

Truck Utility & Functionality in the GM 2-Mode Hybrid

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ABSTRACT

The present production General Motors 2-Mode Hybrid system for full-size SUVs and pickup trucks integrates truck utility functions with a full hybrid system. The 2-mode hybrid system incorporates two electro-mechanical power-split operating modes with four fixed-gear ratios. The combination provides fuel savings from electric assist, regenerative braking and low-speed electric vehicle operation. The combination of two power-split modes reduces the amount of mechanical power that is converted to electric power for continuously variable transmission operation, meeting the utility required for SUVs and trucks.

This paper describes how fuel economy functionality was blended with full-size truck utility functions. Truck functions described include: Manual Range Select, Cruise Control, 4WD-Low and continuous high load operation.

INTRODUCTION

The 2-Mode Hybrid system was originally designed for GM's Full-Size Truck family which includes the Tahoe SUV, as well as the Silverado pickup truck. The center of the 2-mode system is an EVT (Electrically Variable Transmission), which uses a pair of electric motors to choose nearly any ratio through the transmission. Though mechanically very different from the conventional Continuously Variable Transmission (CVT), the EVT allows ratio slewing like a CVT. Utilizing the electric motors in the transmission also allows hybrid functions such as: electric vehicle (EV) operation, electric

assist, regenerative braking, as well as engine starting. The 2-Mode Hybrid transmission is also an automatic transmission with conventional hydraulically-applied wet-plate clutches to allow automatic shifting among two continuously variable modes and four fixed gears. The system has a total of six mechanical configurations: EVT mode 1, EVT mode 2, and fixed gears 1, 2, 3, and 4. This combination is integrated into a package similar in size to a conventional automatic transmission, with added cables leading to electronic control modules and a high-voltage battery.

Considerable effort was expended in the 2-Mode system to develop class-leading fuel economy, while also maintaining the truck utility functions expected from a full-size SUV. Functions developed for fuel economy had to be balanced with those required for truck utility capabilities without sacrificing key vehicle characteristics.

The general specifications of the Tahoe 2-mode hybrid system are given in [Table 1](#).

<[table 1](#) here>

INTRODUCTION TO THE 2-MODE HYBRID SYSTEM

An EVT uses electric motors to control its speed ratio, enabling a continuous choice of transmission ratios. The input, output, and electric motors are connected to planetary gearing. In a set of planetary gears, the speed of a planet carrier is the weighted average of the speeds of its sun gear

Table 1. General specifications for the Tahoe 2-Mode hybrid SUV.

Engine	6.0L V8 with Active Fuel Management and Variable Valve Timing, 323 hp at 5100 rpm, 505 Nm at 4500 rpm.
Electric Drive Unit (Hybrid Transmission)	2-Mode EVT w/ 4 fixed-ratio gears.
Electric Motors	Two IPM (Interior Permanent Magnet) machines, 350 Nm peak, 60 kW from ~1700 to 12,000 rpm (nominal ratings).
Hybrid Battery	NiMH, 288V, 6.5 Ahr, 30 kW (nominal ratings).
Vehicle Mass	6000 lb (EPA Test Weight Class).
Vehicle GCVW	~ 12,000 lbs.

and its ring gear. In a given EVT mode, the speed of the transmission output is a weighted average of the speeds of the engine and each of the electric motors, as determined by the planetary gearing. Therefore, a vehicle equipped with an EVT can be driven by the electric motor with the engine at zero speed (transmission ratio of zero), or the engine can be spinning while connected to the output with the vehicle at zero speed (transmission ratio of infinity), or anywhere in between.

EVT MODE AND FIXED GEAR RANGE-SHIFT KINEMATICS

The 2-Mode Hybrid transmission cross-section is shown in [Figure 1](#). A schematic representation of this cross-section is shown in [Figure 2](#). This schematic can be represented as a lever diagram as shown in [Figure 3](#). This lever diagram can be further simplified for kinematic visualizations by combining the two levers representing the first two planetary gear sets as a single four-node lever as shown in [Figure 4](#) [1]. An example of this two-lever diagram for fixed Gear-2 operation is shown in [Figure 5](#). The relationship between transmission range (EVT modes, fixed gears) and clutch application is summarized in [Table 2](#).

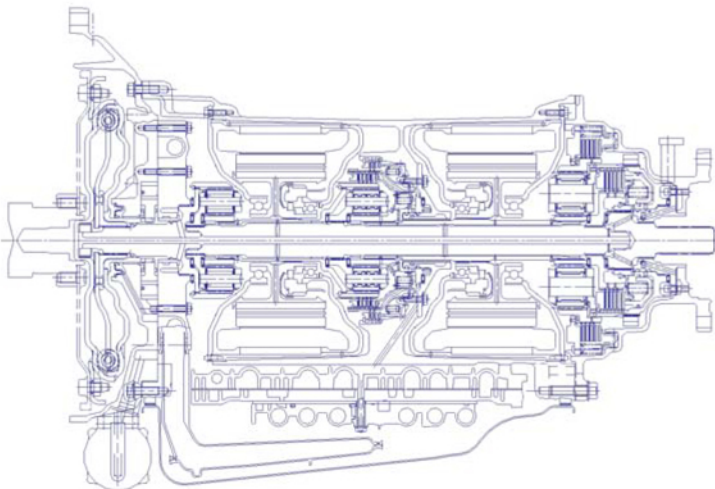


Figure 1. 2-Mode Hybrid transmission cross-section.

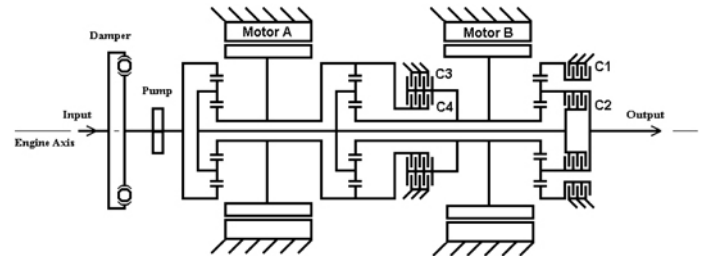


Figure 2. Schematic of 2-Mode Hybrid transmission cross-section.

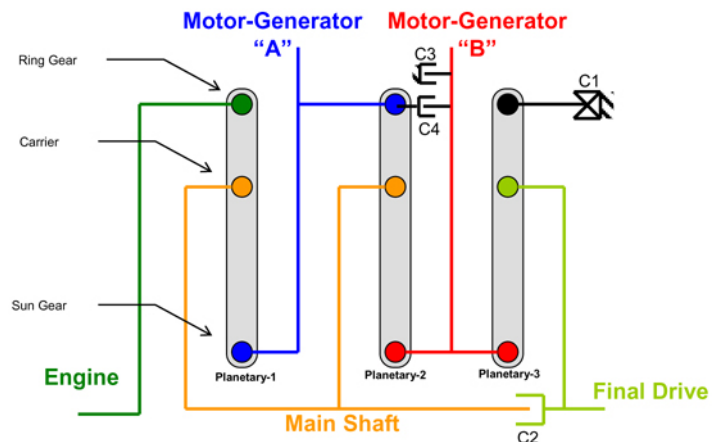


Figure 3. Lever diagram representation of the 2-Mode Hybrid transmission.

Table 2. Transmission Ratios and Clutch Application for Range States

Operation and Range State	Ratio	C1	C2	C3	C4
EV Launch and Drive mode, Engine stop-start in EVT Mode-1	Inf~1.70 : 1	x			
Launch with Engine Running in EVT Mode-1	Inf~1.70 : 1	x			
Fixed Gear-1	3.69 : 1	x			x
Fixed Gear-2	1.70 : 1	x	x		
EVT Mode-2	1.70~0.50 : 1		x		
Fixed Gear-3	1.00 : 1		x		x
Fixed Gear-4	0.74 : 1		x	x	

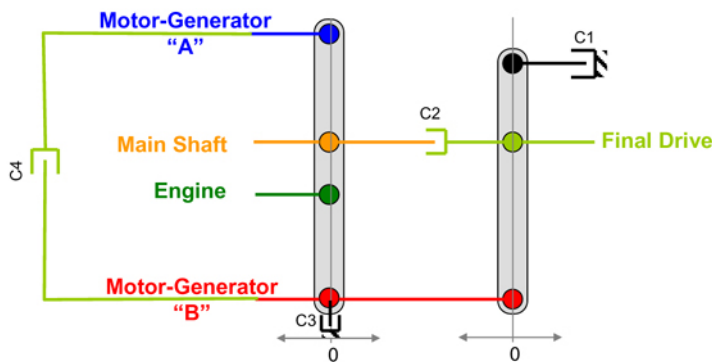


Figure 4. Simplified lever diagram representation of the 2-Mode Hybrid transmission. In this figure, the output speed, and the MG-A, MG-B and engine speeds are all zero.

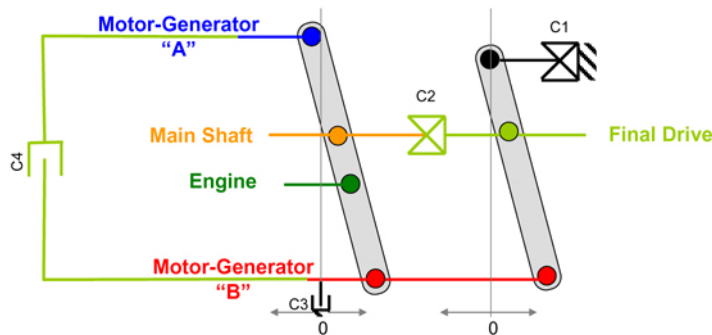


Figure 5. Simplified lever diagram representation of the 2-Mode Hybrid transmission showing Fixed Gear-2. In this figure, MG-A is rotating backwards, and MG-B is rotating forwards with the engine.

<table 2 here>

An example of a part-throttle acceleration event is shown in Figure 6a to illustrate the kinematics of the 2-Mode Hybrid system. A detailed dynamic analysis of the 2-Mode Hybrid is given in [2]. As the vehicle is gradually accelerated from 0-125 kph, the system undergoes six “range shifts,” demonstrating the usage of both EVT modes and the four fixed gears. The sequence of the range shifts is summarized in Table 3.

In the example shown in Figure 6a, the engine is idling with the vehicle at zero speed at the start of the trace, and the accelerator pedal is depressed at the 10-second mark. The vehicle is launched in Mode-1 (EVT-M1), where MG-B's speed rises with vehicle speed. At the same time, MG-A is used to optimize the engine speed. As the vehicle speed, and thus MG-B speed, rises to the range where Fixed Gear-1 (FG1) is available, if the real-time energy optimizer control system deems that FG1 would be advantageous, MG-A is used to synchronize the engine speed for FG1 to the MG-B speed. At this point (a), the two MG speeds and the engine speed are synchronous, and clutch C4 is applied, while clutch C1 continues to be applied.

At shift (b), the system shifts back to EVT-M1. To initiate this shift, the MGs are controlled to unload clutch C4, before its release. Once only C1 is applied, the MGs are used to control the engine speed to the optimal value for EVT-M1 operation.

At shift (c), the system shifts from EVT-M1 to Fixed Gear-2 (FG2). To execute this shift, the MGs are used to synchronize the planet-carrier speeds to apply C2. With only C1 applied, the transmission approaches the FG2 gear ratio of 1.70:1 before C2 is applied. (This range state is also illustrated in Figure 5.) Numerically, this is the ratio below which the higher speed Mode (EVT-M2) and the higher fixed gears (FG3 and FG4) take over.

At shift (d), the system shifts from FG2 to EVT-M2. First, the MGs are used to unload C1 before C1 is released. Once only C2 is applied, the MGs are used to control the engine speed to the optimal value for EVT-M2 operation. The ratios possible in EVT-M2 range from 1.70:1 to an overdrive value of approximately 0.50:1.

At shift (e), the system shifts from EVT-M2 to Fixed Gear-3 (FG3). The MGs are used to synchronize MG-A and MG-B to the engine speed for FG3 in order to apply C4. With C2 still applied, the transmission is in a fixed gear with a ratio of 1.00:1.

Finally, at shift (f), the system shifts from FG3 to Fixed Gear-4 (FG4). The MGs are used to unload C4 before C4 is released. Once only C2 is applied, the MGs control the

Table 3. Range states during acceleration shown in Figure 6a. Shifts (a) ~ (f) are also shown in Figure 6a.

Action	Shift Description
Mode-1 launch with Engine On	---
(a) Mode-1 to Gear-1 shift	Synchronize MG-A and engine RPM (for FG1) to MG-B speed, then apply C4. C1 still applied.
Gear-1 acceleration	---
(b) Gear-1 to Mode-1 shift	Unload C4, release C4. C1 still applied. MGs used to target optimal engine RPM.
Mode-1 acceleration	---
(c) Mode-1 to Gear-2 shift	Synchronize planet-carriers then apply C2. C1 still applied.
Gear-2 acceleration	---
(d) Gear-2 to Mode-2 shift	Unload C1, then release C1. C2 still applied. MGs used to target optimal engine RPM.
Mode-2 acceleration	---
(e) Mode-2 to Gear-3 shift	Synchronize MG-A and MG-B speeds to engine RPM (for FG3), then apply C4. C2 still applied.
Gear-3 acceleration	---
(f) Gear-3 to Gear-4 shift	Unload C4, then release C4. Electrically brake MG-B to 0 rpm, then apply C3. C2 still applied.
Gear-4 acceleration	---

engine speed to the FG4 value, and MG-B is electrically braked to a stop to enable C3 application. With C2 and C3 applied, the transmission is in fixed gear with an overdrive ratio of 0.74:1.

An example showing a gradual launch from engine-stopped EV drive is shown in Figure 6b. Since engine stop is only allowed in EVT-M1, the engine is initially refueled in EVT-M1, but to optimize fuel-on FE, the system shifts to EVT-M2 before resuming an acceleration schedule similar to that shown in Figure 6a.

<table 3 here>

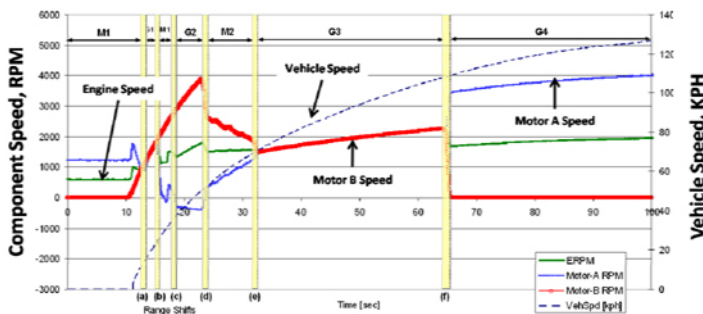


Figure 6a. An example of a gradual acceleration of a 2-Mode Hybrid starting from idle.

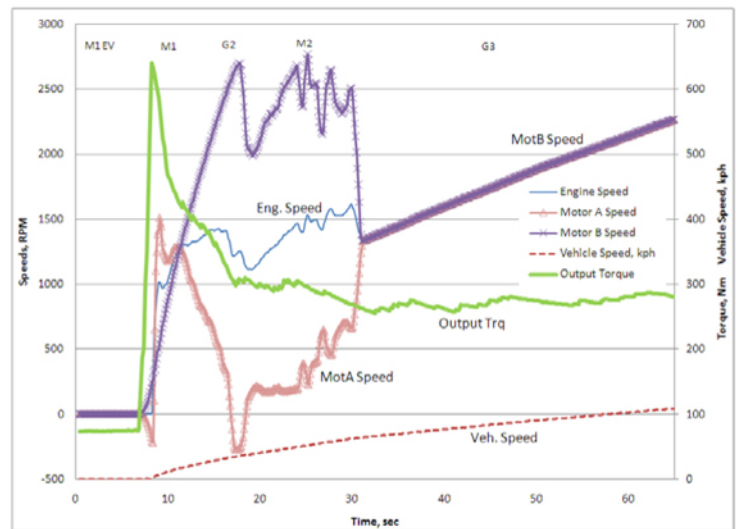


Figure 6b. An example of a gradual acceleration of a 2-Mode Hybrid starting from EV drive.

2-MODE HYBRID FUNCTIONALITY FOR FUEL ECONOMY

Fuel economy development was aggressively pursued via both vehicle and powertrain improvements. The following sections describe how truck utility characteristics were integrated with fuel economy functionality.

Vehicle improvements included:

- a. Aerodynamic improvements: Front air dam, rear spoiler, gap sealing, and lower ride height.
- b. Lower rolling resistance tires.