_{r_2}, \dots, \delta_s I_{r_s}, \Delta_1, \Delta_2, \dots, \Delta_F) \quad (2)$$

where, $\delta_i \in C$, $\Delta_j \in C^{m_j \times m_j}$, $1 \leq i \leq S$, $1 \leq j \leq F$. δ_i and Δ_j represent structural uncertain parameters and non-structural uncertainty blocks, respectively; r_i is the dimension of scalar uncertainty, and m_j is the dimension of full uncertainty. The LFT has two forms of upper LFT and lower LFT, and the corresponding calculation formula is:

$$F_u(M, \underline{\Delta}) = M_{22} + M_{21} \underline{\Delta} (I - M_{11} \underline{\Delta})^{-1} M_{12} \quad (3)$$

$$F_l(M, \underline{\Delta}) = M_{11} + M_{12} \underline{\Delta} (I - M_{22} \underline{\Delta})^{-1} M_{21} \quad (4)$$

$$M = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \quad (5)$$

where (3) is the upper LFT form, (4) is the lower LFT form, and M is the corresponding variable parameter of the system.

Uncertainty can generally be described by structural uncertain parameters, but at this time the parameter perturbation is linear. If the parameter perturbation is non-linear, it can be expressed as an m -degree order polynomial function $N(\delta) = a_0 + a_1 \delta + \dots + a_m \delta^m$ of δ . After ignoring the higher-order smaller terms of order 3 and above, set $\delta_1 = \delta$, $\delta_2 = \delta^2$, then $N(\delta) = F_l(X, \delta I)$, in this way, the non-linear part becomes linear. Where:

$$X = \begin{bmatrix} a_0 & a_1 & a_2 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \quad (6)$$

In addition, it is necessary to expand the terms related to the uncertain parameter $A_0 + \sum \delta_i A_i$ in the system, and ignore the higher-order terms in $B_0 + \sum \delta_i B_i$. The structured uncertainty can be expressed as:

$$\begin{aligned} \begin{bmatrix} x \\ y \end{bmatrix} &= \begin{bmatrix} A_0 + \sum_{i=1}^m \delta_i A_i & B_0 + \sum_{i=1}^m \delta_i B_i \\ C_0 + \sum_{i=1}^m \delta_i C_i & D_0 + \sum_{i=1}^m \delta_i D_i \end{bmatrix} \begin{bmatrix} x \\ u \end{bmatrix} \\ &= \left(\begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} + \sum_{i=1}^m \delta_i \begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} \right) \begin{bmatrix} x \\ u \end{bmatrix} \quad (7) \end{aligned}$$

If the uncertain term is used as the denominator, it can be transformed into a product form by fractional transformation.

The structured uncertain LFT model can be obtained by decomposing the perturbation matrices A_i , B_i , C_i , D_i . The standardization of unstructured uncertainty is the same as that in [33]. In this way, the LFT uncertainty model of the AC-DC hybrid transmission system is established.

III. MODEL OF BATTERY ENERGY STORAGE AND REGENERATIVE ELECTRIC BOILER

A. Battery Energy Storage

The state-of-charge (SOC) model of battery energy storage is defined as follows:

$$SOC(t) = [E_{BES}(t-1) + (\eta_{EI}P_{EI}(t) - P_{EO}(t)/\eta_{EO})\Delta t] / E_{BES,max} \quad (8)$$

where $E_{BES}(t)$ is the battery capacity at time t ; $P_{EI}(t)$ and $P_{EO}(t)$ are the battery storage power at time t ; η_{EI}, η_{EO} are the battery storage and discharge efficiency; Δt is the operational period. $E_{BES,max}$ is the total energy that can be stored in the battery.

B. Regenerative Electric Boiler

A regenerative electric boiler consists of an electric heating unit and heat storage unit:

$$\begin{cases} P_{EB,h}(t) = P_{EB,e}(t)\eta_{EB} \\ SOH(t) = [E_{EB}(t-1) + (P_{EB,h}(t) - P_{HO}/\eta_{HO})\Delta t] / E_{HS,max} \end{cases} \quad (9)$$

where $P_{EB,h}(t)$, $P_{EB,e}(t)$ are the power consumption and heating power of the electric boiler; η_{EB} is the electro-thermal conversion efficiency; $H_{EB}(t)$ is the heat storage capacity at time t ; $P_{HO}(t)$ is the heat release power at time t ; η_{HO} is heat release efficiency of heat storage. $SOH(t)$ is the state of heat of the regenerative electric boiler at time t . $E_{HS,max}$ is the total energy that can be stored by the regenerative electric boiler.

In the hybrid AC-DC transmission control system, the power of the battery energy storage and the regenerative electric boiler can be controlled according to the SOC of the battery energy storage and the SOH of the regenerative electric boiler, and the wind power fluctuation can be compensated.

IV. CONTROL STRATEGY AND CONTROLLER DESIGN

The LFT model of uncertainty is applied to the hybrid AC-DC control system. The controller uses a combination of inner loop dynamic inversion control and outer loop robust control to guarantee the stable operation and robustness of the system. The hybrid AC-DC control system designed in this paper is shown in Fig. 1. The inner loop is composed of a dynamic inversion fast loop and a hybrid AC-DC nonlinear model. The outer loop is a fast loop robust controller.

The dynamic inversion inner loop can cancel the nonlinear term of the model, so the closed loop system of the inner loop presents a linear system characteristic. The perturbed part primarily manifests as system uncertain parameters, structure perturbation and unmodeled errors. In order to directly avoid using the high-order controller brought by the H_∞ robust control, an outer-loop robust controller with a lower order and fixed structural parameters can be designed.

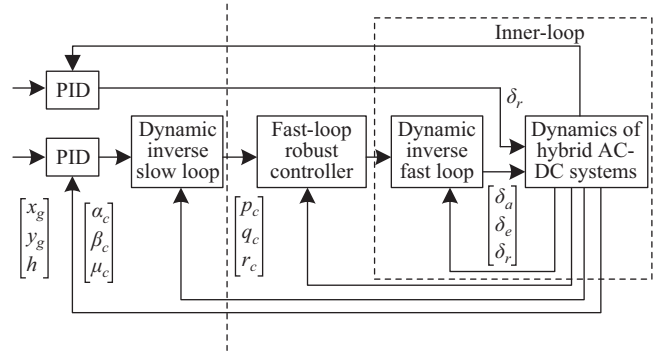


Fig. 1. Hybrid AC-DC transmission control system structure.

A. Nonlinear Dynamic Inversion Control Law-Inner Loop

The dynamic inversion method is a control method for decoupling the coupled quantities. In this paper, the nonlinear term is used for dynamic inversion design of the inner loop. The equation of state in the nonlinear equation of the hybrid AC-DC transmission system is:

$$\begin{cases} \dot{x} = f(x) + g(x)u \\ y = h(x) \end{cases} \quad (10)$$

where $x \in R^n$ is the state quantity of the hybrid AC-DC power systems, such as active and reactive power in each regional power grid, and the SOC of battery energy storage and SOH of regenerative electric boiler; $u \in R^p$ is the control quantity, which is the variable parameter of the control system such as the motor rotor speed, power angle and power of energy storage; $y \in R^m$ are the active and reactive outputs of the hybrid AC-DC transmission system. The dynamic inversion of the system can be obtained by taking the derivative of the output y until u appears in the result. Moreover, assuming that $g(x)$ is invertible for all values of x , the control law can be obtained by the algebraic inverse method to select the appropriate input u .

If $p = m$, the control law can be written as:

$$u = \left[\frac{\partial CV}{\partial x} g_m(x) \right]^{-1} \left[C\dot{V}_d - \frac{\partial CV}{\partial x} f_m(x) \right] \quad (11)$$

where g_m is a dynamic model; f_m is a control distribution function; $CV(x)$ and $C\dot{V}_d$ are a function of the state variable and a desired control command, respectively. If the hybrid AC-DC power systems model is accurate, then $g_m = g$, $f_m = f$. When $y = x$, i.e., when the output quantity is equal to the state quantity, $\dot{y} = \dot{x} = f(x) + g(x)u$, the closed loop becomes $\dot{y} = \dot{x} = C\dot{V}_d$. Set $C\dot{V}_d = K_c(x_c - x)$, x_c and K_c are the desired output and band bandwidth, respectively. The control inputs of the fast loop are:

$$\begin{bmatrix} \delta_a \\ \delta_e \\ \delta_r \end{bmatrix} = g^{-1}(x) \left(\begin{bmatrix} \dot{p}_d \\ \dot{q}_d \\ \dot{r}_d \end{bmatrix} - \begin{bmatrix} f_p(x) \\ f_q(x) \\ f_r(x) \end{bmatrix} \right) \quad (12)$$

where δ_a , δ_e , δ_r are 3 units of hybrid AC-DC transmission systems, AC section, DC section and energy storage.

B. H_∞ Control and NDI-outer Loop

The H_∞ control problem of a hybrid AC-DC system can be expressed as:

$$N = \begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix} = \begin{bmatrix} A & B_1 & B_2 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{bmatrix} \quad (13)$$

where N is the object of augmentation.

The fast loop closed loop is formed by the dynamic inversion method, the input is the power command of the hybrid AC-DC power system, and the output is the active and reactive output of each unit. In an ideal state, the object $G_{\text{inner-loop}}$ is a decoupling integral system in the form of a 3×3 matrix. It needs to be augmented into $N_{\text{outer-loop}}$ and added to the outer loop H_∞ control.

Figure 2 shows the outer loop of the control system and augmentation of uncertainty for hybrid AC-DC transmission systems. In this figure, r is the control command on the hybrid AC-DC transmission control system; n and d are noise and disturbance respectively; W_1, W_2, W_3 are third-order weight function matrices.

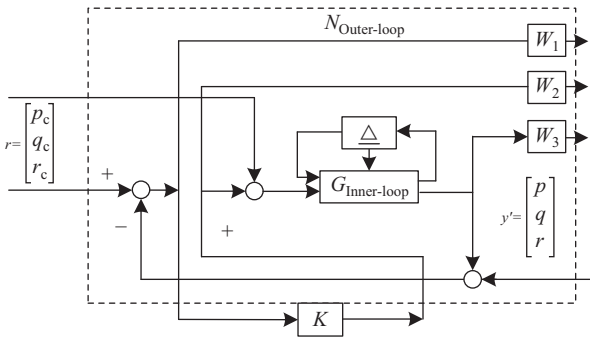


Fig. 2. Outer loop of the control system and augmentation of uncertainty for hybrid AC-DC transmission systems.

After adding the uncertainty to the augmented mode, the state space of $N_{\text{outer-loop}}$ can be expressed as:

$$N_{\text{outer-loop}} = \begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix} = \begin{bmatrix} A + \Delta A & B_1 & B_2 + \Delta B_2 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{bmatrix} \quad (14)$$

C. System Robust Stability and μ - H_∞ Controller

For general unstructured disturbances, stability can be achieved by H_∞ controller (such as loop forming H_∞ control), but for some elements with structured disturbances, it cannot be taken into account. The controller is conservative, and the stability and robustness of the system cannot be easily guaranteed with structural disturbances.

Zhou *et al.* [34] gave the internal stability conditions required by the control structure similar to Fig. 1, and transformed them into μ boundary value conditions to unify the robust stability and robust performance. It is pointed out that stability is not the only property that a closed-loop system must be robust to perturbation. When there is perturbation, the influence of interference on tracking and adjustment errors will be greatly enhanced. In most cases, long before instability

occurs, the closed-loop performance will deteriorate to an unacceptable level. Therefore, the worst-case parameter analysis of robust performance is also needed.

It is difficult to obtain the μ value according to the definition of μ value. The D-K iterative method [35] can be used to approximate the μ boundary of the system. Although the μ boundary obtained by this method is not accurate, it has greater value in practical applications.

According to the system model corresponding to the inner loop dynamic inversion method, its uncertainty includes 4 uncertain parameters $\delta_1, \delta_2, \delta_3, \delta_4$ with a dimension of 1×1 . There are two 3×3 non-structured uncertain blocks Δ_1 and Δ_2 at the input and output. Therefore, $\underline{\Delta} = \text{diag}(\delta_1, \delta_2, \dots, \delta_4, \Delta_1, \Delta_2)$. The H_∞ augmented uncertain system model has 12 inputs and 12 outputs, and the closed-loop feedback loops p, q, r form a 3×3 feedback matrix. Matlab's robust control toolbox provides a graphical user interface for μ calculations. After calling this interface for 5 iterations, the μ value is stable at about 0.91, which meets the condition of robust stability $\mu < 1$.

V. SIMULATION

Take the four-region hybrid AC-DC power system in Fig. 3 as an example for simulation. The equivalent load of the G2 grid is 1200 MW, and the equivalent loads of the three regional grids of G1, G3, and G4 are 2200 MW. The installed capacity of G2 is 2400 MW, including 1300 MW of wind power. The installed capacity of the G2, G3 and G4 regions is 1600 MW, 1600 MW and 1400 MW, respectively. Four regions have 300 MW of power storage and 200 MW of heat storage. Under the stable operating conditions of the rated parameters, the wind power transmitted by Line 1, Line 2 and Line 4 are: 500 MW, 400 MW and 400 MW, respectively. Table I shows some simulation system parameters.

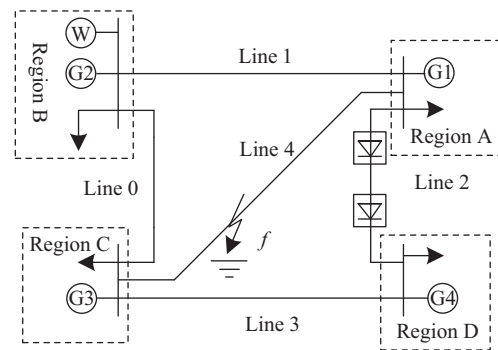


Fig. 3. Structure of hybrid AC-DC power system.

TABLE I
SIMULATION SYSTEM PARAMETERS

Parameter Type	Parameter settings
DC line power	1000 MW
Rated DC voltage	± 500 kV
Rated DC current	2 kA
AC line voltage	500 kV

A. Simulation Analysis of Response Characteristics of a Transient Stability Control Strategy

Figure 4 is a singular value curve diagram of the sensitivity function SF (a) and the complementary sensitivity function CSF (b) after taking into account the uncertainty factor of the hybrid AC-DC transmission control system by μ - H_∞ control. $SF = (I + N_{\text{outer-loop}}K_{\mu-H_\infty})^{-1}$, $CSF = N_{\text{outer-loop}}K_{\mu-H_\infty}(I + N_{\text{outer-loop}}K_{\mu-H_\infty})^{-1}$, the solid line represents the design state point, and the circle line represents the state point. It can be seen from the Fig. 4 that for the two state points of hybrid AC-DC hybrid systems, when the uncertainty perturbation is taken into account, show that the amplitude of SF in the low frequency band is small, thereby maintaining the system's anti-interference ability; and the amplitude decays quickly, which can maintain the uncertainty suppression ability of the system. The deviation of the amplitude of SF and CSF from the design state point has increased, but it is still within the allowable range.

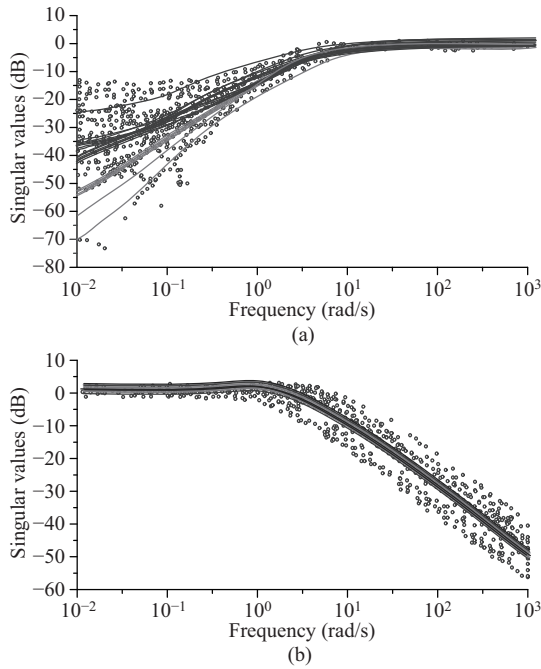


Fig. 4. Closed-loop singular values with uncertainty using μ - H_∞ controller. (a) SF curve of μ - H_∞ controller. (b) CSF curve of μ - H_∞ controller.

Figure 5 shows the singular value curve of the sensitivity function and the complementary sensitivity function when the system is in two state points, using the controller of [31]. Compared with Fig. 4, it can be seen that the controller of [31] has a certain stability for parameter perturbation. However, when the parameter changes greatly, the control effect of the μ - H_∞ controller designed in this paper is better than that of [31].

B. Transient Stability Control Strategy Response Characteristic Simulation Analysis

To verify the robustness of the control strategy, a 20% wind power output uncertainty is added when the system experiences large disturbances. The system power balance control response is shown in Fig. 6.

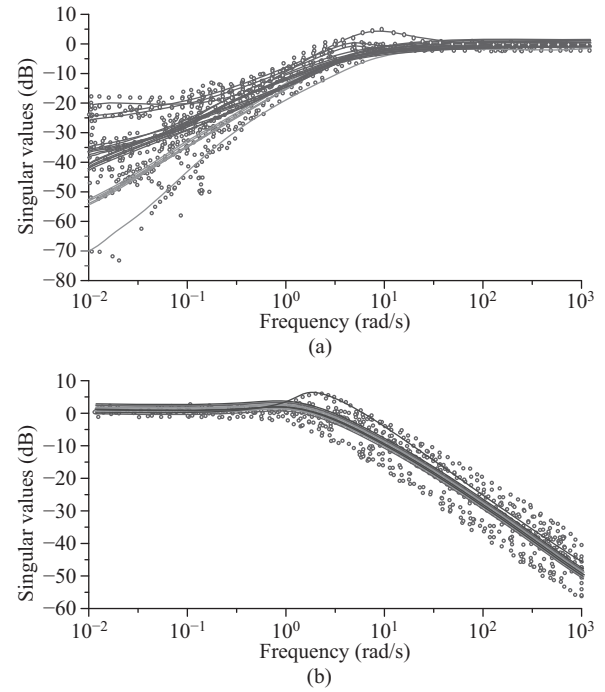


Fig. 5. Closed-loop singular values with uncertainty using μ - H_∞ controller. (a) SF curve of controller of [31]. (b) CSF curve of controller of [31].

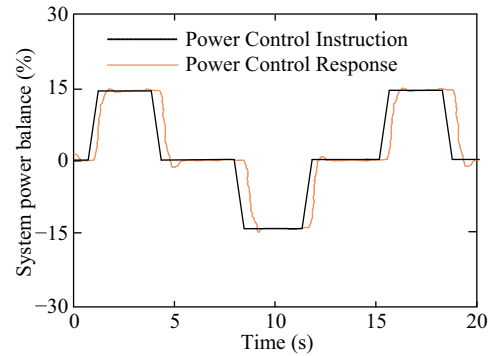


Fig. 6. Response of power control under wind power uncertainty.

It can be seen from Fig. 6 that when the power control command of the interconnected system is issued, the lag in the power response will cause a delay in the power response. Under the uncertainty of wind power, the response of the system can track the reference command very well. The adjustment time does not exceed 2s, which has good robustness and tracking performance.

C. Simulation Analysis of Transient Stability Control Performance of Interconnected Systems

In order to verify the control effect of the LFT robust control method, as compared with the robust controller of the full-order observer (FOO), the weight functions and controller order are set the same as the original system.

The initial state of the system is normal operation. A robust controller based on LFT and a robust controller based on FOO is added to the DC rectification side of the four-region interconnected power system [36]. Perturb the system at 0.6 s: A three-wire ground short circuit occurs at point f on the

AC contact line Line4, which lasts for 0.2 s, and the fault is removed at 0.8 s. The stability control of the transient process under disturbance is simulated and analyzed.

Assume that the power difference in the system during the fault is 8%. The uncertain parameters set in case 1 are 10%, and the uncertain parameters set in case 2 are 20%. Figs. 7 and 8 show the change trends of DC power and AC power of the hybrid AC-DC system in case 1 under the two robust controllers.

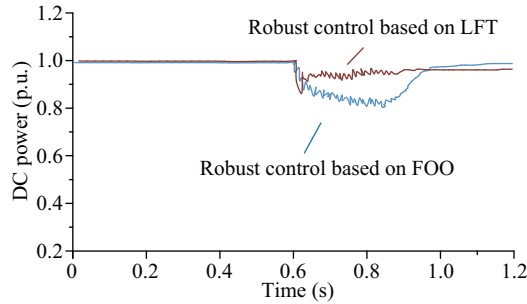


Fig. 7. DC Power Control in Transient Process (case 1).

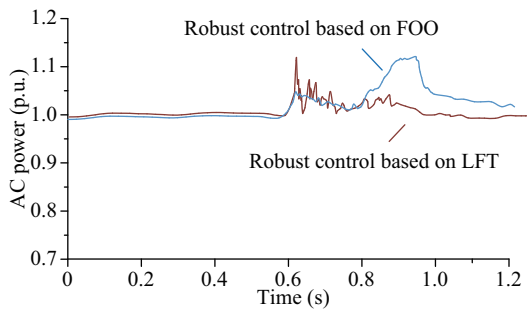


Fig. 8. Power Control of AC System during the transient process (case 1).

During the disturbance process, the communication lines between the grids in the G2 and G4 regions were cut out, and the DC communication lines operated independently. At this time, the outbound wind power from the regional grids G2 to G4 must be transferred to the DC line and other AC lines. Due to this fact, the power of the DC channel can't be increased rapidly, which will lead to a large increase in the power angle and frequency of the generator in the region 2 of the wind power transmission end. In severe cases, it will cause wind curtailment. If the stability control in the hybrid AC-DC power systems are uncoordinated, the frequency of the system will also deteriorate, and in severe cases it will cause the system to crash [37].

In order to verify the robustness of the system, the effect of the control strategy was tested for the worst case of the system (case 2, uncertainty 20%). The control effect of the proposed transient stability strategy is shown in Figs. 9 and 10. The comparison of voltage changes in the two scenarios is shown in Fig. 11.

The robust output feedback control method based on LFT established in this paper makes full use of the short-term overload capacity of the DC wind power transmission channel, and effectively suppresses the power fluctuation in the hybrid

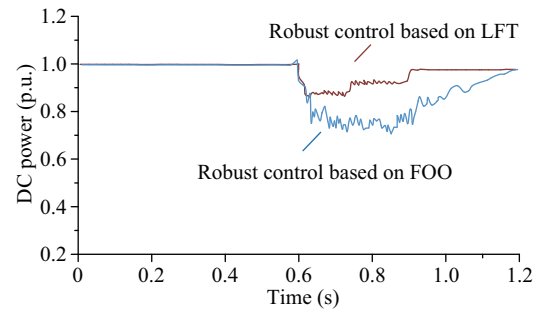


Fig. 9. DC Power Control in Transient Process (case 2).

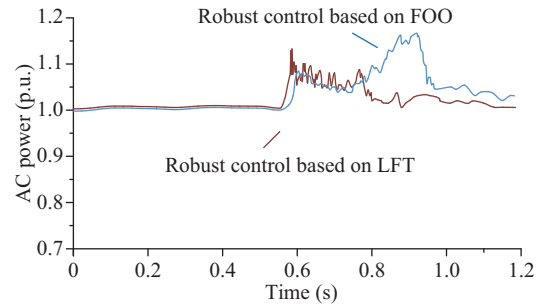


Fig. 10. Power Control of AC System During Transient Process (case 2).

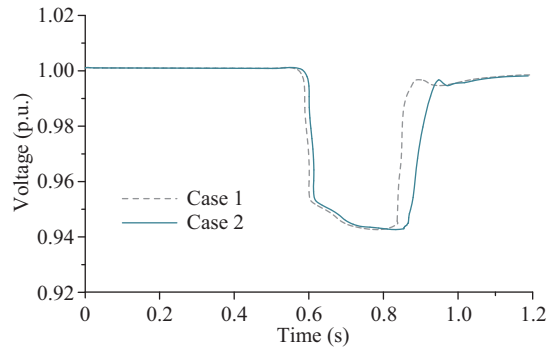


Fig. 11. AC voltage change in the transient process of two cases under LFT robust control.

AC-DC power systems. In this paper, the dynamic inversion is used as the inner loop, and the inner loop is used as the control object of the outer loop. The comprehensive model with linearization characteristics of the inner loop is subjected to LFT transformation to establish an uncertain model of the inner loop. By using μ synthesis and analysis, the μ - H_∞ controller design of the fast loop outer loop is designed. The robustness to the high share of wind power uncertainty and the performance of the transient suppression ability in the hybrid AC-DC power systems is able to achieve satisfactory results.

VI. CONCLUSION

In view of the problem of robust optimal control of hybrid AC-DC power systems consisting of multiple regional power grids and containing multiple energy sources, a transient stability control method for hybrid AC-DC transmission systems is proposed, which combines both dynamic inversion and robust control based on linear fractional transformation.

1) Based on the structured and unstructured uncertainty

characteristics of hybrid AC-DC transmission systems, a linear fractional transformation model for uncertainty for hybrid AC-DC transmission systems is proposed

2) For the linear fractional transformation state equation for hybrid AC-DC transmission systems, a controller model combining the dynamic inversion of transient stability control and H_∞ robust control is designed.

3) Taking an AC-DC transmission system composed of four regional equivalent grids as an example for simulation analysis, the results show that the control method proposed in this paper has a certain degree of robustness and a good suppression effect on transient processes.

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accommodation," *CSEE Journal of Power and Energy Systems*, vol. 3, no. 1, pp. 74–83, Mar. 2017.



Peng Sun is currently pursuing the Ph.D. degree at the school of Electrical Engineering, Shenyang University of Technology. His major research interest is multi-energy system optimization operation and control.



Yun Teng (M'18) received the Ph.D. degree in Electrical Engineering from Shenyang University of Technology, Shenyang, China, in 2009. He joined Shenyang University of Technology in 2010, where he is currently a Professor in Electrical Engineering. He is a standing director of the IEEE PES DC Distribution Network Technical Subcommittee. His research interests include multi-energy system dispatching automation and smart grid control theory.



Ouyang Leng received the Bachelor of Accounting degree from the North China Electric Power University, China, in 2009. She is currently working for the State Grid East Inner Mongolia Economic Research Institute. Her research interests include multi-energy system economic operation.



Zhe Chen (M'95–SM'98–F'19) received the B.Eng. and M.Sc. degrees from Northeast China Institute of Electric Power Engineering, Jilin City, China, and his Ph.D. degree from the University of Durham, Durham, U.K. He is a Full Professor with the Department of Energy Technology, Aalborg University, Aalborg, Denmark, where he is the leader of the Wind Power System Research program at the Department of Energy Technology. He is also the Danish Principle Investigator for Wind Energy of the Sino-Danish Center for Education and Research. His research areas are power systems, power electronics and electric machines; and his main current research interests are wind energy and modern power systems. He has led many research projects and has authored or coauthored more than 400 publications in his technical field.

Dr. Chen is a Fellow of the Institution of Engineering and Technology and a Chartered Engineer in the U.K. He is an editor of the *IEEE Transactions on Power Systems* and an associate editor of the *IEEE Transactions on Power Electronics*.