

Performance Evolution of a One-motor Two-Clutch Parallel Full Hybrid System

Kayo Otokawa, Koichi Hayasaki, Tatsuo Abe, and Kenichiro Gunji
Nissan

ABSTRACT

This paper describes the performance evolution and key breakthroughs of the world's first one-motor two-clutch (1M2CL) parallel full hybrid system without a torque converter that was developed and implemented on a hybrid luxury sedan in November 2010.

The high potential of this hybrid system was brought out further to improve fuel economy without sacrificing acceleration performance. The resultant second generation of the 1M2CL parallel full hybrid system was applied to a hybrid premium sports sedan in August 2013. In order to improve these performance attributes, the following key technical measures were adopted:

1. Motor torque during the EV mode was increased to expand the EV drive region.
2. Maximum motor torque and battery power at engine startup were boosted to reduce the engine start time.
3. Integrated control of the motor and clutches was improved.
4. Mechanical efficiencies were improved for higher fuel economy.

Increasing the motor torque was an especially key technical measure for expanding the EV drive region and reducing the engine start time. That was achieved by confirming system durability based on extensive data obtained in public road testing. As a result, the motor torque in the EV mode and at engine start was increased by 20 Nm over that of the first-generation system. Owing to these breakthrough advances, both fuel economy and acceleration time was improved from the first-generation system to achieve the fastest acceleration of all vehicles in its category.

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INTRODUCTION

In November 2010, Nissan developed the world's first one-motor-two-clutch (1M2CL) parallel full hybrid system, which was adopted on a luxury sedan that was launched in the Japanese, United States, European and Chinese markets. An introduction to the technology was presented at the 2011 SAE Congress. This system has the following three advantages due to its simple and highly efficient architecture:

1. Lightweight and low cost
2. High efficiency and excellent fuel economy
3. Quick response and a direct acceleration feeling

This type of 1M2CL parallel full hybrid system was not mass produced for a long time because of the difficulty in assuring drivetrain smoothness. In order to switch the system's

operating mode frequently, two mechanical clutches have to be engaged or disengaged often. This issue was overcome by adopting both a fast charging/discharging lithium-ion battery with high output and a precise, high-speed motor control. Since the launch of the hybrid luxury sedan, other automotive companies have been adopting the same type of hybrid system. This 1M2CL parallel full hybrid system has created new excitement in the luxury sedan market.

In October 2011, Nissan announced a medium-term environmental action plan. One of the important targets of this plan is to expand a hybrid system to rear-wheel-drive vehicles. Under this plan, the high potential of the 1M2CL parallel full hybrid system was brought out to improve both fuel economy and acceleration performance. This second generation of the 1M2CL parallel full hybrid system was applied to a premium sports sedan that was launched in global markets.

1. FEATURES OF HYBRID SYSTEM

1-1. Architecture

The architecture of the second-generation hybrid system is basically the same as that of the first-generation system, as shown in [Figure 1](#) and [Figure 2](#). The 1M2CL parallel full hybrid system is composed of gasoline engine, one electric motor/generator, inverter, lithium-ion battery and two mechanical clutches. The motor can be used for several purposes—motor-only driving, engine assist, engine start, regeneration during coasting, and engine-based generation—owing to both the high-output, fast charging/discharging lithium-ion battery and the precise, high-speed motor control.

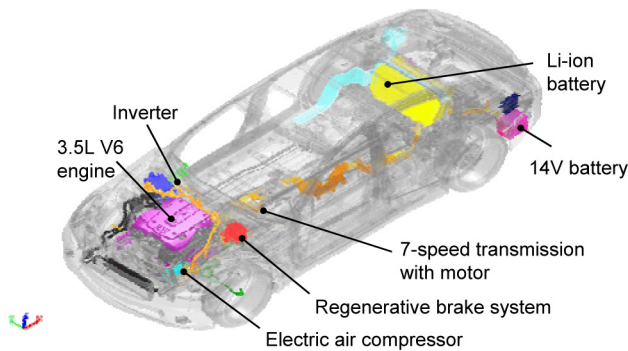


Figure 1. Architecture of hybrid vehicle

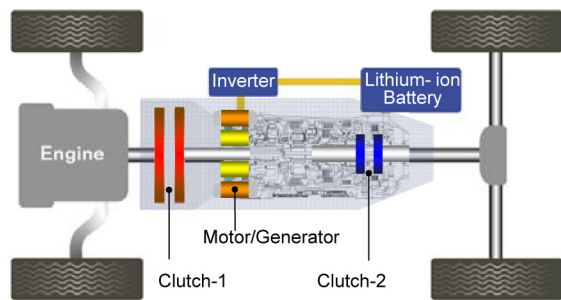


Figure 2. Overview of hybrid system

As shown in [Figure 3](#), the torque converter was removed from the transmission and a dry single-plate clutch (clutch-1) with a hydraulic actuator was positioned in its place to achieve both excellent fuel efficiency and a direct acceleration feeling. Owing to complete disconnection of the engine and the motor by clutch-1, the vehicle can be propelled by the motor alone and the region of EV driving has been expanded to even the high-speed range by the high-capacity battery. A wet multi-plate clutch (clutch-2) inside the 7-speed automatic transmission is used as a launching element instead of the torque converter. The vehicle is launched smoothly by allowing clutch-2 to slip at low speeds.

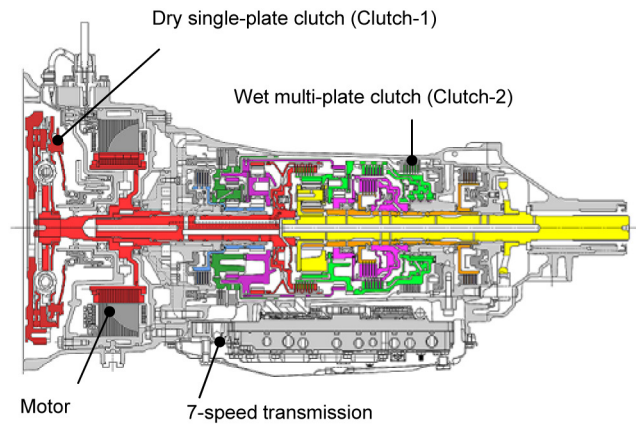


Figure 3. Overview of hybrid transmission

1-2. Comparison of 1M2CL Parallel Full Hybrid Systems

As mentioned previously, other automotive companies have adopted the same type of hybrid systems. [Figure 4](#) shows two other typical types of 1M2CL parallel full hybrid system in comparison with Nissan's system. Other hybrid systems have dedicated components, such as a side-mounted starter generator (SSG), a starter, a torque converter or an alternator (ALT), in order to start the engine, generate power, and absorb torque fluctuations at engine startup. In contrast, our system has only one motor that performs all these roles. This is the simplest and lightest system among the full hybrid varieties that provide motor-only driving. Though many other hybrid vehicles have been produced in the past few years, our parallel full hybrid vehicle fitted with the first-generation 1M2CL system still ranks near the top in both fuel economy and high acceleration performance.

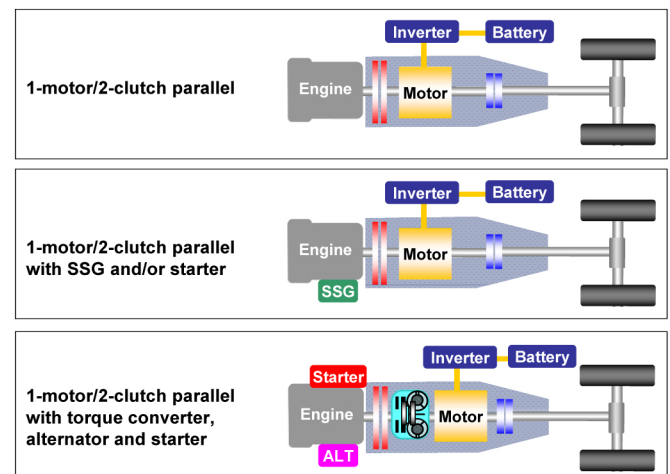


Figure 4. Comparison of 1M2CL parallel full hybrid systems

2. EVOLUTION OF HYBRID SYSTEM

Our concept for the evolution of the hybrid system was to construct the second-generation without changing the key hybrid components of the first-generation system so as to achieve maximal performance with minimal investments. Therefore, we aimed to bring out the full potential of the hybrid system in order to improve both fuel economy and acceleration performance for application to a premium sports sedan. The following are the breakthrough measures adopted for the evolution of each performance attribute.

For acceleration performance:

1. Boosting the maximum motor torque and battery power at engine startup for reducing the engine start time.
2. Improving the clutch-1 response.
3. Improving the integrated control of the motor and clutches.

For fuel economy:

1. Increasing the motor torque during the EV mode to expand the EV drive region.
2. Improving mechanical efficiencies.

The engine start time was reduced to improve its acceleration performance. The EV drive region was expanded and mechanical efficiencies were improved to increase fuel economy. The details of these measures are described in [section 3](#).

2-1. Specifications

[Table 1](#) shows the specifications of the key hybrid components of the second-generation system. Only the specifications of the starting engine power of the motor, the inverter, and the battery were changed from the first-generation system using the same components. However, these small specification changes contributed greatly to the following vehicle performance attributes. Boosting the maximum motor torque and battery power at engine startup contributed to reducing the engine start time and quickened acceleration time.

2-2. Improved Performance

The wide EV drive region is one of the advantages of this 1M2CL parallel full hybrid system, and expanding the EV drive region contributes to higher fuel economy. For the second-generation of the hybrid system, two specifications in particular were improved.

The first specification to be improved was to increase the maximum motor torque during the EV mode by 20 Nm (during driving from 120 Nm to 140 Nm; during regeneration from 200 Nm to 220 Nm). [Figure 5](#) shows the expanded EV drive region by increasing motor torque. This expansion was accomplished by confirming motor durability in relation to the 20 Nm increase in the motor torque as described in [section 3](#).

Table 1. Specification of key components

Item		Unit	Value (or Details)
Engine	Type	-	VQ35HR
	Max. Power	kW/rpm	225/6800
	Max. Torque	Nm/rp	350/5000
Motor	Type	-	Permanent magnet
	Max. Torque/Power	Nm/kW	270/50 *290 (during engine start)
Inverter	Max. AC current	Arms	*431
Battery	Type	-	Laminated Lithium-ion
	Voltage	V	346
	Capacity	kWh	1.4
	Number of cells	-	8 cells/module, 12 modules
	Max. Power	kW	50 *75 (during engine start)
Transmission	Gear ratios	-	4.783/3.103/1.9846/1.371 /1.0/0.871/0.776/3.859
	Final gear ratio	-	2.611

*Changed from the first-generation system

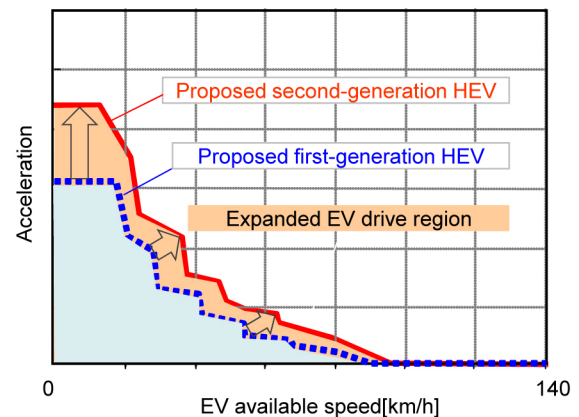


Figure 5. Expansion of EV drive region

The second was to adopt a control procedure that judges whether to start the engine, according to the driver's acceleration intention based on both the accelerator pedal angle (APA) and the rate of change in APA (Δ APA), as shown in [Figure 5](#). For example, when both APA and Δ APA are small, the system estimates that the driver has no intention to accelerate, so it chooses not to start the engine and continues to give priority to the EV drive mode. Owing to this control, the frequency of EV mode was increased. On the other hand, when both APA and Δ APA are large, the system chooses to start the engine, which contributes to improving the sense of acceleration.