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Energy Management for Hybrid Electric Vehicle (HEV) Power Train Using PV-Battery Model


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ABSTRACT

A hybrid electric vehicle (HEV) is a type of hybrid vehicle and electric vehicle that combines a conventional internal combustion engine (ICE) propulsion system with an electric propulsion system (hybrid vehicle drivetrain). The presence of the electric powertrain is intended to achieve either better fuel economy than a conventional vehicle or better performance. There are a variety of HEV types, and the degree to which each functions as an electric vehicle (EV) varies as well. The most common form of HEV is the hybrid electric car, although hybrid electric trucks (pickups and tractors) and buses also exist.

Modern HEVs make use of efficiency-improving technologies such as regenerative brakes, which converts the vehicle's kinetic energy into electric energy to charge the battery, rather than wasting it as heat energy as conventional brakes do. Some varieties of HEVs use their internal combustion engine to generate electricity by spinning an electrical generator (this combination is known as a motor–generator), to either recharge their batteries or to directly power the electric drive motors. Many HEVs reduce idle emissions by shutting down the ICE at idle and restarting it when needed; this is known as a start-stop system. A hybrid-electric produces less emissions from its ICE than a comparably sized gasoline car, since an HEV's gasoline engine is usually smaller than a comparably sized pure gasoline-burning vehicle (natural gas and propane fuels produce lower emissions) and if not used to directly drive the car, can be geared to run at maximum efficiency, further improving fuel economy.

This paper presents an innovative design concept and method to obtain a power management strategy for HEVs, which is independent of future driving conditions. A quadratic performance index is designed to ensure the vehicle drivability, maintain the PV battery energy sustainability and average and smooth the engine power and motor power to indirectly reduce fuel consumption. To further improve the fuel economy, two rules are adopted to avoid the inefficient engine operation by switching control modes between the electric and hybrid modes according to the required driving power. The derived power of the engine and motor are related to current vehicle velocity and battery residual energy, as well as their desired values. The simulation results over different driving cycles in Advanced Vehicle Simulator (ADVISOR) show that the proposed strategy can significantly improve the fuel economy, which is very close to the optimal strategy based on Pontryagin's minimum principle.

Introduction

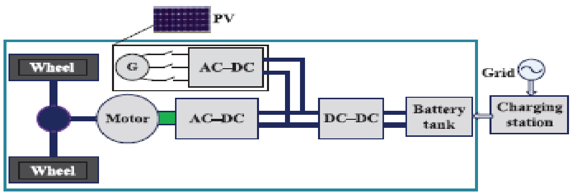
Electric vehicles (EVs) have taken a significant leap forward by advances in motor drives, power converters, batteries, and energy management systems [1]–[4]. However, due to the limitation of current battery technologies, the driving miles are relatively short that restricts the wide application of EVs [5]–[7]. In terms of motor drives, high-performance permanent-magnet (PM) machines are widely used while rare-earth materials are needed in large quantities, limiting the wide application of EVs [8], [9].

In order to overcome these issues, a photovoltaic (PV) panel and a switched reluctance motor (SRM) are introduced to pro-vide power supply and motor drive, respectively. First, by adding the PV panel on top of the EV, a sustainable energy source is achieved. Nowadays, a typical passenger car has a sur-face enough to install a 250-W PV panel [10]. Second, a SRM needs no rare-earth PMs and is also robust so that it receives increasing attention in EV applications [11]–[16]. While PV panels have low-power density for traction drives, they can be used to charge batteries most of time.

Generally, the PV-fed EV has a similar structure to the hybrid electrical vehicle (HEV), whose internal combustion engine (ICE) is replaced by the PV panel. The PV-fed EV system is illustrated in Fig. 1. Its key components include an off-board charging station, a PV, batteries, and power converters [17]– [19]. In order to decrease the energy conversion processes, one approach is to redesign the motor to include some onboard charging functions [20]–[22].

For instance, paper [22] designs a 20-kW split-phase PM motor for EV charging, but it suffers from high harmonic contents in the back electromotive force (EMF). Another solution is based on a traditional SRM. Paper [23] achieves onboard charging and power factor correction in a 2.3-kW SRM by employing machine windings as the input filter inductor. The concept of modular structure of driving topol-ogy is proposed in paper [24]. Based on the intelligent power modules (IPMs), a four-phase half bridge converter is employed to achieve driving and grid-charging. Although modularization supports mass production, the use of half/full bridge topol-ogy reduces the system reliability (e.g., shoot-through issues). Paper [25] develops a simple topology for plug-in HEV that supports flexible energy flow. But for grid-charging, the grid should be connected to the generator rectifier that increases the energy conversion process and decreases the charging effi-ciency. Nonetheless, an effective topology and control strategy for PV-fed EVs is not yet developed. Because the PV has differ-ent characteristics to ICEs, the maximum power point tracking (MPPT) and solar energy utilization are the unique factors for the PV-fed EVs.

In order to achieve low-cost and flexible energy flow modes, a low-cost tri-port converter is proposed in this paper to coor-dinate the PV panel, SRM, and battery. Six operational modes are developed to support flexible control of energy flow.



Existing method:

The existing method describes that the electric vehicles have taken a significant leap forward, by advances in motor drives, power converters, batteries and energy management systems. However, due to the limitation of current battery technologies, the driving miles is relatively short that restricts the wide application of EVs. In terms of motor drives, high-performance permanent-magnet (PM) machines are widely used while rare-earth materials are needed in large quantities, limiting the wide application of EVs.

Drawbacks:

- The primary disadvantage of solar power is that it obviously cannot be created during the night.
- The power generated is also reduced during times of cloud cover (although energy is still produced on a cloudy day).
- Solar panel energy output is maximized when the panel is directly facing the sun.

Proposed method:

In order to overcome these issues, a photovoltaic panel and a switched reluctance motor (SRM) are introduced to provide power supply and motor drive, respectively. Firstly, by adding the PV panel on top of the EV, a sustainable energy source is achieved. Second, a SRM needs no rare-earth PMs and is also robust so that it receives increasing attention in EV applications. While PV panels have low power density for traction drives, they can be used to charge batteries most of time. Generally, the PV-fed EV has a similar structure to the hybrid electrical vehicle, whose internal combustion engine (ICE) is replaced by the PV panel. The PV-fed EV system is illustrated in Fig. 1. Its key components include an off-board charging station, a PV, batteries and power converters.In order to decrease the energy conversion processes, one approach is to redesign the motor to include some on-board charging functions.

Advantages:

- Solar energy i.e. energy from the sun provide consistent and steady source of solar power throughout the year.
- As our non-renewable resources are set to decline in the years to come, it is important for us to move towards renewable sources of energy like wind, hydropower, biomass and tidal.
- The main benefit of solar energy is that it can be easily positioned by both home and business users as it does not require any huge set up like in case of wind or geothermal power.

Control strategy

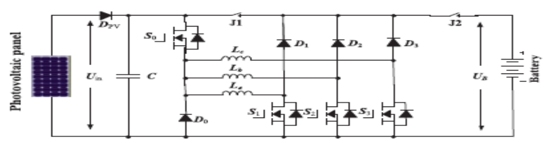


Fig. 2. Proposed tri-port topology for PV-powered SRM drive.

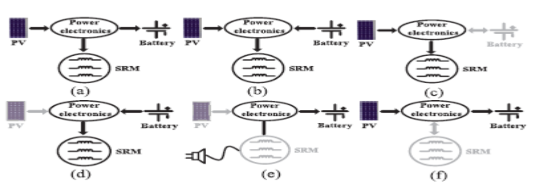


Fig. 3. Six operation modes of the proposed tri-port topology. (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4. (e) Mode 5. (f) Mode 6.

Simulation results

This example shows a multi-domain simulation of a HEV power train based on SimPowerSystems and SimDriveline. The HEV power train is of the series-parallel type, such as the one found in the Toyota Prius car [2]. This HEV has two kinds of motive power sources: an electric motor and an internal combustion engine (ICE), in order to increase the drive train efficiency and reduce air pollution. It combines the advantages of the electric motor drive (no pollution and high available power at low speed) and the advantages of an internal combustion engine (high dynamic performance and low pollution at high speeds).

The Electrical Subsystem is composed of four parts: The electrical motor, the generator, the battery, and the DC/DC converter.

- The electrical motor is a 500 Vdc, 50 kW interior Permanent Magnet Synchronous Machine (PMSM) and srm with the associated drives. This motor has 8 pole and the magnets are buried (salient rotor's type). A flux weakening vector control is used to achieve a maximum motor speed of 6 000 rpm.
- The solar cell is a 100 Vdc
- The generator is a 500 Vdc, 2 pole, 30 kW PMSM with the associated. A vector control is used to achieve a maximum motor speed of 13000 rpm.
- The battery is a 6.5 Ah, 200 Vdc, 21 kW Nickel-Metal-Hydride battery.
- The DC/DC converter (boost type) is voltage-regulated. The DC/DC converter adapts the low voltage of the battery (200 V) to the DC bus which feeds the AC motor at a voltage of 500 V.

The Planetary Gear Subsystem models the power split device. It uses a planetary device, which transmits the mechanical motive force from the engine, the motor and the generator by allocating and combining them.

The Internal Combustion Engine subsystem models a 57 kW @ 6000 rpm gasoline fuel engine with speed governor. The throttle input signal lies between zero and one and specifies the torque demanded from the engine as a fraction of the maximum possible torque. This signal also indirectly controls the engine speed. The engine model does not include air-fuel combustion dynamics.

The Vehicle Dynamics subsystem models all the mechanical parts of the vehicle:

- The single reduction gear reduces the motor's speed and increases the torque.
- The differential splits the input torque in two equal torques for wheels.
- The tires dynamics represent the force applied to the ground.
- The vehicle dynamics represent the motion influence on the overall system.
- The viscous friction models all the losses of the mechanical system.

The Energy Management Subsystem (EMS) determines the reference signals for the electric motor drive, the electric generator drive and the internal combustion engine in order to distribute accurately the power from these three sources. These signals are calculated using mainly the position of the accelerator, which is between -100% and 100%, and the measured HEV speed. Note that a negative accelerator position represents a positive brake position.

The Battery management system maintains the State-Of-Charge (SOC) between 40 and 80%. Also, it prevents against voltage collapse by controlling the power required from the battery.

- The Hybrid Management System controls the reference power of the electrical motor by splitting the power demand as a function of the available power of the battery and the generator. The required generator power is achieved by controlling the generator torque and the ICE speed.

There are five main scopes in the model:

- The scope in the Main System named Car shows the accelerator position, the car speed, the drive torque and the power flow.
- The scope in the Electrical Subsystem named PMSM and srm Motor Drive shows the results for the motor drive. You can observe the stator currents ia, the rotor speed and the motor torque (electromagnetic and reference).
- The scope in the Electrical Subsystem named PMSM and srm Drive shows the results for the PV drive. You can observe the stator currents ia, the rotor speed and the motor torque (electromagnetic and reference).
- The scope in the Electrical Subsystem/Electrical measurements shows the voltages (DC/DC converter, DC bus and battery), the currents (motor, generator and battery) and the battery SOC.
- The scope in the Energy Management Subsystem/Power Management System shows the power references applied to the electrical components.

Demonstration

The demonstration shows different operating modes of the HEV over one complete cycle: accelerating, cruising, recharging the battery while accelerating and regenerative braking. Start the simulation. It should run for about one minute when you use the accelerator mode. You can see that the HEV speed starts from 0 km/h and reaches 73 km/h at 14 s, and finally decreases to 61 km/h at 16 s. This result is obtained by maintaining the accelerator pedal constant to 70% for the first 4 s, and to 10% for the next 4 s when the pedal is released, then to 85% when the pedal is pushed again for 5 s and finally sets to -70% (braking) until the end of the simulation. Open the scope “Car” in the main system. The following explains what happens when the HEV is moving:

- At t = 0 s, the HEV is stopped and the driver pushes the accelerator pedal to 70%. As long as the required power is lower than 12 kW, the HEV moves using only the electric motor power fed by the battery. The generator and the ICE provide no power.

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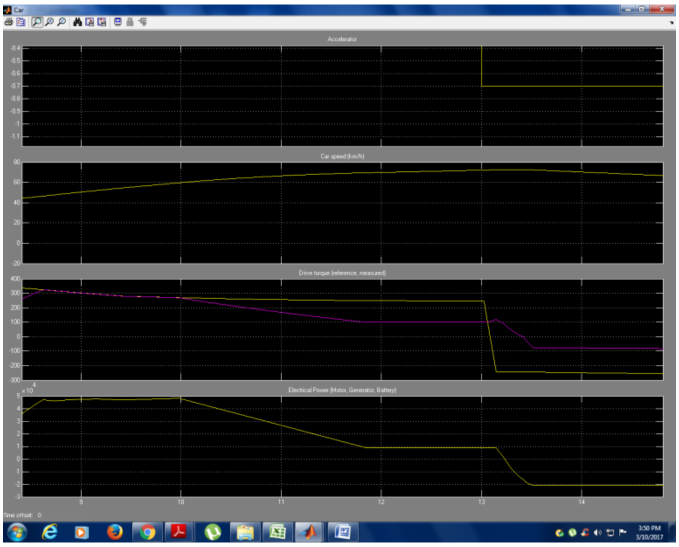
- At t = 1.4 s, the required power becomes greater than 12 kW triggering the hybrid mode. In this case, the HEV power comes from the ICE and the battery (via the motor). The motor is fed by the battery and also by the generator. In the planetary gear, the ICE is connected to the carrier gear, the generator to the sun gear and the motor and transmission to the ring gear. The ICE power is split to the sun and the ring. This operating mode corresponds to acceleration.
- At t = 4 s, the accelerator pedal is released to 10% (cruising mode). The ICE cannot decrease its power instantaneously; therefore the battery absorbs the pv power in order to reduce the required torque.
- At t = 4.4 s, the generator is completely stopped. The required electrical power is only provided by the battery.
- At t = 8 s, the accelerator pedal is pushed to 85%. The ICE is restarted to provide the extra required power. The total electrical power (generator and battery) cannot reach the required power due to the generator-ICE assembly response time. Hence the measured drive torque is not equal to the reference.
- At t = 8.7 s, the measured torque reaches the reference. The PV provides the maximum power.
- At t = 10 s, the battery SOC becomes lower than 40% (it was initialised to 41.53 % at the beginning of the simulation) therefore the battery needs to be recharged. The generator shares its power between the battery and the motor. You can observe that the battery power becomes negative. It means that the battery receives power from the PV and recharges while the HEV is accelerating. At this moment, the required torque cannot be met anymore because the electric motor reduces its power demand to recharge the battery.
- At t = 13 s, the accelerator pedal is set to -70% (regenerative braking is simulated). This is done by switching off the PV (the PV power takes 0.5 s to decrease to zero) and by ordering the motor to act as a PV driven by the vehicle's wheels. The kinetic energy of the HEV is transformed as electrical energy which is stored in the battery. For this pedal position, the required torque of -250 Nm cannot be reached because the battery can only absorb 21 kW of energy.
- At t = 13.5 s, the generator power is completely stopped.

Some interesting observations can be made in each scope. During the whole simulation, you can observe the DC bus voltage of the electrical system well regulated at 500 V. In the planetary gear subsystem, you can observe that the Willis relation is equal to -2.6 and the power law of the planetary gear is equal to 0 during the whole simulation.



CONCLUSION

In order to increase the range of EVs and decrease the system cost, a combination of the PV panel and SRM is proposed as the EV driving system. DC motors were the preferred option in variable-speed operation applications before the development of advanced power electronics. The main disadvantages are low power density compared with alternative technologies, costly maintenance of the coal brushes (about every 3000 h), and low efficiency, although efficiency values over 85% are feasible. The low utilization factor of private vehicles makes the coal brushes essentially maintenance free. DC motors still have a wide market of lower and middle power range commutation vehicles. In earlier, in terms of motor drives, high-performance permanent-magnet (PM) machines are widely used. In PM machines there is no field winding and the field is provided by the permanent magnet. Most commonly rare earth materials are used. But they are very costlier. So by the use of PM machines it will also reduce the wide application of electric vehicles. To overcome these issues a photovoltaic panel and a switched reluctance motor can be used for power supply and motor drive.

A tri-port converter is used to coordinate the PV panel, battery, and SRM. Six working modes are developed to achieve flexible energy flow for driving control, driving/charging hybrid control, and charging control. A PV-fed battery charging control scheme is developed to improve the solar energy utilization. Since PV-fed EVs are a greener and more sustainable technology than conventional ICE vehicles, this work will provide a feasible solution to reduce the total costs and CO_2 emissions of electric vehicles.

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