Chapter 7 Automotive Applications

7.1 System Configurations of Hybrid Electric Vehicles

- Series Hybrid
- Parallel Hybrid
- Prius Hybrid System
  ✓ System Configuration
  ✓ Operation Modes
  ✓ Specs

Q: Compare the two hybrid systems.

Example:

1. Design a main circuit that accomplishes the inverter functions described and used in Prius.
2. Assume the battery with a nominal voltage of 274 is directly feeding the inverter, determine MG2’s rated voltage.
3. MG2 is rated at 40 HP at 940 ~ 2000 rpm. Calculate the rated ac current for the rated voltage obtained in 2. Determine the average charge current to the battery during a full-power regenerative braking.
4. Assume the vehicle is traveling at 100 km/h with a total weight of 1,500 kg, calculate the total kinetic energy that can be regenerated.

7.2 Integrated Starter/Generator (ISG) Systems

- System Configuration
- Inverter Design
- Motor Control

Q: Power flow and control of the inverter? Inverter --> Rectifier?

7.3 Fuel Cell Vehicles

- System Configuration
- DC-DC converter and Its Design
Q: How to configure and control a bi-directional DC-DC converter?
Low-emission & high-fuel efficiency. TOYOTA hybrid system leading the way into the next generation.

Tackling the challenge for high fuel efficiency and low emissions

Prius - the mass-production gasoline hybrid car - already meets all of the various strict emission levels being proposed throughout the world, well ahead of the competition. What's more, through the use of the hybrid system, we have realized surpassing fuel efficiency and a massive reduction in CO2. The Prius can truly be acclaimed as "the clean and environmentally friendly car."

PRIUS = Clean and Environmentally Friendly Car

Emission Reduction Features

1. Vapor Reducing Fuel Tank System
We have developed a new fuel tank system that can dramatically reduce the amount of fuel vapor generated in the tank both when the vehicle is moving as well as when it is at a standstill. This system is the first one in the world to be used.

2. TOYOTA HC Adsorption Catalyst System
A new system has been adopted which adsorbs the HC that is emitted between the time the engine is cold-started and the catalytic converter is still cool and not yet activated, until the time the catalytic converter becomes active. After the catalytic converter has been activated, the HC disassociates little by little and is then purified.

3. Adoption of a thin-walled high-density cell catalytic converter
In order to reduce the amount of time taken until the catalytic converter is activated, we developed and adopted a catalytic chamber with a super thin ceramic wall. Also, high-density cells have been utilized as a measure to improve strength and increase contact area with exhaust gas. Through these measures we have been able to achieve a balance of purification efficiency and reliability.
TOYOTA Hybrid System (THS)

The Toyota hybrid system has two drive sources, one is the gasoline engine and the other, the AC motor. The power train system selects the best combination of the different characteristics of both depending on driving conditions. Also, through the adoption of a regenerative braking system, which recovers energy during deceleration and "idling stop" whereby the engine is stopped during idling, we have been able to provide for maximum energy conservation. This has resulted in a vastly superior fuel economy compared with that of gasoline A/T vehicles of the same displacement.

Gasoline engine + AC motor = Toyota Hybrid System (THS)

Tremendous improvement in fuel efficiency achieved!

Features of the System

1. Optimum distribution of drive sources
The most efficient engine operating zone is automatically selected by controlling the optimum distribution of the engine and motor drive energy sources.

2. Highly efficient engine
Adoption of a super fuel-efficient engine developed for use with THS. Its high expansion ratio cycle is achieved by applying the Atkinson cycle \(^{1}\) which obtains high thermal efficiency.

3. Reduced energy loss
The engine is automatically stopped when halting or descending a slope to reduce fuel consumption. \(^{2}\)
The kinetic energy that used to be lost through engine or foot braking is recovered by the regenerative braking system and used for recharging, thereby contributing to improved fuel efficiency.

\(^{1}\): Atkinson Cycle: Proposed by an English engineer named James Atkinson, this thermal cycle enables the compression stroke and the expansion stroke of the mechanism to be set independently of each other.

\(^{2}\): In some cases, the engine does not stop, depending on the air conditioner and HV battery (Hybrid Vehicle Battery) status.

System configuration

◆ 1NZ-FXE Engine
A newly-developed excellent fuel economy and highly efficient 1.5 liter, 1NZ-FXE gasoline engine.

◆ P111 HYBLID TRANAXLE
Fitted with built-in THS transaxle MG1 (Motor Generator No.1), MG2 (Motor Generator No.2), planetary gear and reduction gear for the hybrid system. These function to switch engine operation to MG2 assistance, HV battery charging and power generation for driving MG2.

◆ Inverter
This controls the current between MG1, MG2 and HV battery and converts DC to AC power.

◆ HV Battery
This supplies power to the motor at full load or on engine stopping and stores power recovered by regenerative braking. 228 nickel-metal hybrid batteries are connected in series to obtain a voltage of 274 VDC.
System operation

Starting and travelling at low speeds
When the engine efficiency is low such as when starting, traveling at low speeds or descending slopes, the fuel supply is reduced or the engine is stopped, permitting travel by MG2; however the engine may start under SOC (State Of Charge) of the HV battery.

Normal running
The engine energy is divided into two. One portion directly drives the wheels. The other portion drives MG1 and the power generated is used to drive both MG2 and wheels. The ratio of the two is controlled for maximum efficiency.

Full acceleration
In addition to the 2-way system for normal travelling, the drive power of MG2 is further supplemented by the power stored in the HV battery, resulting in powerful and smooth acceleration.

At deceleration or braking
The wheels drive MG2 which acts as the generator for regenerative power generation. The power recovered by generation is stored in the HV battery.

When the car is stopped
When the car is stopped, the engine comes to a stop under SOC(State Of Charge) of the HV battery. However, when it is necessary to run the air conditioner compressor, the engine will not stop.
During Battery Charging
When high load operation is continued, the engine does not stop to charge the battery even if the vehicle is stopped, in order to keep the battery charged to a given level. (when ignition switch is ON) However, the engine does not charge the battery when the lever is shifted into the "N" position.

The engine speed may also be increased during normal traveling in order to charge the battery.

1NZ-FXE Engine

The new Prius is fitted with a 1.5L gasoline engine which has been developed for use with the Toyota hybrid system. A mass of leading-edge technology has been implemented to achieve excellent fuel economy, low emissions, light weight, compactness, and low vibration and noise.

Outline of the 1NZ-FXE Engine

<table>
<thead>
<tr>
<th></th>
<th>1NZ-FXE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>(m³)</td>
</tr>
<tr>
<td>Type</td>
<td>DOHC 4 valves</td>
</tr>
<tr>
<td>Bore X Stroke</td>
<td>(mm) 75.0 X 84.7</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>13.0</td>
</tr>
<tr>
<td>Maximum output [kW/HP/rpm]</td>
<td>52(70)/4,500</td>
</tr>
<tr>
<td>Maximum torque [N·m/(b·fl)/rpm]</td>
<td>111(82)/4,200</td>
</tr>
<tr>
<td>Fuel</td>
<td>Gasoline</td>
</tr>
</tbody>
</table>

Engine performance curve

![Engine performance curve graph]
Chapter 8 Utility Applications

8.1 Reactive & Harmonic Compensation –Load Compensation

- Traditional Reactive Power/Current Definitions
- Non-active Power/Current Definitions (Article by Peng & Tolbert)
- Inverter Circuit to Implement a Compensator
  - Voltage-source PWM
  - Control schemes (Current control & PWM methods)
  - Design parameters (I, V, Vdc, Cdc, etc.)

Q: How to configure a 3-phase 4 wire compensator? What inverter configurations can be used?

8.2 Static Shunt Compensators: SVC & STATCOM –System-Level Compensation

- Why a power system needs reactive power compensation?
- SVC: TCR & TSC
- STATCOM: Multipulse (48-pulse) Inverter


Q: How to determine the required output voltage, \( V_o \), for an inverter to generate \( \pm Q \) Mvar reactive power into a power system?

\[
V = V \angle 0^\circ
\]

\[
\pm Q \text{ MVAr}
\]

\[
V_o = V_o \angle \alpha
\]

Inverter
8.3 Unified Power Flow Controller (UPFC)

―“Understanding FACTS” Chapter 8.

- UPFC Principle
- UPFC Implementation –Back-to-back voltage-source converters
- Independent Control of Real & Reactive Power Flow
- Control Structures

Q: Discuss the real and reactive power flow and relationship between the two back-to-back voltage-source converters (inverters).

8.4 DER Grid Interconnection

- DER Benefits and Challenges (DOE Strategic Plan)
- General System Configurations (GE DG Interconnection)
- Key Issues

**Vision**

Distributed Energy Resources (DER) have great potential for supplying low cost, clean electricity, and for making our grid more reliable and less susceptible to market vagaries. In the near term future, a user will be able to “plug in” an energy resource as easily as one “plugs in” to the world wide web today. DER will be controlled by local and distributed software agents that assess adequacy and security with only high level oversight from the central control authority. Distribution system and transmission grid reliability will actually be enhanced by higher levels of DER using power electronics to control and manage power flow.

**Benefits**

- DER will help to solve grid and distribution problems, not create them. They will supply all the services presently provided by large turbine generators, and more.
- DER will be provided in “plug and play” systems that can be easily interconnected, operated, and maintained.
- When combined with energy storage and power electronics, DER will be able to supply the extremely high reliability power needed for today’s computer processes.
- Contingencies will be sensed and responded to locally, reducing their impact.
- The systems will operate transparently and the DER owner will not need to be aware of the many control interactions that are handling his power transmission.
- Commercial and industrial facilities will have an economical method of ensuring the level of power delivery reliability that they need with a net reduction in emissions.
• Natural gas and other fuels control and distribution systems will be integrated with building heating and DER energy production to optimize fuel distribution and use.
• Power electronic devices, combined with energy storage, will control the power flow and manage disturbances in the grid and distribution system with an associated reduction in distribution system and grid infrastructure cost.

**Challenges**
Research is needed in the following enabling technologies:

• Combustion systems to improve efficiencies and lower emissions.
• Fuel processing and delivery systems to eliminate shortages and price excursions.
• Materials and manufacturing to reduce DER cost and improve lifetime.
• Energy storage – batteries, ultra capacitors, super conducting magnetic energy storage, dc buses to provide ride through capability.
• Power electronics circuits, devices, packaging, and materials to lower cost, improve reliability, and increase power and voltage levels.
• Power electronics interface designs that enable ancillary services from DER such as reactive power, frequency and voltage regulation.
• Low cost and reliable sensors, communications and control to allow widespread, in depth, system monitoring.
• Systems control architecture where distributed, intelligent agents report back to the central control authority to receive “upper level” management direction, but are capable of local, instantaneous control.

*Q: Design a main circuit and control block diagram of an interconnection system for fuel cell or photovoltaic power generation.*