Gen 1 and 2 Volt Transmission Operating Modes Explained

Posted by **Jeff Cobb** in: General with 131 Comments

Share:

By Jeff N, Patrick Groeneveld and George Bower

Preface

This article is based on a GM patent US 8,602,938, issued in December 2013, and presentations by GM at an SAE vehicle electrification conference on February 11, 2015 in Los Angeles. The presentations by GM verify that the patent described here is indeed used as the basis for the next generation “Voltec” transmission. This may be the first article to describe the design of the new transmission in detail.

Introduction

Gen 2 Volt in Heather Gray

The new 2nd generation Volt transmission is truly a work of art. It increases vehicle acceleration and efficiency while lowering cost, weight and size. The new Voltec system retains the EREV (Extended Range Electric Vehicle) design philosophy in which it operates as an electric vehicle without starting the gasoline range extender due to speed or acceleration as long as usable energy remain in the battery pack. How is this done and how does this new transmission operate?

The new transmission now has an integrated inverter eliminating heavy current conducting cables and the separate inverter assembly that was used in the original design. While the transmission offers increased efficiency and more flexible operating modes it does this without significantly increasing the parts count. The new transmission has the same number of clutches as the original. Extended range operation now has 3 modes and EV operation has 2 modes where the original transmission had 2 extended range modes and 2 EV modes.

The use of so-called rare earth metals (often imported from China) has been eliminated in the smaller motor (48 kW) and reduced by 40% in the bigger motor (87 kW). In EV driving, GM can now additively link the 2 motors together so the total power is actually higher than the original Volt which allows the 2016 Volt to accelerate from 0-30 mph in a very aggressive 2.6 seconds. The Tesla Model S60 reportedly does 0-30 mph in 2.5 seconds. Each motor contributes using different gear ratios to optimize its unique power and torque characteristics. The overall weight of the transmission system has been reduced by 100 pounds or 45 kg (27%).

GM’s new linked motor configuration provides for a wider torque band which is referred to as “torque spread” by GM engineer Tim Grewe in the video at minutes 1:50.

The new transmission has 5 operating modes which are shown in figure 2.

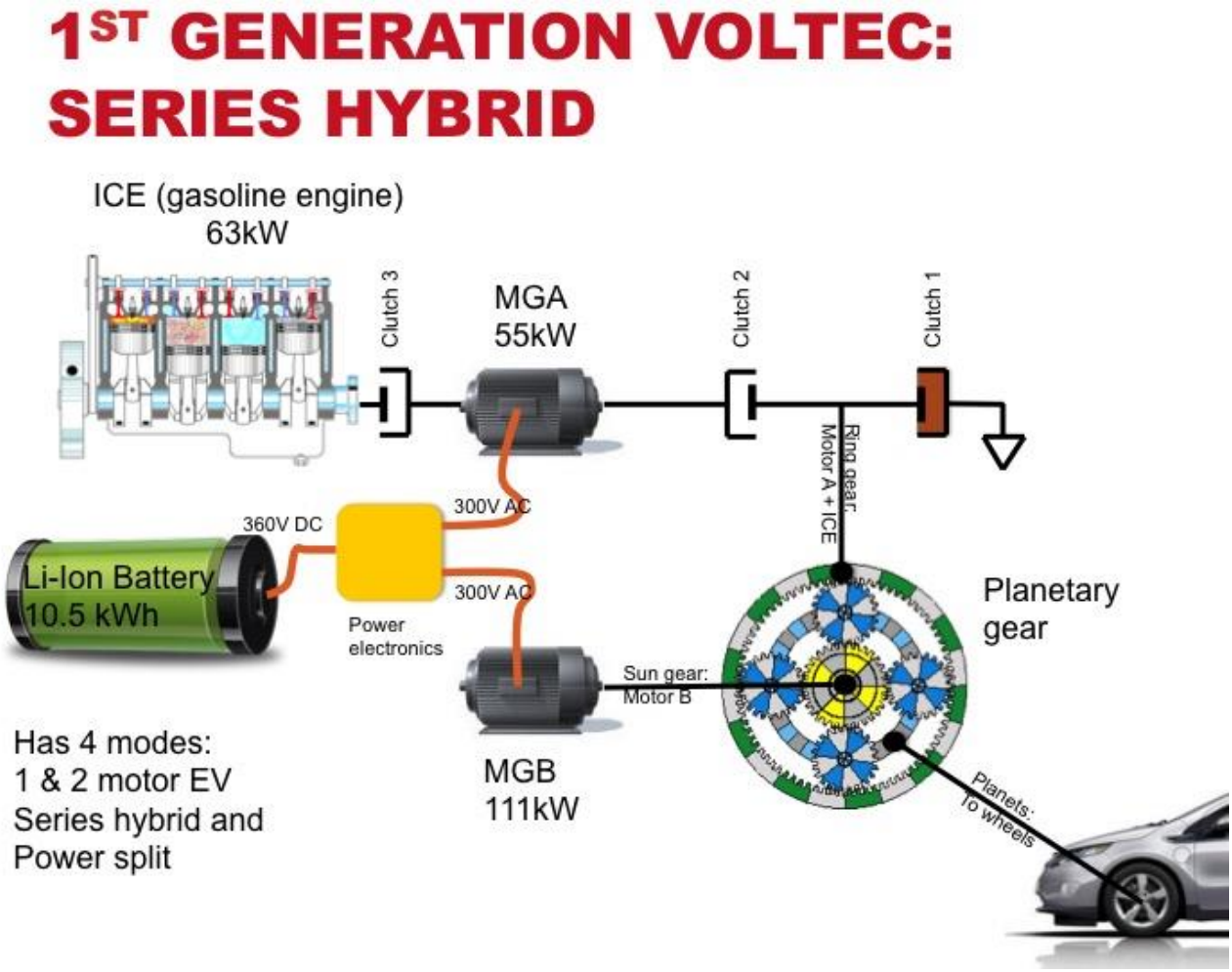
Gen 2 5ET50
5 Transmission Operating Modes

EV Mode	Extended Range Mode
-1 Motor EV	-Low Extended Range
-2 Motor EV	-Fixed Ratio Extended Range
	-High Extended range

5 operating modes listed

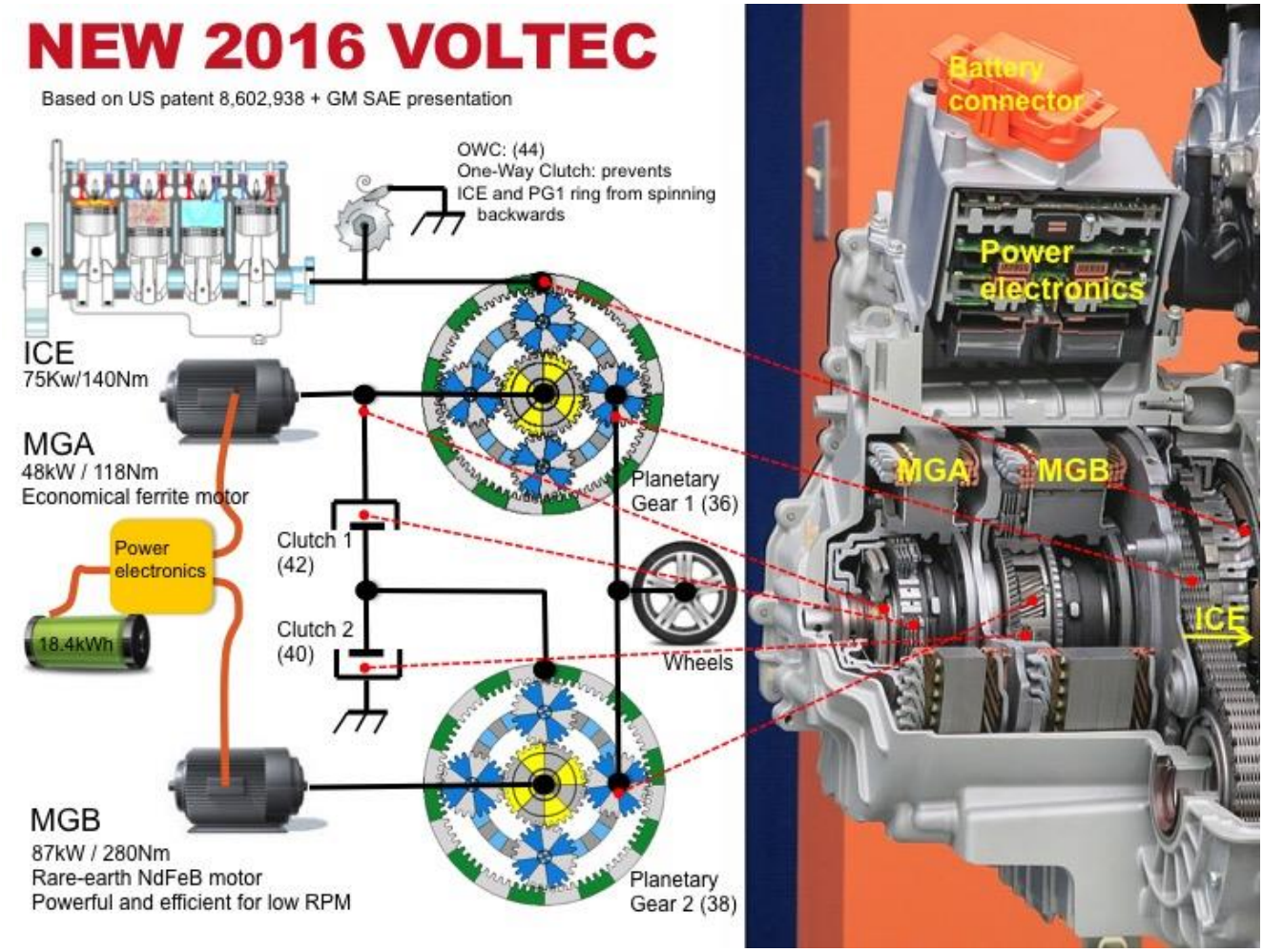
Detailed Description of Operating Modes

An overview of the new transmission is shown below. It shows 2 planetary gear sets where the original design used only 1. There are 3 clutches which are used to optimally reconfigure the power flow through the transmission at differ vehicle speeds and torque requirements (accelerator pedal position).
A simple planetary gear set consists of 3 geared components meshed together which have a fixed ratio to one another. A so-called Sun gear is in the middle and planetary gears connected to a common carrier plate rotate around it while also meshing with an outer ring with inward facing gear teeth.



In the original Voltec transmission, the large motor (111 kW) was connected to the Sun gear, the gasoline range extender and smaller motor (55 kW) was connected to the ring gear, and the planetary carrier was connected to the output leading to the wheels.

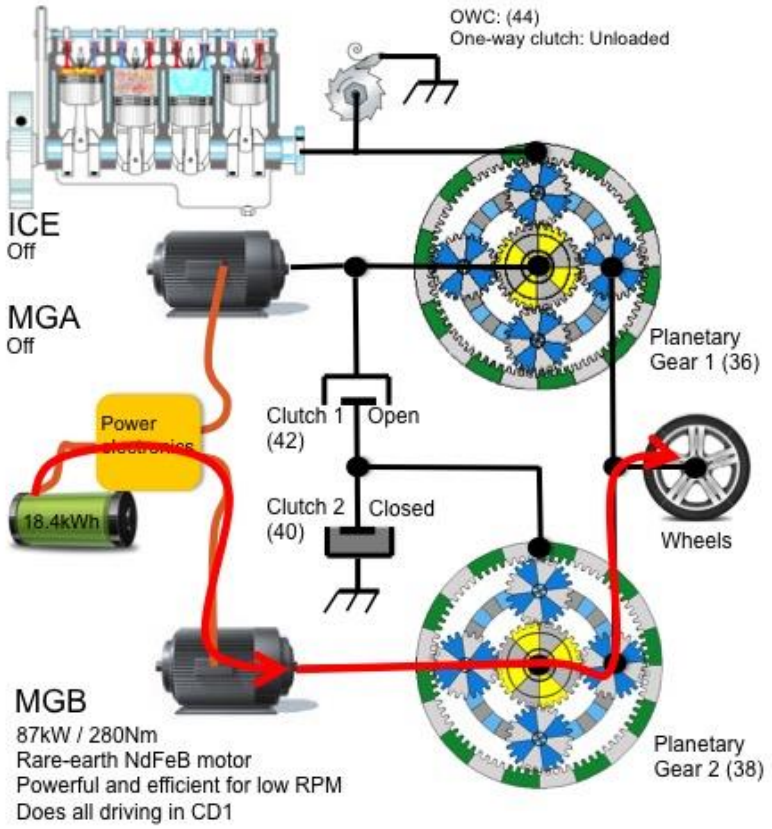
The illustration below shows the new Voltec transmission in which the engine is connected to the ring of the first planetary gear set (PG1) and the smaller motor is connected to the Sun gear. The larger motor is connected to the Sun gear of the second planetary gear set (PG2). The two planetary gear sets are connected to each other and to the output to the wheels by the planetary carriers of each gear set. There are 3 clutches which are used to change the flow of power through the transmission.
When Clutch 1 is closed it mechanically links the PG1 Sun gear and its smaller motor to the ring gear of PG2. When clutch 2 is closed it mechanically links the ring gear of PG2 to the outer transmission case — it brakes or locks up the ring gear so it cannot move. The OWC or One-Way Clutch is a special clutch design which only allows rotation in one direction. The illustration below shows the approximate physical layout of these components in a cutaway image of the new Voltec transmission.

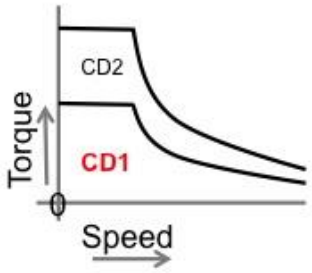


New 2016 Voltec

EV Operating Modes Description
The new transmission does most of its EV driving using the larger motor known as MGB, just like the original design. This motor is slightly smaller (87 kW vs 111 kW) than the original Voltec MGB but uses 40% less so-called rare earth metals. These metals allow increased torque density and help protect the permanent magnets in the motor from conditions such as high temperatures which would lead them to being demagnetized. The new MGB uses better manufacturing techniques which concentrates these reduced rare earth metals at the edges of the magnets segments where demagnetization is a concern.

CD1: ONE MOTOR EV MODE





Mode **CD1**: (74)
One Motor EV

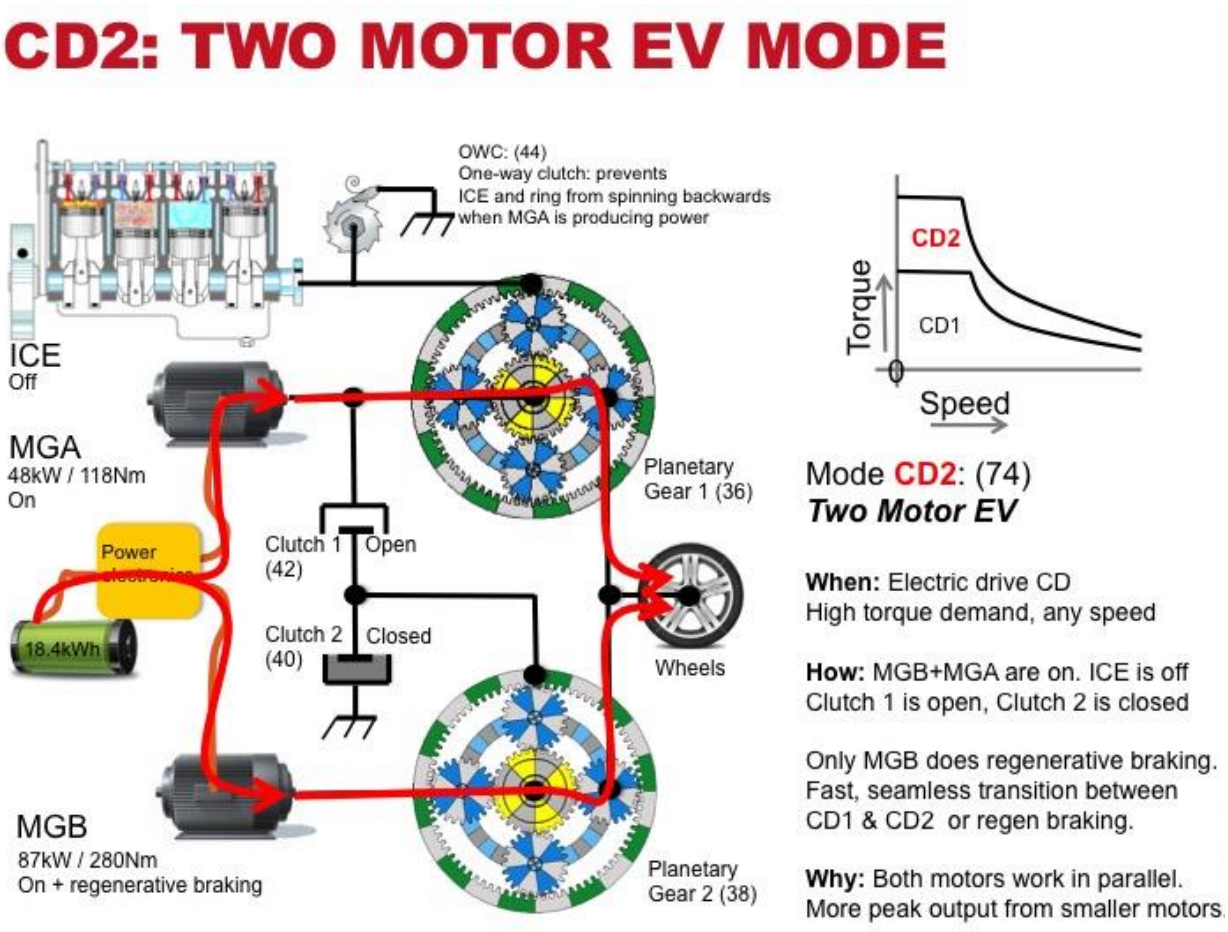
When: Electric drive CD
Low & medium torque demand.
Any speed including reverse.
+ CS mode low speed & low torque.

How: MGB is on. MGA & ICE are off
Clutch 1 is open, Clutch 2 is closed.
MGB also does regenerative braking.

Why: Most efficient since MGB is efficient for low torque.

CD1: One Motor EV Mode

The new two-motor mode used for high torque output is shown next. This is a very simple operating mode to understand. Power is delivered straight to the wheels. However, as mentioned, each motor goes thru a different gear ratio resulting in a wider torque band. Note that in this mode the ring gears of the planetary gear sets are locked so the PG set is merely acting as a gear reduction.



Two Motor EV Mode

Extended Range Operating Modes Description

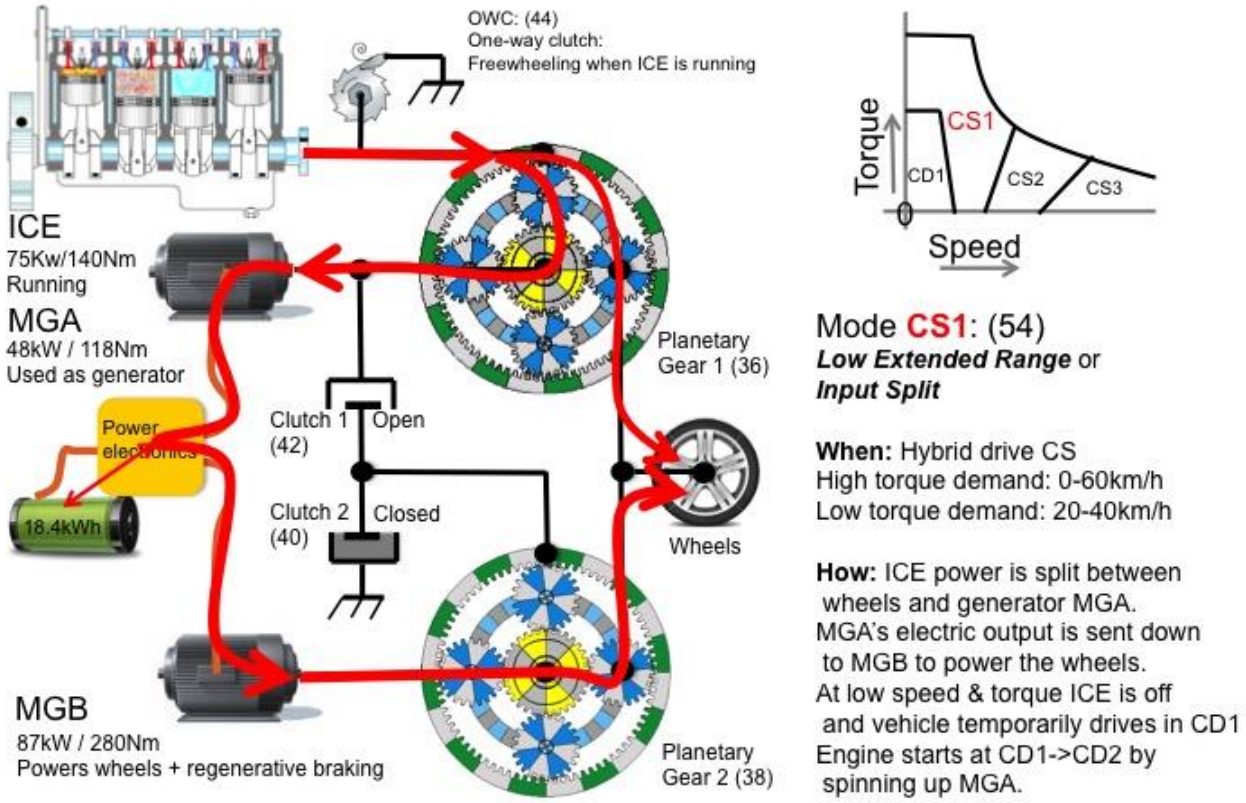
Extended range, when the gas engine starts up, now has 3 modes instead of 2 in the original Voltec design. The new operating modes increase efficiency, especially in city driving. In 2 of the modes the motors can be dynamically “mixed” with the gas engine output in an eCVT or electrically continuously variable transmission mode. The 2 Modes where “mixing” is used are Low Extended Range and High Extended Range.

Low extended range is technically an “input split” style of eCVT. In this mode the large motor MGB is driving the vehicle through PG 2 to the wheels with the PG 2 ring gear locked together with the mechanical power from the gasoline engine on PG 1 and the electrical power generated by MGA on PG 1. By adjusting the power generated by and used by the two motors the engineers can put the ICE at its most efficient operating point.

This type of power splitting between the gas engine, the battery, and two electric motors was first developed by TRW around 1970 and its modern implementation was patented by GM in 1995 and by Toyota in 1997. It is used as the only mode in the Toyota and Ford hybrid transmissions and at lower city speeds and high torque conditions in the GM 2-mode hybrids. It replaces the less efficient “pure” series mode in the original Voltec transmission which was used at speeds under 35-40 mph and under high torque requirements.

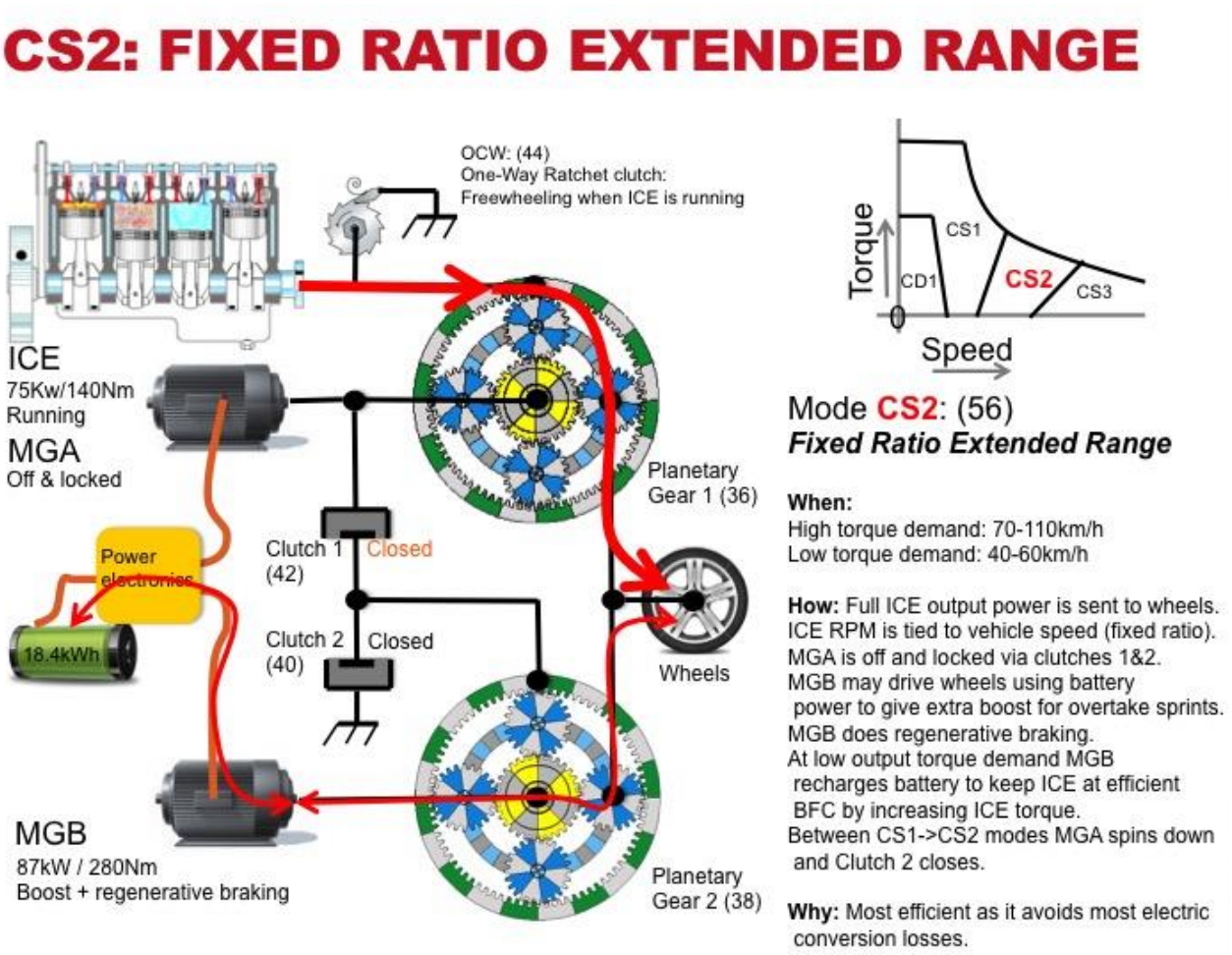
Low Extended Range is shown below.

CS1: LOW EXTENDED RANGE MODE



CS1: Low Extended Range Mode

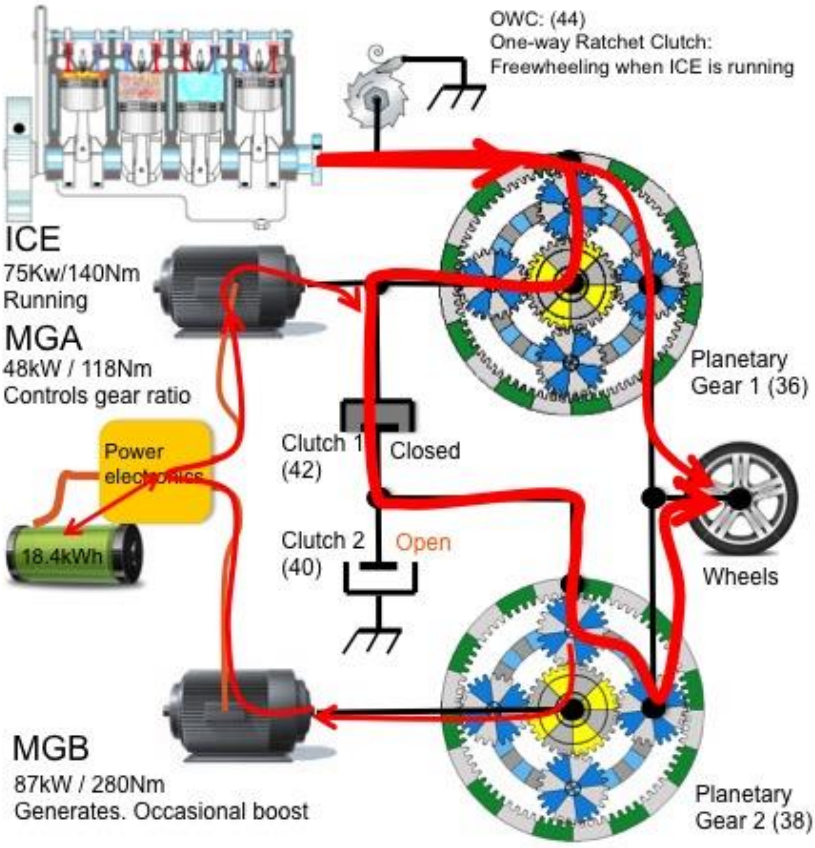
Fixed Ratio Extended Range mode is shown below. It can be used at moderate speeds and at moderate torque demand and allows the engine to directly drive the wheels with minimal electrical conversion losses.

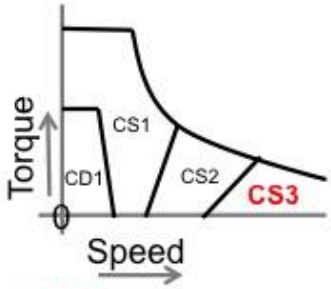


CS2: Fixed Ratio Extended Range

High extended range mode is shown below. In this mode neither motor is directly tied to engine speed or vehicle speed. This is technically known as a compound split mode and is similar but not identical to the output split mode of the original Voltec transmission where there was a more efficient mechanical path between the gas engine and the wheels at speeds over 35-40 mph with no more than light acceleration (torque demand).

CS3: HIGH EXTENDED RANGE MODE





Mode **CS3**: (56)
High Extended Range or
Compound Split

When:
High torque demand: above 110km/h
Low torque demand: above 60km/h

How: ICE output power is mechanically split between wheels and the ring of PG2.
This effectively gives a higher gear ratio.
By controlling the RPM of MGA and by turning MGB slowly or backwards the ICE RPM and torque can be controlled.
The energy siphoned off by MGB is sent up to MGA or to the battery during regenerative braking.
Between CS2->CS3 modes MGB powers off allowing Clutch 2 to open with no torque.

CS3: High Extended Range Mode

Conclusion
The new transmission is lighter and lower cost. Lower cost is achieved by using a smaller traction motor with fewer rare earth materials along with using an integrated inverter. Linking the 2 motors provides more torque and better acceleration than the first generation Voltec design. We may see this new transmission, or slightly modified variants of it, in other GM plugin and non-plugin hybrids in the future. It is hard to argue that this new transmission is anything other than a home run for GM.
More complete details will be released in a full GM technical paper to be published in April in conjunction with the SAE World Congress.
Hat tip to BillR for his contribution.