Charging service vehicle networks are among the embodiments disclosed herein, including battery module-powered EV charging roadside service vehicles. Battery modules are removably mounted to the service vehicles and manually exchanged within a system of battery module storage locations. Some embodiments provide resupply vehicles for delivering battery modules between storage locations and/or service vehicles, and may be used to exchange battery modules. Controllers are used to reserve battery modules at the storage locations to ensure availability for high priority activities. Some storage locations have charging apparatus to recharge battery modules stored there, and some storage locations are repositionable mobile units. Multiple tiers or levels of system controllers used by service vehicles to control centers are implemented to manage operations and optimize usage of battery modules and charging services across wide areas, including providing additional service vehicles to supply temporary needs for charging services.
FIG. 1C

Internal Combustion Engine or Electric Motor (or Hybrid Gas/Electric or Hybrid Diesel/Electric)

Vehicle

Charging Electronics

Alternator (Optional)

Large Battery

FIG. 1D

Internal Combustion Engine

Vehicle

Additional Power Line

Charging Electronics

Vehicle Battery

Alternator

Battery Modules

Expandability of Battery Modules
FIG. 2A

Additional Battery Module Storage 200
Charging Electronics 110
Battery Modules 108

FIG. 2B

Additional Battery Module Storage 200
Charging Electronics 110
Battery Modules 108
FIG. 5A

Alternate-Sized Battery Modules 508

Storage or Swap-out Facility or Warehouse 500

Resupply Vehicle 504

Roadside Assistance or Rescue Vehicle 502

Stored Battery Modules 506
FIG. 5B

Small Storage or Swap-out Facility or Warehouse 500

Stored Battery Modules 506

Resupply Vehicle 504

Roadside Assistance or Rescue Vehicle 502
Storage or Swap-out Facility or Warehouse

Primary Battery Modules 506

Alternate Battery Modules 508

Small Storage or Swap-out Facility or Warehouse 500

Resupply Vehicle 504

Rescue Vehicle Fleet

Alternate Battery Rescue Vehicle 510

Roadside Assistance or Rescue Vehicle with Additional Storage 502

Rescue Vehicles 510

FIG. 5C
FIG. 7A
FIG. 15

START

1500 Monitor vehicle and charging system status and location

1502 Report status and location to vehicle operator

1506 Monitor vehicle systems; Alert operator and/or second-level controller of system exceedences

1508 Analyze data and events; Take automated actions if required including safing system

1510 Report status of vehicle to operator/second-level controller

1504 Report status and location to second-level controller

1512 Direct vehicle operator to repair, refuel, or go to service location

1514 Receive second-level controller analysis & alerts of system safety

RETURN
FIG. 16

START

1600
Monitor vehicle, vehicle location, and charging system status for individual rescue vehicles

1602
Detect potential defect in rescue vehicle

1604
Report status of vehicle to rescue vehicle operator

1606
Direct vehicle operator to repair, refuel, or go to service location

RETURN
FIG. 17

1700 Monitor vehicle communication system link to/from second-level controller

1702 Detect communication disruption

1704 Poll alternate communication links, reconfigure & attempt to reestablish communication link

1706 Update status/alert data base at first and/or second levels

1708 Resume normal operation

1710 Link not reestablished

1712 Store available vehicle data; operate under stored operational rules

1714 Continue attempting communication link reconnection

1716 Exchange stored data to/from 2nd-level controller

RETURN
Dispatch selected rescue vehicle to disabled EV

Evaluate EV charging location options given traffic and related factors

Determine best available charging location

Determine amount of charge to be provided for EV to reach a charging station and safety factor

Reserve a charging station for disabled EV

Provide directions to EV station & reservation information to EV operator

Provide optimized charge to disabled EV

Confirm safe arrival of EV at charging location & restored charge

RETURN

Monitor status & support as required

Validate charging location selection

Support as required, approve point of sale transaction

Validate payment has been approved & EV charging station recommendation

Validate EV rescue completed, log status information

*Second-level controller can replicate critical functions of first level near real time.
In cases where first-level controller has degraded performance, second-level controller will provide requisite recommendations & commands near real time.
FIG. 19

START

Analyze pairing information about rescue vehicles and potential service missions at second-level controller

Rescue vehicle selected & assigned; notification sent from second-level controller

Second-level controller monitors rescue vehicle location & status information, including POS information

Rescue vehicle controller selects optimized route, transits to stranded EV, performs required services. Routing data provided to EV operator & second-level controller

Database updated at second-level controller, routing info verified; payment approved

RETURN

Rescue vehicle operator accepts assignment?

NO

YES

Second-level controller re-assigns task to another rescue vehicle
Second-level controller determines that rescue vehicle needs refueling or other consumables.

Routing information optimized and sent to rescue vehicle.

Rescue vehicle refuels or obtains other consumables.

Updated routing information sent to rescue vehicle from second-level controller for next mission.

RETURN
FIG. 21

START

2100

Second-level controller monitors rescue vehicle fleet's status including charging system, fuel, system alerts, and location

2102

Optimize necessary rescue vehicle assignments; Assign rescue vehicles to tasks based on capability of performing the rescue, minimizing response time & optimizing fleet asset utilization

2104

Receive acceptance or override from rescue vehicles

2106

Are all necessary tasks accepted?

YES

NO

2108

Validate successful rescue or assign other assets as required

RETURN
FIG. 22

Aggregate operational data, equipment trends, and failure data from first- and second-level controllers and systems

Analyze data & recommend:
(a) preventative maintenance actions,
(b) reassignment or elimination of assets,
(c) optimization efficiencies (routing of assets, use of assets, etc.),
(d) ordering of replacements or new equipment,
(e) scheduling of deliveries, and/or
(f) equipment orders

Provide relevant information to first- and second-level controllers

RETURN
FIG. 23

First-Level Controller
One real-time controller located onboard a service/rescue vehicle
Provide control of vehicle & charging equipment

Second-Level Controller
One or more real-time (or near real-time) controllers located in central control or operational center(s)
Provide service vehicle utilization optimization across an area, region, or globally, distribute vehicle assignments, and schedule services

Third-Level Controller
One or more controllers located in central control or operational center(s)
Provide business management optimization across the entire system, coordinate special needs of regions
CHARGING SERVICE VEHICLE NETWORK
CROSS-REFERENCE TO RELATED APPLICATIONS


BACKGROUND

[0002] The present invention is directed to the fields of roadside assistance, electric vehicle charging, modular energy storage systems, and related fields.

[0003] In recent years, the popularity and affordability of electric vehicles (EVs) such as battery-powered EVs, hybrid gasoline-electric EVs (or HEVs), and other vehicles having motors and engines powered by electrical energy has grown dramatically. As these vehicles gain more market penetration and presence, there will be a need for increased on-the-road-servicess for EVs, such as providing a “boost charge” to the EV, similar to how service vehicles provide a motorist with a gallon of gasoline to get them to the next fueling station today. One of the challenges in providing these services will be the numerous differing standards used in the batteries of electric vehicles that are coming to market, since their various battery chemistries, capacities, and dimensions make the range and charging requirements of each vehicle quite different. For example, small EVs will only need a small amount of energy to allow them to travel safely to a dedicated service or charging area, but large electric vehicles will require a relatively large charge of energy to reach a service area due to their larger energy consumption rates.

[0004] Furthermore, vehicles involved in roadside assistance will be compelled to recharge or refill their boost charging equipment, resulting in losses due to inefficiency and downtime. Recharging energy storage takes time, so although batteries and chargers are improving in their ability to accomplish this in less time, this process will always set a lower limit on the time interval between uses of a battery-based EV-recharging rescue vehicle with built-in energy storage.

[0005] Removable batteries are common in electrical equipment, and even some EVs have removable batteries to provide motive power to the vehicle. One of the challenges in using removable batteries is the danger to operators that arises from the high powered connectors for the batteries. Some inventors use plastic shrouds or robotic battery manipulation for personal protection from exposed electrodes or simply use no protection at all, leaving the operator and equipment at risk. These systems can make it dangerous to use and store a battery-powered EV charging system. Some systems with removable batteries insert a “dead” power supply or other electronic device into a “live” backplane. This configuration is not ideal since it doesn’t allow for the de-activation of a “live” battery tray during handling without some human intervention, like opening a switch or removing a fuse, and since humans can forget to take these safety measures there is a greater risk of personal injury in these systems. Some systems envision large battery swap-out stations for EV batteries instead of recharging them while in the EV. The EV batteries swapped out therein can be approximately 25 kWh in capacity, can weigh 500 pounds or more, and require robotic devices to remove and install them. They also typically have a multi-person crew. This is expensive, and the proprietary nature of the swappable battery designs leads to difficulties in compatibility of vehicle systems and swapping stations.

[0006] Another challenge in this field relates to how to minimize the size and weight of the battery and the balance of the onboard systems of the rescue vehicle’s onboard electrical generation system. This optimization makes it more efficient to recharge an energy store for repeated uses over relatively short time intervals. Sizing an onboard battery pack for the most demanding, worst-case stranded vehicle is impractical and expensive. Some assistance solutions use permanently installed batteries which occupy the battery housing at all times and can only be removed with labor-intensive and time-consuming effort. Permanently installed batteries render the host vehicle completely dependent on said batteries both in charging time and charging frequency, since it takes time for a charging event to complete, and the batteries require a resting period between recharges to prevent overheating. Large batteries are also expensive and heavy so a generator system having them is burdensome and oversized when charging events are relatively infrequent when compared to other activities of a rescue vehicle.

[0007] Near-term future deployments of rescue vehicles are likely to initially require minimal electrical storage capability due to the limited market penetration of EVs. However with increased EV market penetration it will become increasingly important to gracefully grow rescue vehicle electrical capability to meet customer demand without needlessly expending large capital outlays for battery systems before such larger systems are required by the marketplace. Even if charging systems are designed with removable batteries and quick disconnects, swapping them out between one location and another can raise challenges for operators. Operators may need to rapidly respond to an emergency situation while on heavy trafficked road, and there are many potential safety-related issues associated with moving high-energy battery modules.

BRIEF SUMMARY

[0008] Various embodiments of the invention disclosed herein provide a roadside assistance and rescue vehicle charging system (which system may be alternately referred to herein as an Adaptable Multifunction Emergency EV Charging System or “AMEECS”) and related systems and methods that allow the charging system to charge EVs in need. An EV rescue vehicle of one such embodiment has a set of a modular batteries (which modules may be alternately referred to herein as Rescue Operation Battery Modules or “ROBM”) which may be linked together to form a high-capacity battery, such as a high-capacity 12-volt battery bank, having much larger energy storage capacity than the onboard battery of a traditional roadside assistance vehicle or tow truck. The battery modules are used to provide power to an EV charging station transported by the vehicle.

[0009] The modular features of the battery system allow service providers to anticipate and adapt to future growth of the rescue vehicle’s onboard recharging capacity by allowing the user to add additional battery modules and thereby increase capacity of the energy storage. In some embodiments, future battery module additions may be placed inside an enclosure of the charging system of the rescue vehicles or may be stowed elsewhere on the vehicle.
In some embodiments the battery modules are linked to the rescue vehicle or charging system with quick disconnecting links and contactors. Such quick disconnecting apparatuses provide safety by preventing users from electrical shock exposure or arcing due to improper removal of the battery modules. In some embodiments the battery modules in a vehicle have electrical and mechanical disconnects so that, after one or more stranded EVs are charged, depleted batteries can be quickly replaced with fully charged batteries when they are available. A quick disconnect system minimizes the need to wait for the charging system's battery module to be recharged either at a charging location or by using the onboard organic charging system/alternator and enables more efficient redeployment of the rescue vehicle.

In some embodiments battery modules are sized to comply with individual lifting recommendations, such as Occupational Safety and Health Administration (OSHA) recommendations, to allow a rescue vehicle operator to manually lift them and install them in a vehicle, but in some embodiments the modules may be larger in size. Therefore, in some embodiments, this means that the OSHA-approved National Institute for Occupational Safety and Health (NIOSH) lifting guidelines are followed. In many cases these rescue vehicle components are housed, charged and deployed from enclosures (which may be unstaffed) that are conveniently located for rescue vehicles to resupply when their battery modules are depleted. Additionally, some embodiments of the invention include a system of resupplying vehicles that deliver modules as needed to service vehicles to keep the service vehicle operational.

In some embodiments the rescue vehicle's onboard battery system is configured to provide energy for normal rescue vehicle functions and electrical equipment but also has adequate capacity to provide a boost charge to a stranded EV. In these embodiments the built-in, inherent, or "organic" electrical system of the vehicle (e.g., a commercial truck or van) is modified by adding connections to the charging system and battery modules. In some of these embodiments, battery modules are used to supplement the energy supplied by the organic electrical energy storage of the vehicle. In some embodiments the vehicle's alternator or other electrical generation device will work with the modular battery system to power the charger or recharge the battery modules at some rate. In yet further embodiments the battery modules are recharged by a connection to a distribution grid while carried by the rescue vehicle or when stored at a grid-connected charging station.

Some embodiments of the invention allow the battery modules to be recharged remotely and/or separately from the rescue vehicle's onboard charging system, such as at a warehouse or other facility. In effect, this system decouples the time required for charging an onboard energy storage system from the minimum time required between EV service events performed by rescue vehicles. In these embodiments, instead of having to wait for batteries to recharge, the lower limit is constrained only by how long it takes to disconnect a discharged battery module and reconnect a charged module. In this embodiment any exposed electrodes are de-energized as long as they are accessible to human hands.

Battery modules in a rescue vehicle may be discharged sequentially or simultaneously. Sequential discharging means fewer batteries are dealt with daily since only certain modules will need recharging after a day of assisting EVs instead of all batteries being partially discharged, but sequential discharging means the batteries are subjected to deeper discharges before they are replaced.

Embodiments of the invention using battery modules allow rescue vehicles to follow economic incentives to be out and ready to serve customers as many hours of the day as possible so that they can maximize turnover of successful assignments. Running out of electrical charge and having to return to a home base charging station to recharge onboard energy storage is time consuming, and therefore reduces the number of operations each rescue vehicle can achieve. In some embodiments the rescue vehicles run on diesel and do not have large battery modules.

Additional embodiments describe quick connectable battery modules and enclosures that provide safety to users while providing accessibility to components by using relays and disconnects to energize battery modules when they are securely positioned. Some embodiments use deliverable automotive batteries as a power source of charging equipment, or charge the deliverable batteries using an alternator or generator on the service vehicle while the batteries are transported by the vehicle. Battery modules may be subject to charging and discharging while on the vehicle in accordance with reservation and prioritization systems and methods employed by a system controller on the vehicle.

Some embodiments include service vehicles having ports for connection of charging cables positioned on the service vehicle for accessibility and efficiency. The charging cables may be segmented to allow extension of the cables to greater distances and to allow a single user to be able to move the cables longer distances while being OSHA recommendation-compliant.

In some embodiments, a networked system for providing energy to discharged batteries of electric vehicles (EVs) is provided wherein service vehicles transporting EV charging equipment, controllers, and removably-mounted battery modules and storage locations storing battery modules compatible with the charging equipment wherein the battery modules are manually exchangeable between the storage location and the service vehicle. In some additional embodiments, resupply vehicles are provided to deliver and resupply batteries for service vehicles and/or storage locations. A scheduling controller may be employed to reserve battery modules at stations, and the stations may be configured to resupply the battery modules while they are stored. In other embodiments, the storage location is a mobile unit that is repositionable when needed.

The networked system may also comprise three levels of controllers configured to organize and implement the charging service vehicles throughout a region.

Embodiments of methods of charging service operation are also described, including charging an EV with a limited amount of charge that is calculated based on the distance between the EV and a grid-connected charging station or other factors. Routing of service vehicles, routing of EVs being charged, and distributing assignments and information may be performed at a control center and then sent to relevant recipients.

Additional and alternative features, advantages, and embodiments of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by the practice of the invention. The features and advantages of the invention may be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims.
These and other features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] In addition to the novel features and advantages mentioned above, other objects and advantages of the present invention will be readily apparent from the following descriptions of the drawings and exemplary embodiments.

[0023] FIG. 1A shows a vehicle with a charging system powered by battery modules according to an embodiment of the present invention.

[0024] FIG. 1B shows a vehicle with a charging system powered by a large battery module according to another embodiment of the present invention.

[0025] FIG. 1C shows a vehicle with a charging system powered by a large battery module according to yet another embodiment of the present invention where the vehicle may use an electric or hybrid motor or engine without a vehicle battery, or the large battery is used as the vehicle battery, and an alternator is optionally also included.

[0026] FIG. 1D shows a vehicle with a charging system powered by battery modules and a vehicle alternator/generator according to yet another embodiment of the present invention.

[0027] FIG. 2A shows a vehicle with a charging system powered by battery modules disconnected from the electrical system of the vehicle wherein the vehicle has additional battery module storage according to another embodiment of the present invention.

[0028] FIG. 2B shows a vehicle with a charging system powered by battery modules connected to the electrical system of the vehicle wherein the vehicle has additional battery module storage according to yet another embodiment of the present invention.

[0029] FIG. 2C shows a perspective view of a vehicle with compartments for battery storage trays and additional battery storage indicated.

[0030] FIG. 2D shows a perspective view of a vehicle section with a compartment for battery storage and replaceable battery modules connected according to an embodiment of the present invention.

[0031] FIG. 3 shows a vehicle with a charging system and enclosure according to yet another embodiment of the present invention.

[0032] FIG. 4 shows a vehicle for transporting battery modules according to an embodiment of the present invention.

[0033] FIG. 5A is a diagram of the relationship between a storage facility, resupply vehicle, and roadside assistance or rescue vehicle according to an embodiment of the present invention.

[0034] FIG. 5B is a diagram of the relationship between another storage facility, resupply vehicle, and roadside assistance or rescue vehicle according to an embodiment of the present invention.

[0035] FIG. 5C is a diagram of the relationship between multiple storage facilities, resupply vehicles, and roadside assistance or rescue vehicles according to an embodiment of the present invention.

[0036] FIG. 5D shows a side perspective view of a service vehicle with detail showing the interior of the vehicle having a status display component of an embodiment of the invention.

[0037] FIG. 5E shows a frontal perspective view of a status display component installed in the interior of a service vehicle with detail of the information presented on the display of an embodiment of the invention.

[0038] FIG. 5F shows a rear perspective view of a service vehicle with a status display component installed near the rear tailgate and bumper of the vehicle.

[0039] FIG. 5G shows a rear perspective view of a service vehicle with a status display component installed on the rear portion of a charging system enclosure installed on the vehicle.

[0040] FIG. 6A is an isometric view of a quick-disconnect system with a battery module drawer installed and a retaining bar closed according to an embodiment of the present invention.

[0041] FIG. 6B is an isometric view of a quick-disconnect system with a retaining bar open according to an embodiment of the present invention.

[0042] FIG. 6C is a front plan view of a quick-disconnect system with a battery module drawer installed and a retaining bar closed according to an embodiment of the present invention.

[0043] FIG. 6D is a top plan view of a quick-disconnect system with a battery module drawer installed according to an embodiment of the present invention.

[0044] FIG. 6E is front plan view of a quick-disconnect system with a battery module drawer installed and a retaining bar open according to an embodiment of the present invention.

[0045] FIG. 6F is an isometric view of a quick-disconnect system with a battery module drawer installed and a retaining bar open according to an embodiment of the present invention.

[0046] FIG. 7A is an isometric view of a quick-disconnect system with multiple battery module drawers installed and retaining bars closed according to an embodiment of the present invention.

[0047] FIG. 7B is an isometric view of a quick-disconnect system with multiple battery module drawers installed and retaining bars open according to an embodiment of the present invention.

[0048] FIG. 8A is a side plan view of a modular battery system with quick-disconnect capability according to an embodiment of the present invention with stackable and/or chain-connecting characteristics.

[0049] FIG. 8B is an exploded side plan view of the modular battery system with stackable and/or chain-connecting characteristics wherein battery modules are separated from one another according to an embodiment of the present invention.

[0050] FIG. 9A is an isometric view of a quick-disconnect battery module drawer and receptacle embodiment with the door open.

[0051] FIG. 9B is a left side plan view of a quick-disconnect battery module receptacle embodiment.

[0052] FIG. 9C is a top plan view of a quick-disconnect battery module receptacle embodiment.

[0053] FIG. 9D is a front plan view of a quick-disconnect battery module drawer and receptacle embodiment.

[0054] FIG. 9E is a left side plan view of a quick-disconnect battery module receptacle embodiment with section lines indicated.
FIG. 9F is a section view of a quick-disconnect battery module drawer and receptacle embodiment according to section line B-B in FIG. 9E.

FIG. 10A shows various isometric perspective views of a rescue vehicle and identifies a number of potential sites on the vehicle where a charging cable connection port may be located.

FIG. 10B shows a top perspective view of a rescue vehicle and identifies a number of potential sites on the vehicle where a charging cable connection port may be located.

FIG. 11A shows a side view of exemplary charging equipment connectors and cables.

FIG. 11B shows a perspective view of an exemplary female cable connector and/or charging equipment connector.

FIG. 11C shows a perspective view of an exemplary male cable connector and/or charging equipment connector.

FIG. 12A is a diagram of a rescue vehicle with a charging cable and connectors and an EV.

FIG. 12B is a diagram of a rescue vehicle with charging cables and connectors and an EV with a charging cable extension in use.

FIG. 13A shows a side perspective view of a service vehicle with storage capability according to an embodiment of the invention.

FIG. 13B shows a side perspective view of a service vehicle with open storage compartments according to an embodiment of the invention.

FIG. 14A shows a top view of a service vehicle with electrical lines indicated according to an embodiment of the invention.

FIG. 14B shows a top view of a service vehicle with electrical lines and converters indicated according to an embodiment of the invention.

FIG. 14C shows a top view of a service vehicle with alternate charging lines indicated according to an embodiment of the invention.

FIG. 14D shows a top view of a service vehicle with batteries that are connected to an alternator according to an embodiment of the invention.

FIG. 14E shows a top view of a service vehicle with batteries that are connected to charging equipment according to an embodiment of the invention.

FIG. 14F shows a top view of a service vehicle with batteries that are connected to charging equipment and batteries that are connected to an alternator according to another embodiment of the invention.

FIG. 15 is a process flowchart showing an example of a monitoring and alert process performed by a first- and second-level controller according to an embodiment of the invention.

FIG. 16 is a process flowchart showing an example of a monitoring, notification, alert and direction process performed by a second-level controller or control center according to an embodiment of the invention.

FIG. 17 is a process flowchart showing an example of a communication link management process performed by a first- and second-level controller according to an embodiment of the present invention.

FIG. 18 is a process flowchart showing an example of an optimized EV recommendation and rescue process performed by a first and second-level controller according to an embodiment of the present invention.

FIG. 19 is a process flowchart showing an example of a fleet optimization process performed by a first and second-level controller according to an embodiment of the present invention.

FIG. 20 is a process flowchart showing an example of a consumable management and optimization process performed by the first- and second-level controllers and/or vehicles and control centers according to an embodiment of the present invention.

FIG. 21 is a process flowchart showing an example of a fleet optimization process performed by the second-level controller(s) according to an embodiment of the present invention.

FIG. 22 is a process flowchart showing an example of a regional fleet management process performed by the third-level controller(s) according to an embodiment of the present invention.

FIG. 23 is a hierarchical diagram of the controller levels according to an embodiment of the present invention.

DETAILED DESCRIPTION

Vehicle-Mounted EV Charging System

Some embodiments of the invention may be referred to as an Adaptable Multifunction Emergency EV Charging System (“AMEECS”). The AMEECS is designed to carry enough energy in a chemical battery pile and, potentially, in onboard gasoline, diesel or other fuel, to recharge an EV. Preferably, the EV is charged with sufficient kilowatt-hours permit the EV to get out of a roadway and/or get to a suitable charging station.

FIGS. 1A, 1B, 1C, and 1D show various examples of a vehicle-mounted EV charging system according to embodiments of the present invention. The system of FIG. 1A is a vehicle 100 that is used to assist stranded EVs that has an internal combustion engine 102. The vehicle 100 may run on gasoline, diesel, or another standard fuel. The vehicle engine 102 has an alternator 104 used to provide electricity to the vehicle systems and to recharge the vehicle battery 106, which may be a standard 12-volt type. In some embodiments, the alternator 104 may be a generic electricity generator powered by the engine 102 of the vehicle or an output from the engine such as through a power take-off. This vehicle has additional battery modules 108 (e.g., Rescue Operation Battery Modules or “ROBM”) connected to the electrical system of the vehicle, and the battery modules 108, vehicle battery 106, and/or the alternator 104 of the vehicle are the power source for the changing electronics 110 used for recharging EV batteries. The battery modules are preferably configured to be expandable (as indicated by module 112), so that a user can insert more battery modules into the system to increase overall storage capacity or instantaneous available output power from the charging electronics 110 by using more modules 108 at once. In this embodiment, the battery modules 108 essentially act as an oversized vehicle battery, and can therefore also provide energy to the vehicle electrical system (e.g., starter, lights, etc.) and can be recharged by the vehicle’s alternator 104.

In some embodiments the modules 108 are discharged according to a predetermined sequence, and in other embodiments, the modules 108 are discharged simultaneously. If the modules 108 are discharged according to a sequence, discharged modules may be exchanged for fully charged modules with less work required since fewer modules need to be exchanged. However, the circuitry may be less
expensive and complicated, and the time for recharging may be reduced when the modules discharge simultaneously, so simultaneous discharging may also be a feature of some embodiments.

The charging electronics 110 include electric vehicle supply equipment (EVSE), indicators, EV connectors, step-up transformers or DC-DC converters for converting the battery voltage to the desired EV charging voltage, and/or inverters or other DC-AC converters to provide the proper current to the EVs being charged. Some embodiments use a 12-volt charge system of the service vehicle along with a small battery pack (e.g., ROBM) to charge an EV using a step-up transformer in order to comply with the TEPCO® CHAdEMO specification, the SAE J1772 specification, or other similar vehicle battery charging interface.

FIG. 1B shows a similar system to FIG. 1A. The interchangeable battery modules 108 are replaced by a large battery 114 that is designed to be charged as a whole instead of in parts. The large battery has high capacity and supplements the vehicle battery 106 in providing energy to the vehicle electrical system and to the charging electronics 110. This large battery 114 can be recharged by the alternator, and may also need to be recharged by external means if a substantial charge is required. A vehicle having a large battery 114 in place of interchangeable battery modules 108 may have reduced maintenance requirements due to the lower number of batteries in total and may be more efficient in charging using the electronics 110 due to needing fewer inefficient connections between the large battery 114 and the electronics 110. The large battery 114 may be comprised of an array of smaller batteries, but these batteries do not feature quick-disconnects, individual lifting requirements, and other modular features that allow the interchangeable battery modules 108 to be exchanged with fresh modules when the batteries are depleted. These features make the large battery 114 more permanently installed than the interchangeable battery modules 108 while still providing power to the charging electronics 110 and being charged by an alternator 104. The large battery 114 is also integrated into electrical systems of the vehicle 100 and supplements and replicates the functions of the vehicle battery 106 in supplying energy to the other vehicle electrical systems such as lighting, powered windows, engine start, and other electricity-consuming systems and devices of the vehicle.

FIG. 1C shows another vehicle-mounted EV charging system. In this embodiment the large battery 114 is the vehicle battery, and no additional vehicle battery (e.g., 106) is provided to the vehicle. Instead of merely supplementing or replicating the functions of the vehicle battery as in FIG. 1B, the large battery 114 in this embodiment replaces the vehicle battery altogether. Thus, this alternative vehicle 100 has an electric motor or hybrid internal combustion/electric engine 116, where at least the electrical portion of the propulsion system is powered by the large battery 114 for locomotion of the vehicle 100. The rescue vehicle 100 is therefore itself an EV or partially electric vehicle that uses its storage battery as the reserve energy storage for charging other EVs using the charging electronics 110 that are linked to the large battery 114. This storage battery can be supplemented by battery modules in a manner similar to how battery modules are added to the 12-volt standard vehicle batteries in FIG. 1A. The vehicle 100 may also have onboard generation capabilities, such as an alternator 104, that are used to recharge the large battery 114 using the fuel-based portion of the engine or hybrid engine 116.

FIG. 1D illustrates another embodiment with battery modules 108 where the battery modules 108 provide energy to the charging electronics 110 and the alternator 104/vehicle battery 106 provides energy to the charging electronics 110 along a separate power line 118. Thus, when the charging electronics 110 are used to recharge an EV, the alternator 104 may be used to provide additional energy to the charging electronics 110 along the additional power line 118 when desired. This embodiment may also connect the alternator 104 to the battery modules 108 to recharge them while the vehicle is in motion if the connection between those parts is included. In this embodiment, it may be preferable to exchange the alternator for a higher-power generator operated by a power source such as a power take-off when available in order to provide more support to the charging electronics 110.

Fig. 2A shows another embodiment of the vehicle charging system. As shown here, the charging electronics 110 and battery modules 108 may be isolated from the vehicle’s electrical system. In other embodiments, connection to the electrical system is also contemplated (see, e.g., FIG. 2B). In either case, these vehicles provide additional battery module storage 200, wherein the additional or spare battery modules 200 are transported by the vehicle without being electrically connected to power lines between the vehicle engine and charging electronics 110 like the other battery modules 108.

FIGS. 2A and 2B show vehicles with capacity to transport or store additional battery modules 200. When they store additional modules 200, this configuration allows the vehicle operator to simultaneously connect as many modules at once as required to the charging electronics for higher power requirement scenarios, swap in or swap out modules when other modules are depleted, provide modules to other parties such as other vehicle operators, or charge the additional battery modules with the vehicle’s electrical system while the other modules are isolated or are busy charging an EV battery.

In some embodiments, spare battery modules 200 can be carried on the rescue vehicle, delivered to the rescue vehicle, or can be made available at a battery swap-out station. Additional spare electrical battery modules can be carried onboard the rescue vehicle. See, for example, FIGS. 2A, 2B, 2C, 2D, and 3, where additional battery modules are shown being stored on a vehicle. This configuration enables the possibility of greater average electrical capacity for the rescue vehicles and provides a means to gracefully increase that overall total as demand for rescue missions increases over time. Since the battery modules are interchangeable, they can serve to gracefully increase the electrical capacity of the rescue vehicle (such as its charging capacity) without significant infrastructure cost. In some cases the size or number of battery modules may increase or decrease over time as mission requirements evolve, but quick disconnect points on the vehicle will remain substantially in the same configuration. Quick disconnect features of battery modules are discussed in more detail below.

The modular feature of the battery system allows for future growth of the rescue vehicle’s onboard battery capacity. Future battery module additions may be placed inside the rescue vehicle’s charging enclosure or may be stowed else-
where on the vehicle. This defers capital investment in expensive batteries until market demand warrants that investment. Spare battery modules may in some cases be located in the rescue truck main box/enclosure, a storage rack, or at other locations on the vehicle. FIGS. 2C and 2D show that storage compartments 202 for battery trays or modular racks may be located on the rescue vehicle in some embodiments. FIG. 2D is an example of a battery management tray apparatus. The battery modules/cells are stowed on a retractable battery tray and have quick-disconnects for easy replacement. Battery wiring is not shown in FIG. 2D.

0093 [FIG. 3 depicts another embodiment of the charging system mounted in a vehicle. Here, an enclosure 300 keeps the battery modules 108 and charging electronics 110 under common protection, and optionally has space for additional battery module storage 302 inside and/or outside the enclosure 300. The embodiments discussed in connection with FIGS. 1A through 2B may also incorporate enclosures to protect the equipment borne by the vehicle which may or may not have storage capability.]

0094 Battery Module/ROBM Resupply Vehicles and Delivery

0095 Rescue vehicle operators and administrators have an economic incentive to maximize turnover of successful missions and as such want to be out on the road and ready to serve the maximum number of hours per day. Among other problems, running out of electrical charge and having to return to a “home base” or other charging location to recharge a built-in or large battery takes time and reduces the number of recharging operations each vehicle can achieve. Some embodiments of the invention provide that rescue vehicle battery modules may be resupplied in the field by a battery resupply vehicle. A resupply vehicle of these embodiments is in communication with rescue vehicles and provides replacement battery modules for depleted batteries.

0096 FIG. 4 is a depiction of a dedicated resupply vehicle according to an embodiment of the invention. Battery modules 108 are stored in the vehicle and are transported to rescue vehicles or battery module roadside swap-out locations or battery charging stations. The vehicle can store various types of battery modules 108 if its delivery destinations use different types of batteries (see also FIG. 5C). The resupply vehicle’s onboard electrical system can be utilized to provide charge to the battery modules 108 in order to keep them at full charge at the time of delivery. In some embodiments the resupply vehicle carries other EV rescue-related equipment, handheld devices capable of providing EV operators with essential information, and/or communication links.

0097 In some embodiments a smart controller optimizes the routes of the rescue vehicles and of resupply actions. In some embodiments resupply action may be initiated at the time the rescue vehicle identifies that it is being routed to a stranded EV. In other embodiments the controller optimizes based on rescue vehicle location, resupply vehicle location, traffic, onboard ROBM status, rescue call volume, and other factors. It may also wait until a predetermined number of stranded EVs have been serviced by the same rescue vehicle or until the rescue vehicle’s onboard system indicates that it is “low” or out of available energy storage, then dispatch battery modules to replenish the storage of the rescue vehicle.

0098 FIGS. 5A and 5B illustrate the relationship between battery module storage facilities 500, rescue vehicles 502, and resupply vehicles 504. The modules 506 and/or 508 may be exchanged between the storage facilities 500 and the resupply vehicles 504, between the resupply vehicles 504 and the rescue vehicles 502, and/or between the facilities 500 and the rescue vehicles 502.

0099 Some embodiments would allow the resupply vehicle 504 to provide multiple battery modules 506 and/or 508 to one or more rescue vehicles 502 during a single delivery trip. Other embodiments would permit the rescue vehicles 502 to act as resupply vehicles when they have enough battery modules to respond to another rescue vehicle’s need for modules 506 and/or 508. See, for example, FIG. 5C, wherein a rescue vehicle 502 is shown transferring modules 506 and/or 508 to other rescue vehicles 510.

0100 In additional embodiments, a smart controller routes the resupply vehicle 504 to an optimal roadside battery swap-out station 500 or to an optimal central battery module recharging station 500 to keep the battery modules 506 and/or 508 of the fleet at full capacity for the maximum length of time. To this end, in additional embodiments, a system of quick disconnects is utilized to facilitate fast and efficient battery module exchange out from the resupply vehicle 504 and these battery modules 506 and/or 508 may be sized to meet Occupational Safety and Health Administration (OSHA) recommendations or other safety or regulatory lifting requirements for manually exchanging the modules.

0101 FIG. 5C shows the relationship between the resupply vehicles 504, the rescue vehicles 502 and 510, and the storage facilities 500. Resupply vehicles 504 transfer and/or recharge battery modules 506 and/or 508 and provide them to the rescue vehicles 502 or storage facilities 500. Different resupply vehicles 504 may be necessary to provide different types of batteries (e.g., 506 or 508) to the rescue vehicles 502 and 510 or storage facilities 500, since in some embodiments not all of the facilities’ vehicles will be compatible with the same battery modules.

0102 Battery Module Optimization

0103 In some embodiments, the battery modules are designed to be lightweight and/or U.S. Occupational Safety and Health Administration (OSHA) recommendation compliant, thereby allowing manual removal and installation of the modules. The modules are therefore analyzed under the National Institute for Occupational Safety and Health (NIOSH) lifting equation, where a recommended weight limit is calculated by multiplying a load constant (LC), horizontal multiplier (HM), vertical multiplier (VM), distance multiplier (DM), asymmetric multiplier (AM), frequency multiplier (FM), and coupling multiplier (CM) from a NIOSH table described in connection with the NIOSH lifting equation (last revised in 1991). To avoid lifting injuries, the recommended weight limit is at or below 3.0 as calculated by this formula. In some embodiments, this means battery modules are light enough to be carried by a user and are changed out either manually or with a labor-saving device, and if manual labor is required, the weight of the device is 42 pounds or less, and ideally 35 to 42 pounds each, in order to maximize the capacity of each module by making them as large as possible. The 35-pound lower boundary is selected according to a recommendation set by OSHA. These figures also assume that the battery modules are stored in the service vehicle in such a manner that the lifting does not take place at full arm-extension nor with the lifter’s trunk twisted to a significant degree. These weight and size figures are not intended to define the absolute limits of the scope of the dimensions and weight of the battery modules, but as a preferred guideline for common embodiments of the invention.
These OSHA-recommendation-compliant embodiments are advantageous because no special lifts or other equipment are required for the quick disconnection and replacement of the onboard energy store, so the overall system has the flexibility of single-operator operation. Only the rescue vehicle driver is required to operate the system, with no additional supporting personnel or lifting equipment. Other embodiments use OSHA-compliant lifting equipment to manipulate the battery modules if the size and number of modules requires.

Some embodiments feature battery modules with a capacity sized to correspond with logical units of charge required to move an EV sufficient distance to reach an EV charging station. For example, consider a typical EV assistance scenario. Since typical EVs can currently travel approximately 4 miles per kWh of battery storage, and since most rescue operations can be accommodated in 12 miles, and assuming a battery size of 4 kWh would weigh approximately 85 pounds, two battery modules of approximately 42 pounds each would be used to perform this rescue recharging operation. Other similarly optimized system sizes are envisioned over time. Battery modules would be optimized to provide a boost charge to less-efficient vehicles stranded on the roadways by increasing the capacity or number of modules set to be used for those charging events. This optimization allows standardized battery modules to be used to charge EVs with a wide range of different electrical efficiencies. The rescue vehicle is therefore sized in some embodiments to carry many more battery modules than are necessary for a charging event of a single, efficient EV, so that the rescue vehicle can be dispatched to provide charge to less efficient EVs, additional EVs, and can be loaded to meet other demands of the charging assignments given.

Onboard Battery Module Charging

Some embodiments of the invention minimize the required capacity of battery modules by leveraging the rescue vehicle’s onboard electrical system to provide additional charging capacity when needed. See, for example, FIGS. 1A, 1B, 1C, 1D, and 2B, where the alternator of the vehicle is used to assist in charging the battery modules. In this manner the onboard energy storage modules can be maximized beyond the physical constraints of the isolated battery capacity since recharging supplies additional energy that can then be used in rescue operations. The onboard organic charging system typically comprises the vehicle’s alternator, battery, and other electrical components, but it may also include a more substantial or modified electrical system used in the normal function of the vehicle. The vehicle’s electrical system may be merely involved by recharging a storage battery or battery modules, or the vehicle’s system may be directly involved in providing power to the charging electronics on the vehicle.

For example, some embodiments allow battery modules to be stowed in a rack which provides a trickle charge from the rescue vehicle’s alternator or another onboard energy generation device. This system ensures that fully charged batteries remain charged and can eventually recharge a battery to a normal state of full charge from a state of depletion.

Connecting and Managing Multiple Battery Modules

In some embodiments, battery modules are grouped together into clusters of modules. These clusters can be reconfigured into OSHA-recommendation-compliant weight groupings in some embodiments when appropriate.

In some embodiments, the battery modules (ROBM) stowed in the rescue vehicle’s storage rack systems may be electrically connected to the AMEECS, charging equipment, or vehicle’s electrical system. Each battery module or cluster of battery modules may have a connector switch that can be enabled or disabled, wherein when the switch is disabled, the battery module is isolated from other modules. In some embodiments these switches are opened or closed manually and in another embodiment they are controlled through use of an onboard command panel of the vehicle or module charging station. In one embodiment the command panel may be manually overridden by a manual switch. In this manner individual battery modules or clusters do not have to be moved to a particular rack to be used or recharged. This reduction in battery module movement improves field operations efficiency and reduces exposure of operators to potential safety issues.

Some module storage locations may not have electrical connectivity and require the battery module to be moved to be utilized to support rescue operations. This condition may occur during periods of capability expansion or to address unique storage requirements.

Where practical, the systems are automated and/or provide the operator with a mechanical advantage. This facilitates installation and removal of the modules.

In some embodiments, depleted battery modules are identified and displayed on an onboard controller or display. FIG. 5D shows side perspective view of a rescue vehicle having an onboard display 512 for indicating the status of onboard charging electronics 514 and battery modules stored in compartments on the vehicle 516. In this embodiment, the display 512 is located in the passenger compartment 518 of the vehicle. The onboard controller is a computer, microprocessor, or other similar programmable logic device that reads and executes instructions or code. The controller may have output connections, input connections, and displays or other elements designed for user access and interaction. The controller may be "smart," meaning the controller’s functions may be automated to some extent to serve the user with minimal user input, such as by predicting and anticipating future user needs. Furthermore, controls 520 and indicators 524 of the display 512, which may be a touchscreen display 522, may allow the vehicle to send and receive information about nearby stranded EVs, instructions to or from a control center, or control the operation of the onboard charging electronics 514 or battery modules 516. The instrument panel 524 of the vehicle may also be available to the user to integrate the controller and display with other functions of the vehicle. Buttons may adjust the power, brightness, and/or contrast, navigate through menus, or input commands into the display 512. Lights may be used to indicate alternative information such as charge status or power indication, for example. In this embodiment, the display assembly 512 is positioned below the instrument panel 524 of the vehicle, but it may also be placed in other locations in the vehicle, such as, for example, above the dashboard, near the vehicle dials or other controls, integrated into a screen already installed in the vehicle (such as a global positioning system (GPS) navigation client or media control display), placed in a compartment or enclosure on the service vehicle, or placed on the exterior of the vehicle.

The display 512 may present various pieces of data to the user, as indicated in the frontal perspective view of FIG. 5E. Here, the charging system status display 512 shows a status dial 526, status gauges 528, and status text/messages
Buttons 532 on the status display 512 allow the user to adjust the settings of the display and/or charging equipment. For example, the buttons 532 may be used in one embodiment to adjust the amount of charge transferred to a stranded EV in a single charging event, enabling an automatic charging cutoff of energy at a predetermined energy level. Graphics 534 are also shown on the display, and may be modified to provide status information, alerts, graphs, and other system information to the service vehicle operator.

In this embodiment, the status dial 526 shows a representation of the state of charge of the battery storage of the charging station in a manner similar to a fuel gauge of a vehicle, with full state of charge of the battery modules at “F” and depleted state of charge at “E”. Color coding with green near “F” and red near “E” allows a user to quickly determine the health and state of the batteries on one dial. Other charging system information may be displayed on the status dial 526, such as, for example, voltage of the batteries or converter.

The sliding gauges 528 in this embodiment show temperatures of the battery module bank and the voltage converter of the charging system, and the black bar overlayed on the gauge slides up and down to indicate temperature rises and drops, respectively. Color coding is also implemented in the gauges 528, such as with red indicating high temperature to give a quick reading to the user regarding whether temperatures are in a safe range. The gauges may also show other or additional information as the user sees fit, such as state of charge of batteries, battery health, or other important factors for charging station operation.

The status text/messages 530 show detailed information about the battery temperature, converter temperature, battery voltage, and DC voltage of the charging system. This allows more detailed information to be accessed by the user for statistical analysis or data logging. The status text 530 may display any information displayed using other indicators as well. Messages from other vehicles and control centers may also appear on the display 512 to notify the service vehicle operator of instructions or nearby needs for charging or charged battery modules.

Some embodiments use a system of coded lights (such as red, yellow, and green) at each battery module’s rack storage location visible to the operator which identifies the individual battery’s state of charge. This allows the user to quickly identify batteries requiring a swap out or recharge. In an alternate embodiment the state of charge of individual battery modules is displayed on meters or a control panel or display such as display 512 that is located out of the cabin area 518 of the vehicle.

FIGS. 5F and 5G show a rear perspective view of a service vehicle 536 with a status display component 538 installed. The view of FIG. 5F has a status display component 538 installed near the rear tailgate 540 and bumper 542 of the vehicle 538, and the view of FIG. 5G has a status display component 538 installed on the rear portion of a charging system enclosure 514 installed on the vehicle 536. In these embodiments, lights 544, 546, 548 indicate connection status, charging status, and done/fault status, respectively. A start button 550 and emergency stop button 552 are provided as user inputs for operation of the charging system, and other system information 554 is recorded for convenience of the user.

The lights 544, 546, and 548 may vary in size, shape, color, and signal indicated, and may be used to indicate multiple signals using a single lamp. For example, the done/fault light 548 is used to indicate when charging is done, but it can also indicate when there has been a fault in the charging system by indicating a different color, blinking pattern, brightness, etc. The start button 550 and emergency stop button 552 may be used in similar fashion by varying in size, shape, appearance, and function, and may directly or indirectly adjust the operating conditions of the charging system on the vehicle.

FIGS. 5F and 5G are an example of an exterior-mounted status display, wherein the components are weatherproofed and designed for operation in extreme and outdoor conditions and may be sealed without serious interference with operation of the charging system or display. The embodiment in FIG. 5F is advantageously positioned for being accessed while charging a stranded EV that is behind the service vehicle, or when cords and connectors for the charging system are located at the rear of the service vehicle, and the embodiment of FIG. 5G is advantageously positioned for access when the user is charging a stranded EV that is positioned to the sides of the service vehicle since he or she may look over the side of the service vehicle without having to go to either end of the service vehicle to check on the status of the charging equipment. It is noted that the display may beneficially be located at the front of the vehicle, on the sides or on the compartments of the sides of the vehicle, on top of the vehicle at any point, or within the vehicle or enclosure 514 of the charging system.

Battery Module/ROBM Resupply Facilities

In some embodiments depleted battery modules/ROBM on a rescue vehicle are changed out at resupply stations. Such resupply stations are not intended to provide batteries that power EV propulsion systems, but instead provide batteries and battery modules that are used in EV recharging stations, especially recharging stations mounted in rescue vehicles, unless the rescue vehicles themselves are incidentally propelled by energy from the battery modules which power their onboard EV recharging stations. Battery modules are not used for traction or providing motive power directly to an EV motor, but are used to provide a boost charge to stranded EVs, requiring, e.g., 4-8 kWh of charge.

In some embodiments, these stations are repositories for battery modules capable of providing a boost charge through the charging systems of the rescue vehicles. Resupply stations are normally unmanned and can be conveniently located for use by emergency rescue vehicles to respond to rescue calls in high-traffic or freeway areas. The stations may also include quick disconnect systems for the batteries to facilitate quick, efficient, and safe battery exchanges.

In some embodiments, batteries are housed in a secured recharger bin populated with level 1, 2 or 3 EV chargers at roadside stations. The chargers provide different rates of change and can change different types of modules depending on their power output and other electrical characteristics. See, e.g., FIGS. 5A and 5C, where a storage facility 500 stores more than one type of battery module, and, in FIG. 5C, where the rescue vehicles use different types of modules (e.g., 506 and 508). The battery modules stored in the stations may therefore also vary in size and capacity. In that case, the battery modules may be recharged and stored on shelves holding similar types of battery modules to simplify the electrical system of the facility.

In the storage area, a state of charge (SOC) indicator or additional display may show the charge status of battery modules. The battery modules’ state of charge is therefore
available locally but may also be provided to remote rescue vehicles via cellular, Wi-Fi, or other electronic communications transmission media. In some embodiments, rescue vehicles may reserve battery modules available at roadside resupply stations so as to provide time economies. A controller or computer at the roadside battery module exchange station can be programmed to reserve battery modules based on first come first serve, state of emergency service required, prepaid priority, or other reservation prioritization schemes. For example, if the controller uses the state of emergency service required in a reservation program, the relative urgency of assignments given to various service vehicles is compared, and the more urgent assignments are given heightened priority so that even if the service vehicles having extra urgent needs are not first to arrive at a storage location, those vehicles are still able to complete their assignments due to a delay in allowing other service vehicles to access batteries.

[0128] In some embodiments a controller at the station determines which module is to be charged on a rack and manages facility electrical load to avoid exceeding the facility or local grid load requirements. The battery modules may be charged in groups or phases in order to comply with overall facility loads or utility requirements and preferences. For example, the scheduling or reservation controller would not allow certain battery modules to be reserved at a location if charging those modules before they are picked up would cause the overall facility load exceed a certain limit, such as a demand charge-inducing limit or a utility service limit or rating for the facility.

[0129] Chargers at the stations may be connected to individual or multiple batteries. Systems with level 2 and/or level 3 chargers may be configured to charge multiple battery modules sequentially or simultaneously according to rules executed by a charging controller. Larger charging systems may use multiple "hoses" or cables per charger or may utilize a bus to connect to multiple modules.

[0130] Embodiments with the smaller storage or swap out facilities 500 (as shown in FIGS. 5B and 5C) are advantageous in that the smaller facilities can be more easily distributed in a service area, thereby reducing the need for resupply vehicles since the roadside assistance vehicle operators can more readily access the battery modules stored in the smaller facilities.

[0131] In another embodiment a battery module roadside facility may provide energy storage support to an adjacent facility such as an office complex, convenience store, fast food store etc. In this way the energy management capability could at times provide a secondary service to load level a local facility or provide load relief to congested areas on the local distribution grid by discharging the stored battery modules into the electrical system of those areas when provided.

[0132] In another embodiment, the battery module roadside facility may be a mobile unit. It may have significant energy storage capability and may be connected to the grid in different areas. A facility such as this is dispatched when needed to areas having temporary high demand for electricity. This could include being dispatched to a sports arena on a weekend or to a truck stop near a freeway during peak commuting hours. The mobile system plugs into local grid power (e.g., 240-volt, 208-volt or 480-volt) at locations that are configured to accept the system. This system provides the advantage of enabling the system cost to be amortized over multiple use cases and allows more strategic positioning of roadside battery module facilities when needs are temporary.

[0133] Quick-Disconnecting Battery Modules

[0134] In some embodiments electrical energy for the AMEECS is stored in modular battery packs. In some of these embodiments each module has a mechanical quick-disconnecting apparatus to facilitate rapid and convenient changeout of discharged batteries with charged batteries. The quick-disconnect renders a battery easily swappable, and the vehicle's onboard electrical generation system is therefore the only method of replenishing the energy store in the short interval between uses since discharged modules can be exchanged for charged modules. In other embodiments, the quick-disconnectable energy storage battery uses an electrical disconnect that does not use a mechanical switch for mechanical safety interlocking, but instead uses a fully electrical safety interlock.

[0135] The apparatus and processes described herein help to ensure that any electrodes that are exposed during equipment operation or maintenance are de-energized before they become accessible to human hands. Replacement of battery trays/ Drawers or otherwise accessing equipment internals necessitates an action on the part of the person performing the operation to unfasten the tray, drawer, top cover or other protective fixtures surrounding the high-powered electronics inside. Each tray can contain one or more battery module. Accordingly to these embodiments, the human required to unfasten electronics is the same action required to de-energize the electronics therein. This design helps to eliminate risks associated with forgetting to shut down the system prior to disassembly.

[0136] In one embodiment of the invention, tray fasteners for the battery modules are equipped with a magnetically conductive material such as iron or ferrite which would need to be moved out of the way to unfasten a tray or module. This in turn would break an otherwise continuous magnetic circuit. The loss of magnetic flow is detected elsewhere in the system and used as a signal to shut down (or disconnect from a contactor) the battery tray terminals. The use of the magnetic circuit affords flexibility and reliability. Flexibility is provided because the magnetic flow can be routed anywhere in the system (similarly to electric flow) and thus can be used to trigger the disconnect in places far removed from the original source. This provides convenience and practicality to the implementation of the safety interlock. Reliability is provided because magnetic continuity is easier to maintain than electric continuity; even in a small signal circuit the battery disconnect electrical circuits are easily broken or defeated by impatient operators. The magnetic flow would be required to energize the system, so that either opening the interlock or some other unforeseen failure of the magnetic path would de-energize the battery tray with equal surety. Persons with ordinary skill in the art will recognize several pre-existing methods for detecting the magnetic flow in the system and causing the battery de-energization triggered by the loss of magnetic flow.

[0137] FIGS. 6A, 6B, 6C, 6D, 6E, and 6F show various views of one possible embodiment of the present invention. These figures generally show a battery module quick disconnect apparatus and circuit 600 wherein a battery module drawer 602 is inserted into a void between magnetic conductors 604 and a retaining bar 606, and is held in place when the retaining bar 606 is brought down to close contact with a magnetic conductor 604. The battery module drawer 602 connects with a back-plane connector 608 when it is fully inserted (as shown in FIG. 6D), and electrical flow through
the connector 608 is engaged when the retaining bar 606 contacts the magnetic conductor 604. In this embodiment, the magnetically-conductive retaining bar 606 closes a continuous magnetic circuit driven by a permanent magnet 609 or an electromagnet and simultaneously locks the drawer 602 in place. When the retaining bar 606 is opened, sensors, such as the hall-effect sensor 610 shown, detect the loss of magnetic flow in the system and shut down (disconnect with a contactor) the battery tray back-plane connector.

[0138] FIGS. 7A and 7B show an embodiment of the quick disconnect and battery module system with multiple drawers of modules 700 that can be quickly installed or removed. Each drawer 602 can be installed and removed independently, allowing uninterrupted power supplied by the apparatus if a battery module needs to be changed out. Also, if the charging system that the battery modules are powering needs additional storage capacity, the system is expandable to take on additional modules to meet those demands. These figures may represent a battery quick-disconnect system that is present on an apparatus that charges the battery modules when they are removed from a charging station on a rescue vehicle in addition to showing a rack in a vehicle-mounted charging system.

[0139] In another embodiment, a battery tray is de-energized by turning a handle (such as the latches 800 of FIGS. 8A and 8B) to disconnect a control signal pathway connected to a de-energization trigger. This embodiment minimizes the need to wait for the battery to be recharged either at a charging location or by using the onboard organic charging system, so the rescue vehicle can be more quickly redeployed with new battery modules.

[0140] In another embodiment, the quick-disconnectable energy storage battery (or ROBHM) features an electrical disconnect and interlock that prevent removal and replacement of the battery unless the battery is electrically disconnected from the rest of the system, and it is connectable only after mechanical connections of the battery are complete and secure. One advantage provided by the electrical disconnect and interlock is the protection of the operator from electrical shock or burns associated with accidents common to the manipulation of electrical energy storage devices including shorts causing damage to equipment and electrocution causing personal harm. Another advantage of the electrical disconnect and interlock is the preservation of the delicate contacts used in electrical connections by transferring the function of making the initial electrical connection from the connector contacts themselves to a more suitable device such as a circuit breaker or electrical switch which is specifically designed with springs and vacuum chambered contacts in order to handle the sparks and surges associated with this function. This embodiment may also incorporate the interlocking electrical disconnect with a suitably-rated switch or circuit breaker attached to it such that it cannot be moved into the “ON” position unless and until the mechanical connections are complete and secure, and the electrodes of the connector are safely removed from access by human hands.

[0141] In some embodiments, the quick-disconnectable energy storage battery module uses a self-aligning connector at the back of the battery drawer for connecting a battery (e.g., ROBM) to a backplane of a battery connection point which employs extra conductors arranged to complete the connection of a relay coil which, in turn, energizes a larger contactor which completes the electrical connection. In this embodiment, oversized yet delicate contacts in the connector or a mechanical interlock are not needed to prevent the inrush of current through the delicate contacts before they are fully inserted and secure. This embodiment is advantageous because it is fully automated and has no moving parts other than the one necessary moving part inside the contactor that actually does the contacting. Full automation allows for adaptability in function, like a time delay or any other behavior that may be programmed into a processor for deciding if and when to complete the high-current connection. By closing the contactor the extra conductors in the self-aligning connector merely enable the main contactor, but do not necessarily immediately activate the main contactor.

[0142] In yet another embodiment, the extra electrical contacts in the self-aligning connector at the back of the battery (e.g., ROBM) tray are used to activate a fully electronic contactor such as a MOSFET or other solid-state switching device inside the battery tray and electrically positioned between the battery and the connector at the back of the tray. This embodiment deactivates the battery tray and makes the electrical contacts of the tray safe to touch with human hands without human intervention. Using the fully-electronic contactor confers benefits to the battery tray including but not limited to: (1) the extra reliability of no moving parts, (2) the gradual ramp-up of electrical current flow which reduces thermal shock on associated components and the EM pulse associated with sudden current flow, and (3) the option of computer checks of safety conditions before the final decision is made to complete the electrical connection.

[0143] In yet another embodiment, the battery modules are designed to permit expandability of the charging system by connecting to each other. The module housings may be designed much like building blocks that interlink until they are finally connected to the charging station at one end. In this embodiment, the battery modules indicate their present charge capacity and may be sequentially discharged to make a resupply action more fluid.

[0144] For example, if three out of five battery modules are used during the course of a day of use of the charging equipment on the rescue vehicle, the battery modules, arranged in a chain fashion, the modules on the outside end of the chain are discharged and the modules on the inside end of the chain are still charged, so when the operator changes out the discharged batteries for charged batteries, it is easier to see that three of the five need to be switched out and easier to access them as well. Then, because the modules are connected in a chain fashion, the three modules can be removed while they are still interlinked by releasing a quick disconnect latch 800 between the discharged and charged modules without having to disconnect modules one at a time. Likewise, when the battery modules are replaced, three replacement modules can be interlinked and reconnected at the point of the latch at the same time with only one quick-connect latch to reengage. Additional supplemental battery modules can be added to this embodiment by latching a module to the end of the outermost connected module as many times as possible. See also FIGS. 8A and 8B which show a sample embodiment of an expandable battery module design arranged in a chain fashion. The chaining connection pattern allows depleted modules to be positioned at the most convenient (outermost) position in the chain and reduces complexity of adding new modules or the need for additional wiring and connection points that would be needed in another configuration such as a grid-like connection pattern.
FIG. 8A shows a number of battery modules 802 connected with closed latches 800 that keep the modules 802 from disconnecting from the connection to the charging equipment 804 or from other battery modules. FIG. 8B shows a number of disconnected battery modules with open latches to show the individual shape of the battery modules, their male and female electrical connectors 806 and 807, and indicators 808. The latches secure the battery modules together by engaging latch receivers 810 on the modules that keep them secure. In some embodiments, the latch receivers 810 have electrical connections that are closed when a latch 800 is closed on the receiver 810, and when the electrical connections are closed, the female connectors 807 are energized to provide energy to the charging equipment 804. The indicators 808 in these embodiments can be gauges, lights, output connections such as VGA ports, USB ports, simple electrical outputs (e.g., a voltage signal), and other like means of indicating charge or connection information.

FIGS. 9A, 9B, 9C, 9D, 9E, and 9F show an alternative embodiment for a quick disconnect system for securing battery modules with a safety relay. FIG. 9A is a perspective view of a battery module drawer 900 loaded into an enclosure 902 that has an open door 904. FIG. 9B is a left side plan view of the battery module receptacle 906 indicating the door 904 and relay 908 portions. FIG. 9C is a top plan view of the battery module receptacle 906. FIG. 9D is a front plan view of the drawer 900 and door 904 with push buttons 910 indicated. FIG. 9E shows an embodiment of the battery module enclosure 902 indicating the relay 908. FIG. 9F is a section view across section line B-B of FIG. 9E showing the internal portions of the battery module drawer 900 and receptacle 906 within the enclosure 902, including the push buttons 910, electrical connector 912 on the rear side of the module drawer 900, and the corresponding relay 908 on the module enclosure 902. In this embodiment, the drawer 900 may be quickly disconnected from the receptacle 906 with no risk of electrical shock-related injury to the user. The relay 908 is not energized until the drawer 900 is fully inserted, with the electrical connector 912 in position, and the door is closed 904, thereby depressing the push buttons 910. Since there are two push buttons 910, there is less opportunity for a user to accidentally energize the relay 908 when the drawer 900 is removed by pressing a button inadvertently when the drawer 900 is open. Yet because the relay 908 is not energized unless the door 904 is closed, the battery module drawer 900 can be quickly replaced by another without risk of electrical shock while the drawer 900 is being or has been removed. Additionally, since the relay 908 is at the rear of the cavity in which the drawer is positioned in this embodiment, it is further removed from human interaction, since the user-operative end of the drawer 900 and receptacle 906 is the front end.

The principles embodied in the subparts of FIG. 9 may be extended to other embodiments as well. For example, the door 904 may be enlarged to cover multiple battery module drawers at once, and the push buttons may be configured to vary in size, position, and number. In such an embodiment, when the door is opened, multiple relays which are connected to the multiple battery module drawers are preferably disengaged simultaneously. This embodiment may be advantageous in reducing the complexity of the hardware used to secure the battery module drawers and to allow the user to quickly deactivate many modules at once. Additionally, the push buttons may instead send a signal to a microcontroller or computer controller of the battery module receptacles that uses other sensors to detect whether energization of the power relays is safe and appropriate.

Furthermore, combinations of the preceding embodiments are possible. Module drawers 900 may comprise battery modules themselves that are inserted into receptacles 906 and locked in by doors 904, and the entire enclosures 902 may be used as battery module drawers shown in embodiments having a retaining bar-activated magnetic conduction system such as the apparatus 600 seen in FIGS. 6A through 7B inclusive. Combining these embodiments allows the user to have an extra layer of protection against accidental energization of battery modules since a door (e.g., 904) and retaining bar (e.g., 606) must both be in the correct positions in order for the battery modules to discharge.

Connection Between Service Vehicle and EV

Rescue vehicles for EVs may need charge depleted batteries onboard distressed EVs using a charging cable that goes from the charging device on the rescue vehicle to a charging port on the EV. Some existing EV charging stations have charging cables that are permanently attached to the charger that connect the charging electronics to an EV charging port. The charging cables may be permanently attached to the charging station, resulting in limits on how far the cables can reach due to their positioning on the service vehicle and their fixed length. Long cables, especially those used in current standards for fast DC charging, are heavy and their transportation is difficult and dangerous by a single human operator. This danger is magnified in situations where the charging station is transported by a vehicle where a misstep by an operator may result in exposure to fast-moving traffic and other hazards.

An aspect of some embodiments of the present invention is a segmented EV charging cable that may be used to connect a service vehicle charging system to a stranded EV. The segmented EV charging cable system may include a port on the service vehicle’s charging system for attachment of one end of the segmented charging cable, but it may also include multiple ports that are on the charging system or that are at different points on the service vehicle but are wired to the charging system components.

A charging equipment system may provide multiple charging ports on the rescue vehicle, enabling the operator maximum convenience and safety while setting up charging equipment by allowing the user to choose the most convenient port to use. Having multiple ports is particularly useful in allowing the rescue vehicle operator to select a port that minimizes exposure of vehicle traffic and road-related hazards when operating near a roadway. Allowing the operator to select the outlet port most convenient to his operation also permits him to reduce the length of the cable required to support his operational need when connecting to EVs at various distances from the charging cable port on the charging system. Some embodiments of the invention use a Risk Class 0 NFPA 70E or equivalent connector which enables an operator who is not a certified electrician to assemble the segmented EV charging cable in the field. The charging ports of the service vehicle and/or charging equipment are preferably capable of performing level 2, level 2 “fast change”, level 3, or otherwise comparable fast EV charging rates and standards in order to minimize the time that the service vehicle is charging the stranded EV and exposing the users, service vehicle, stranded EV, and associated charging equipment to dangers.
The segmented charging cable system also permits the user to change overall length of the charging cable into user-manageable segments or lengths. The length of the charging cable required to service EV rescue operations depends on how close the rescue vehicle is to the charging port on the EV. In many cases a charging cable of 5 to 15 feet in length is sufficient to service a distressed EV, but in certain configurations the EV’s charging port could be a full car length or more away from the rescue vehicle. Charging an EV from such a distance necessitates that the charging cable be longer than a standard length of 5 to 15 feet, and it would require 30 feet or more in length. Due to the bulk of the wiring and wire sheathing used in EV charging cables and their connectors, the cabling may weigh more than the Occupational Safety and Health Administration (OSHA) lifting recommendations set by the United States Department of Labor, and is typically too weighty and cumbersome to handle manually. Therefore, by segmenting the charging cable, a user can transport manageable lengths of extension cables without having to carry too much weight at once to connect to an EV. For example, instead of having a cumbersome and heavy 25 to 35 foot cable the cabling system may enable the operator to use multiple cable segments of approximately 6 to 15 feet and a charging connector to accommodate routine rescue missions. These shorter cable segments are therefore ideally 35 to 42 pounds in weight to fit within OSHA recommendations when the NIOSH lifting equation of 1991 is used, as discussed in connection with the battery module sizes in this document. When the charger operator is confronted with a rescue operation requiring a longer cable he may add a second and/or third cable segment to extend its effective range without having to reposition the service vehicle or charging system. These weight and size figures are not intended to define the absolute limits of the scope of the dimensions and weight of the cables, but as a preferred guideline for common embodiments of the invention.

In some embodiments a basic or standard cable segment includes a charging connector designed to mate with the EV at a charging port, and this basic cable segment can be augmented with other extension cable segments to increase its length. Connections between the segments may include NFPA 70 E compliant connectors (or equivalent) which do not require a certified electrician to make connections in the field. A second modular extension segment may be roughly 12 to 30 feet in length, one end of which having a connector shaped for attaching to a charging port on the service vehicle or another modular segment, and the other end having a connector shaped for attaching to an extension port on the basic cable segment or another end of another modular segment. One end of this cable segment attaches to the charger while the other end attaches to either another charging cable segment or the cable segment that contains the connector to the EV. Such component cable segments may be designed to stay within OSHA weight lifting recommendations.

FIG. 10A shows various isometric perspective views of a rescue vehicle and identifies a number of exemplary sites on the vehicle where a charging cable connection port 1000 may be located. The thickened ovals and circles show some advantageous positions for a charging cable connection port that may be installed to provide power from an onboard charging system to an EV. FIG. 10B shows a top perspective view of a rescue vehicle and also identifies a number of potential sites on the vehicle where a charging cable connection port 1000 may be located.

When two or more of these ports 1000 on the service vehicle are installed, the user may select an advantageous position to connect an EV charging cable, such as on the side of the service vehicle that is closest to the stranded EV’s charging port or on the side of the service vehicle that is safest (e.g., farthest) from nearby roadway traffic. In some instances, the user may connect the charging cable to one of the ports because another port is blocked or inaccessible, such as, for example, if one side of the service vehicle is too close to a wall or a restricted police zone or roadside construction zone. In other cases, one port may be preferable because the surroundings near the other port would pose a danger to the charging cord or the user, such as if the ground near that port was covered in glass shards, thorny plants, deep mud, or water. In yet other embodiments, the port selected would be determined by whether the nearby surroundings could properly support the charging cable, such as when one side of the service vehicle is on a downward slope and the charging cable would have to hang down a long distance to reach the ground and cause strain in the charging cable and connectors.

By selecting one port over another, the user gains the benefit of safer conditions, easier access to the target stranded EV, and less risk to himself and the charging equipment used with the EV. Alternatively, the presence of multiple charging ports on the service vehicle may give rise to the benefit of connecting multiple target stranded EVs to the vehicle for simultaneous charging, with each EV being connected to the nearest or otherwise most appropriate charging port on the service vehicle. These ports are even more beneficial when they are capable of level 2 charging, level 2 fast charging, level 3 charging, or another fast charging standard, as they may allow the EV and service vehicle to return to the roadway in a short time, thereby minimizing exposure to dangerous conditions and maximizing the time that the service vehicle may be out servicing other stranded vehicles. In some embodiments, the charging electronics are capable of output of multiple different charging standards, such as J1772 and TEPCO® CHAdeMO®, and the charging electronics can route the charging output of either standard to the same port. The user then attaches the appropriate charging cable to the port, such as a J1772 cable with a J1772 connector when the charging electronics provide a J1772 level 2 output from the port. When another charging standard is set to current from that port, then the user replaces the charging cable or an attachment of the charging cable such as the charging connector with a cable or attachment that is compatible with the different charging standard.

The depictions of a rescue or service vehicle and EV in the figures are not intended to introduce limitation into the size, shape, and type of vehicles that may be compatible with the present invention, but are merely presented as exemplary embodiments of one potential application of the invention. For instance, a truck is seen as a rescue vehicle in these figures, but a car, van, bus, watercraft, motorcycle, or other vehicle may be selected as well without departing from the invention. Likewise, connection ports 1000 may be positioned on the vehicle at positions other than those illustrated in the figures.

FIG. 11A depicts a segmented charging cable with two segments. A first segment is a standard charging cable 1100 having at a first end an EV charging connector 1102 and at a second end a cable connector or receptacle 1104. In some embodiments, a TEPCO® CHAdeMO® connector is the EV charging connector 1102, but other EV connector types may
be used. The other end 1104 of the first segment may be a NFPA 70 E compliant connector capable of being mated to either a charging equipment connector/receptacle on the rescue vehicle charger or on a cable extension 1106. FIGS. 11B and 11C show perspective views of an exemplary cable connector or receptacle that may be used for this purpose. FIG. 11B is a female connector, and FIG. 11C is a male connector. The male connector is inserted into the female connector, then turned to secure a locking edge and clipped into place by a retention clip.

[0160] Referring again to FIG. 11A, a second segment of the charging cable is a charging cable extension 1106 having a cable connector or receptacle 1104 on both ends that is NFPA 70 E compliant. A first end of the charging cable extension is a cable connector or receptacle 1104 capable of being mated to a cable connector or receptacle 1104 on the standard charging cable 1100. A second end of the charging cable extension is a cable connector or receptacle 1104 compatible with being mated to the charging equipment connector or receptacle 1108 on the service vehicle or the service vehicle charging station. All connectors of FIG. 11A may be NFPA 70 E compliant connectors capable of being field installed without the help of a certified electrician. This may allow a user to quickly set up and break down a charging cord in the field to minimize the exposure of the user, the charging equipment, the service vehicle, and the stranded EV to potentially hazardous roadside conditions.

[0161] FIG. 12A is a diagram of a rescue vehicle with a charging cable and connectors and an EV. The rescue vehicle in this diagram has multiple charging ports 1200, one of which has a standard charging cable 1202 used to charge an EV located near the rescue vehicle. By selecting the charging equipment connector or receptacle that is nearest to the stranded EV, the operator may use the standard cable 1202 without need for extensions, resulting in reduced tripping hazards and risk of damage to the cable from exposure to the roadway. A charging cable extension in this case may be stored in the rescue vehicle, allowing further reach for the charging station if necessary, but protecting the cable extension from potential wear and damage while stored.

[0162] FIG. 12B is a diagram of a rescue vehicle and stranded EV with charging cables and connectors partially connected with the stranded EV beyond the range of a standard charging cable 1200. In a configuration such as this, the rescue vehicle requires a longer charging cable than is normally needed, so the operator elects to use a charging cable extension 1204 and combine the extended length with a selection of the most opportune charging equipment connector on the rescue vehicle. The standard charging cable 1200 is transported near to the stranded EV, the charging cable extension 1204 is moved and mated to the standard charging cable 1200, the charging cable extension 1204 is connected to the rescue vehicle, and the EV charging connector 1208 is connected to the EV charging port 1210. In this manner, the user is not forced to transport a single extra-long heavy weight charging cable to the stranded EV over a long distance, but only has to travel with two smaller and more manageable cables. This may help reduce the manual labor performed by the operator and keep the operation of the charging equipment within OSHA recommendation standards while helping the operator remain away from traffic and other hazards and providing a direct route from the rescue vehicle charging equipment to the EV charging port. In this figure additional vehicles are between the rescue vehicle and the stranded EV, resulting in the inability of the rescue vehicle to reach the stranded EV without a charging cable extension, but other obstacles or hazards may result in a need for connecting to a far-away stranded EV, such as, for example, terrain, structures, other emergency vehicles, fire, oversized stranded EVs, stranded EVs with irregularly-placed charging ports, or even just operator neglect in parking the rescue vehicle too far away from the stranded EV.

[0163] Use and Integration of Deliverable Automotive Service Batteries

[0164] In some embodiments, service vehicles are used to transport and transfer automotive batteries to and from disabled vehicles when their batteries fail. Generally, the deliverable batteries are 12-volt lead-acid batteries (which may also be referred to as starting, lighting, ignition batteries or SLI batteries) transported and used in internal combustion engine (ICE)-based vehicles to start the vehicles and provide electricity when the alternator is not providing electricity to the vehicle. Service vehicles bearing the batteries of these embodiments store them in compartments and bring them to vehicles in need for switching out, and in some embodiments, the service vehicles charge the SLI batteries or use them for supplying energy to EV charging equipment of the service vehicle.

[0165] In another embodiment, the batteries are connected to the alternator of the service vehicle but are not connected to charging equipment on the vehicle. This may allow the batteries to remain at maximum charge when self-discharge would otherwise slowly deplete the batteries. It may also allow the service vehicle to restore energy to a battery if it is placed in the service vehicle having less than full charge. Some more embodiments have connections to allow the batteries to provide power to electrical systems such as lighting, radio, an electric motor, a winch, or other electrical devices on the vehicle.

[0166] In some embodiments the service batteries may be enabled or disabled for charging/discharging to the charging equipment, such as would be desired if the service vehicle operator received a call for a reservation of a particular type of battery. He or she could then disable discharging of that battery to ensure that it was fully charged for the customer who made the reservation. In other embodiments, some of the batteries stored on the vehicle may be used to transfer charge to another battery on the vehicle. For example, if a certain battery type is needed for a service call, but it is not currently fully charged, the other batteries may transfer charge to that battery to ensure that it has maximum charge when it is provided to the customer.

[0167] In some embodiments a controller is provided that may switch charging and discharging of individual batteries on and off as desired, may control the operation of power converters of the batteries, monitor and control charging equipment, and perform other monitoring, recording, and controlling tasks. In some embodiments the power converters are DC-DC converters or AC-DC converters/inverters that are unidirectional or bidirectional, have manual or remote control features, and can be set to receive and output a variety of signals, voltages, and currents.

[0168] These embodiments of the invention may provide cost savings to service vehicle fleet operators that wish to provide charging services to EVs. The service batteries are put to multiple uses by assisting internal combustion engine customers with failed batteries, and may be additionally used to assist charging stranded EVs. Customer satisfaction is
improved because the batteries they receive are more fully charged and the service vehicle may also serve their EVs. Providing charging services to EVs has lower barriers to entry for service vehicle fleet operators since the batteries purchased for EV charging may also be used in a battery replacement program using the same service vehicles and transporting structures.

[0169] FIG. 13A shows a side perspective view of a service vehicle 1300 with storage capability according to an embodiment of the invention. Such a service vehicle 1300 may be dispatched with batteries in the closed storage compartments 1302, the cab 1304, the bed 1306, or a charger enclosure 1308 (if present) that may be given to stranded vehicles with failed or depleted batteries. The batteries in the service vehicle 1300 may also be electrically connected for charging electric vehicles (EVs). FIG. 13B shows a side perspective view of a service vehicle 1300 such as the one shown in FIG. 13A with open storage compartments 1310. The open storage compartments 1310 may contain storage racks 1312 or shelves 1314 and may contain service batteries 1316, charging cables 1318, and other electrical equipment. One or more of the service batteries 1316 is connected to other electrical equipment in the service vehicle 1300 by power lines 1320. The compartment doors 1322 may be closed to protect the sensitive electronics within the compartments 1310.

[0170] FIG. 14A shows a top view of a service vehicle 1400 with electrical lines indicated according to an embodiment of the invention. The service vehicle 1400 has an engine 1402 that drives an alternator 1404. The alternator 1404 may include a standard vehicle alternator, an increased output capacity, or heavy duty alternator, or other means of converting power from the engine 1402 into electrical power. Other means of electricity generation may also be implemented with the vehicle 1400, such as a renewable energy generation from solar panels or windmills that are also directly or indirectly connected to the power line 1408 or other electrical systems of the vehicle 1400.

[0171] The alternator 1404 is linked to service batteries 1406 by a power line 1408 running through the vehicle. The service batteries 1406 may include electrochemical cells, arrays, or banks of lead-acid, lithium-ion, nickel metal hydride, nickel cadmium, zinc-based batteries, combinations thereof, and other similar rechargeable energy storage devices, such as, for example, capacitors, supercapacitors, and fuel cells. Preferably, the service batteries 1406 are comprised of models having standardized sizes, voltages, capacities, and other physical characteristics so that they may be more readily connected to disabled vehicles with standardized receptacles and electrical requirements, such as automotive S11 batteries. There may be one service battery 1406, two, three, four, five, ten, twenty, fifty, or more in the service vehicle 1400. Each battery 1406 has a positive and negative terminal that can provide a voltage difference when the battery 1406 is charged.

[0172] One or more of these batteries 1406 is connected to the power line 1408 in the vehicle 1400 to send and receive electricity to and from the alternator 1404, charging equipment 1412, controller 1410, and other batteries 1406. It may also be the case that there are no service batteries 1406 present in or on the service vehicle 1400, but provided that sufficient connectors exist on the vehicle to connect a service battery 1406 to the power line 1408 for the purposes mentioned in this document, a vehicle having this absence of batteries 1406 is still appraised to be within the scope of the invention. These connectors may include wires, plugs, clamps, clips, sockets, conducting racks, or other similar means for linking the electrical connections on the service batteries 1406 to the power line 1408.

[0173] A controller 1410 and charging equipment 1412 are also connected to the power line 1408. The controller 1410 may include a computer, processor with associated memory, control panel, or other means for monitoring, controlling, or recording the flow of electricity through the power line 1408 and charging line 1414, and possibly other electrical systems of the service vehicle 1400. Preferably the controller 1410 may be used to measure voltage, state of charge, current, temperature, and other factors related to the status and operation of the service batteries 1406, power line 1408, alternator 1404, charging equipment 1412, charging line 1414, and charging cables and connectors 1416. However, in some embodiments the controller 1410 may only be able to observe and control a subset of these portions of the system on the vehicle. The controller 1410 may also be able to issue instructions to these portions of the systems of the vehicle, such as, for example, setting the charging equipment 1412 to a certain output voltage, or electrically disconnecting certain service batteries 1406 from the power line 1408 when appropriate. The controller 1410 may also be able to send and receive information from a remote controller or server via a wired or wireless connection means such as infrared or optical transmission, Wi-Fi, Bluetooth® cellular, or other RF transmission.

[0174] A charging line 1414 comes from the charging equipment 1412 to EV charging cables and connectors 1416. In some embodiments, one structure comprises the charging line 1414 and the cables and connectors 1416. The charging equipment 1412 may include one or more DC-DC buck/boost converter, one or more single- or bi-directional inverters, signal conditioning circuitry such as filters and stabilizing capacitors, and combinations thereof. The selection of these elements is significant in relation to the electrical signal(s) required for charging an EV. In some embodiments the settings of the components of the charging equipment 1412 may be set and adjusted by the controller 1410. For example, in order to comply with the SAE J1772 AC charging standard, an inverter would be included in the charging equipment 1412 to convert the DC voltage of the service batteries 1406 into a single-phase 240-volt AC signal that would be supplied to the charging line 1414, and a boost converter may be required to upconvert the voltage of the batteries 1406 to a DC voltage suitable for conversion by the inverter. The charging equipment 1412 may be stored in a charger enclosure 1308, or may be integrated into other portions of the service vehicle 1412 including the cab, the bed, and the storage compartments in which the batteries 1406 are shown. Additionally, charging equipment 1412 may be removable from the vehicle and in that case it may have quick disconnecting connectors between the equipment 1412 and the power line 1408.

[0175] The charging cables and connectors 1416 may include wires, cords, and similar conductors to link the charging equipment 1412 to a nearby EV. The connectors may be standardized connectors such as the SAE J1772 connector or may be non-standardized, popular connectors such as the TEPCO® CHadeMO® connector, or unpopular or customized connectors, as necessary for EV charging. The charging cables and connectors 1416 may be stored in compartments or other areas of the vehicle, and may be disconnectable from the charging line 1414 to be replaced with other charging
cables and connectors 1416 or safety caps to prevent soiling or tampering with the vehicle.

[0176] In some embodiments, it may be advantageous to program the controller 1410 to allow one or more service batteries 1406 to discharge to another service battery 1406 or number of service batteries 1406. For example, if a customer needs a fully charged service battery 1406, but it has recently been used to supply energy to the charging equipment 1412, the controller 1410 may direct other batteries 1406 to discharge into the customer's needed battery in order to increase its state of charge prior to turning it over to the customer. The alternator 1404 may then be used to restore charge to the remaining service batteries 1406 and a battery collected from the customer, if any.

[0177] FIG. 14G shows top view of a service vehicle 1418 similar to FIG. 14A but with power converters 1420 disposed on the power line 1408 between the service batteries 1406 and the charging equipment 1412, controller 1410, and alternator 1404. The power converters 1420 may be useful to install on one or more battery 1406 or on a group of batteries to stabilize and standardize the electrical signals provided to the charging equipment 1412. It may also increase efficiency of charging differing batteries 1406 with the alternator 1404 by preventing circulating currents through the batteries 1406. It may also be advantageous to implement power converters according to the apparatus described in U.S. patent application Ser. No. 13/100,152 (which is hereby incorporated by reference) that render the service batteries 1406 parallelable without regard to the voltage, capacity, or other characteristics of the batteries 1406 to enhance compatibility of the service vehicle 1418 with a wider range of batteries 1406. Another advantage of using converters 1420 with some or all of the batteries 1406 is realized when a controller 1410 is connected to the converters 1420 to enable or disable the converters 1420 to connect or disconnect batteries 1406 from the power line 1408.

[0178] FIG. 14C shows a top view of a service vehicle 1422 with alternate charging lines indicated according to an embodiment of the invention. In this embodiment the charging line 1424 extends to multiple charging ports 1426 that serve as connectors to a detachable charging cable and charging connectors 1428. The charging cable and connectors 1428 may be selectively connected to a charging port 1426 that is most convenient and/or safe for charging an EV to which the service vehicle 1422 is brought. For example, a detachable cable and connector 1428 may be connected to the left side of the vehicle if it is closer to the stranded EV than the right side, or if the right side of the service vehicle 1422 is more exposed to traffic or other hazards.

[0179] FIG. 14D shows a top view of a service vehicle 1430 with batteries 1406 that are connected to an alternator 1404 without being connected to charging equipment. This alternate configuration shows that the batteries 1406 are not required to be used in charging EVs. This figure also shows that an unoccupied battery port 1432 may be present in the system without negatively affecting the operation of the service vehicle. Likewise, all of the battery ports may be unoccupied while still practicing the invention as long as when a service battery 1406 is electrically connected to the power line 1408 in one of the storage port areas of the vehicle 1430, the battery may be charged by the alternator 1404 or discharged to other batteries in the vehicle. A service vehicle 1430 of this embodiment may be routed to a disabled vehicle, exchange a service battery 1406 to the disabled vehicle and take its battery to be recharged via the alternator 1404 and power line 1408 when it is connected to an unoccupied battery port 1432.

[0180] FIG. 14E shows a top view of a service vehicle 1434 with batteries 1406 that are connected to charging equipment 1412 and a controller 1410 without being connected to an alternator. In this embodiment, the batteries 1406 are not recharged while borne by the service vehicle 1434, but may still be leveraged as an energy source of the charging equipment 1412. This system would eventually exhaust its energy storage and would have to be connected to a charging station to restore charge to the batteries 1406 either by connecting directly to the batteries or by connecting the power line 1408 or charging line 1414 to a power source and charging the batteries 1406 indirectly through the power line 1408 and/or charging equipment 1412.

[0181] FIG. 14F shows a top view of a service vehicle 1436 with service batteries 1406 that are connected to a first power line 1438 that is linked to an alternator 1404, and service batteries 1406 that are connected to a second power line 1440. In this configuration, the user may opt to use service batteries 1406 as a source of power for the charging equipment by connecting them to the second power line 1440, or may connect the batteries 1406 to the first power line 1438 for recharging (or maintenance of charge) via the alternator 1404. In this embodiment, the controller 1410 may be able to control the charging operations of the devices connected to the second power line 1440, and may also be able to monitor and control the charging of the service batteries 1406 in the first power line 1438. This embodiment allows the user to easily manage whether the batteries 1406 on the service vehicle 1436 will be charging or discharging by deciding which power line the batteries should be connected to. Thus it may be advantageous to arrange the power lines 1438 and 1440 in the vehicle so that it is clear to the user whether a battery receptacle is connected to a charging line or a discharging line, such as, for example, making all battery receptacles or connections on the left side of the vehicle charging connections and making all battery receptacles or connections on the right side of the vehicle discharging connections. This embodiment may also be advantageous in simplifying a battery reservation system, since if a battery is reserved on the service vehicle 1436, the vehicle operator can reserve that battery by simply connecting the battery to the first power line 1438 with an assurance that it will not discharge any more until the reserved battery is delivered to the entity that made the reservation. In an alternative embodiment, the first and second power lines 1438 and 1440 are connected to a switch at each service battery 1406 receptacle/connector such that the vehicle operator may selectively choose a preferred power line for each battery 1406 without having to move the battery to a new receptacle or connector.

[0182] Monitoring, Management, and Control of Service Vehicles and Battery Modules

[0183] In some embodiments a network of system controllers tracks the status of a number of rescue vehicle charging systems, evaluates options, recommends actions, and, at times, takes automated action regarding the control of the service vehicles or battery modules. In one embodiment, “first-level” controllers in the network are associated with each of the rescue vehicles, where they monitor the health and status of the vehicle and its systems. They record vehicle location, operational status, fuel level, and vehicle maintenance alerts. In some embodiments, the first-level rescue
vehicle controllers communicate this information to the rescue vehicle operator and in some embodiments this information is sent to a second level of controllers (that may, for example, reside in a control center) for analysis and optimization of multiple first-level controller operations. The first-level controllers may use one or more computers or other interfaces located on the vehicle or a handheld device to gather and serve this information to the rescue vehicle operator.

[0184] In some embodiments the first-level controllers communicate with “second-level” controllers via cellular, radio or other electronic communication systems. In the case of communication link failures, the first and second level controllers search for alternate link pathways while storing accumulated relevant data for future transmission. The first-level controllers may also take automated actions where appropriate.

[0185] The second-level controllers receive data feeds from the first-level controllers on rescue vehicles in their service area. The data feeds may include, for example, location, the state of energy storage available for EV charging, and health management data from vehicle systems including alerts and trends for key systems. The rescue vehicle power electronics data may include, for example, temperature, high and low voltage, current draw, electric fault exceedances, and unusual trends of the energy storage, chargers, inverters, and other power electronics. The second-level control center controller may maintain a maintenance log and may recommend preventative maintenance actions and schedules and communicate this information to the rescue system operators and/or their supervisors.

[0186] In some embodiments the control center controllers optimize overall rescue systems scheduling based on the availability of assets, state of preparedness, location, lack or presence of system rescue vehicle alerts, customer rescue requests and locations, etc. In some embodiments the control center controllers also schedule rescue vehicle recharging or swap-out of battery modules/Rescue Operations Battery Modules (ROBM) procedures based on vehicle location, work load, and asset status (including but not limited to energy storage status).

[0187] In some embodiments the control center controllers optimize decisions regarding whether fully charged ROBM should be sent to a rescue vehicle by a ROBM resupply/replacement vehicle or to route the rescue vehicle to a ROBM swap out station. Either way, ROBM are reserved for specific rescue vehicles based on a rules-based prioritization system. In this manner, every rescue vehicle is guaranteed availability of a ROBM swap out at a specific time and location. In some cases, the controller directs a rescue vehicle to recharge without unloading any modules, as that may be the most efficient operation at the time.

[0188] A third level of controllers may be utilized in large areas to support long-term asset optimization and logistics coordination and facilitate economies of scale in purchasing and deploying assets. In another embodiment the “third-level” controllers provide recommendation of targeted preventative maintenance, elimination of high failure rate equipment, and provide recommendations for preventative maintenance, training, and order delivery.

[0189] The controller systems may be designed to optimize rescue operations in some of the following ways: (1) minimizing the time required for a rescue vehicle to respond to the stranded vehicle, such as by coordinating rescue vehicles so that the nearest vehicle is assigned to respond to the stranded vehicle, (2) minimizing the time required for the rescue vehicle to recharge the stranded vehicle by deselecting rescue vehicles who do not have adequate consumables (energy storage, fuel, etc.), (3) minimizing the time required for a stranded vehicle to reach a location where a greater charge can be obtained, such as by measuring the distances to the nearest charging locations and selecting the nearest one to which to direct the stranded EV and/or by verifying and reserving a charging location for the stranded EV, (4) minimizing the time required for the rescue vehicle to recharge its charging system’s batteries, such as by coordinating the exchange of fully charged battery modules for discharged modules onboard the rescue vehicle, (5) minimizing the fuel consumed by the rescue vehicle and time to respond in assisting a stranded vehicle, such as by keeping rescue vehicles near areas with high incidence of EV rescue events, (6) increasing rescue vehicle or energy storage device service lifetime and reliability, such as by monitoring the characteristics of the charging systems and scheduling maintenance, (7) minimizing charging equipment costs by increasing its utilization, (8) minimizing rescue vehicle downtime due to maintenance or refueling, (9) minimizing strain of rescue vehicle operators, such as by sending notifications of required maintenance and/or by allowing operators to override commands sent from a control center, and (10) increasing ease of use of rescue vehicle-transported charging systems, such as by displaying important information and automating maintenance decisions.

[0190] In some embodiments a first-level rescue vehicle controller is used to report status information to a rescue vehicle operator, and potentially also report this information to a second-level controller and/or provide charging system control commands to ensure safe and efficient operation of a service vehicle. (See FIG. 23 for a diagrammatic view of the hierarchy of controllers.)

[0191] In this embodiment, as shown in FIG. 15, the rescue vehicle controller monitors vehicle location, vehicle system status, charging system status (step 1500) and reports alerts and system status information to the vehicle operator (step 1502) and, optionally, to a second level of controllers located in a control center (step 1504). Alerts include system-safety-related alerts. Safety-related alerts may involve exceedances of electric fault indication, equipment temperature, vibration, current draw, high or low voltage and other indicators related to system safety. If the system controller detects a safety-related issue it will alert the vehicle operator and the control center controller to take appropriate action (step 1506). Depending on the nature of the alert the controller may command the system to cease charging operations and/or safe the system (step 1508), and report the status to the vehicle to the vehicle operator and, in some cases, a control center (step 1510). The controller will also recommend appropriate actions to the vehicle operator which may include instructions about how to get the vehicle off a freeway and or maintenance actions to take (step 1512).

[0192] In another embodiment the first-level system controller monitors vehicle system status and communicates this to vehicle operator and the second-level control center controller. This may include vehicle fuel status. The first-level controller working with the control center controller could recommend refueling at a specific location or recommend alternative locations prior to commencing another EV charg-
ing session. Alternatively it can recommend taking actions to correct a system overheating indication.

[0193] FIG. 15 is a process flowchart showing an example of a process performed by a first-level controller on a vehicle according to an embodiment of the invention to optimize and coordinate safety and maintenance instructions. Optional paths are indicated by dashed lines.

[0194] In another embodiment the vehicle may receive alerts or unfavorable vehicle operational data from a control center or operational center (step 1514). For example, this may include unfavorable trend data from a fleet of rescue vehicles or data that the control center has analyzed and believes action is warranted. The rescue vehicle may be put on alert and asked to monitor certain vehicle systems or types of activities and may be instructed concerning certain remedial actions to take. The rescue vehicle may be pulled from operations and either safed at its current location or advised to relocate to a new location which may have repair or replacement capability. Optimum routing information may be provided to the rescue vehicle operator as part of this communication.

[0195] In one embodiment the second-level controller analyzes vehicle system trends, safety or critical operational alerts, and analyzes maintenance records may recommend maintenance proactively (in preference to reacting to system failures after the fact) to minimize unplanned downtime for the rescue vehicle or its EV charging system. In the case of safety critical alerts or emergent action required, the second level controller may alert and/or command the rescue vehicle to take certain actions to keep the rescue vehicle and or its operations safe. It may follow these actions with a closed loop system to ensure the vehicle is safe and that no further safety or mission-critical actions or support is required. If support is deemed to be required, the rescue vehicle may initiate a support request or the second level controller may recommend support. In either case, the second-level controller may review available assets and send appropriate requests for support and provide a closed loop follow up to ensure required support has been provided and the situation has been remedied.

[0196] FIG. 16 is a process flowchart showing an example of this process performed by a second-level controller or control center according to an embodiment of the invention to optimize and coordinate safety and maintenance instructions. The second-level controller monitors the vehicle, vehicle’s location, and charging system status for individual rescue vehicles (step 1600), and when a potential defect or problem is detected in the rescue vehicle (step 1602), a report is sent to the rescue vehicle operator (step 1604) with that information, and the operator is given directions to repair, refuel, go to a service location, etc. (step 1606).

[0197] The rescue vehicle controller in some embodiments is designed to safely operate without communication with the control center controller in the event of a lapse of communication connectivity or control center unavailability for any other reason. The first-level system performance may degrade in this case as insight into customer rescue requests becomes stale. Operations will continue to be conducted based on the rules based software and firmware on the onboard system controller which includes a comprehensive operational set of rules. This ensures safe operation with potential for appropriate local overrides by the rescue vehicle operator. In a period of interrupted communications with a control center system, data may be stored on board for later communication to the control center when communication links are reestablished. Relevant information from the control center from other pertinent sources may be updated manually, such as, for example, location and vehicle status data for the next customer that may have been received through an alternate communication path.

[0198] Communication paths include onboard cellular transceiver or transceiver systems, radio-based systems, personal cell phones, land line telephone communication systems, and the like. Additionally, voice and/or data communication may be relayed to a rescue vehicle through another rescue vehicle or other associated vehicles to and from a control center, operational center, or operating entity.

[0199] FIG. 17 is a process flowchart showing an example of a process performed by a first-level controller or vehicle controller according to an embodiment of the present invention that is used when there is a communication disruption between a first-level controller and its source of instructions. The first-level controller monitors a vehicle communication system link to a second-level controller (step 1700) and if a communication disruption is detected (step 1702), alternate communication links are polled and a new connection through other channels is attempted (step 1704). If a communication link is reestablished, status and alert information is exchanged between the levels of controllers for the time that the communication disruption took place (step 1706) and normal operations are resumed (step 1708). If a link is not reestablished in step 1704, the first-level controller stores available vehicle data and operates under a vehicle-stored protocol (step 1710) and continues attempting to reconnect the communication link (step 1712). When the communication link resumes (step 1714), the stored data is sent to the second-level controller, and any alert information from the second-level controller that was not transmitted to the vehicle in that time is sent (step 1716).

[0200] In another embodiment the vehicle controller provides recommendations as to how much charge is required to get the EV off of a roadway and to one or more EV charging stations (e.g., in kilowatt-hours). In this manner the amount of charge provided by a rescue vehicle is tailored to the need of the particular EV being assisted. Here the controller identifies nearby charging station location options and recommends one or more of the options to the rescue vehicle operator, along with instructions regarding how much charge to dispense to the EV battery, and then provides driving instructions to the EV operator that direct him or her to the selected location. In some embodiments the controller may also communicate information to the selected charging station regarding the EV operator’s arrival time and make a reservation for a charging session, if possible. A discounted rate could also be applied for using the roadside assistance service in finding a vehicle charging customer.

[0201] FIG. 18 is a process flowchart showing an example of a process performed by a first- and second-level controller according to an embodiment of the present invention that optimizes charge provided to a disabled EV. At the start, the second-level controller dispatches a selected rescue vehicle to a disabled or depleted EV (step 1800). This may include sending dispatch information to the service vehicle that comprises the location of the EV and other identifying information about the EV, such as the EV’s state of charge, the model of the EV, charging standards supported by the EV, the length of time that the EV has been in need of charge, the EV operator’s identification information, a license plate number,
customer number, and other EV information that assists the service vehicle operator or first-level controller to provide effective or efficient service.

[0202] The first level controller evaluates EV charging location options given traffic and related factors (step 1802) and determines the best available charging location (step 1804). For example, the first level controller may determine the best route that the EV driver would follow to reach a charging location due to traffic, the range of the EV, the change in elevation between the EV and the dedicated charging location, whether the EV would be compatible with the charging equipment at the charging location, the price of recharging the EV at the charging station, the expected average rate of energy consumption of the EV between the location of the EV and the charging station location, the distance between the EV and the charging location, and other factors relevant to selecting the most efficiently accessed and utilized charging point. Additionally, a charging station may be selected based on the proximity of the charging location to an intended destination of the EV or proximity of the charging location to a path that would be used to reach the intended destination. For example, a charging location that is in a direction toward the EV's home garage may be preferred over a charging location that is in the opposite direction, even if the charging location in the opposite direction is closer to the distressed EV. Likewise, if a charging location is close to the route the EV driver would use to reach his intended destination, it may be preferred over charging locations in other directions even if the other locations are closer at the time the EV is charged by the service vehicle.

[0203] In the execution of step 1804, functions may be performed in parallel by the second-level controller to improve or confirm the decision making of the first-level controller, since the second level controller will typically have more information available, including but not limited to the location of other service vehicles, replacement battery module locations for the service vehicle, other distressed EVs in the range of the service vehicle, and more. Thus, in steps 1806 and 1808 the second-level controller monitors and supports the first level controller. Additionally, the first-level controller determines an amount of charge to provide to the EV, preferably including a safety factor, and the second-level controller may support the service vehicle in this action such as by approving a point-of-sale transaction that takes place between the EV and the service vehicle (steps 1810 and 1812). The first- or second-level controller may then reserve a charging station for the disabled EV (if the charging station supports reservations compatible with the first-level controller) (step 1814), and the service vehicle provides directions and/or reservation information to the EV (step 1816). Such reservation process may include electronically reserving a charging station for the EV or gathering charging station reservation availability information to be given to an occupant of the EV. Charging station reservation availability information is information that allows the EV occupant to make his own reservation or alternatively may define how long a reservation will remain available to the EV. The service vehicle is connected to the EV and provides an optimized amount of charge from its onboard charging system so that the EV can safely reach the charging station (step 1818). At this time, if a second-level controller communication link is available, the second-level controller validates the payment and the recommendation determined by the first-level controller (step 1820). Finally, the first-level controller may confirm the arrival of the EV at the charging location and that charge has been restored, such as through an internet- or cellular-network-based LAN or WAN messaging confirmation sent to or from the EV (step 1822). Alternatively, the service vehicle may accompany the EV to the charging station. The second-level controller validates that the EV has been served and logs status information about the EV and/or service vehicle such as the remaining charge in the charging equipment of the service vehicle, the fuel level of the service vehicle, and other service-related metrics (step 1824).

[0204] In this embodiment, with a sufficient communications link between the first- and second-level controllers, the second-level controller may replicate the steps performed by the first-level controller in near real-time. When the first-level controller experiences degraded performance, the second-level controller may actively provide recommendations and commands to the service vehicle in lieu of the first-level controller.

[0205] In some embodiments, a first-level rescue vehicle controller interacts with a second-level controller or operational center or control center and receives commands and/or status update information from the second level controller or operational control center. The rescue vehicle receives information regarding (1) future customers requiring rescue or other support, (2) availability of recharging capacity for its onboard battery-driven EV recharger, (3) optimum location and routing for the rescue vehicle to be refueled or repaired, (4) optimum routing to other planned stops, (5) information regarding rescheduling of operations, and (6) off-normal events and alerts including trend data regarding its onboard systems and recommended actions.

[0206] In another embodiment shown in the flowchart of FIG. 19, pairing information for a rescue vehicle and recharging mission is evaluated at an operations or control center. The controller determines that a rescue vehicle has the requisite equipment and capacity to charge the stranded vehicle for a potential mission and selects that vehicle for performing that mission (step 1900). Once selected, the rescue vehicle receives a rescue request including location and job information from a control or operational center located at a fixed (or potentially mobile) location (step 1902). Optimum routing from his current location to the rescue location is provided. In some variations of this embodiment, the rescue vehicle operator may have to first decide to accept or override the request (step 1904). In these embodiments, the second-level controller reassigns the task to another rescue vehicle if the vehicle operator rejects or overrides the instruction (step 1906).

[0207] The second-level controller then monitors the rescue vehicle location its status, including point-of-sale information when the rescue vehicle performs some charging (step 1908), as the rescue vehicle controller communicates its location and vehicle status information to the control center controller while the rescue vehicle is en route and performing rescue operations (step 1910). The command center controller updates its database, and rerouting information and status information may be provided to the rescue vehicle while in transit or at the service location (step 1912).

[0208] In some other embodiments, the rescue vehicle is sent instructions to deviate from currently planned or known operations and to proceed to a new operational assignment. For example, this may include performing rescue related operations or other operations as assigned from the control or operational center, such as, for example, delivering battery...
modules to another rescue vehicle or transferring battery modules between a charging location and another service vehicle.

[0209] FIG. 20 shows some other embodiments of routing rescue vehicles and the interaction between first-level controllers and second-level controllers. In steps 2000 to 2010, a rescue vehicle receives a recommendation from an operational control center that its onboard energy storage battery capacity is depleted or needs to be charged. The rescue vehicle then receives a command to rendezvous with a battery resupply vehicle and exchange out some number of depleted or partially depleted energy storage battery modules. Routing information may be provided to optimize time spent and expense. In some embodiments, these steps instead define a rendezvous or exchange instruction for the service vehicle to exchange one or more battery modules with a battery module storage location or another service vehicle instead of exchanging with a resupply vehicle.

[0210] In another embodiment, a rescue vehicle may receive a recommendation to proceed to an energy storage battery module resupply station specially designed to accommodate battery modules from rescue vehicle charging systems, as shown in steps 2012 through 2016. Optimum routing information may be provided from the vehicle’s current location to the resupply station. The onboard charging system batteries are swapped out for fully-charged battery modules, and the rescue vehicle is provided information requisite to proceed on other rescue missions.

[0211] In another embodiment, the rescue vehicle controller monitors a vehicle’s location and the availability of energy storage on the vehicle and reports this information to the vehicle operator and to the second-level/center control controller. The rescue vehicle controller receives recommendations from the control center controller relative to charging out batteries or charging up existing batteries. Based on actual status, customer requests and other factors, the control center controller may reserve a battery for the rescue vehicle’s charging system at an energy storage swap out station and recommend the vehicle proceed to that location after the EV rescue operation is completed. In this case, the rescue vehicle operator will review the recommendation and may accept or override it. Alternatively, the control center controller may recommend to the first-level controller that one or more battery modules be delivered by a vehicle battery delivery truck based on location, battery availability, anticipated EV battery charging service needs, and other factors. The vehicle operator may be allowed to either accept or override this recommendation. In some of these embodiments, the primary objective of this process is to maximize vehicle rescue timeliness while also maximizing equipment utilization and minimizing operational costs over time.

[0212] In another embodiment, the rescue vehicle receives instructions regarding an optimum time to refuel and is given routing instructions to a nearby refueling station, as shown in steps 2018 through 2034. The consumables referenced in these steps may include battery modules, charging devices, vehicle parts, and other components used in vehicle service operations. Instructions to the vehicle may be modified by including consideration for current traffic in the area near the service vehicle, queuing at a refueling station, and other relevant routing considerations.

[0213] In another embodiment the control center controller may recommend that a rescue vehicle take time out to refuel at a specific location in preparation for other planned or probabilistic activity. Optimized routing information may be developed and pushed to the rescue vehicle along with other related instructions. Similarly, the second-level controller may recommend other onboard consumables or other operational equipment to be repaired or replaced when such action is most cost-effective.

[0214] In the process depicted in FIG. 21, a second-level controller optimizes actions of a fleet of EV-charging rescue vehicles. Here, the second-level control center controller receives status-related information and requests from a fleet of rescue vehicles and other sources (step 2100) and optimizes rescue vehicles’ performance across a service area, determining maintenance needs and schedules of rescue vehicles in the fleet, minimizing response times between receiving EV charging requests and performing EV charging, and otherwise optimizing fleet asset utilization (step 2102). In this embodiment the second-level control center controller is designed to optimize rescue vehicle fleet system performance at a higher level than an individual rescue vehicle controller. The control center controller receives customer rescue requests and optimizes rescue vehicles’ response to the requests based on availability of the rescue vehicles, their respective locations, and the condition of other assets across a designated service area in combination with the suitability and readiness of their systems.

[0215] In this embodiment the second-level controller may recommend optimization actions as to when and where to utilize specific rescue vehicles. It may match availability of GPS-based asset location communicated to it from the onboard rescue vehicle systems with status information for onboard systems, customer requests, routing information, traffic information, status of on board fuel, refueling options, energy storage recharge battery status, and location of battery replacement options and other relevant information. It may then assign specific rescue vehicles to specific job assignments. It may use a closed loop system to verify that requisite actions are taken or recommend subsequent actions to address residual operational needs, if such needs exist. Optimization criteria may include response time, safety optimization, customer satisfaction factor optimization, vehicle utilization optimization, cost optimization, probabilistic impact to planned or unplanned but probable operations, and other factors.

[0216] In some embodiments, the second-level controller distributes tasks to rescue vehicles and ensures that all necessary tasks are accepted by reassigning tasks that are not accepted by rescue vehicle operators (steps 2104 and 2106). After tasks are accepted and completed, the success of the tasks is validated and new assets are given assignments as required by the second-level controller (step 2108).

[0217] Third-level controllers are another hierarchical tier of controls used to optimize staging and prepositioning of assets in a large area, primarily managing and advising multiple local regional control centers and their rescue vehicle fleets. In the embodiment shown in FIG. 22, the third level of controllers is implemented at a regional level. The controller implementing this process may be non-real-time server-based controller designed to optimize top level and system wide needs. It may be co-located with a second level controller in a control center or may be associated with a separate server and/or location. The third-level controller aggregates operational needs for replacement parts and systems of the tiers of controllers and fleets below it (step 2200). For example, it may aggregate energy storage battery failure
information across the country or around the world and recommend new parameters for battery reordering or reusing based on widespread failure rates. The controller may aggregate failure data and identify equipment and systems having unusually high failure rates or undesirable reliability characteristics for further review. This may also include other components such as inverters or chargers that are associated with rescue vehicles. The third-level controllers may also coordinate changing out system-level assets across a region. This may include eliminating specific rescue vehicles or a class of rescue vehicles having a poor history of safety issues and reassigning other assets to replace them from areas of lower demand. The third-level controller’s data compilations and analysis serve to provide a basis for bulk ordering and implementation of critical components and systems (steps 2202 and 2204).

[0218] Another task suited for these controllers is the aggregation of certain requirements for operational support to meet certain future needs such as a surging of assets to support a large near-term temporary localized need for EV charging services. For example, a World Series baseball game could require mobilizing special EV charging support vehicles for a few days in a localized area around a stadium or in a city, where the support vehicles are drawn from a regional or global inventory of assets. The third-level controller would recognize assets managed by different second-level controllers that could be used to meet the temporary charging needs that arise in this situation and identify how to resume normal operations afterward.

[0219] FIG. 23 provides an overview of the hierarchy of controllers at the first, second, and third levels as described previously. This figure sets forth that the first-level controller or controllers operate in real-time control onboard a rescue/service vehicle to provide real-time control of aspects of the service vehicle and its charging equipment, the second-level controller or controllers operate in real-time (or near real-time) from a central control or operational center to optimize assets across an area, region, or globally, distribute vehicle assignments, and schedule vehicle service/maintenance and EV assistance services, and the third-level controller or controllers are located in control or operational centers and provide business management optimization across the entire system and coordinate special needs of regions or areas that are managed on a day-to-day basis by first- and second-level controllers.

[0220] Miscellaneous Definitions and Scope Information

[0221] Battery modules are described herein as a preferable means for storing and transporting electrical energy, but other equivalent means for storing energy may be used, such as, for example, electrochemical batteries, compressed gas storage, pumped hydro storage, flywheel energy storage, capacitive energy storage, superconductive magnetic energy storage, fuel cell energy storage, combinations thereof, and other similar devices for energy storage known in the art. If the modules are battery-based, the battery types may include rechargeable or non-rechargeable chemistries and compositions, such as, for example, lead-acid, alkaline, secondary lead acid, lithium-ion, sodium (zebra), nickel-metal hydride, nickel cadmium, combinations thereof, and other energy storage chemistries known in the art. Energy storage devices such as these may be comprised of small or large numbers of cells, capacities, voltages, amperages, and other battery properties. They may be configured in unitary or modular designs and may follow standardized guidelines or customized specifications.

[0222] Some methods and systems of the embodiments of the invention disclosed herein may also be embodied as a computer-readable medium containing instructions to complete those methods or implement those systems. The term “computer-readable medium” as used herein includes not only a single physical medium or single type of medium, but also a combination of one or more tangible physical media and/or types of media. Examples of a computer-readable medium include, but are not limited to, one or more memory chips, hard drives, optical discs (such as CDs or DVDs), magnetic discs, and magnetic tape drives. A computer-readable medium may be considered part of a larger device or it may be itself removable from the device. For example, a commonly-used computer-readable medium is a universal serial bus (USB) memory stick that interfaces with a USB port of a device. A computer-readable medium may store computer-readable instructions (e.g., software) and/or computer-readable data (i.e., information that may or may not be executable). In the present example, a computer-readable medium (such as memory) may be included to store instructions for the controller to operate the heating of the ESD and historical or forecasted temperature data for the ESD or its surroundings.

[0223] The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalent of the claims are to be embraced within their scope.

[0224] In addition, it should be understood that the figures described above, which highlight the functionality and advantages of the present invention, are presented for example purposes only and not for limitation. The exemplary architecture of the present invention is sufficiently flexible and configurable, such that it may be utilized in ways other than that shown in the figures. It will be apparent to one of skill in the art how alternative functional, logical or physical partitioning, and configurations can be implemented to implement the desired features of the present invention. Also, a multitude of different constituent modules or step names other than those depicted herein can be applied to the various partitions. Additionally, with regard to flow diagrams, operational descriptions and method claims, the order in which the steps are presented herein shall not mandate that various embodiments be implemented to perform the recited functionality in the same order unless the context dictates otherwise.

[0225] Although the invention is described above in multiple various exemplary embodiments and implementations, it should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described, but instead can be applied, alone or in various combinations, to one or more of the other embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the
present invention should not be limited by any of the above-described exemplary embodiments.

[0226] Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term “including” should be read as meaning “including, without limitation” or the like; the term “example” is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; the terms “a” or “an” should be read as meaning “at least one,” “one or more” or the like; and adjectives such as “typical,” “conventional,” “traditional,” “normal,” “standard,” “known” and terms of similar meaning should not be construed as limiting the time described to a given time period or to an item available as of a given time, but instead should be read to encompass conventional, traditional, normal, or standard technologies that may be available or known now or at any time in the future. Likewise, where this document refers to technologies that would be apparent or known to one of ordinary skill in the art, such technologies encompass those apparent or known to the skilled artisan now or at any time in the future.

[0227] A group of items linked with the conjunction “and” should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as “and/or” unless expressly stated or context dictates otherwise. Similarly, a group of items linked with the conjunction “or” should not be read as requiring mutual exclusivity among that group, but rather should also be read as “and/or” unless expressly stated or context dictates otherwise. Furthermore, although items, elements or component of the invention may be described or claimed in the singular, the plural is contemplated to be within the scope thereof unless limitation to the singular is explicitly stated. The presence of broadening words and phrases such as “one or more,” “at least,” “but not limited to” or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent.

[0228] Additionally, the various embodiments set forth herein are described in terms of exemplary block diagrams and other illustrations. As will become apparent to one of ordinary skill in the art after reading this document, the illustrated embodiments and their various alternatives can be implemented without confinement to the illustrated examples. For example, block diagrams and their accompanying description should not be construed as mandating a particular architecture or configuration.

[0229] Further, the purpose of the Abstract is to enable the U.S. Patent and Trademark Office and the public generally, and especially the scientists, engineers, and practitioners in the art who are not familiar with patent or legal terms or phraseology to determine quickly from a cursory inspection the nature and essence of the technical disclosure of the application. The Abstract is not intended to be limiting as to the scope of the present invention in any way.

What is claimed is:

1. A network for providing energy to discharged batteries of electric vehicles (EVs), the network comprising: a service vehicle transporting electric vehicle (EV) charging equipment, transporting a first-level controller, and capable of transporting battery modules removably mounted to the service vehicle, wherein the battery modules are configured as a source of electrical energy, the electrical energy transferable to an EV using the EV charging equipment; and a storage location storing battery modules compatible with the EV charging equipment of the service vehicle, wherein the battery modules are manually exchangeable between the storage location and the service vehicle, such that a removably mounted battery module on the service vehicle is replaced by a battery module stored by a storage location.

2. The network of claim 1, further comprising: a resupply vehicle configured to deliver battery modules between a storage location and a service vehicle.

3. The network of claim 2, wherein the resupply vehicle comprises an alternator or generator, the alternator or generator configured to charge a battery module while the battery module is delivered by the resupply vehicle.

4. The network of claim 1, where the service vehicle may remotely reserve one or more battery modules at the storage location.

5. The network of claim 4, further comprising: a scheduling controller at the storage location programmed to reserve battery modules for rescue vehicles based on an emergency state of service required.

6. The network of claim 1, further comprising: a charging apparatus at the storage location, the charging apparatus configured to charge the battery modules at the storage location.

7. The network of claim 6, wherein a charging controller at the storage location charges the battery modules sequentially.

8. The network of claim 6, wherein a charging controller at the storage location charges the battery modules simultaneously.

9. The network of claim 6, wherein a charging controller is configured to prevent charging battery modules if charging would exceed a demand threshold for the storage location.

10. The network of claim 6, wherein the charging apparatus is an electric vehicle supply equipment (EVSE) having an EV charging connector, and the battery modules comprise a charging port configured to receive the EV charging connector.

11. The network of claim 1, wherein the storage location is a repositionable mobile unit.

12. The network of claim 11, wherein the mobile unit is repositioned to a location having a temporary need for battery modules.

13. The network of claim 11, wherein the mobile unit is connectable to a utility distribution grid in such a manner that the battery modules of the mobile unit are charged by the utility distribution grid.

18. The network of claim 1, the service vehicle further comprising: an onboard controller device configured to monitor and report status conditions of the EV charging equipment and battery modules of the service vehicle and configured to communicate operational assignments for the service vehicle.

19. The network of claim 1, the service vehicle further comprising: an onboard controller device configured to monitor and report status conditions of the EV charging equipment and battery modules of the service vehicle and configured to indicate a status condition of battery modules at the storage location or on another vehicle.
20. The network of claim 1, the service vehicle further comprising:
an onboard controller device configured to monitor and report status conditions of the EV charging equipment
and battery modules of the service vehicle and configured to indicate a status of the battery modules and the charging equipment to a network operations center.

21. The network of claim 1, the service vehicle further comprising:
an onboard controller device configured to monitor and report status conditions of the EV charging equipment
and battery modules of the service vehicle and configured to control operation of the EV charging equipment
and the battery modules.

22. The network of claim 1, wherein the service vehicle is assigned to a service location, and the service vehicle transports a number of battery modules roughly proportional to the distance between the service location and the storage location.

23. A system comprising:
a first-level controller onboard a service vehicle, the first-level controller providing real-time control and alerts for the service vehicle and charging equipment transported by the service vehicle within an assigned area;
a second-level controller at a control center, the second-level controller configured to:
communicate with the first-level controller to aggregate real-time control and alert data, and
provide optimized service vehicle assignments, schedules, or alerts for one or more service vehicles in a region, the region comprising a plurality of areas assigned to the service vehicles; and
a third-level controller at a control center, the third-level controller configured to communicate with the second-level controller to provide charging service management optimization across the region.

24. The system of claim 23, wherein the second-level controller provides service vehicle assignments, schedules, or alerts in real-time or near real-time.

25. The system of claim 23, wherein the service management optimization across the region includes recommending preventative maintenance actions, reassignment of assets, ordering of equipment, scheduling of deliveries, and providing information to the first-level controller and the second-level controller.

26. The system of claim 23, wherein the third-level controller temporarily stages a service vehicle in a region having temporary need for service vehicles.

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