A Characterization of All Retrofit Controllers

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Outline

1. Introduction

2. Retrofit Control
   - Definitions
   - Retrofit Controller
   - Performance Analysis

3. Numerical Example
   (Power System)
design of sub-controllers in a large-scale system

Traditionally Treated Difficulty:
- sparsity constraints/communication delay
- information constraints

Roughly, \( QI \iff \text{tractable (convex)} \) (quadratic invariance)

Remaining Issues
- scalability issue
- model unavailability
- existence of multiple operators

Scalability Issue

collectors are synthesized in a **centralized** manner under QI

_not scalable_ with the size of the plant

How to resolve this issue?
How to synthesize a controller with the access only to the partial model information?

consider a different situation

entire model: unavailable
partial model: available

- too large for modeling
- security of privacy

How to synthesize a controller with the access only to the partial model information?
Under Multiple Operators

suppose: multiple operators

other operators design independently

other’s control actions may vary

How to synthesize a controller that can deal with the possibly varying controllers?
Example: Power System

- multiple ISOs (independent system operator)
- too large to capture the entire system model
- other ISOs may change their control policy

Objective:

improve the control performance by attaching (retrofitting) a controller only with the partial model
Retrofit Control

Existing: entire system model

novel: local model information

Our proposal

retrofit control: improving local performance

today’s talk: necessary and sufficient structure for all retrofit controllers

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Definition: Retrofit Controller

case 1: $G_E$ is any element s.t. $G_P$ is stable

$G_P$: the interconnected system $(G, G_E)$

case 2: $G_E'$ is any element s.t. $G_P$ is stable

$K$ is called a retrofit controller if it stabilizes the system for any $G_E$ s.t. $G_P$ is stable
Equivalent Condition

\( \omega, \nu \): interconnection signals

\( Y, u \): measurement, control

**Theorem**

\[ K \text{ is a retrofit controller} \]

\[ \iff G_{wu} Q G_{yu} = 0 \]

and \( Q \in \mathcal{RH}_\infty \)

\[ Q = (I - KG_{yu})^{-1} K \]

\( G \): assumed to be stable
**Equivalent Condition**

\( \omega, \nu \): interconnection signals

\( y, u \): measurement, control

**Theorem**

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\( G \): assumed to be stable
Equivalent Condition

\[ \mathcal{W}, \mathcal{U} : \text{interconnection signals} \]
\[ \mathcal{Y}, \mathcal{U} : \text{measurement, control} \]

**Theorem**

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**Theorem**

\( K \) is a retrofit controller

\[ \Leftrightarrow G_{wu} Q G_{yu} = 0 \]

and \( Q \in \mathcal{RH}_\infty \)

\[ Q = (I - KG_{yu})^{-1} K \]

\( G \): assumed to be stable

constrained Youla parameterization

\[ Q_E G_{wu} Q G_{yu} \]

loop transfer matrix

because \( Q_E \): arbitrary

\[ G_{wu} Q G_{yu} = O \]
Two Classes of Retrofit

1. Output rectifying retrofit controller
   \[ Q G_{yv} = O \]

2. Input rectifying retrofit controller
   \[ G_{wu} Q = O \]

simple structure, easy to design
Output Rectifying Retrofit Controller

Assumption

\( Q G_{yv} = O \)

\( \mathcal{U} \) can be fed back

Theorem

All output rectifying retrofit controllers have the structure

\( \hat{K} : \) stabilizes \( G_{yu} \)

(locally stabilizing controller)
resultant control system

\[ K \text{ : output-rectifying retrofit controller} \]
both should be taken into account
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PV-Integrated
IEEJ EAST30 model
(The Institute of Electrical Engineers of Japan)

Fukushima
Parameters

- initial deviation at the 2\textsuperscript{nd} generator
- objective: suppressing peak value

PV: 30\% of total demand

\# of gen.: 30
whole dim.: 390
Results(1)

frequency deviation

free response peak: 0.0904 [Hz]

ignoring env. (infinite-bus)

destabilized
Results (2)

**frequency deviation**

- Free response peak: 0.0904 [Hz]
- Retrofit Control (low gain) peak: 0.0753 [Hz]

Stability is preserved

Improvement: 1.59 [dB]
Results (3)

**frequency deviation**

- **free response**
  - peak: 0.0904 [Hz]

- **Retrofit Control (high gain)**
  - peak: 0.0505 [Hz]

**improvement:** 5.06 [dB]
Conclusion

Problem:

novel control theory for large-scale systems

→ Retrofit Control
  - high effectiveness

Thank you for your kind attention