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(54) LOCOMOTIVE AND RAIL CAR BRAKING REGENERATION AND PROPULSION SYSTEM AND METHOD

(76) Inventors: **Thomas Lee Bartley**, San Diego, CA (US); **Paul Everett Kaufman**, Bernardsville, NJ (US)

Correspondence Address:
PROCOPIO, CORY, HARGREAVES & SAVITCH LLP
530 B STREET, SUITE 2100
SAN DIEGO, CA 92101

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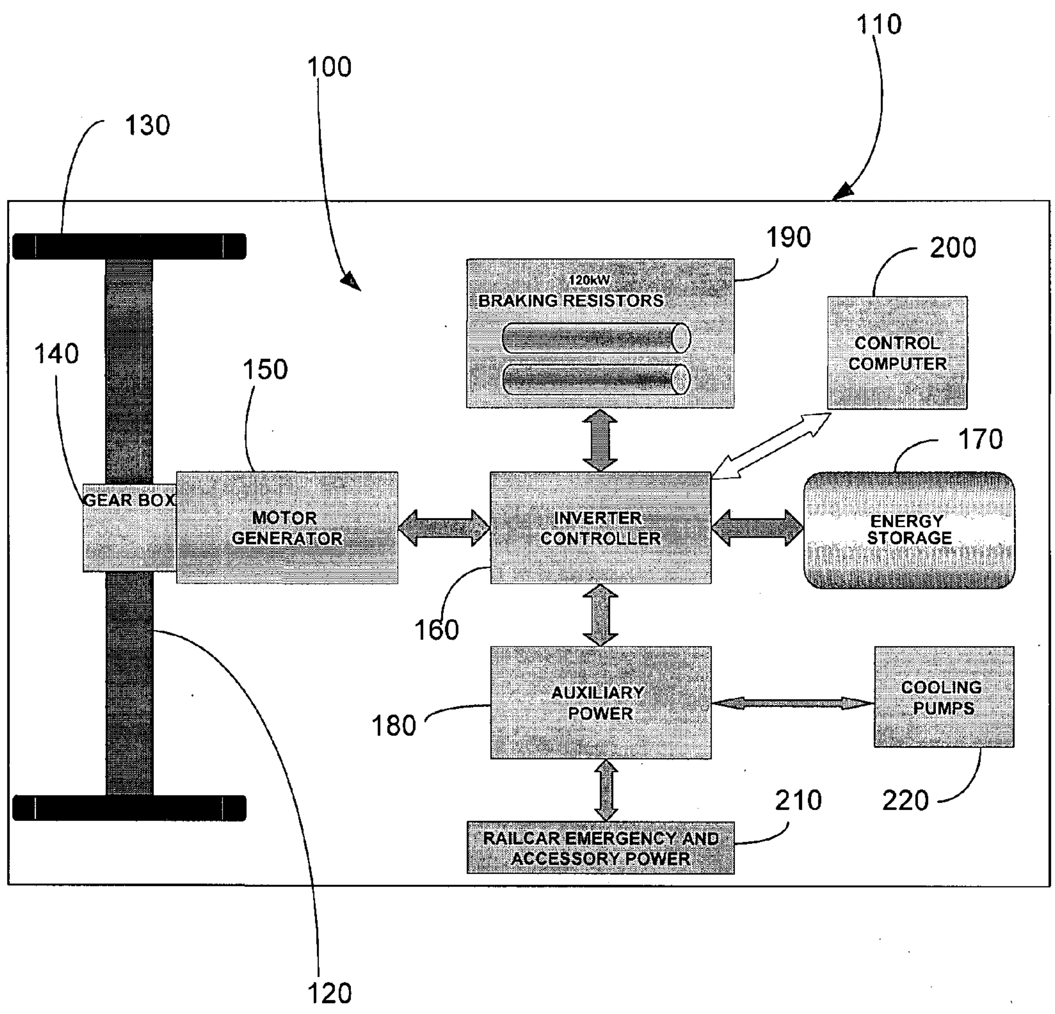
B61C 7/04 (2006.01)

(52) **U.S. Cl.** **105/35**; 903/903

(57) **ABSTRACT**

A method of using one or more electric locomotive and energy storage car combinations to assist a train consist up an uphill climb, the one or more electric locomotive and energy storage car combinations each having one or more diesel electric locomotives and one or more separate energy storage cars, including adding the one or more electric locomotive and energy storage car combinations to the train consist prior to an uphill climb; using the one or more electric locomotive and energy storage car combinations to assist the train consist up the uphill climb; and removing the one or more electric locomotive and energy storage car combinations from the train consist after the uphill climb. The one or more electric locomotive and energy storage car combinations are added to a train consist traveling downhill to assist with the downhill slowing through dynamic braking regeneration that is used to recharge the energy storage of the one or more separate energy storage cars.



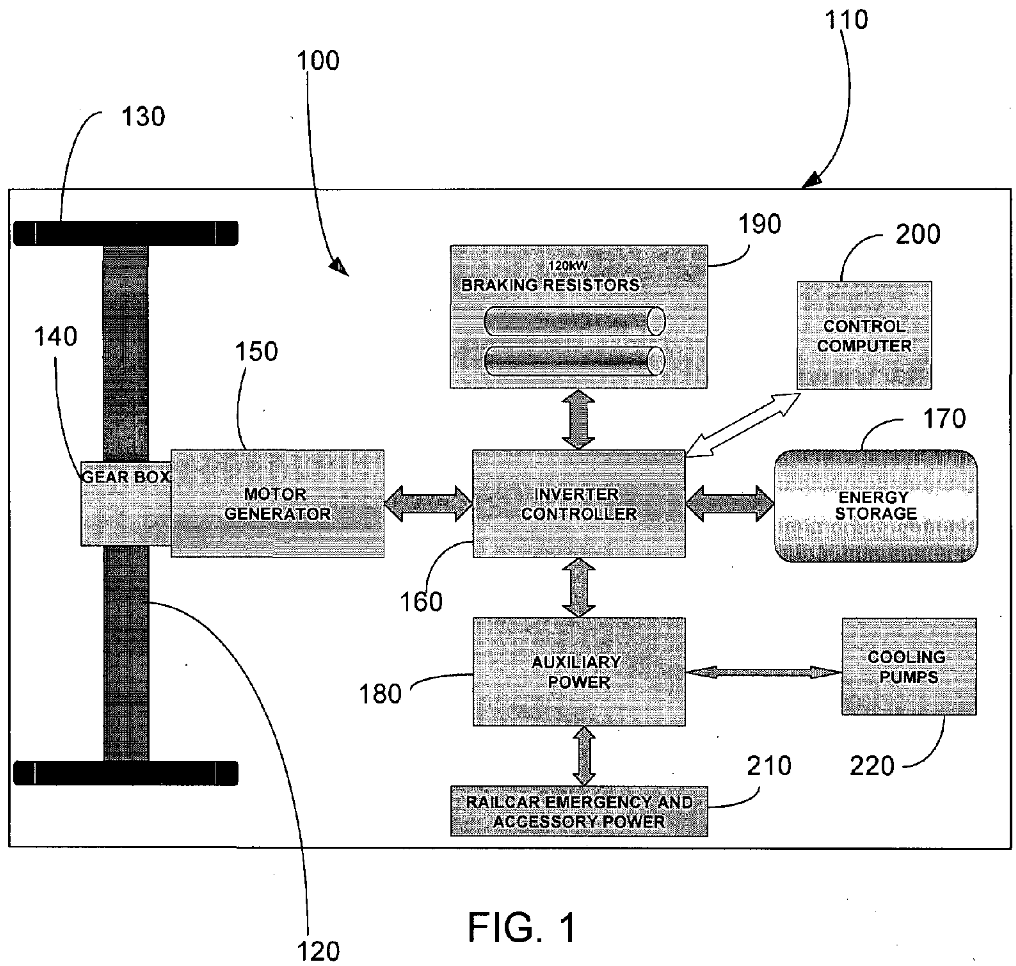

110
100
130
190
120kW
BRAKING RESISTORS
200
CONTROL COMPUTER
140
150
170
GEAR BOX
MOTOR GENERATOR
INVERTER CONTROLLER
ENERGY STORAGE
160
AUXILIARY POWER
COOLING PUMPS
180
210
220
RAILCAR EMERGENCY AND ACCESSORY POWER
120

FIG. 1

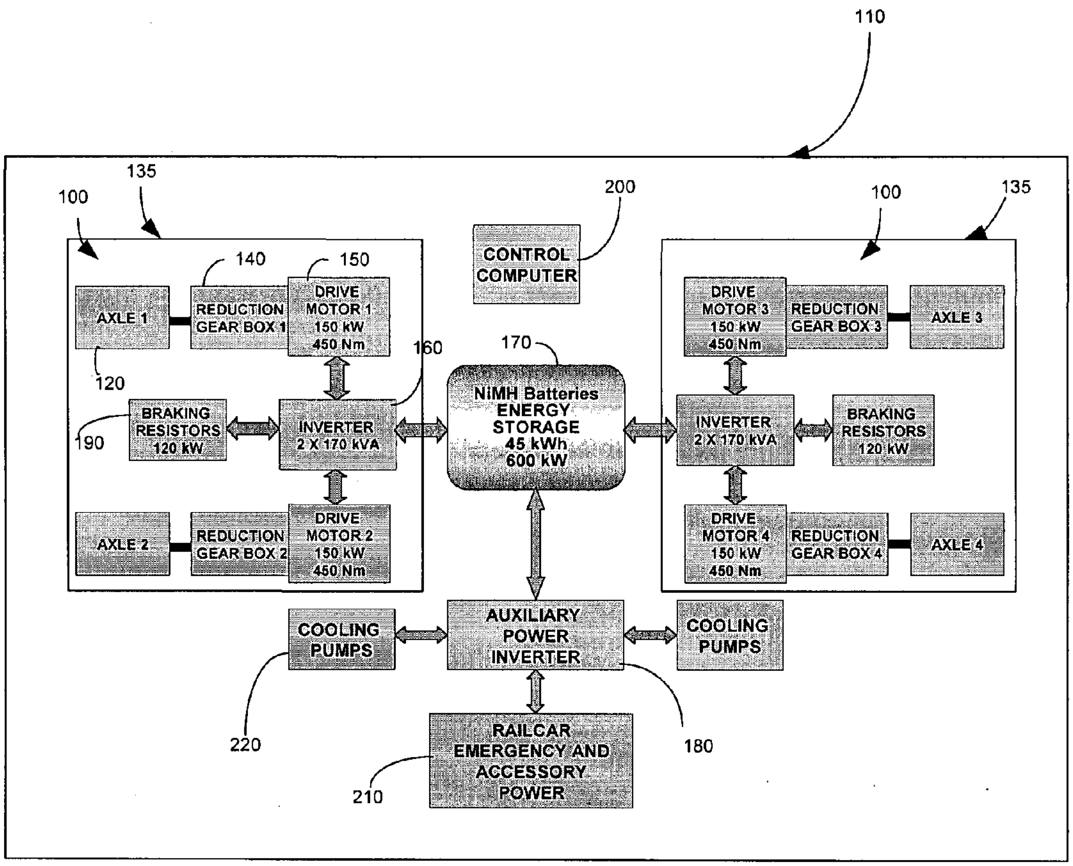

110
135
100
200
100
135
CONTROL COMPUTER
140
150
AXLE 1
REDUCTION GEAR BOX 1
DRIVE MOTOR 1 150 kW 450 Nm
160
170
DRIVE MOTOR 3 150 kW 450 Nm
REDUCTION GEAR BOX 3
AXLE 3
120
BRAKING RESISTORS 120 kW
INVERTER 2 X 170 kVA
NiMH Batteries ENERGY STORAGE 45 kWh 600 kW
INVERTER 2 X 170 kVA
BRAKING RESISTORS 120 kW
190
AXLE 2
REDUCTION GEAR BOX 2
DRIVE MOTOR 2 150 kW 450 Nm
DRIVE MOTOR 4 150 kW 450 Nm
REDUCTION GEAR BOX 4
AXLE 4
COOLING PUMPS
AUXILIARY POWER INVERTER
COOLING PUMPS
220
RAILCAR EMERGENCY AND ACCESSORY POWER
180
210

FIG. 2

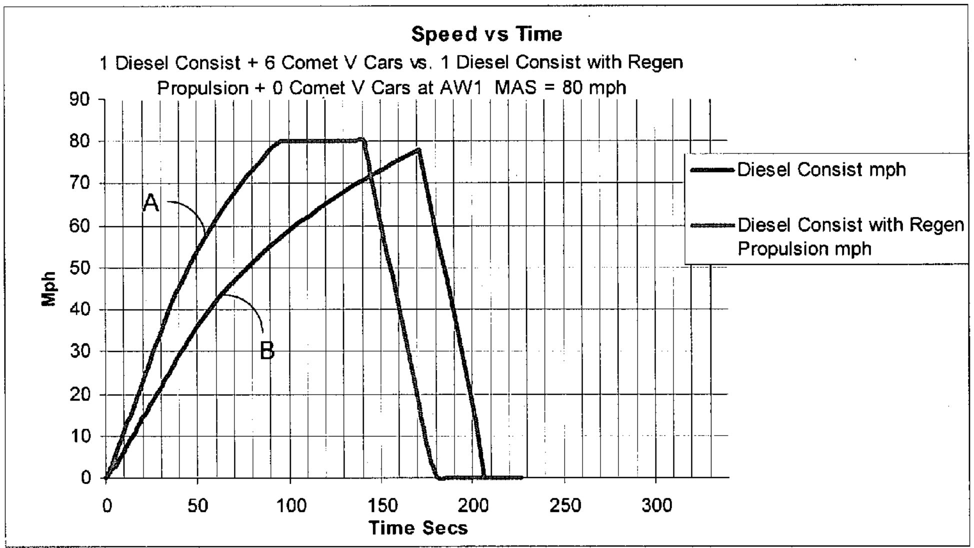

Speed vs Time
1 Diesel Consist + 6 Comet V Cars vs. 1 Diesel Consist with Regen Propulsion + 0 Comet V Cars at AW1 MAS = 80 mph
Mph
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Time Secs
A
B
Diesel Consist mph
Diesel Consist with Regen Propulsion mph

FIG. 3

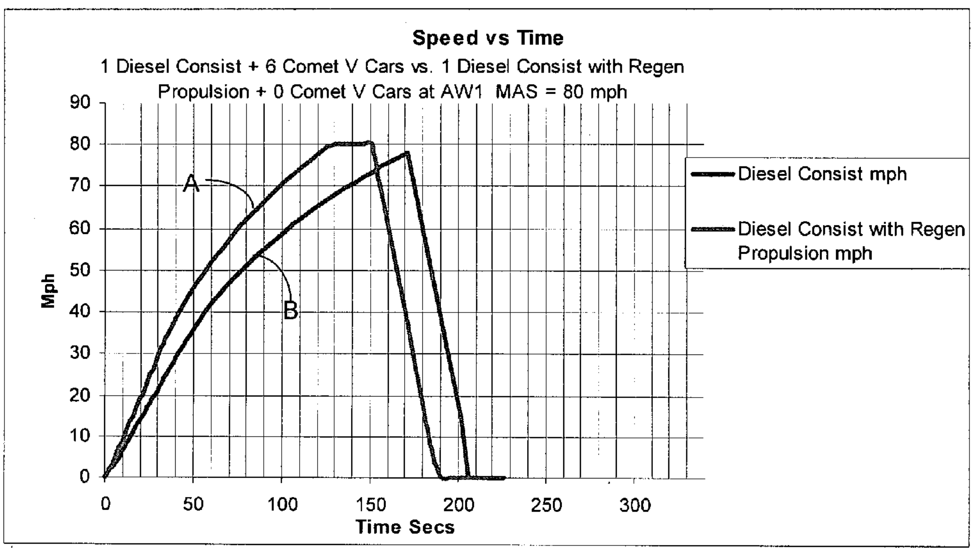

Speed vs Time
1 Diesel Consist + 6 Comet V Cars vs. 1 Diesel Consist with Regen Propulsion + 0 Comet V Cars at AW1 MAS = 80 mph
Mph
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Time Secs
A
B
Diesel Consist mph
Diesel Consist with Regen Propulsion mph

FIG. 4

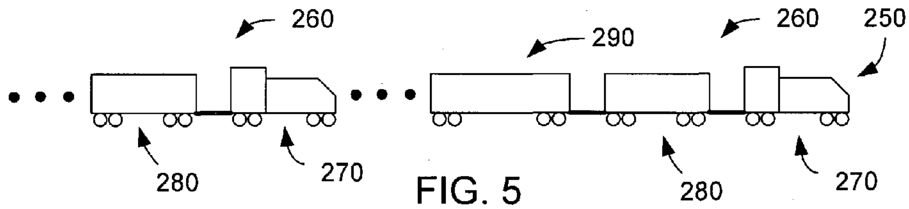


FIG. 5

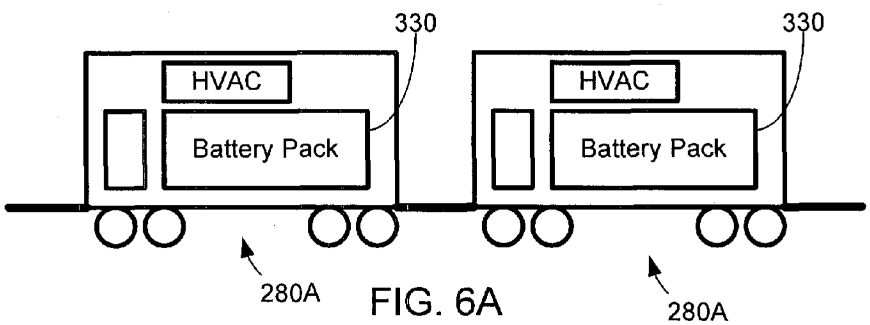


FIG. 6A

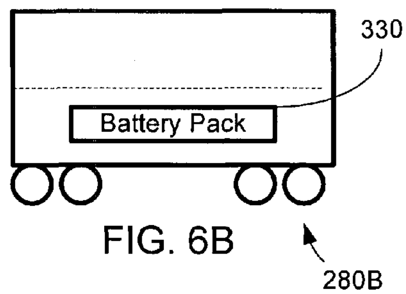


FIG. 6B

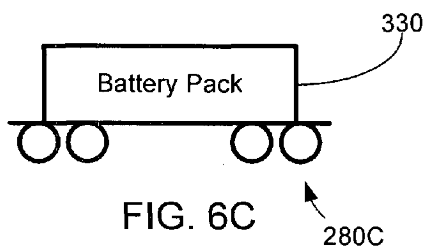


FIG. 6C

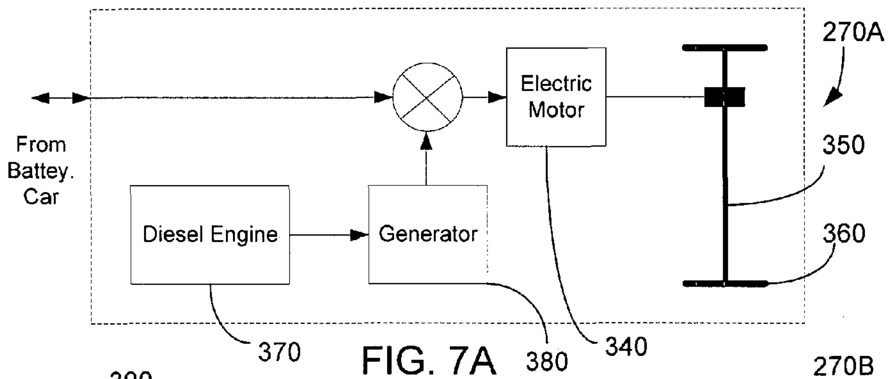


FIG. 7A

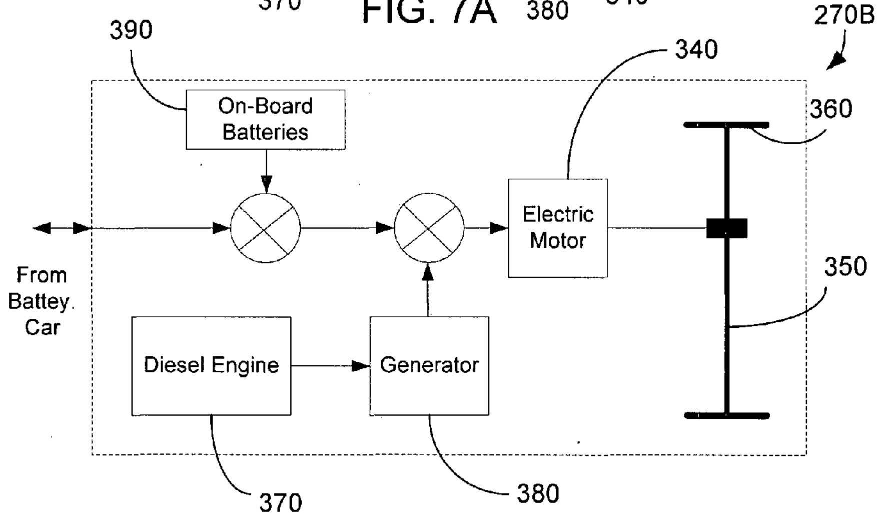


FIG. 7B

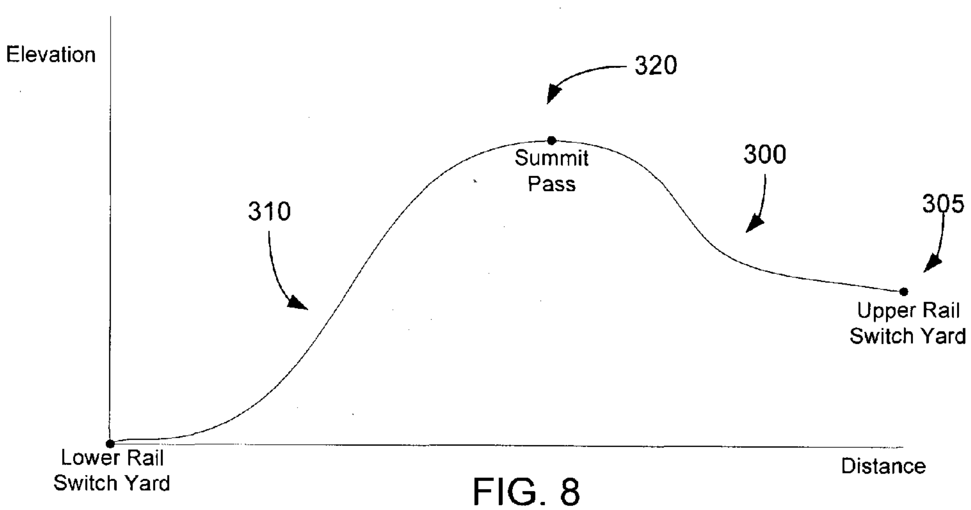


FIG. 8

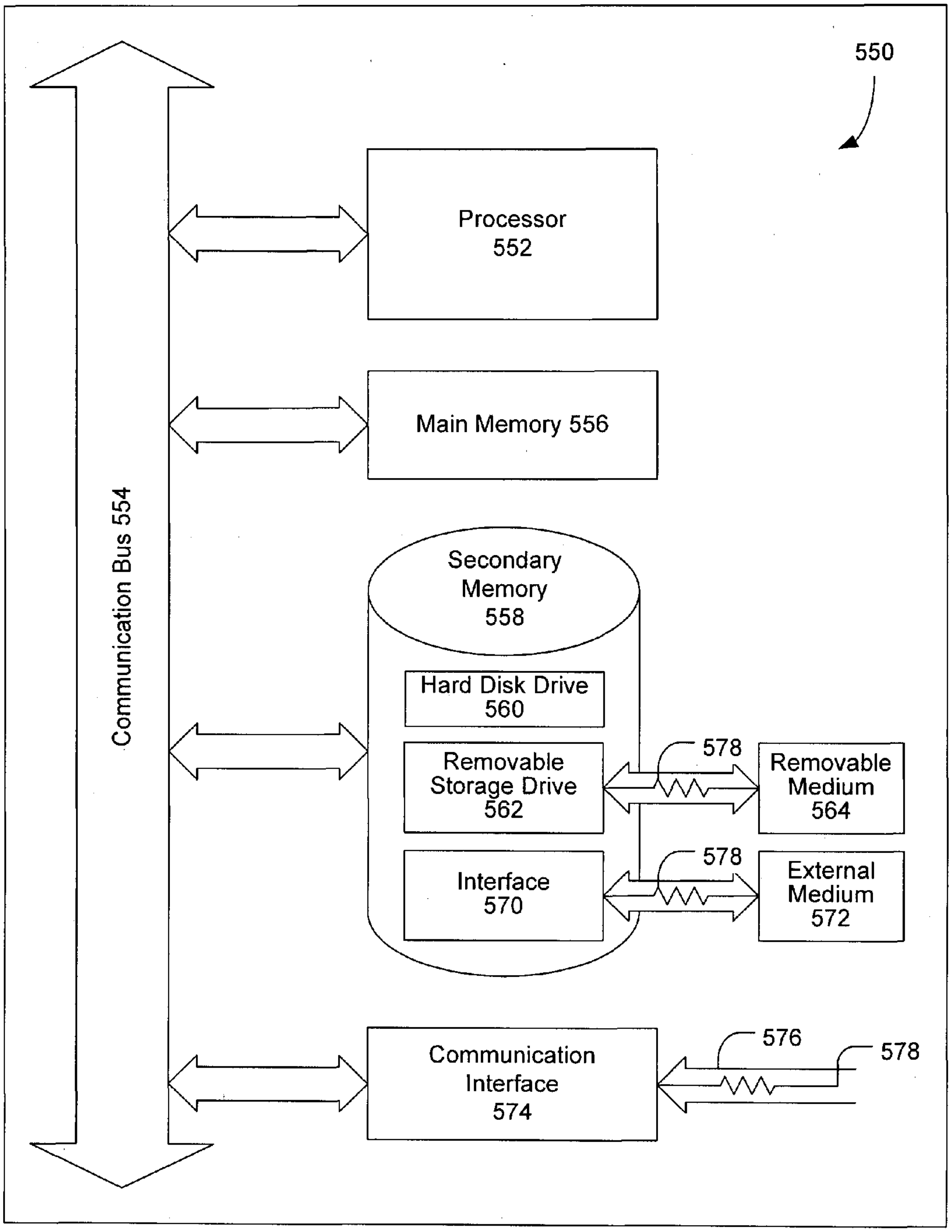

550
Processor
552
Main Memory 556
Secondary
Memory
558
Hard Disk Drive
560
Removable
Storage Drive
562
Interface
570
578
Removable
Medium
564
578
External
Medium
572
Communication Bus 554
Communication
Interface
574
576
578

FIG. 9

LOCOMOTIVE AND RAIL CAR BRAKING REGENERATION AND PROPULSION SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation-in-part application of U.S. patent application Ser. No. 11/420,064, filed May 24, 2006. This application claims the benefit of this prior application and this prior application is incorporated by reference herein as though set forth in full.

FIELD OF THE INVENTION

[0002] The field of the invention relates to locomotive assists to assist the propulsion of freight trains up long grades.

BACKGROUND OF INVENTION

[0003] Railroad operations often use one or more additional diesel locomotives to assist the propulsion of freight trains up long grades. At the top of the grades the locomotives are uncoupled from the train at a switch yard or siding and sent back to the bottom of the grade to assist additional trains requiring assistance up the long grades.

[0004] A problem with these diesel locomotives used to assist the propulsion of freight trains up long grades is that the diesel locomotives consume a lot of diesel fuel and pollute the environment during this frequently repeated process.

SUMMARY OF THE INVENTION

[0005] Accordingly, an aspect of the invention involves recycling freight train braking energy from downhill grades to use as an assist to the propulsion of freight trains traveling uphill. Rather than using one or more diesel locomotives to assist moving the train uphill, the method of this invention uses one or more electric powered locomotives with one or more attached energy storage car(s) to provide the electric power. The energy storage car(s) contain electrical energy storage, e. g., a battery pack, which is charged by the electric motor/generators of the locomotive from a previous descent of the grade. At the top of the grade the additional electric locomotives with attached energy storage car(s) are coupled to a descending train to provide dynamic braking and charge the energy storage device.

[0006] Another aspect of the invention involves a method of using one or more electric locomotive and energy storage car combinations to assist a train consist up an uphill climb. The one or more electric locomotive and energy storage car combinations each have one or more diesel electric locomotives and one or more separate energy storage cars. The method includes adding the one or more electric locomotive and energy storage car combinations to the train consist prior to an uphill climb; using the one or more electric locomotive and energy storage car combinations to assist the train consist up the uphill climb; and removing the one or more electric locomotive and energy storage car combinations from the train consist after the uphill climb.

[0007] A further aspect of the invention involves a method of using one or more energy storage cars to assist a train consist up an uphill climb, the consist having one or more electrically propelled locomotives for primary propulsion power. The method includes adding the one or more energy storage cars to the train consist prior to an uphill climb; using the one or more energy storage cars to supply additional power to the one or more dual mode locomotives to assist the train consist up the uphill climb; and removing the one or more energy storage cars from the train consist after the uphill climb.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The accompanying drawings, which are incorporated in and form a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of this invention.

[0009] FIG. **1** is a block diagram depicting an embodiment of an axle-mounted braking regeneration system for a passive rail car.

[0010] FIG. **2** is a block diagram depicting an embodiment of the axle-mounted braking regeneration system on a multi-axle passive rail car.

[0011] FIG. **3** is a graph of speed versus time for a diesel consist with a braking regeneration, energy storage, and acceleration system that runs at a continuous power level of 300 kW and consumes 8.4 kWh of energy, and a diesel consist without a braking regeneration energy storage and acceleration system.

[0012] FIG. **4** is another graph of speed versus time for a diesel consist with a braking regeneration, energy storage, and acceleration system that runs at a continuous power level of 133 kW and consumes 4.8 kWh of energy, and a diesel consist without a braking regeneration energy storage and acceleration system.

[0013] FIG. **5** is a block diagram of an embodiment of a train consist with multiple electric locomotive and battery car combinations.

[0014] FIG. **6**A is a diagram of an embodiment of multiple unit electric commuter rail cars configured to haul large battery packs rather than passengers.

[0015] FIG. **6**B is a diagram of an embodiment of a modified converted double deck commuter rail car with a battery pack mounted in the rail car to provide a low center of gravity.

[0016] FIG. **6**C is a diagram of an embodiment of a flat rail car or specialty built rail car chassis with a battery pack mounted thereon.

[0017] FIG. **7**A is a block diagram depicting an embodiment of a dual mode locomotive configured to accept electric power from an external battery car.

[0018] FIG. **7**B is a block diagram depicting an embodiment of a hybrid-electric locomotive configured to accept power from an external battery car.

[0019] FIG. **8** is a graph of an exemplary rail road elevation grade profile with a summit pass.

[0020] FIG. **9** is a block diagram illustrating an exemplary computer system that may be used in connection with the various embodiments described herein.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0021] With reference to FIGS. **1** and **2**, an axle-mounted braking regeneration energy storage and acceleration system **100** for a passive rail car **110** will be described. As used herein, "passive rail car" refers to rail car primarily propelled (e.g., pulled, pushed) by a separate driving rail car (e.g., locomotive). A passive rail car has no primary power unit for the conversion of chemical fuel into electric or kinetic energy used to propel the vehicle. A rail car is defined as a flange wheeled vehicle where the wheels roll on and are guided by rails on a road bed also known as a railroad track. Although the braking regeneration system **100** will be described as being axle-mounted, in alternative embodiments, the braking regeneration system **100** is mounted to other and/or additional structures of a passive rail car.

[0022] In the embodiment shown, the passive rail car **110** is a Comet V commuter rail car including multiple axles **120** with wheels **130** on opposite ends of the axles **120** and a friction braking system attached to multiple axles. The axles **120** rotate with rotation of the wheels **130**. In the embodiment shown in FIG. **2**, each rail car includes two trucks **135**. Each truck **135** carries two axles **120**. The drive and braking regeneration system **100** is repeated for each rail car truck **135**. Although the braking regeneration system **100** will be described as being used with a commuter rail car, in alternative embodiments, the braking regeneration system **100** is applied to other passive rail cars other than a commuter rail car such as, but not by way of limitation, flat car, tank car, box car, bulk material car, fuel car, container car, and caboose. Further, although the braking regeneration system **100** will be described at times as being used with a single passive individual rail car **110**, in alternative embodiments, the axle-mounted braking regeneration system **100** is applied to an entire train of (or linked series of) passive rail cars often referred to as a "consist".

[0023] The braking regeneration system **100** may include a gear box **140** and a motor/generator **150** for each axle **120**, a single dual-inverter/controller **160** per truck **135** (per two axles **120**), a single energy storage **170** per rail car **110**, a single auxiliary power inverter **180** per rail car, a single set of braking resistors **190** per truck, and a single control computer **200** per rail car **110**. In alternative embodiments, one or more of the number of trucks, axles, passive rail cars, braking regeneration systems, components of the braking regeneration system, and/or other elements described herein may vary from that shown and described herein. For example, but not by way of limitation, in an alternative embodiment, the braking regeneration system **100** includes one larger generator/motor incorporated on one axle **120** per rail car **110** instead of four smaller gearbox/motor/generator systems, one on each axle **120** of the rail car **110**.

[0024] The gear box **140** is mechanically connected to the axle **120**. The gear box **140** transfers torque between the axle **120** and the motor/generator **150**. At the same time as the gear box **140** provides a speed reduction to match the motor rpm to the axle shaft rpm, the torque increases by the same ratio as the speed reduction. In another alternative embodiment any required rpm speed reduction occurs in the motor connection to the axle **120** and a separate gear box **140** is not required. In yet other alternative embodiments the gear box **140** may include a clutch, multiple gears and a transmission. The single dual-inverter **160** controls both axle drive motor/generators **150** on the truck **135** and performs the power flow switching for the operation of the energy storage **170** and the braking resistors **210**. The motor/generator **150** along with the dual-inverter **160** can be Siemens ELFA components that are used on electric and hybrid-electric heavy-duty vehicles or other manufacturer's components used on electrically propelled trains. The motor/generator **150** generates energy during braking regeneration and powers the wheels **130** via the gear box **140** and axle **120** during an acceleration mode. In the embodiment shown, the motor/generator **150** is a combined, integrated motor and generator; however, in an alternative embodiment, motor/generator **150** includes physically separated motor and generator. The energy storage **170** includes a central energy storage system, which provides the energy storage for the energy needs of the whole rail car **110**. In alternative embodiments, one or more other types of energy storage systems are used such as, but not limited to, one or more or a combination of different battery chemistries, ultracapacitors, flywheels, or springs. A single inverter and power conditioning module **180** provides for the power needs **210** (e.g., rail car emergency power, rail car accessory power, cooling pumps **220**) on the rail car **110**. A typical commuter rail car accessory power draw may include lighting, heating, ventilation, air conditioning (HVAC), and plug-in power for electronic devices. The inverter and power conditioning module **180** may replace all or part of the power normally supplied by the head-end power (HEP) from the train locomotive.

[0025] The motor/generator **150**, the dual-inverter **100**, the energy storage **170**, the auxiliary power inverter **180**, and the braking resistors **190** may be liquid cooled. The liquid cooling loop, not shown, consists of liquid coolant, typically 50/50 water/ethylene glycol, a heat exchanger radiator with electric fans, and coolant pumps **220** to circulate the coolant. One or more coolant loops may be used on the rail car to manage the temperature of the electric power components **150**, **160**, the energy storage **170**, the power conditioning module **180**, and the HVAC system.

[0026] One of the cooling loops may include the braking resistors **190** that may serve two different functions. The braking resistors **190** are high power electrical resistors that dissipate power by heating a circulating fluid. The coolant heat may be dissipated in one or more of a heat exchanging radiator that radiates heat to the air passing through the heat exchanger, a heat exchanging radiator to heat passenger compartment air, a coolant loop through the energy storage to warm the energy storage **170**, and any other component on the rail car that would benefit from receiving additional heat from the coolant or heated air from a heat exchanger. When the motor/generator **150** is generating more power than can be stored in the energy storage **170** and used by the auxiliary power **180**, the inverter controller **160** can switch the excess power to the braking resistors to heat the circulating coolant. This may occur when the braking regeneration electromagnetic braking is used rather than add wear to the normal friction brakes. The braking resistors **190** may also be heated by the energy storage **170** and used to supply heat via the circulating fluid to a heat exchanger radiator for heating the passenger compartment of the commuter rail car.

[0027] The control computer **200** controls operation of the braking regeneration system **100** in the manner described herein. The braking regeneration systems **100** are controlled by the control computer **200** to initiate the acceleration and deceleration modes without lurching the rail cars **100** and compressing the couplers. Real time onboard sensors along with train communications provide input that is processed by processor(s) of the control computer **200** using the computer control algorithms related to applying power or drag to the consist.

[0028] The braking regeneration system **100** will now be described during deceleration and acceleration of the consist.

[0029] On deceleration, the generator **150** puts a drag on the axle **120** to slow down the rail car **110**. System controls prevent the rail cars **110** from abruptly compressing and extending the couplers. The individual rail cars **110** have their systems activated in an in-line or series configuration, one at a time, to prevent lurching. The independent control system may be transparent to the remainder of the consist or may operate as an integrated control system with other cars of the consist. Below a minimum speed, for example 3 mph, the braking regeneration system is turned off and the standard friction brake system is applied to stop the train.

[0030] The energy captured from deceleration would, in turn, be fed through the inverter/controllers **160** and into the nickel metal hydride (NiMH) battery energy storage system **170**. The charge and discharge levels of the nickel metal hydride (NiMH) battery energy storage system **170** may be limited to extend the cycle life of the energy storage system **170**. Ultracapacitors lack sufficient energy storage for this application. However, in an embodiment of the invention, an ultracapacitor pack is incorporated with the battery pack to protect and extend the life of the battery pack. Other types of energy storage, either singly or in combinations, can replace or be added to batteries and/or ultracapacitors.

[0031] On acceleration, the recycled stored energy is consumed as the motor/generators **150** are then configured as electric motors **150** to help the locomotive accelerate the consist. As an example of high power operation, the electric motor/generators **150** operate at least 60 seconds at a 282 kW power level before exhausting the scheduled amount of stored energy. A lower power level for a longer period of time during acceleration puts less stress on the components resulting in lower maintenance costs, increased system life, and improved reliability. The energy management system is designed to have infinite variability of control parameters to provide for optimization of the energy capture and recycle. The power is applied until the approximate 4.8 kWh (on average for this embodiment) are delivered for acceleration.

[0032] The performance curves in FIGS. **3** and **4** show the acceleration improvement that can be obtained by using the recycled braking regeneration energy from each rail car **110** to assist the diesel locomotive. Higher top speeds can be achieved and, thus, regenerate more braking energy.

[0033] The performance is provided by a simulation of a PL42 diesel locomotive with a six car Comet V consist. It is based on test track performance for a 0% grade. The 0% grade assumption is representative of an elevation energy neutral model for two way travel over the route.

[0034] FIG. **3** graphically shows the acceleration and braking performance for an average 2.6 mile distance between stations. The acceleration curve A for the braking regeneration system **100** is calculated at a continuous power level of 300 kW. As shown by the curves A, B, a diesel consist with the braking regeneration system **100** accelerates faster and has a greater average speed than a diesel consist without the braking regeneration system **100**. The performance curve A for the diesel consist with braking regeneration propulsion shows that the consist can achieve 60 mph in 60 seconds time and can reach maximum track speed inside of 100 seconds. The standard diesel consist (curve B) requires 105 seconds to reach 60 mph and cannot reach maximum track speed in 2.6 miles. This benefit is created by having the braking regeneration system **100** powering a total of 24 driven axles along with the locomotive versus four for just the locomotive. However, this performance uses 8.4 kWh of energy, more than is available from the average recycled braking regeneration. In the embodiment shown, the braking regeneration system **100** assists the rail car **110** in acceleration, but does not provide all required power to accelerate the rail car **110** to top speed. In an alternative embodiment, the braking regeneration system **100** provides all required power to accelerate the rail car **110** (or passive rail car) to top speed.

[0035] The graph shown in FIG. **4** is for a more efficient and practical configuration that consumes 4.8 kWh, the same amount of energy as is available from the average recycled braking regeneration event. In this example, the consist can achieve 60 mph in 75 seconds while operating at a continuous power level of 133 kW. This remains a very impressive acceleration curve for a diesel hauled 6-car consist that can achieve a maximum track speed of 80 mph in 130 seconds in a 2.6 mile average distance between stations.

[0036] These two graphs demonstrate the unique benefit of the braking regeneration system **100** and the almost infinite flexibility available to optimize energy capture. The backup emergency energy remains available at all times in spite of the energy consumed by acceleration. In addition, the anticipated battery life, due to a reduction in system stress, is increased.

[0037] One of the advantages of the braking regeneration system **100** is that it allows the elimination of the emergency power battery system on the rail car along with the battery charger. The braking regeneration system **100** is located under floor, so eliminating the existing emergency power battery system frees up space for the components of the braking regeneration system **100**, which may be retrofitted onto existing commuter rail cars **110** (and/or passive rail cars) and/or implemented into the original manufacture of the rail car (and/or passive rail cars) and/or rail car chassis/trucks. The energy storage **170** is managed to guarantee at least two hours of emergency backup energy at any time to comply with the Federal Railway Administration (FRA) regulations. This is done by establishing a depletion point of the energy storage system **170** at a level that insures that the energy storage system **170** will always be able to operate. Present rail cars are marginal or non compliant for providing two hours of emergency backup power when the rail car is just going into revenue service after sitting for a day. The capacity of the energy storage system **170** eliminates any concern about meeting the emergency backup power requirement.

[0038] With the amount of onboard energy storage, the braking regeneration system **100** will start up automatically from an overnight layover. Should the energy drop to a minimum threshold, three ways to start up the braking regeneration system **100** include: 1) pull or push the rail car **110** to turn the axles **120** and generators **150**, 2) use a Head-end Power (HEP) connection to provide electric power from the auxiliary engine generator in the locomotive, and 3) use a grid-based charger.

[0039] The first method is preferred and self managed. At start up, the generators **150** operate while the locomotive is pulling or pushing the rail car **110**. The generators **150** place an extra drag on the locomotive but would only be active until the energy storage system **170** was at an operating level ready to accept the first deceleration energy capture. Normally, the first train deceleration would bring the energy storage system **170** to an operating capacity level, preparing it for the next acceleration event. Each deceleration event adds to the energy storage **170** state of charge (SOC) to achieve a full working level.

[0040] If desired, the other two methods are available for emergency backup. An HEP approach is similar to the current practice: start up the HEP and let it charge the system. A grid based charger could be used to connect the energy storage system **170** to a wayside power supply.

[0041] By way of example but not limitation of other types of passive rail cars, another advantage of implementation of the braking regeneration system **100** on a Comet V commuter rail car is an estimated fuel savings of $22,500 annually and in excess of $675,000 over the 30-year life of the rail car. This is based on the following assumptions: one 125,000 pound rail car generates 4.7 kWh of energy savings per deceleration act from an average speed of 70 mph; assuming that the rail car is in service 320 days out of the year and makes four revenue service trips per day (two AM peak and two PM peak) plus weekend service and holiday service, there are 25,600 energy reclamation opportunities (320 days at four passenger trips a day equates to 1280 trips a year of local service stopping 20 times); 25,600 opportunities at 4.7 kWh per stop per car results in a total recoupable energy level of 120,320 kWh, annual fuel savings would be approximately 9,000 gallons of diesel fuel based on an energy efficiency of 30%; at $2.50 per gallon for diesel fuel, fuel savings would total $22,500 annually and in excess of $675,000 over the 30-year life of the rail car. Since fuel costs generally rise over time, future savings are expected to be even greater than $22,500 annually. An additional benefit associated with the reduction in fuel use would be the reduction in exhaust emissions that the combustion of that fuel would have generated.

[0042] Also, by way of example but not limitation of other types of passive rail cars, additional advantages of implementation of the braking regeneration system **100** on a Comet V commuter car include benefits to the subsystems on the rail car. For example, because the recovered energy has been taken away from the generation of heat and wear in the brake system, the brake wear and corresponding maintenance for the brake system is reduced. The rail car decelerates by capturing energy on deceleration, while reducing the burden on the braking system. In hybrid-electric buses that use brake regeneration, brake maintenance intervals have been at least doubled. Therefore, a conservative estimate is that a 50% savings would be realized on the maintenance of the rail car brake system. This would double the current reline interval of the rail car **110** along with the subsequent labor and materials required to perform the reline.

[0043] The emergency power system would be the next area of savings. By way of example but not limitation of other types of passive rail cars, the Comet V commuter rail car currently has a 74 volt DC emergency power system and battery charger on board each commuter rail car. Other rail cars may operate their emergency power system at other voltages. This method of generating and storing energy for an emergency application period of up to 2 hours could be completely eliminated from the rail car and would then be incorporated into the energy storage system **170** and the auxiliary power inverter and conditioning module **180**. The functions of the battery charger and the battery system are now assumed by the main energy storage **170** and can easily provide the emergency requirements. One clear benefit to this approach would be that the system **100** would be able to easily provide more than the two hours of required run time for the emergency backup at any point in time.

[0044] A more advanced potential for savings is the concept that the system **100** could actually be configured to provide adequate power so that each rail car **110** could provide energy for itself, thus, reducing head-end power (HEP) requirements. Under this concept, the braking regeneration energy storage system **100** could provide power for all hotel loads on the rail car **110** including HVAC, lighting and communications. Because the 50 kWh of battery energy storage supplies power to the rail car **110** through the inverter and power conditioning module **180**, the HEP requirements are significantly reduced or eliminated. If it is desired to transfer power from the locomotive to the passenger rail car, it can be done through the wheels **130** by using the braking generator **150**. This approach would reduce the electrical load and extend the life of the HEP system while saving HEP fuel and reducing diesel engine emissions. Recent locomotive designs have completely eliminated the use of an HEP engine-generator and, instead, operate the HEP generator from a power take off of the main diesel engine of the locomotive. In this type of system the braking regeneration system eliminates the need for the additional generator and could contribute to the reduction in total overall horsepower required of the main diesel engine of the locomotive, thus, further reducing fuel consumption and diesel exhaust emissions.

[0045] An alternative embodiment of a braking regeneration system uses hydraulic components where a hydraulic motor/pump replaces the electric motor/generator **150**; a hydraulic valve controller replaces the electric inverter switch controller **160**; a hydraulic accumulator replaces the energy storage **170**; and a hydraulic retarder replaces the braking resistors **190**. The hydraulic retarder requires some form of liquid or air heat exchanger to dissipate energy. In its simplest form a hydraulic braking regeneration system is the hydraulic analog of the electric braking regeneration system and is a potentially lower cost alternative to an electric braking regeneration system to save fuel costs. Such systems have been built for medium duty hydraulic truck drive systems.

[0046] The amount of energy stored in an accumulator is a function of the accumulator pressure and the volume of fluid stored in the accumulator. The temperature of the system, the type of gas used to pre-charge the system, and the initial pressure of the pre-charge gas can impact the amount of energy stored at a given accumulator pressure. The equation to calculate the energy stored in an accumulator is:

$$E=(Pc*Vc-(P*Vc*((Pc/P)\hat{}(1/k))))/(1-k)$$

[0047] Where: E is the energy stored in the accumulator.

[0048] Pc is the pre-charge pressure of the accumulator.

[0049] Vc is the volume of gas in the accumulator at pre-charge.

[0050] P is the current accumulator pressure. And

[0051] k is ratio of specific heats (Boltzmann constant) for the pre-charge gas.

[0052] The value of k for a gas varies with pressure at high pressures;

[0053] values of 1.3 to 1.8 may be used for typical gases and pressures.

The pre-charge gas, pre-charge pressure, and volume of gas in the accumulator will not vary on a rail car over a route cycle. Thus, the State Of Charge (SOC) of a hydraulic accumulator is a function only of its pressure. Although the accumulator pressure will vary with charge gas temperature, the SOC can be determined with acceptable accuracy even if this term is ignored.

[0054] A hydraulic braking regeneration system is potentially less expensive than an electric braking regeneration system, but, depending on the practical limits of the size of the accumulator, may have limited energy storage. In concept, a hydraulic motor generator would replace the auxiliary power inverter **180** to power the auxiliary emergency and accessory electrical loads **210**.

[0055] With reference to FIG. **5**, an embodiment of a train consist **250** with multiple electrically propelled locomotive (e.g. diesel electric-powered locomotive) and battery car combinations **260** and method of recovering and recycling braking energy of the consist **250** operating over a long grade with a significant elevation change will be described. The train consist **250** is a long train of one or more electrically propelled locomotives **270**, battery cars **280**, and passive rail cars **290** (e.g., passive rail car(s) **110**). Each multiple electrically propelled locomotive and battery car combination **260** includes at least one electrically propelled locomotive **270** and at least one battery car **280**. As an alternative to putting all the energy storage on individual passive rail cars as previously described, all the energy storage or additional energy storage is put in a battery car **280** connected to the electrically propelled locomotive **270**.

[0056] Railroad operations often use one or more additional diesel electric locomotives to assist the propulsion of freight trains up long grades. At the top of or some point beyond the summit of the grades the locomotives are uncoupled from the train at a switch yard or siding and sent back to the bottom of the grade, where they may be used again for the same purpose with the next freight train requiring assistance.

[0057] With reference additionally to FIG. **8**, in this aspect of the invention, freight train braking energy from the downhill grade **310** is recycled to use as an assist in the propulsion of freight trains traveling uphill **310**. Similarly, freight train braking energy from the downhill grade **300** past the summit **320** is recycled to use as an assist in the propulsion of freight trains traveling uphill **300**. Rather than using one or more diesel electric-powered locomotives to assist moving the train uphill, one or more diesel electric-powered locomotives **270** (or other electric-powered locomotive(s)) with attached energy storage car(s) **280** are used to provide the electric power to assist moving the train uphill **310**, **300**. At an upper rail switch yard **305**, one or more additional diesel electric-powered locomotives **270** with attached energy storage car(s) **280** are coupled to a descending train first traveling uphill **300** to the summit **320** then traveling downhill **310** to provide dynamic braking and charge the energy storage of the energy storage cars **280**. The one or more additional diesel electric-powered locomotives **270** with attached energy storage car(s) **280** may be the same or different than the one or more additional diesel electric-powered locomotives **270** with attached energy storage car(s) **280** that assisted in moving an ascending train uphill. Although the external battery car(s) **280** have been described as obtaining energy from braking regeneration by the diesel electric locomotive during travel downhill **310**, **300**, additionally or alternatively, the external battery car(s) **280** obtain energy from braking regeneration by one or more passive rail cars **110** as described above with respect to FIGS. **1-4**. Additionally or alternatively, one or more passive rail cars **110** such as those described above with respect to FIGS. **1-4** are used to assist moving the train (e.g., uphill, on level ground, etc.).

[0058] The battery cars **280** and associated electric locomotives **270** of the combinations **260** are strategically placed at railroad grades where they ascend and descend continually with the passing railroad traffic. Additionally or alternatively, only the battery cars **280** are strategically placed at railroad grades where they ascend and descend continually with passing railroad traffic hauled by a diesel electric-powered locomotive that has been configured to accept energy from an energy storage car.

[0059] With reference to FIGS. **6A-6C**, a number of different embodiments of energy storage cars **280A**, **280B**, **280C** will be described. The energy storage cars **280A**, **280B**, **280C** contain electrical energy storage **330**, e. g., a battery pack, which is charged by electric motor(s)/generator(s) of the locomotive **270** (and/or from electric motor(s)/generator(s) of other rail cars) from a previous descent of the grade.

[0060] With reference to FIG. **6A**, an embodiment of multiple unit electric commuter rail cars **280A** configured to haul large battery packs **330** rather than passengers is shown. The HVAC (heating, ventilation, and air conditioning) environmental control system originally installed in the commuter rail car for passenger comfort may be retained for the battery pack operation. The electric commuter rail cars **280A** are configured to operate in pairs to share subsystems, but each car includes its own motor(s)/generator(s) for propulsion and dynamic braking regeneration that can charge and accept energy from the battery pack in place of, or in addition to, an electrically propelled locomotive.

[0061] With reference to FIG. **6B**, an embodiment of a modified converted double deck commuter rail car **280B** with a battery pack **330** mounted in the rail car **280B** to provide a low center of gravity is shown. Similar to commuter rail car **280A**, the HVAC environmental control system originally installed in the commuter rail car for passenger comfort may be retained for the battery pack operation.

[0062] With reference to FIG. **6C**, an embodiment of a flat rail car **280C** or specialty built rail car chassis **280C** with a battery pack **330** mounted thereon is shown. The battery pack **330** may include an enclosed shelter and battery mounting structure, and HVAC environmental control system for the battery pack.

[0063] With reference to FIGS. **7A** and **7B**, a number of different embodiments of diesel electric locomotives **270A**, **270B** will be described. The locomotives **270A**, **270B** include one or more electric motors **340** coupled to an axle **350** for driving the locomotive drive wheels **360**. One or more diesel engine(s) **370** power one or more generator(s) **380** that supply electric power for powering the electric motor **340**. Although not shown, the locomotives **270** include an onboard diesel fuel tank for supplying fuel to the diesel engine **370**.

[0064] With reference to FIG. **7A**, an embodiment of a dual mode locomotive **270A** configured as a multi mode locomotive to accept electric power from the external battery car **280** is shown. The dual mode locomotive **270A** uses either diesel electric or all electric power to power the electric motor(s) **340** to turn the drive wheels **250** in pushing and pulling operations. The multi mode locomotive **270**A is a modified dual mode locomotive configured to combine diesel electric with battery electric power to power the electric motors(s) **340** to turn the drive wheels **250** in pulling and pushing operations. Through braking regeneration, the motor(s)/generator(s) **340** of the locomotive **270**A charge the energy storage(s) **330** of the external battery car(s) **280**. This way, freight train braking energy from downhill grades is recycled to use as an assist to the propulsion of freight trains traveling uphill. In another embodiment the multi mode locomotive **270**A or the hybrid locomotive **270**B is configured to allow the diesel engine-generator to charge the batteries in the energy storage car (and/or the on-board energy storage **390**) for special operations such as low noise travel with the engine idling or turned off.

[0065] With reference to FIG. **7**B, an embodiment of a hybrid-electric locomotive **270**B configured to accept power from an external battery car **280** is shown. The hybrid-electric locomotive **270**B includes on-board energy storage **390** (e.g., batteries) that are charged by the generator **380** for supplying power to the motor(s) **340** to turn the axle **350** and the drive wheels **360** in pushing and pulling operations. Similar to the locomotive **270**A, through braking regeneration, the motor(s)/generator(s) **340** of the locomotive **270**B charge the energy storage(s) **330** of the external battery car(s) **280** (and/or the on-board energy storage **390**). This way, freight train braking energy from downhill grades is recycled to use as an assist to the propulsion of freight trains traveling uphill.

[0066] GG and GK, "Green Goat," hybrid-electric rail yard switching locomotives have been built by RailPower Technologies Corporation. These "switchers" have up to 840 kWh of energy storage on-board with maintenance free lead-acid batteries in addition to a 200 to 500 KW diesel generator set. The weight is about 275,000 pounds with an equivalent 2000 horsepower. The inventors have determined that these hybrid locomotives could be used/modified in accordance with the principles of the invention described herein to perform a grade "assist" function.

[0067] The following are some sample calculations by the inventors in determining potential energy savings with the present invention.

[0068] Equating energy saved to diesel fuel gallons and fuel costs follows below:

- **[0069]** 1 gallon diesel=130,000 Btu
- **[0070]** 1 kWh=3414 Btu
- **[0071]** 1 gallon diesel=38.1 kWh
- **[0072]** Energy conversion efficiency of diesel electric locomotive=26%
- **[0073]** 1 gallon diesel=10 kWh recycled energy
- **[0074]** 1 MWh recycled energy=100 gallons diesel fuel saved

[0075] Li ion battery energy storage parameters:

- **[0076]** From A123 Corporation data sheets:
  - **[0077]** 10-15 year calendar life
  - **[0078]** 3000-7000 life cycles at 100% DoD (Depth of Discharge)
  - **[0079]** 220 Wh/liter (6.2 kWh/cu. ft.)
  - **[0080]** 110 Wh/kg (50 Wh/lb)
- **[0081]** From Report ANL/ESD-42, "Costs of Lithium-ion Batteries for Vehicles," by Linda Gaines and Roy Cuenca, Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Ill. 60439, US Department of Energy, May 2000:
  - **[0082]** Baseline Lithium-ion battery cost—$706/kWh
  - **[0083]** USABC Goal—$150/kWh (US Advanced Battery Consortium)

[0084] Recycling freight train braking energy from downhill grades to use as an assist to the propulsion of freight trains traveling uphill saves a considerable amount of energy compared to using one or more additional diesel electric-powered locomotives to assist the propulsion of freight trains up long grades. Rather than using one or more diesel electric-powered locomotives to assist moving the train uphill, the one or more multi mode diesel electric-powered locomotives with one or more attached energy storage cars assist moving the train uphill. The energy storage car contains electrical energy storage, e. g., a battery pack, which is charged by the electric motor/generators of the locomotive or other cars from a previous descent of the grade. At the top of the grade the additional electric locomotives with attached energy storage cars are coupled to a descending train to provide dynamic braking and charge the energy storage.

[0085] By way of example, but not limitation, one typical railroad grade extends from San Bernardino, Calif. (elevation 1118 feet) up the El Cajon Pass Summit (elevation 3855 feet), for an elevation change of 2735 feet, and back down to the switch yard at Barstow, Calif. (elevation 2163 feet). The 2735 foot elevation descent from the summit to the switch yard at San Bernardino represents about 207 kWh of energy for a loaded freight car of 200,000 pounds.

$$1\text{ foot-pound}=3.766\times10^{-7}\text{ kWh}$$

$$200{,}000\text{ pounds}\times2735\text{ feet}=206\text{ kWh}$$

Therefore, 20 rail cars descending the grade have about 4.1 megawatt hours (MWh) of energy. For a long consist of 100 rail cars the energy is about 20.6 MWh not including the locomotives.

[0086] Assuming that 50% of the energy is recoverable from dynamic braking regeneration capture and recycling, about 103 kWh of useable energy storage is required per rail car. Operating at 50% depth of discharge (DoD) to get 12,000 life cycles the energy storage requirement is 206 kWh per 200,000 pound freight car. From the Lithium-ion battery parameters the battery pack characteristics are:

- **[0087]** Weight—4120 lbs
- **[0088]** Volume—33.2 cu. ft.
- **[0089]** Baseline Cost—$145,436

[0090] Goal Cost—$30,900

[0091] At 80% battery efficiency each of the above cycles saves 81.6 kWh. At a diesel fuel cost of $3.00/gallon, the break even point ($145,436/$3.00=48,479) is a fuel savings of 48,479 gallons diesel or 485 MWh. At 81.6 kWh per cycle the break even point is 5944 battery energy storage cycles. This is well within the expected 12,000 life cycles and suggests that another $148,000 of diesel fuel savings (at $3.00/gallon) would accumulate before battery replacement to help pay for the cost of installing the batteries, motor/generators, and control equipment. With the anticipated increasing future fuel prices and decreasing future energy storage prices the projected savings increases beyond these estimates. However, if the energy storage was placed on each individual rail car, thereby adding significant weight to the rail car, this savings is achieved only if the individual rail car experiences thousands of life cycles within the 10 year calendar life of the batteries.

[0092] The energy savings can be more cost effectively achieved when the battery cars and associated electric locomotives (or the battery cars only) are strategically placed at railroad grades where they ascend and descend continually with the passing railroad traffic. For the above El Cajon Summit example, one method is to have an energy storage car for every 20 freight cars. The required energy storage characteristics are 20 times those for a single car:

[0093] Energy Storage—2060 kWh

[0094] Weight—82,400 lbs

[0095] Volume—664 cu. ft.

[0096] Baseline Cost—$2.91 million

[0097] USABC Goal Cost—$618,000

[0098] Similar to the El Cajon Pass summit grade described above, most grade applications will experience 1½ to 2 cycles per round trip because of the high point (summit) in the middle and lower points at each of the rail switch yards. Therefore, estimating 1000 cycles per year, the fuel savings would pay for the batteries in less than 6 years and at the end of 12 years (12,000 cycle life of the batteries) there would be an extra fuel savings of $2.96 million that would have paid back more than the capital cost of building the energy storage freight car. With the anticipated increasing fuel costs and decreasing energy storage costs the extra fuel savings will continue to increase. Extending this projection from year 13 to end of year 36 (estimated rail car life) results in an estimated $6 million diesel fuel cost savings ($250,000 per year average over years 13 to 36) per energy storage rail car beyond the capital costs and the energy storage costs. The estimated energy savings is 1632 MWh per energy storage rail car per year, or 163,200 gallons of diesel fuel per energy storage rail car per year.

[0099] For fewer charge/discharge cycles per year or for different energy storage life characteristics, the size of the energy storage can be decreased for a greater DoD such that the energy storage cycle life and the energy storage calendar life match, thus saving the overall energy storage costs while providing the required energy storage. Alternatively, the energy storage can be sized for a greater or lesser number of rail cars than the 20 rail cars described in the example above.

[0100] FIG. **9** is a block diagram illustrating an exemplary computer system **550** that may be used in connection with the various embodiments described herein. For example, the computer system **550** (or various components or combinations of components of the computer system **550**) may be used in conjunction with the control computers, controllers, or to control the functions described herein. However, other computer systems and/or architectures may be used, as will be clear to those skilled in the art.

[0101] The computer system **550** preferably includes one or more processors, such as processor **552**. Additional processors may be provided, such as an auxiliary processor to manage input/output, an auxiliary processor to perform floating point mathematical operations, a special-purpose microprocessor having an architecture suitable for fast execution of signal processing algorithms (e.g., digital signal processor), a slave processor subordinate to the main processing system (e.g., back-end processor), an additional microprocessor or controller for dual or multiple processor systems, or a coprocessor. Such auxiliary processors may be discrete processors or may be integrated with the processor **552**.

[0102] The processor **552** is preferably connected to a communication bus **554**. The communication bus **554** may include a data channel for facilitating information transfer between storage and other peripheral components of the computer system **550**. The communication bus **554** further may provide a set of signals used for communication with the processor **552**, including a data bus, address bus, and control bus (not shown). The communication bus **554** may comprise any standard or non-standard bus architecture such as, for example, bus architectures compliant with industry standard architecture ("ISA"), extended industry standard architecture ("EISA"), Micro Channel Architecture ("MCA"), peripheral component interconnect ("PCI") local bus, or standards promulgated by the Institute of Electrical and Electronics Engineers ("IEEE") including IEEE 488 general-purpose interface bus ("GPIB"), IEEE 696/S-100, and the like.

[0103] Computer system **550** preferably includes a main memory **556** and may also include a secondary memory **558**. The main memory **556** provides storage of instructions and data for programs executing on the processor **552**. The main memory **556** is typically semiconductor-based memory such as dynamic random access memory ("DRAM") and/or static random access memory ("SRAM"). Other semiconductor-based memory types include, for example, synchronous dynamic random access memory ("SDRAM"), Rambus dynamic random access memory ("RDRAM"), ferroelectric random access memory ("FRAM"), and the like, including read only memory ("ROM").

[0104] The secondary memory **558** may optionally include a hard disk drive **560** and/or a removable storage drive **562**, for example a floppy disk drive, a magnetic tape drive, a compact disc ("CD") drive, a digital versatile disc ("DVD") drive, etc. The removable storage drive **562** reads from and/or writes to a removable storage medium **564** in a well-known manner. Removable storage medium **564** may be, for example, a floppy disk, magnetic tape, CD, DVD, etc.

[0105] The removable storage medium **564** is preferably a computer readable medium having stored thereon computer executable code (i.e., software) and/or data. The computer software or data stored on the removable storage medium **564** is read into the computer system **550** as electrical communication signals **578**.

[0106] In alternative embodiments, secondary memory **558** may include other similar means for allowing computer programs or other data or instructions to be loaded into the computer system **550**. Such means may include, for example, an external storage medium **572** and an interface **570**. Examples of external storage medium **572** may include an external hard disk drive or an external optical drive, or and external magneto-optical drive.

[0107] Other examples of secondary memory **558** may include semiconductor-based memory such as programmable read-only memory ("PROM"), erasable programmable read-only memory ("EPROM"), electrically erasable read-only memory ("EEPROM"), or flash memory (block oriented memory similar to EEPROM). Also included are any other removable storage units **572** and interfaces **570**, which allow software and data to be transferred from the removable storage unit **572** to the computer system **550**.

[0108] Computer system **550** may also include a communication interface **574**. The communication interface **574** allows software and data to be transferred between computer system **550** and external devices (e.g. printers), networks, or information sources. For example, computer software or executable code may be transferred to computer system **550** from a network server via communication interface **574**. Examples of communication interface **574** include a modem, a network interface card ("NIC"), a communications port, a PCMCIA slot and card, an infrared interface, and an IEEE 1394 fire-wire, just to name a few.

[0109] Communication interface **574** preferably implements industry promulgated protocol standards, such as Ethernet IEEE 802 standards, Fiber Channel, digital subscriber line ("DSL"), asynchronous digital subscriber line ("ADSL"), frame relay, asynchronous transfer mode ("ATM"), integrated digital services network ("ISDN"), personal communications services ("PCS"), transmission control protocol/Internet protocol ("TCP/IP"), serial line Internet protocol/point to point protocol ("SLIP/PPP"), and so on, but may also implement customized or non-standard interface protocols as well.

[0110] Software and data transferred via communication interface **574** are generally in the form of electrical communication signals **578**. These signals **578** are preferably provided to communication interface **574** via a communication channel **576**. Communication channel **576** carries signals **578** and can be implemented using a variety of wired or wireless communication means including wire or cable, fiber optics, conventional phone line, cellular phone link, wireless data communication link, radio frequency (RF) link, or infrared link, just to name a few.

[0111] Computer executable code (i.e., computer programs or software) is stored in the main memory **556** and/or the secondary memory **558**. Computer programs can also be received via communication interface **574** and stored in the main memory **556** and/or the secondary memory **558**. Such computer programs, when executed, enable the computer system **550** to perform the various functions of the present invention as previously described.

[0112] In this description, the term "computer readable medium" is used to refer to any media used to provide computer executable code (e.g., software and computer programs) to the computer system **550**. Examples of these media include main memory **556**, secondary memory **558** (including hard disk drive **560**, removable storage medium **564**, and external storage medium **572**), and any peripheral device communicatively coupled with communication interface **574** (including a network information server or other network device). These computer readable mediums are means for providing executable code, programming instructions, and software to the computer system **550**.

[0113] In an embodiment that is implemented using software, the software may be stored on a computer readable medium and loaded into computer system **550** by way of removable storage drive **562**, interface **570**, or communication interface **574**. In such an embodiment, the software is loaded into the computer system **550** in the form of electrical communication signals **578**. The software, when executed by the processor **552**, preferably causes the processor **552** to perform the inventive features and functions previously described herein.

[0114] Various embodiments may also be implemented primarily in hardware using, for example, components such as application specific integrated circuits ("ASICs"), or field programmable gate arrays ("FPGAs"). Implementation of a hardware state machine capable of performing the functions described herein will also be apparent to those skilled in the relevant art. Various embodiments may also be implemented using a combination of both hardware and software.

[0115] Furthermore, those of skill in the art will appreciate that the various illustrative logical blocks, modules, circuits, and method steps described in connection with the above described figures and the embodiments disclosed herein can often be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled persons can implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the invention. In addition, the grouping of functions within a module, block, circuit or step is for ease of description. Specific functions or steps can be moved from one module, block or circuit to another without departing from the invention.

[0116] Moreover, the various illustrative logical blocks, modules, and methods described in connection with the embodiments disclosed herein can be implemented or performed with a general purpose processor, a digital signal processor ("DSP"), an ASIC, FPGA or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor can be a microprocessor, but in the alternative, the processor can be any processor, controller, microcontroller, or state machine. A processor can also be implemented as a combination of computing devices, for example, a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[0117] Additionally, the steps of a method or algorithm described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module can reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium including a network storage medium. An exemplary storage medium can be coupled to the processor such the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor. The processor and the storage medium can also reside in an ASIC.

[0118] The above description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles described herein can be applied to other embodiments without departing from the spirit or scope of the invention. Thus, it is to be understood that the description and drawings presented herein represent a presently preferred embodiment of the invention and are therefore representative of the subject matter which is broadly contemplated by the present invention. It is further understood that the scope of the present invention fully encompasses other embodiments that may become obvious to those skilled in the art and that the scope of the present invention is accordingly limited by nothing other than the appended claims.

What is claimed is:

1. A method of using one or more electric locomotive and energy storage car combinations to assist a train consist up an uphill climb, the one or more electric locomotive and energy storage car combinations each having one or more diesel electric locomotives and one or more separate energy storage cars, comprising:

adding the one or more electric locomotive and energy storage car combinations to the train consist prior to an uphill climb;

using the one or more electric locomotive and energy storage car combinations to assist the train consist up the uphill climb;

removing the one or more electric locomotive and energy storage car combinations from the train consist after the uphill climb.

2. The method of claim **1**, further including running the one or more electric locomotive and energy storage car combinations downhill, and using braking regeneration to charge the one or more separate energy storage cars of the one or more electric locomotive and energy storage car combinations.

3. The method of claim **2**, wherein the one or more electric locomotive and energy storage car combinations are added to the train consist at a first switch yard to assist the train consist uphill, the one or more electric locomotive and energy storage car combinations are removed from the train consist at a second switch yard.

4. The method of claim **3**, wherein the second switch yard is a summit location.

5. The method of claim **3**, wherein the second switch yard is a downhill location.

6. The method of claim **5**, wherein the one or more electric locomotive and energy storage car combinations are reversed in direction at the second switch yard, and are added to a train consist heading uphill at the second switch yard to assist the train consist uphill.

7. The method of claim **1**, wherein the one or more diesel electric locomotives are one or more dual mode diesel electric locomotives.

8. The method of claim **1**, wherein the one or more diesel electric locomotives are one or more hybrid-electric diesel electric locomotive.

9. The method of claim **1**, wherein the one or more separate energy storage cars are one or more electric commuter rail cars configured to haul one or more large energy storage packs.

10. The method of claim **1**, wherein the one or more separate energy storage cars are one or more converted double deck commuter rail cars with one or more energy storage packs mounted therein to provide a low center of gravity.

11. The method of claim **1**, wherein the one or more separate energy storage cars are at least one of one or more flat rail cars and one or more specialty built rail car chassis with a energy storage pack mounted thereon.

12. A method of using one or more energy storage cars to assist a train consist up an uphill climb, the consist having one or more electrically propelled locomotives for primary propulsion power, comprising:

adding the one or more energy storage cars to the train consist prior to an uphill climb;

using the one or more energy storage cars to supply additional power to the one or more dual mode locomotives to assist the train consist up the uphill climb;

removing the one or more energy storage cars from the train consist after the uphill climb.

13. The method of claim **12**, further including running the one or more energy storage cars downhill, and using braking regeneration to charge the one or more separate energy storage cars from the motor/generators of the dual mode locomotives or other rail cars.

14. The method of claim **13**, wherein the one or more energy storage cars are added to the train consist at a first switch yard to assist the train consist uphill, the one or more energy storage cars are removed from the train consist at a second switch yard.

15. The method of claim **14**, wherein the second switch yard is a summit location.

16. The method of claim **14**, wherein the second switch yard is a downhill location.

17. The method of claim **6**, wherein the one or more energy storage cars are reversed in direction at the second switch yard, and are added to a train consist heading uphill at the second switch yard to assist the train consist uphill.

18. The method of claim **12**, wherein the one or more electrically propelled locomotives are one or more dual mode diesel electric locomotives.

19. The method of claim **12**, wherein the one or more electrically propelled locomotives are one or more hybrid-electric diesel electric locomotive.

20. The method of claim **12**, wherein the one or more separate energy storage cars are one or more electric commuter rail cars configured to haul one or more large energy storage packs.

21. The method of claim **12**, wherein the one or more separate energy storage cars are one or more converted double deck commuter rail cars with one or more energy storage packs mounted therein to provide a low center of gravity.

22. The method of claim **12**, wherein the one or more separate energy storage cars are at least one of one or more flat rail cars and one or more specialty built rail car chassis with a energy storage pack mounted thereon.

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