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Application of Soft-Constrained Differential Games Theory to Robust Load Frequency Control

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Abstract

The high penetration of renewable energy sources in power systems will deteriorate power quality and affect frequency stability. This issue is more severe in a small-capacity area or island power system that is weakly linked to the main grid. For the deviations of frequency and tie-line power exchange in power systems with multi-source generation units, we proposed a new robust control strategy based on linear quadratic soft-constrained differential games theory to reduce the influence from variations of wind farms output. The results of simulation testify its effect and robustness.

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Keywords: robust control strategy, differential games theory, load frequency control

1. Introduction

Renewable energy sources, such as the wind and solar power, are stochastic and intermittent. The high penetration of renewable energy sources in power systems will deteriorate power quality and affect frequency stability. It is important that deviations of system frequency and power exchange between areas should be regulated

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within certain standards. The large integration of wind power poses challenges to this task. This paper applies differential games theory to solve this problem, which can produce control strategies that are acceptable for different types of generation units. The effectiveness of proposed method is tested by the simulation based on a two-area interconnected power system.

Power systems contain different types of power sources generation units, such as coal, hydro, and gas. Load frequency control (LFC) is used for interconnected power systems which specific criteria under load disturbance. LFC aims to regulate deviations of frequency and scheduled tie-line power exchange. LFC studies should consider all these units. Optimal control theory (OCT) has been applied in LFC studies[1]. However, these studies consider only the situation of one type of unit in the control area. Differential games theory (DGT) provides an effective solution to such problem[2]. The results of OCT-based optimal tracking control theory (OTCT) are extended to the framework of linear quadratic DGT. The paper[3] uses similar techniques to enhance the robustness of control strategy based on linear quadratic soft-constrained differential games theory (LQSCDGT).

2. Tracking Control based on LQSCDGT

2.1. Linear Soft-constrained Differential Games Theory

The following equation describe a system with N players,

$$\dot{x}(t) = Ax(t) + \sum_{i=1}^{N} B_i u_i(t) + \Gamma w(t) \tag{1}$$

Where $x(t) \in R^{n\times 1}$ is a state vector, $w(t) \in R^{k\times 1}$ is a disturbance vector, $u(t) \in R^{m_i \times 1}$ is a control vector, the letter i on behalf of the player number. $A \in R^{n\times n}$, $B_i \in R^{n\times m_i}$ and $\Gamma \in R^{n\times k}$ are real matrices respectively.

The following type cost function is adopted for simplicity,

$$J_i = \int_{t_0}^{\infty} \left\{ x(t)^T Q_i x(t) + u_i(t)^T R_i u_i(t) - w(t)^T V_i w(t) \right\} dt \tag{2}$$

Where $Q_i \in R^{n\times n}$ is a symmetric matrix, $R_i \in R^{m_j \times m_j}$, $V_i \in R^{k\times k}$ are symmetric and positive definite matrices

The linear feedback control used by the *i*th player can be expressed as $u_i = F_i x$. Here, $F_i \in R^{m_i \times n}$, $(F_{1,} \cdots F_N)$ belongs to the set $F = \left\{ F = (F_1, ..., F_N) \,|\, A + \sum_i^N B_i F_i \ \ is\ stable \right\}$.

Theorem[4]: N real symmetric n×n matrices P_i and N real symmetric n×n matrices Y_i that satisfy the following conditions are assumed to exist,

$$(A - \sum_{j\neq i}^{N} S_j P_j)^T P_i + P_i (A - \sum_{j\neq i}^{N} S_j P_j) - P_i \left(S_i - M_i \right) P_i + Q_i = 0 \tag{3}$$

The expressions $A - \sum_{j=1}^{N} S_j P_j$ and $A - \sum_{j=1}^{N} S_j P_j + M_i P_i$ are stable.

$$(A - \sum_{j\neq i}^{N} S_j P_j)^T Y_i + Y_i (A - \sum_{j\neq i}^{N} S_j P_j) - Y_i S_i Y_i + Q_i \geq 0 \tag{4}$$

Where $S_i = B_i R_i^{-1} B_i^T$, $M_i = \Gamma V_i^{-1} \Gamma^T$. Define the N-tuple $F^* = (F_1^*, F_2^*, ..., F_N^*)$ *by*