(19) **United States**

(12) **Patent Application Publication** (10) Pub. No.: **US 2005/0017580 A1**

Cikanek et al. (43) **Pub. Date:** **Jan. 27, 2005**

(54) **HILL HOLDING BRAKE SYSTEM FOR HYBRID ELECTRIC VEHICLES**

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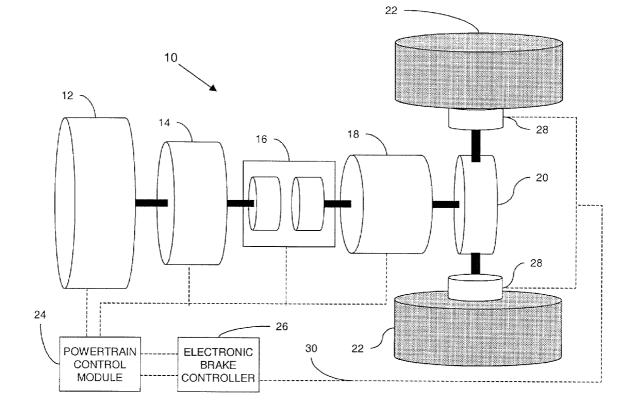**SOUTHFIELD, MI 48075-1238 (US)**

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(21) Appl. No.: **10/604,464**
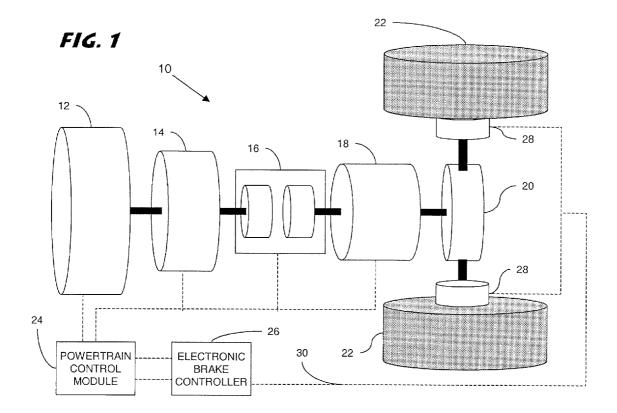
(22) Filed: **Jul. 23, 2003**
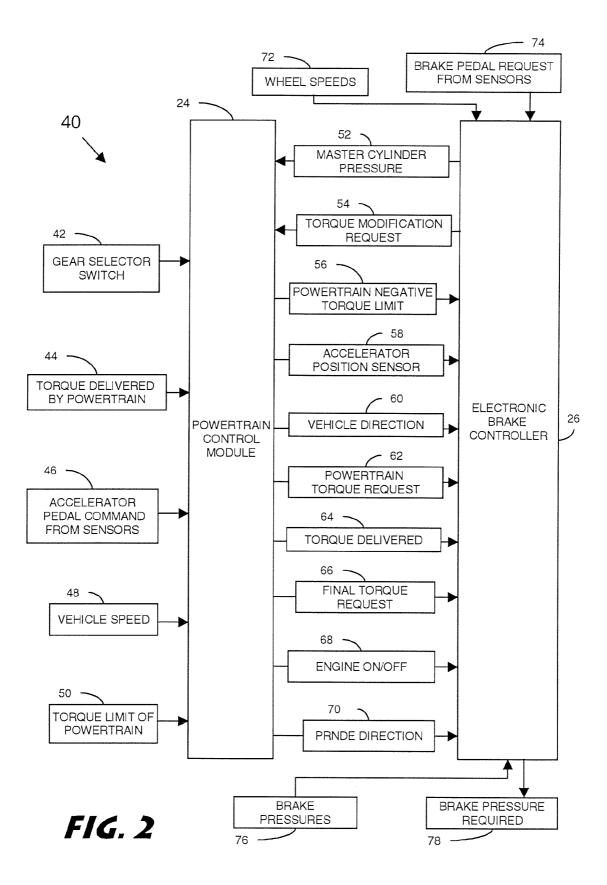
Publication Classification

(51) Int. Cl.^{7} **B60T 8/32**

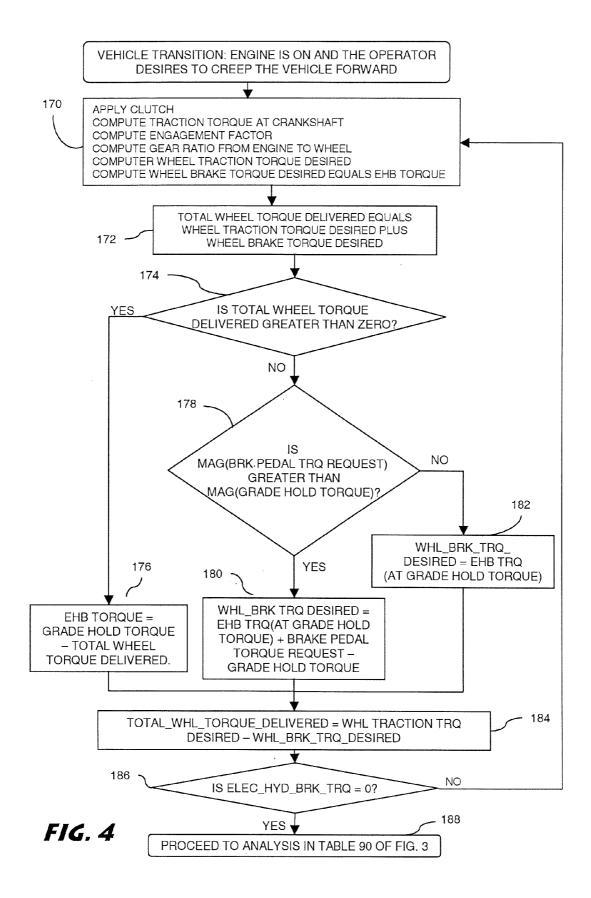(52) U.S. Cl. 303/191

(57) **ABSTRACT**

A hill holding function of a hybrid electric vehicle is initiated when the powertrain control module determines that a hill holding condition exists. In the hill holding condition, the electro-hydraulic brakes will provide brake torque to each wheel and the powertrain control module will turn off the internal combustion engine. The system can also detect a two footer condition where the vehicle operator requests both acceleration torque and brake torque simultaneously. The hill holding function of the hybrid electric vehicle in a two footer situation will apply the electro-hydraulic brakes and turn off the internal combustion engine. When the operator requests acceleration in either the hill holding or the two footer condition, the electric brake controller will transition the release of the electro-hydraulic brakes and the powertrain control module will turn on the internal combustion engine.
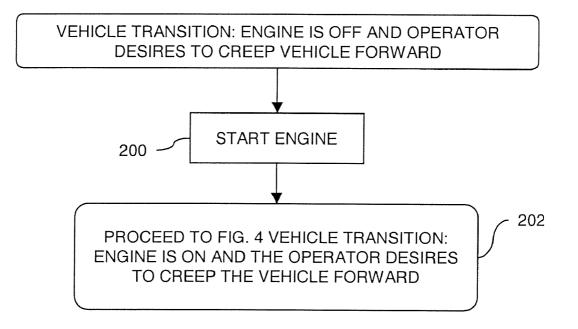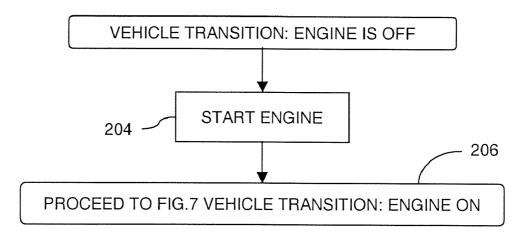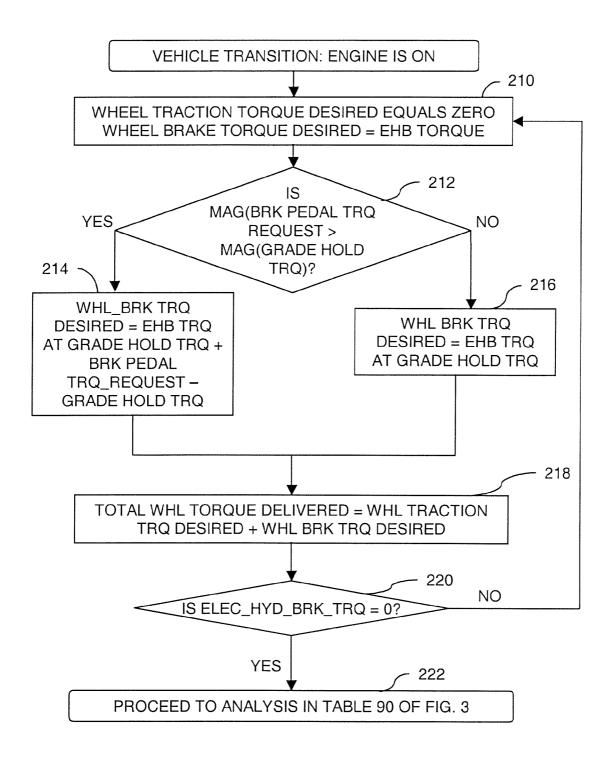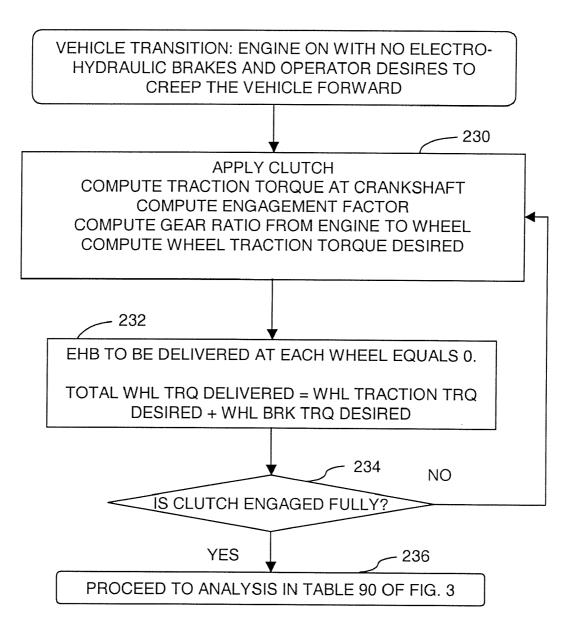
FIG. 1

POWERTRAIN
CONTROL
MODULE

ELECTRONIC
BRAKE
CONTROLLER

FIG. 2

Vehicle Speed < Creep Speed	Rollback	Brake Pedal > X psi	Accel Pedal > Z	Engine On	
Y	Y	Y	Y	Y	— 102
Y	Y	Y	Y	N	— 104
Y	Y	Y	N	Y	— 106
Y	Y	Y	N	N	— 108
Y	Y	N	Y	Y	— 110
Y	Y	N	Y	N	— 112
Y	Y	N	N	Y	— 114
Y	Y	N	N	N	— 116
Y	N	Y	Y	Y	— 118
Y	N	Y	Y	N	— 120
Y	N	Y	N	Y	— 122
Y	N	Y	N	N	— 124
Y	N	N	Y	Y	— 126
Y	N	N	Y	N	— 128
Y	N	N	N	Y	— 130
Y	N	N	N	N	— 132
N	Y	Y	Y	Y	— 134
N	Y	Y	Y	N	— 136
N	Y	Y	N	Y	— 138
N	Y	Y	N	N	— 140
N	Y	N	Y	Y	— 142
N	Y	N	Y	N	— 144
N	Y	N	N	Y	— 146
N	Y	N	N	N	— 148
N	N	Y	Y	Y	— 150
N	N	Y	Y	N	— 152
N	N	Y	N	Y	— 154
N	N	Y	N	N	— 156
N	N	N	Y	Y	— 158
N	N	N	Y	N	— 160
N	N	N	N	Y	— 162
N	N	N	N	N	— 164

FIG. 3

VEHICLE TRANSITION: ENGINE IS ON AND THE OPERATOR
DESIRES TO CREEP THE VEHICLE FORWARD

170

APPLY CLUTCH
COMPUTE TRACTION TORQUE AT CRANKSHAFT
COMPUTE ENGAGEMENT FACTOR
COMPUTE GEAR RATIO FROM ENGINE TO WHEEL
COMPUTER WHEEL TRACTION TORQUE DESIRED
COMPUTE WHEEL BRAKE TORQUE DESIRED EQUALS EHB TORQUE

172

TOTAL WHEEL TORQUE DELIVERED EQUALS
WHEEL TRACTION TORQUE DESIRED PLUS
WHEEL BRAKE TORQUE DESIRED

174

YES ← IS TOTAL WHEEL TORQUE
DELIVERED GREATER THAN ZERO?

NO

178

IS
MAG(BRK PEDAL TRQ REQUEST)
GREATER THAN
MAG(GRADE HOLD TORQUE)?   NO →

182

WHL_BRK_TRQ_
DESIRED = EHB TRQ
(AT GRADE HOLD TORQUE)

176

EHB TORQUE =
GRADE HOLD TORQUE
– TOTAL WHEEL
TORQUE DELIVERED.

180   YES

WHL_BRK TRQ DESIRED =
EHB TRQ(AT GRADE HOLD
TORQUE) + BRAKE PEDAL
TORQUE REQUEST –
GRADE HOLD TORQUE

TOTAL_WHL_TORQUE_DELIVERED = WHL TRACTION TRQ
DESIRED – WHL_BRK_TRQ_DESIRED   184

186 ← IS ELEC_HYD_BRK_TRQ = 0?   NO

FIG. 4   YES

188
PROCEED TO ANALYSIS IN TABLE 90 OF FIG. 3

VEHICLE TRANSITION: ENGINE IS OFF AND OPERATOR
DESIRES TO CREEP VEHICLE FORWARD

200 — START ENGINE

PROCEED TO FIG. 4 VEHICLE TRANSITION:
ENGINE IS ON AND THE OPERATOR DESIRES
TO CREEP THE VEHICLE FORWARD — 202

FIG. 5

VEHICLE TRANSITION: ENGINE IS OFF

204 — START ENGINE

206

PROCEED TO FIG.7 VEHICLE TRANSITION: ENGINE ON

FIG. 6

VEHICLE TRANSITION: ENGINE IS ON

210

WHEEL TRACTION TORQUE DESIRED EQUALS ZERO
WHEEL BRAKE TORQUE DESIRED = EHB TORQUE

212

IS
MAG(BRK PEDAL TRQ
REQUEST >
MAG(GRADE HOLD
TRQ)?

YES   NO

214

WHL_BRK TRQ
DESIRED = EHB TRQ
AT GRADE HOLD TRQ +
BRK PEDAL
TRQ_REQUEST –
GRADE HOLD TRQ

216

WHL BRK TRQ
DESIRED = EHB TRQ
AT GRADE HOLD TRQ

218

TOTAL WHL TORQUE DELIVERED = WHL TRACTION
TRQ DESIRED + WHL BRK TRQ DESIRED

220

IS ELEC_HYD_BRK_TRQ = 0?   NO

YES

222

PROCEED TO ANALYSIS IN TABLE 90 OF FIG. 3

FIG. 7

VEHICLE TRANSITION: ENGINE ON WITH NO ELECTRO-HYDRAULIC BRAKES AND OPERATOR DESIRES TO CREEP THE VEHICLE FORWARD

— 230

APPLY CLUTCH
COMPUTE TRACTION TORQUE AT CRANKSHAFT
COMPUTE ENGAGEMENT FACTOR
COMPUTE GEAR RATIO FROM ENGINE TO WHEEL
COMPUTE WHEEL TRACTION TORQUE DESIRED

— 232

EHB TO BE DELIVERED AT EACH WHEEL EQUALS 0.

TOTAL WHL TRQ DELIVERED = WHL TRACTION TRQ DESIRED + WHL BRK TRQ DESIRED

— 234   NO

IS CLUTCH ENGAGED FULLY?

YES   — 236

PROCEED TO ANALYSIS IN TABLE 90 OF FIG. 3

FIG. 8

VEHICLE TRANSITION: ENGINE IS OFF WITH NO ELECTRO HYDRAULIC BRAKES AND OPERATOR DESIRES TO CREEP VEHICLE FORWARD

240 — START ENGINE

242 — PROCEED TO FIG. 8 VEHICLE TRANSITION: ENGINE IS ON WITH NO ELECTRO HYDRAULC BRAKES AND THE OPERATOR DESIRES TO CREEP THE VEHICLE FORWARD

FIG. 9

VEHICLE TRANSITION: ENGINE IS OFF WITH NO ELECTRO HYDRAULIC BRAKES

244 — START ENGINE

246 — PROCEED TO FIG. 11 VEHICLE TRANSITION: ENGINE ON WITH NO ELECTRO HYDRAULIC BRAKES

FIG. 10

VEHICLE TRANSITION: ENGINE IS ON WITH
NO ELECTRO-HYDRAULIC BRAKES

260

WHEEL TRACTION TORQUE DESIRED EQUALS ZERO

262

EHB TORQUE TO BE DELIVERED AT EACH WHEEL = ZERO

WHL BRK TRQ DESIRED = WHL BRK TRQ DESIRED

264

TOTAL WHL TRQ DELIVERED = WHL TRACTION TRQ
DESIRED + WHL BRK TRQ DESIRED

266

IS CLUTCH FULLY ENGAGED?   NO

YES   268

PROCEED TO ANALYSIS IN TABLE 90 OF FIG. 3

FIG. 11

HILL HOLDING BRAKE SYSTEM FOR HYBRID ELECTRIC VEHICLES

BACKGROUND OF INVENTION

[0001]   1. Field of the Invention

[0002]   The present invention relates generally to a braking system for a hybrid electric vehicle and, more particularly, to a hill holding brake system for a hybrid electric vehicle.

[0003]   2. Background Art

[0004]   A conventional wheeled automotive vehicle includes an internal combustion engine powered by fossil fuels. The desire to reduce emissions and consumption of fossil fuels in an internal combustion engine vehicle is well established.

[0005]   An electric vehicle comprises a battery and an electrical generator motor powerplant system to provide torque to a set of wheels. However, electric vehicles have limited range, limited power capabilities, and require a substantial amount of time to recharge the battery. Additionally, electric vehicles require the development of an extensive infrastructure to recharge the battery and service the electric vehicles.

[0006]   A hybrid electric vehicle includes a conventional internal combustion engine powertrain and an electrical generator motor powerplant. Hybrid electric vehicles reduce emissions and consumption of fossil fuels. Hybrid electric vehicles address the limitations of the electric vehicle relating to battery life, vehicle range, vehicle performance, and vehicle infrastructure development requirements.

[0007]   Hybrid electric vehicles can have many different configurations. A limited storage requirement hybrid electric vehicle is one configuration having an internal combustion engine, providing tractive power to the wheels, in combination with an integrated starter generator motor powerplant, providing a small amount of tractive torque to the wheels. The integrated starter generator motor powerplant tractive torque is provided mainly as a boost. The integrated starter generator motor starts the internal combustion engine and charges the battery.

[0008]   Vehicle operators prefer hybrid electric vehicles that have braking and acceleration characteristics that are similar to a conventional internal combustion engine vehicle with an automatic transmission. Holding a vehicle on a hill when an operator's foot is taken off of the brake pedal, called hill holding, is a characteristic desired by vehicle operators. Hill holding in a conventional vehicle occurs when the vehicle is on a hill, the brake pedal and accelerator pedal are not actuated, and the automatic transmission is engaged. The vehicle powertrain delivers enough torque at idle from the internal combustion engine through the transmission to the wheels to hold the vehicle on a hill. The internal combustion engine in a hybrid electric vehicles wastes fuel and produces undesirable emissions to hold the vehicle on a hill because the internal combustion engine must continue to operate while the vehicle is stopped.

[0009]   The integrated starter generator motor in a hybrid electric vehicle is capable of delivering enough torque to hill hold. However, the use of the integrated starter generator motor in a hybrid electric vehicle wastes battery power and requires additional cooling during hill holding conditions.

[0010]   U.S. Pat. No. 6,321,144 to Crombez, for example, discloses a method and system for preventing roll back in an electric vehicle and a hybrid electric vehicle. The rotary electric traction motor disclosed in Crombez is capable of bi-directional operation and is not directly connected to the internal combustion engine.

[0011]   The present invention is directed to providing a robust hill holding system that reduces emissions, increases battery range, and reduces fuel consumption in a hybrid electric vehicle with an integrated starter generator motor.

SUMMARY OF INVENTION

[0012]   The present invention relates to a hill holding control method and system for a hybrid vehicle having an internal combustion engine, an integrated starter generator motor, and a electro-hydraulic brake system that provides hydraulic brake torque during a hill holding condition. The present invention improves the operating efficiency and driveability of the hybrid electric vehicle.

[0013]   According to one aspect of the invention, a hybrid electric vehicle is provided that includes an internal combustion engine that rotates in a single direction and is connected to an integrated starter generator motor. The integrated starter generator motor is provided for starting the internal combustion engine. The internal combustion engine and the integrated starter generator motor may selectively drive a set of wheels and provide brake torque at each driven wheel. A vehicle operator can selectively actuate the electro-hydraulic brake system. An electronic brake control system also controls the electro-hydraulic brake system and controls the level of electro-hydraulic brake torque applied to the wheels by the electro-hydraulic brake system. The electronic brake control system actuates the electro-hydraulic brake to hold the vehicle on a hill instead of using engine compression braking torque or integrated starter generator motor braking torque. A powertrain control module turns off the internal combustion engine while the electro-hydraulic brakes are applied during hill holding conditions.

[0014]   When a vehicle operator requests acceleration during the hill holding condition, the electronic brake control system reduces electro-hydraulic brake torque at the wheels and the powertrain control module turns on the internal combustion engine. A vehicle transmission is engaged for seamless acceleration following the hill holding brake application.

[0015]   Another aspect of the invention relates to the method of holding a hybrid electric vehicle on a hill. A vehicle roll-back state, a vehicle brake pedal actuation measurement, a powertrain pedal actuation measurement, and an internal combustion engine running state are monitored by the powertrain control module to determine if the hybrid electric vehicle is in a hill holding condition. In a hill holding condition the electronic brake controller actuates the electro-hydraulic brakes and the powertrain control module turns off the internal combustion engine.

[0016]   There are numerous benefits accruing to the method and system of the present invention. For example, the method and system:

   [0017]   1) improves the operating efficiency of the hybrid electric vehicle by not using the integrated starter generator motor to provide this function and

eliminates the need for additional cooling for the integrated starter generator motor;

[0018]   2) improves the drive-ability of the hybrid electric vehicle;

[0019]   3) is capable of holding the hybrid electric vehicle on a hill of greater grade than present transmissions;

[0020]   4) allows a manual transmission vehicle to emulate the hill holding function of a automatic transmission vehicle;

[0021]   5) allows automatic transmissions a more efficient method of hill holding since the clutch pressure does not have to be maintained to provide hill holding; and

[0022]   6) allows hill holding to be performed more efficiently than present day transmission hill holding systems by not using the transmission to provide this function saving energy by not keeping the clutch pressure on and eliminating the need for additional cooling for the transmission.

[0023]   These and other aspects of the invention will be apparent to one of ordinary skill in the art in view of the attached drawings and following detailed description of the preferred embodiment.

BRIEF DESCRIPTION OF DRAWINGS

[0024]   **FIG. 1** is a schematic diagram illustrating a preferred hybrid electric vehicle configuration on which the method of the present invention can be implemented;

[0025]   **FIG. 2** is a schematic diagram illustrating a representative torque controller for the hybrid electric vehicle's dual powerplants;

[0026]   **FIG. 3** is a table of hybrid electric vehicle conditions which dictate hill holding strategies;

[0027]   **FIG. 4** is a flowchart of vehicle transition when the engine is on and the operator desires to creep the vehicle forward;

[0028]   **FIG. 5** is a flowchart of vehicle transition when the engine is off and the operator desires to creep the vehicle forward;

[0029]   **FIG. 6** is a flowchart of vehicle transition for when the engine is off;

[0030]   **FIG. 7** is a flowchart of vehicle transition for when the engine is on;

[0031]   **FIG. 8** is a flowchart of vehicle transition for when the engine is on with no electro-hydraulic brakes and the operator desires to creep the vehicle forward;

[0032]   **FIG. 9** is a flowchart of vehicle transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward;

[0033]   **FIG. 10** is a flowchart of vehicle transition for when the engine is off with no electro-hydraulic brakes; and

[0034]   **FIG. 11** is a flowchart of vehicle transition for when the engine is on with no electro-hydraulic brakes.

DETAILED DESCRIPTION

[0035]   Referring now to the drawings figures, there is illustrated in **FIG. 1 a** representative configuration of a hybrid electric vehicle 10 having a internal combustion engine 12 coupled to an integrated starter generator motor 14. The two powerplants are coupled by a clutch 16 to a transmission 18, and a differential 20 to provide torque to a set of vehicle wheels 22. A powertrain control module 24 controls the operating parameters of the internal combustion engine 12 and the integrated starter generator motor 14. An electronic brake control system 26 controls a set of electro-hydraulic brakes 28. Both controllers are shown as logical units, and can be embodied in one or more separate controller or computer-controlled devices. A vehicle communication data network 30 enables communications between the hybrid electric vehicle components, the electronic brake controller 26 and the powertrain control module 24 at suitable update rates.

[0036]   The powertrain control module 24 provides adaptive filtering that activates when the clutch 16 is engaged as the vehicle accelerates from a hill holding condition. The adaptive filtering could be continuously variable or could be provided by a sequence of individual filters.

[0037]   Referring now to **FIG. 2**, a diagram of the hybrid electric vehicle torque control system is provided. The system coordinates the powertrain control module 24 with the electronic brake controller 26 to provide hill holding in the hybrid electric vehicle.

[0038]   Inputs to the powertrain control module 24 include a gear selector switch 42 that provides the powertrain control module 24 with information relating to the position of the gear selector switch 42. A powertrain torque sensor provides information relating to the amount of torque delivered by the powertrain 44 to the powertrain control module 24. An accelerator pedal sensor 46 provides the powertrain control module 24 with information corresponding to the position of an accelerator pedal. A vehicle speed sensor 48 provides a value corresponding to the speed of the vehicle to the powertrain control module 24. Values corresponding to a torque limit of the powertrain are obtained at 50 from a lookup tables and provided to the powertrain control module 24.

[0039]   Inputs to the powertrain control module 24 from the electronic brake control system 26 include a master cylinder pressure 52 measured by a master cylinder pressure sensor. The electronic brake control system 26 sends a torque modification request at 54 to the powertrain control module 24.

[0040]   Inputs to the electronic brake control system 26 from the powertrain control module 24 include the powertrain negative torque limit from a powertrain torque sensor at 56. The powertrain control module 24 provides information from an accelerator position sensor at 58 to the electronic brake controller 26. The vehicle speed sensors 48 and the gear selector switch 42 are analyzed by the powertrain control module to provide a vehicle direction at 60. The powertrain control module 24 provides the electronic brake controller 26 with data representative of the powertrain torque request at 62, the torque delivered at 64, the final torque request at 66, and the engine on/off state 68.

[0041] The powertrain control module, using inputs from the gear selector switch **42** and vehicle speed **48**, provides the electronic brake controller **26** with the PRDNE direction **70**.

[0042] Inputs to the electronic brake controller **26** also include the wheel speed data at **72** from the wheel speed sensors. Brake pedal position sensors provide information relating to a brake pedal request at **74**. Brake pressure sensors provide an input for brake pressures at **76**.

[0043] The electronic brake controller **26** provides a brake pressure required output at **78** that controls the electro-hydraulic brakes **28** of the vehicle.

[0044] The data inputs and outputs of the powertrain control module **24** and the electronic brake controller **26** process in a vehicle level algorithm and a brake algorithm. The hybrid electric vehicle using the vehicle level algorithm and brake algorithm provides electro-hydraulic brake torque reduction by the electronic brake control system during driver commanded vehicle acceleration from a vehicle stopped on a hill.

[0045] When the vehicle begins to accelerate under normal driving conditions, the vehicle algorithm reduces the electro-hydraulic brake torque using an adaptive filter that allows the powertrain system to start and provide the traction torque at the same rate. The adaptive filtering can be continuously variable or a sequence of individual filters. The different filters and control logic are determined by vehicle conditions, including environmental conditions, and conditions of vehicle components such as: the clutch, the transmission, the brakes, the engine, the motor, and the battery. Clutch filters may be dependent upon the clutch status, clutch wear, clutch temperature, clutch pressure, and clutch input and output speeds. Transmission filters may be dependent upon transmission current gear, transmission next gear, and transmission configuration. Brake filters may be dependent upon the driver brake pedal command, brake system fault conditions, brake fade/temperature conditions, and the ABS status. Engine and motor filters may be dependent upon master cylinder pressure, throttle angle, engine friction, engine speed, motor speed, motor efficiency, engine brake torque, engine emissions and engine fuel rate. Other miscellaneous filters and control logic may include such factors as the battery state of charge, energy storage device fault conditions, wheel slip conditions, driveline resonance and road surface conditions.

[0046] When the acceleration is complete and the vehicle engages the clutch, the vehicle algorithm decreases the powertrain negative torque limit **62** with an adaptive filter such that the electro-hydraulic brake torque goes off at the same rate and the traction torque is increased. This method of control provides optimal drive-ability and energy savings allowing a seamless handoff between the electro-hydraulic brake torque and the powertrain torque.

[0047] Referring now to **FIG. 3**, a table **90** of hybrid electric vehicle conditions that dictate the hill holding strategy is provided.

[0048] The powertrain control module compares the vehicle speed **48** from the wheel speed sensor with a calibratable vehicle creep speed in column **92**. The vehicle creep speed is typically set at **6** miles per hour on a zero percent grade. The application of both the brake pedal and the accelerator pedal determines the existence of a two footer condition. During a two footer condition the vehicle can be on a grade in a forward or a reverse gear, the vehicle operator actuates both the accelerator pedal for a accelerator torque request and the brake pedal for a brake torque request, and the magnitude of the brake torque request is greater than the accelerator torque request.

[0049] The results of the vehicle rollback determination is displayed in column **94**. Vehicle rollback occurs when the driver releases both the accelerator and brake pedals with the vehicle at a rest condition on a grade, while the vehicle is in a forward gear **82** and starts rolling backwards, or when the vehicle is in a reverse gear **82** and starts rolling forward. Column **96** displays the results of electronic brake controller comparison of the brake pedal actuation received by a brake pedal sensor with a calibratable predetermined force X, measured in pounds per square inch. Column **98** displays the powertrain control module comparison of an accelerator pedal actuation, measured by an accelerator pedal sensor, with a calibratable predetermined percentage value Z. Column **100** displays the internal combustion engine's running state from an engine sensor.

[0050] Rows **102** and **134** result in the vehicle in a two footer condition with the engine on and the electro-hydraulic brakes applying at grade hold torque. The electro-hydraulic brakes applies at the wheel cylinders and is mechanically summed with the total torque request, which is applied additionally. The hill holding strategy maintains electro-hydraulic brakes at the grade hold torque amount, for example, the amount of torque needed to hold the vehicle on approximately 3% grade. The hill holding strategy calculates the total torque request by summing the accelerator pedal torque request and brake pedal torque request.

[0051] When the total torque request is greater than zero, the accelerator pedal torque request at the total torque request amount is added if the magnitude of total torque request is greater than the magnitude of grade hold torque. The hill holding strategy proceeds to the **FIG. 4** flowchart of the vehicle transition when the engine is on and operator desires to creep vehicle forward.

[0052] When the total torque request is less than zero, additional vehicle friction brake torque is applied as follows.

[0053] If the magnitude of brake pedal torque request is greater than the magnitude of grade hold torque, then the brake torque request applies at the brake pedal torque request minus the grade hold torque.

[0054] If the magnitude of brake pedal torque request is less than the magnitude of grade hold torque, then no additional friction brake torque is applied and the hill holding strategy proceeds to the **FIG. 7** flowchart of the transition for when the engine is on.

[0055] If total torque request equals zero, then the hill holding strategy proceeds to the **FIG. 7** flowchart of the transition for when the engine is on.

[0056] Rows **104** and **136** result in the vehicle in a two footer condition with the engine off and the electro-hydraulic brakes applying at grade hold torque. The hill holding strategy continues to apply electro-hydraulic brakes at the grade hold torque amount and adds total torque request as follows.

[0057] When the total torque request is greater than zero, the vehicle acceleration pedal at total torque request amount is added if the magnitude of total torque request is greater than the magnitude of grade hold torque. The hill holding strategy proceeds to the **FIG. 5** flowchart of vehicle transition when the engine is off and the operator desires to creep the vehicle forward.

[0058] When the total torque request is less than zero, the vehicle brake torque is added as follows.

[0059] If the magnitude of the brake pedal torque request is greater than magnitude of grade hold torque, brake pedal torque request applies at brake pedal torque request minus the grade hold torque.

[0060] If the magnitude of the brake pedal torque request is less than the magnitude of grade hold torque, no additional friction brake torque is applied. The hill holding strategy proceeds to the **FIG. 6** flowchart of the vehicle transition for when the engine is off.

[0061] If the total torque request equals zero, the hill holding strategy proceeds to the **FIG. 6** flowchart of the transition for when the engine is off.

[0062] Rows **106** and **138** result in the engine on with a brake pedal torque request, and the electro-hydraulic brakes applying at grade hold torque. Additional brake pedal torque request is added as follows.

[0063] When the magnitude of the brake pedal torque request is greater than magnitude of the grade hold torque, electro-hydraulic brakes apply at the grade hold torque adding the difference between the brake pedal torque request and grade hold torque.

[0064] When the magnitude of the brake pedal torque request is less than the magnitude of grade hold torque, electro-hydraulic brakes apply at grade hold torque.

[0065] Rows **108** and **140** result in the engine off with a brake pedal torque request, and electro-hydraulic brakes applying at the grade hold torque.

[0066] The strategy continues with the electro-hydraulic brakes applying at the grade hold torque plus additional brake pedal torque request is added as follows.

[0067] When the magnitude of the brake pedal torque request is greater than the magnitude of grade hold torque, electro-hydraulic brakes apply at grade hold torque amount adding the difference between the brake pedal torque request and the grade hold torque.

[0068] When the magnitude of the brake pedal torque request is less than the magnitude of grade hold torque, the electro-hydraulic brakes apply at grade hold torque.

[0069] When the magnitude of the brake pedal torque request is less than X psi, where X is predetermined and calibratable pressure measured in psi, the hill holding strategy proceeds to the **FIG. 6** flowchart of the vehicle transition for when the engine is off.

[0070] Row **110** results in the engine on with an accelerator pedal torque request, and electro-hydraulic brakes applying at grade hold torque. The electro-hydraulic brakes applies at the grade hold torque amount with the additional accelerator pedal torque request is added as follows.

[0071] When the magnitude of the accelerator pedal torque request is greater than the magnitude of grade hold torque, the hill holding strategy proceeds to the **FIG. 4** flowchart of the vehicle transition when the engine is on and operator desires to creep vehicle forward.

[0072] When the magnitude of the accelerator pedal torque request is less than magnitude of grade hold torque, the hill holding strategy proceeds to the **FIG. 7** flowchart of the vehicle transition for when the engine is on.

[0073] Row **112** results in engine off with an accelerator pedal torque request, and electro-hydraulic brakes applying at grade hold torque. Additional accelerator pedal torque request is added as follows.

[0074] When the magnitude of the accelerator pedal torque request is greater than the magnitude of grade hold torque, the hill holding strategy proceeds to the **FIG. 5** flowchart of the vehicle transition when the engine is off and the operator desires to creep the vehicle forward.

[0075] When the magnitude of the accelerator pedal torque request is less than the magnitude of grade hold torque, the hill holding strategy proceeds to the **FIG. 6** flowchart of the vehicle transition for when the engine is off.

[0076] Row **114** results in the engine on and the electro-hydraulic brakes applying at grade hold torque. The hill holding strategy proceeds to the **FIG. 6** flowchart of the vehicle transition for when the engine is off.

[0077] Row **116** results in the engine off and the electro-hydraulic brakes applying at grade hold torque with the hill holding strategy waiting for a vehicle condition change.

[0078] Rows **118** and **150** result in the vehicle engine on in the two footer condition. The total torque request applies as follows.

[0079] When the total torque request is greater than zero, vehicle acceleration pedal applies at the total torque request amount. The hill holding strategy proceeds to the **FIG. 8** flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0080] When the total torque request is less than zero, vehicle brake torque applies at the total torque request amount, the hill holding strategy proceeds to the **FIG. 11** flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes.

[0081] When the total torque request equals zero, apply nothing. The hill holding strategy proceeds to the **FIG. 11** flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes.

[0082] Row **120** results in the engine off in a two footer condition. The total torque request applies according to the following.

[0083] When the total torque request is greater than zero, the vehicle acceleration applies at total torque request amount. The hill holding strategy proceeds to the **FIG. 9** flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0084] When the total torque request is less than zero, the vehicle brake torque applies at total torque request amount.

5

The hill holding strategy proceeds to the **FIG. 10** flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes.

[0085] When the total torque request equals zero, apply nothing. The hill holding strategy proceeds to the **FIG. 10** flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes.

[0086] Rows **122** and **154** result in engine on and applying the brake pedal torque request.

[0087] Rows **124** and **156** result in engine off and applying the brake pedal torque request. If the magnitude of brake pedal torque request is less than X psi, the hill holding strategy proceeds to the **FIG. 6** flowchart of the vehicle transition for when the engine is off.

[0088] Rows **126** and **158** results in engine on and applying the accelerator pedal torque request. If the vehicle speed is less than or equal to the creep speed then the hill holding strategy proceeds to the **FIG. 8** flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes and the operator desires to creep the vehicle forward. If the vehicle speed is not less than the creep speed then the hill holding strategy proceeds to **FIG. 11** flowchart of the vehicle transition for when the engine is on with no electro-hydraulic brakes.

[0089] Rows **128** and **160** result in the engine off and applying the accelerator pedal torque request. The hill holding strategy proceeds to the **FIG. 9** flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0090] Rows **130** and **162** results in the engine on and applying nothing.

[0091] Row **132** results in engine off and the hill holding strategy proceeds to the **FIG. 6** flowchart of the vehicle transition for when the engine is off.

[0092] Row **142** results in engine on with an accelerator pedal torque request and the electro-hydraulic brakes applying at the grade hold torque. The accelerator pedal torque request is added as follows.

[0093] When the magnitude of the accelerator pedal torque request is greater than or less than the magnitude of grade hold torque, the hill holding strategy proceeds to the **FIG. 4** flowchart of the vehicle transition when the engine is on and operator desires to creep vehicle forward.

[0094] Row **144** results in engine off and electro-hydraulic brakes applying at the grade hold torque plus the accelerator pedal torque request.

[0095] When the magnitude of the accelerator pedal torque request is greater than or less than the magnitude of grade hold torque, the hill holding strategy proceeds to the **FIG. 5** flowchart of vehicle transition when the engine is off and the operator desires to creep the vehicle forward.

[0096] Row **146** results in the engine on and the electro-hydraulic brakes applying at grade hold torque.

[0097] Row **148** results in engine off, electro-hydraulic brakes applying at grade hold torque, the hill holding strategy proceeds to the **FIG. 6** flowchart of the vehicle transition for when the engine is off.

[0098] Row **152** results in engine off in the two footer condition. The total torque request applies according to the following.

[0099] When the total torque request is greater than or less than zero, vehicle acceleration applies at the total torque request amount. The hill holding strategy proceeds to the **FIG. 9** flowchart of the vehicle transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0100] When the total torque request equals zero, apply nothing. The hill holding strategy proceeds to the **FIG. 9** flowchart of transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0101] Row **164** results in the engine off and nothing applied. The hill holding strategy proceeds to the **FIG. 6** flowchart of the vehicle transition for when the engine is off.

[0102] Referring to **FIG. 4**, flowchart of the vehicle transition when the engine is on and operator desires to creep vehicle forward is provided.

[0103] In step **170**, during each frame interval the following events occur. The forward clutch is applied. Next, a crankshaft torque sensor computes a traction torque at the crankshaft. The crankshaft torque can also be determined by sensing various engine factors such as speed, throttle angle, and fuel rate. Corrections to these input factors should be made if these factors were modified to perform additional functions that do not normally translate to drag on the drivetrain, for example some of the load of the engine may be diverted to supply the auxiliary load or charge or discharge the energy storage subsystem and may reflect as a higher throttle angle. The engagement factor is determined by sensing various clutch factors, such as pressure, to obtain the knowledge of what percentage of the torque applied to the clutch can be obtained at the clutch output. The gear ratio from the engine to the wheel is computed by knowledge of the present gear. The traction torque at the crankshaft computation, the engagement factor computation and the gear ratio from the engine to the wheel computation are a function of the driver accelerator pedal command and may be preprogrammed in an accelerator pedal map. The traction torque at the crankshaft computation, the engagement factor computation and the gear ratio from the engine to the wheel computation compute the desired traction torque at each wheel.

[0104] Next in step **172**, wheel traction torque desired is summed with the wheel brake torque desired to compute the total wheel torque delivered.

[0105] In decision step **174**, the total wheel torque delivered is compared to zero.

[0106] If the total wheel torque delivered is greater then zero, then the flowchart continues to step **176**. In step **176**, the electro-hydraulic brakes torque is computed as the difference between the grade hold torque and the total wheel torque delivered.

[0107] If the total wheel torque delivered is less than or equal to zero, then the flowchart continues to decision step **178**. In step **178**, the magnitude of the brake pedal torque request is compared with the magnitude of the grade hold torque.

[0108] When the magnitude of the brake pedal torque request is greater than the magnitude of the grade hold torque, the flowchart proceeds to step **180** where wheel brake torque desired is calculated by summing the electro-hydraulic brakes torque at grade hold torque and the brake pedal torque request minus the grade hold torque.

[0109] When the magnitude of the brake pedal torque request is less than or equal to the magnitude of the grade hold torque, the flowchart proceeds to step **182** where wheel brake torque desired is set to the electro-hydraulic brakes torque at grade hold torque.

[0110] Steps **176**, **180** and **182** then proceed to step **184** where the total wheel torque delivered is computed as the difference between the wheel traction torque desired and the wheel brake torque desired.

[0111] Next in step **186** the electro-hydraulic brake torque is compared to zero. If the electro-hydraulic brake torque is equal to zero, then the hill holding strategy returns to the analysis in table of **FIG. 3**. If the electro-hydraulic brake torque is not equal to zero the analysis returns to the top of the flowchart to step **170**.

[0112] Referring to **FIG. 5**, a flowchart of vehicle transition when the engine is off and the operator desires to creep the vehicle forward is provided. During each frame interval the powertrain control module starts the engine in step **200**. Step **202** shows that the hill holding strategy proceeds to the **FIG. 4** flowchart of the vehicle transition when the engine is on and the operator desires to creep the vehicle forward.

[0113] Referring to **FIG. 6**, a flowchart of the vehicle transition for when the engine is off is provided. During each frame interval the powertrain control module starts the engine in step **204**. Step **206** shows that the hill holding strategy proceeds to the **FIG. 7** flowchart of the vehicle transition for when the engine is on.

[0114] Referring to **FIG. 7**, a flowchart of the vehicle transition for when the engine is on is provided. In step **210**, the desired traction torque at each wheel is zero. The wheel brake torque desired is equal to the electro-hydraulic brakes torque. The flowchart continues to decision step **212** where the magnitude of the brake pedal torque request and the magnitude of the grade hold torque are compared to each other. The comparison is used to compute the amount of electro-hydraulic brake torque to be delivered at each wheel by the hydraulic system.

[0115] When the magnitude of the brake pedal torque request is greater than magnitude of grade hold torque, the flowchart goes to step **214**. In step **214**, the wheel brake torque desired equals electro-hydraulic brake torque at grade hold torque plus the difference between the brake pedal torque request and the grade hold torque.

[0116] When the magnitude of the brake pedal torque request is less than or equal to the magnitude of grade hold torque, the flowchart goes to step **216**. No additional friction brake torque is applied. The wheel brake torque desired equals electro-hydraulic brake torque at grade hold torque.

[0117] Steps **214** and **216** continue to step **218** where the total wheel torque delivered is computed by adding the wheel traction torque desired with the wheel brake torque desired.

[0118] The flowchart continues with decision step **220** where the electro-hydraulic brake torque is compared to zero. If the electro-hydraulic brake torque is equal to zero the flowchart goes back to the initial analysis in **FIG. 3** table as shown in step **222**. If the electro-hydraulic brake torque is not equal to zero the system returns to step **210** of the **FIG. 7** flowchart.

[0119] Referring to **FIG. 8** flowchart of the vehicle transition when the engine is on with no electro-hydraulic brakes and operator desires to creep vehicle forward.

[0120] In step **230**, during each frame interval the following events occur. The forward clutch applies. Next, a crankshaft torque sensor, or other sensing methods enable the computation of the traction torque at the crankshaft. Clutch sensors enable computation of the engagement factor. Knowledge of present gear enables computation of the gear ratio from the engine to the wheel. The traction torque at the crankshaft computation, the engagement factor computation and the gear ratio from the engine to the wheel computation are a function of the accelerator pedal command and may be preprogrammed in an accelerator pedal map. The traction torque at the crankshaft computation, the engagement factor computation and the gear ratio from the engine to the wheel computation are used to compute the desired traction torque at each wheel.

[0121] Next in step **232**, wheel traction torque desired is summed with the wheel brake torque desire to compute the total wheel torque delivered.

[0122] Next in step **234**, the clutch is determined to be fully engaged or not. If the clutch is determined to be fully engaged, then the flowchart strategy returns to the analysis in table **90** of **FIG. 3**. If the electro-hydraulic brake torque is not equal to zero the analysis returns to step **230** of the flowchart of the vehicle transition when the engine is on with no electro hydraulic brakes and operator desires to creep vehicle forward.

[0123] Referring to **FIG. 9**, a flowchart of transition for when the engine is off with no electro-hydraulic brakes and the operator desires to creep the vehicle forward is provided.

[0124] In step **240**, the powertrain control module turns the engine on. The flowchart continues to step **242**, where the hill holding strategy proceeds to the **FIG. 8** flowchart of the vehicle transition when the engine is on with no electro-hydraulic brakes and the operator desires to creep the vehicle forward.

[0125] **FIG. 10** flowchart of transition for when the engine is off with no electro-hydraulic brakes. In step **244**, the powertrain control module turns the engine on. The flowchart continues to step **246**, where the hill holding strategy proceeds to the **FIG. 11** flowchart of the vehicle transition when the engine is on with no electro-hydraulic brakes.

[0126] Referring to **FIG. 11**, a flowchart of transition when the engine is on with no electro-hydraulic brakes is provided.

[0127] In step **260**, the wheel traction torque desired at each wheel is zero.

[0128] In step **262**, the amount of electro-hydraulic brake torque to be delivered at each wheel by the hydraulic system is zero and wheel brake torque desired equals brake pedal torque request.

[0129] In step **264**, the total wheel torque delivered equals wheel traction torque desired plus the wheel brake torque desired.

[0130] The flowchart continues with decision step **266** where the decision on clutch engagement is made. If the clutch is engaged the flowchart goes back to the initial analysis in **FIG. 3** table **90**. If the clutch is not fully engaged the flowchart proceeds to step **260** of the **FIG. 11** flowchart.

[0131] While the best mode for carrying out the invention has been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.

1. A hybrid electric vehicle comprising:

an internal combustion engine configured to rotate in a single direction to selectively drive a drive wheel and provide engine compression braking torque to the drive wheel;

an integrated starter generator motor connected to the internal combustion engine that rotates in a same direction as the internal combustion engine, the integrated starter generator motor adapted to selectively start the internal combustion engine;

a powertrain control module that controls the operating parameters of the internal combustion engine and the integrated starter generator motor, the powertrain control module being selectively actuated by a vehicle operator by actuating an accelerator pedal to request an accelerator torque;

an electro-hydraulic brake system for vehicle braking, the electro-hydraulic brake system being selectively actuated by the vehicle operator by actuating a vehicle brake pedal to request a brake torque;

an electronic brake controller for controlling the brake torque applied to the drive wheel by the electro-hydraulic brake system; and

a vehicle rollback sensor for determining a vehicle rollback state;

wherein the electronic brake controller actuates the electro-hydraulic, brake system in a hill holding condition, when vehicle rollback is detected, the requested brake torque is less than a first predetermined level, the requested accelerator torque is less than a second predetermined level, and the internal combustion engine is running.

2. The hybrid electric vehicle of claim 1 wherein the powertrain control module turns off the internal combustion engine in the hill holding condition.

3. The hybrid electric vehicle of claim 1 wherein, the internal combustion engine is started to provide torque to the drive wheel and an adaptive filter is applied to decrease the brake torque exerted by the electro-hydraulic braking system when the accelerator pedal is actuated and the hybrid electric vehicle is in a hill holding condition in which the hybrid electric vehicle is stationary on an inclined surface.

4. The hybrid electric vehicle of claim 1 further comprising a transmission having a plurality of gear ratios and wherein the electronic brake controller does not actuate the

electro-hydraulic brake system during a vehicle creep condition, in which the accelerator and brake pedals are not actuated, a gear ratio of the transmission is engaged and the powertrain control module determines whether vehicle creep will be powered by the internal combustion engine, the integrated starter generator motor or both;

5. The hybrid electric vehicle as set forth in claim 1 further comprising a transmission having a plurality of gear ratios and wherein the electronic brake controller actuates the electro-hydraulic brake system during a predetermined two footer condition in which, the hybrid electric vehicle is on a grade, the transmission is in gear, the accelerator pedal and the brake pedal are actuated, and the brake torque requested is greater than the accelerator torque requested.

6. The hybrid electric vehicle as set forth in claim 5, wherein the powertrain control module turns off the internal combustion engine in the predetermined two footer condition.

7. A method of hill holding a hybrid electric vehicle comprising:

measuring a vehicle rollback state based on a first signal from a vehicle rollback sensor;

measuring a brake torque request based on a second signal from a brake pedal sensor;

measuring an accelerator torque request based on a third signal from an accelerator pedal sensor

determining a running state of an internal combustion engine based on a fourth signal from an engine sensor

determining a vehicle creep output by comparing a fifth signal from a vehicle speed sensor to a predetermined vehicle creep speed:

determining whether hill holding condition exists based on the first, second, third, and fourth signals and the vehicle creep output;

actuating a set of electro-hydraulic brakes in the hill holding condition.

8. The method as set forth in claim 7 further comprising turning off the internal combustion engine while in the hill holding condition.

9. The method as set forth in claim 8 further comprising, de-actuating the electro-hydraulic brakes turning on the internal combustion engine and accelerating the hybrid electric vehicle using the internal combustion engine when the vehicle operator actuates the accelerator pedal

10. The method as set forth in claim 7 further comprising detecting a vehicle gear selection using a gear selection sensor calculating presence of a two footer condition when second signal is greater than the third signal, and actuating the electro-hydraulic brakes while in the two footer condition.

11. The method as set forth in claim 10 further comprising turning off the internal combustion engine in the two footer condition.

12. The method as set forth in claim 10 further comprising sensing a vehicle acceleration request using the accelerator pedal sensor, de-actuating the electro-hydraulic brakes turning on the internal combustion engine and accelerating the hybrid electric vehicle using the internal combustion engine.

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