

### Background

- ❖ HEV technology combines electric and other drive systems such as an internal combustion engine or a fuel cell engine to reduce fuel consumption and increase the system efficiency
- ❖ During accelerations, if battery energy is not very low, the demand power is distributed between a FC engine and battery. If battery energy level is very low, then the demand power is supplied by the FC engine only. At the same time, the battery is charged by the FC engine power. During decelerations, regenerative braking energy is captured and stored in the battery

### Objectives

- ❑ To obtain the best system efficiency and fuel economy
- ❑ Methods
  - Sequential Quadratic Programming

Well developed optimization method, but time consuming

#### ➢ Rule Based Technique

Easy to implement; however, performance is not guaranteed

#### ➢ Fuzzy Rule Technique

Practical and robust; in contrast difficult to design fuzzy rules

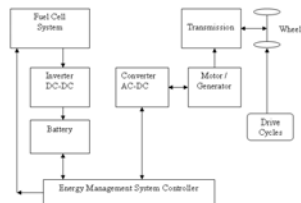


Figure 3 FCHEV simulation model

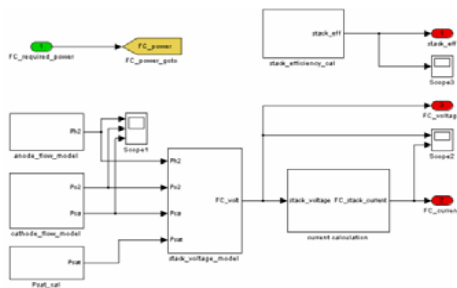


Figure 2 FC Stack simulation model

### Design of Energy Management System Controller

Two cases were studied:

- ❖ Obtaining the best system efficiency
- ❖ Running the FC engine in the best efficient area



Figure 3 Energy management controller model

### Problem Formulation

$$\text{Objective Function: } f = \frac{x_1}{\eta_{fc}(x_1)} + \frac{x_2}{\eta_{bat}(x_2)}$$

$x_1$  and  $x_2$  represent the FC engine power and the battery power respectively.

Subject to:

$$P_{fc} + P_{bat} = P_{demand}$$

$$0 \leq P_{fc} \leq P_{fc,max}, \text{ inequality constraints for the FC engine power}$$

$$0 \leq P_{bat} \leq P_{bat,max}, \text{ inequality constraints for the battery power}$$

$$SOC_{min} \leq SOC \leq SOC_{max}, \text{ SOC lower and upper limits}$$

$$P_{bat,max}(SOC) \leq P_{bat} \leq P_{bat,max}(SOC), \text{ the battery power depends on SOC}$$

level.

### Computer Simulation

Simulation results for EPA city drive cycle (CDC) are presented below using the proposed three methods

- Mathematical optimization method (SQP)
- Rule-based method
- Fuzzy rule-based method

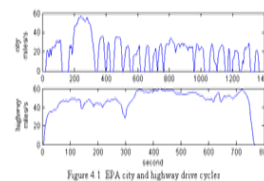


Figure 4 EPA city and highway drive cycles

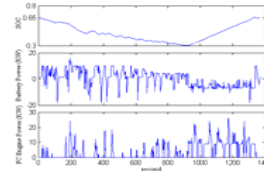


Figure 7 The fuzzy rule technique simulation results in CDC

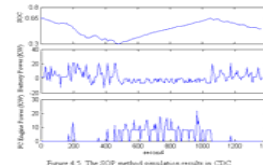


Figure 5 The SQP method simulation results in CDC

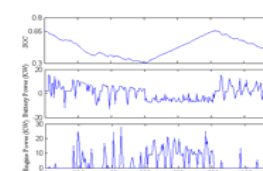


Figure 6 The rule-based technique simulation results in CDC

### Simulation Results

Running the FC engine in the best efficient area did not affect the fuel economy and the system efficiency in overall drive cycles. However, it affected the maximum FC engine power. For the components sizing studies, this strategy plays a significant role

Table 4.1 Fuel economy and the system efficiency comparison I

Drive Cycle	Controller Tech	Efficiency (%)	Fuel Economy(mpg)
City	Rule Based	50	67
	Fuzzy Logic	54	71
	Optimization	61	81
Highway	Rule Based	52	77
	Fuzzy Logic	54	83
	Optimization	59	97
City/Highway	Rule Based	50	71
	Fuzzy Logic	54	78
	Optimization	60	91

Table 4.2 Fuel economy and the system efficiency comparison II

Drive Cycle	Controller Tech	Efficiency (%)	Fuel Economy (mpg)
City	Rule Based	49	65
	Fuzzy Logic	53	70
	Optimization	60	80
Highway	Rule Based	46	70
	Fuzzy Logic	50	80
	Optimization	59	96
City/Highway	Rule Based	48	69
	Fuzzy Logic	52	76
	Optimization	60	89

### Conclusion

- ✓ Using battery energy in a wide range increased the fuel economy
- ✓ Optimization method gave impressive results. In addition, the fuzzy rule technique's algorithm provided satisfactory results
- ✓ Modification reduced the FC engine power values

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