Efficiency Enhancement of a New Two-Motor Hybrid System

Naritomo Higuchi, Hiroo Shimada
Honda R&D Co., Ltd.
CONTENTS

1. Background
2. System Configuration
3. Operation Mode Transition
4. Control Technologies for Efficiency Enhancement
5. Result of Fuel Economy Enhancement
6. Conclusion
CONTENTS

1. Background
   - Conventional Hybrid Systems
   - Basic Concept of Efficiency Enhancement
2. System Configuration
3. Operation Mode Transition
4. Control Technologies for Efficiency Enhancement
5. Result of Fuel Economy Enhancement
6. Conclusion
### Conventional Hybrid Systems

#### Series Hybrid
- **Generator**
- **Motor**
- **Inverter**
- **Battery**

**Merit:**
- Engine operating points can be selected without any restriction related to vehicle speed

**Demerit:**
- Battery input/output loss
- Relatively large battery size

#### Parallel Hybrid
- **Motor**
- **Inverter**
- **Battery**

**Merit:**
- Smaller system size
- Light system weight

**Demerit:**
- Engine operating points are determined by vehicle speed and gear ratio

#### Series/Parallel Hybrid
- **Motor 1**
- **Motor 2**
- **Inverter**
- **Battery**

**Merit:**
- Restriction to select engine operating points is smaller than conventional transmission

**Demerit:**
- Complicated system configuration and control method

### Types of Transmission
- **100% Electric transmission**
- **100% Mechanical transmission**
- **Electric/Mechanical transmission ratio variable**
Basic Concept of Efficiency Enhancement

System efficiency during hybrid operation

- Developed System
- Previous situation
- Conventional two-motor hybrid system

Taking an advantage by enhancing electric efficiency

Electric transmission has an advantage

Electricity generation efficiency
Inverter efficiency
Motor efficiency
CONTENTS

1. Background
2. System Configuration
   - Block Diagram of Powertrain System
   - Operation modes
   - Power Train Overview
   - Overall system configuration
3. Operation Mode Transition
4. Control Technologies for Efficiency Enhancement
5. Result of Fuel Economy Enhancement
6. Conclusion
• Apply Series hybrid based system to enlarge electric transmission
• Battery acts as a power buffer to avoid charge-discharge loss
• Add a mechanical clutch to realize engine direct drive
### Operation Modes

<table>
<thead>
<tr>
<th>EV Drive</th>
<th>Hybrid Drive</th>
<th>Engine Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
<tr>
<td>Use electric energy stored in the battery to drive the motor</td>
<td>Use electric energy generated by the engine to drive the motor, with assistance or charging of the battery</td>
<td>Use engine output to directly drive the wheels, with assistance or charging of the battery</td>
</tr>
</tbody>
</table>

**Change three modes according to system efficiency**
Power Train Overview

- Engine output
- Engine drive clutch
- Power Control Unit (PCU)
- Atkinson Cycle Engine
- electric Coupled CVT (e-CVT)
- Engine Drive
- Hybrid Drive
- EV Drive/Regeneration

Switching engine and motor according to system efficiency
Equip the developed system with practical plug-in EV capability by installing a high capacity battery and an onboard charger.
CONTENTS

1. Background
2. System Configuration
3. Operation Mode Transition
   - Basic Mode Transition
   - Comparison of Power Management Control
4. Control Technologies for Efficiency Enhancement
5. Result of Fuel Economy Enhancement
6. Conclusion
Select suitable operation mode according to driving situation
If the vehicle is cruising, intermittent operation is selected to enhance thermal efficiency of the engine
Comparison of Power Management Control

Mode transition between CD and CS mode

- **CD MODE**
  - CD mode (Charge Depleting)
  - Engine Run
  - EV

- **CS MODE**
  - CS mode (Charge Sustaining)
  - Engine Run
  - EV

Adjust “EV Drive” area depending on battery SOC
CONTENTS

1. Background
2. System Configuration
3. Operation Mode Transition
4. Control Technologies for Efficiency Enhancement
   - Engine Output Adjustment
   - Intermittent Operation
   - Power Management
   - Voltage Amplification
5. Result of Fuel Economy Enhancement
6. Conclusion
Moving engine operating point toward the most efficient area by adjusting engine load.
Intermittent operation is effective if required power is lower than 15kW.
Power Management

- Discharge
- Charge
- Battery Input / Output Power
- Road load
- BSFC Bottom
- Engine Power
- Required Power
Voltage Amplification

- Move highly efficient area depending on required output
- Enhance the motor power without upsizing
CONTENTS

1. Background
2. System Configuration
3. Operation Mode Transition
4. Control Technologies for Efficiency Enhancement
5. Result of Fuel Economy Enhancement
   - Contributions to Fuel Economy Enhancement
   - Achieved Performance
6. Conclusion
Contributions to Fuel Economy Enhancement

Total fuel economy is enhanced approximately 70%
Achieve both high levels of fuel economy and driving performance

**Vehicle size vs MPGe**

- Orange dot: Plug-in HYBRID
- Pink dot: EV
- Red star: Developed system

**Acceleration time vs Fuel consumption**

- Green star: Developed system

---

**Achieved Performance (2014 Accord Plug-In)**

- Combined fuel consumption (MPG)
- 0-60mph acceleration time (sec)
CONTENTS

1. Background
2. System Configuration
3. Operation Mode Transition
4. Control Technologies for Efficiency Enhancement
5. Result of Fuel Economy Enhancement
6. Conclusion
• Reduction of CO2 emission is an urgent issue for the automobile industry.
• A new two-motor hybrid system named "i-MMD" (intelligent Multi-Mode Drive) was developed to maximize powertrain efficiency.
• As a result of installation on Accord Plug-In, following fuel consumption values are achieved.
  EV range: 13 mile
  Fuel economy: 115 MPGe (Charge depleting)
  46 MPG (Charge sustaining)