Future Vehicle Society based on Electric Motor, Capacitor and Wireless Power Supply

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Abstract-- **Future electric vehicles (EVs) will be linked to the electric power system infrastructure; the vehicles will operate through frequent electric charging, as is the case with electric trains. Conventional batteries require a long recharging time; therefore, supercapacitors, rather than batteries, will play an important role in the future for charging of EVs.**

Recently, we manufactured small EVs powered only by supercapacitors. Supercapacitors have a long operating life, large current density, and environmentally friendly composition. Further, their energy level can be estimated from their terminal voltage. Because EVs powered by supercapacitors can operate for more than 20 min after being charged for only 30 s, the requirement for constant recharging of EVs is reduced substantially, thereby increasing the efficiency of these EVs.

Wireless power transfer based on magnetic resonance is an extremely important technique that needs to be considered for enhancing the efficiency of EVs. In a laboratory experiment, this technique enabled approximately 50 W power transfer with more than 95% efficiency at a distance of more than 50 cm.

In order to improve energy efficiency and safety of future EVs, the implementation of novel motion control techniques for EVs is required. Since EVs are powered by electric motors, they have three major advantages: motor torque generation is quick and accurate, a motor can be attached to each wheel, and motor torque can be estimated precisely. These advantages enable the realization of high-performance antilock braking and traction control systems, control of two-dimensional chassis motion, and estimation of road surface condition.

In summary, we can achieve a large-scale development of future vehicles that employ three techniques: Electric Motors, Supercapacitors, and Wireless Power Transfer. This eliminates the requirement for engines, high performance Li-ion batteries, and large charging stations.

Index Terms-- **Electric Vehicle, Motion Control, Supercapacitors, Wireless Power Transfer**

I. SCENARIO TO ELECTRIC VEHICLES

EVS 22, the international conference on Electric Vehicles, held in Yokohama in October 2002 led to the revival of research related to pure electric vehicles. Similarly, EVS 23 was held in the US in 2008 as a conference on hybrid electric vehicles (HEVs). EVS 24 was and in Norway in March 2009. These conferences clearly indicate a renewed, wide-spread interest in EVs. A variety of people with diverse viewpoints attended these conferences.

Currently, we have arrived at the following general agreement in relation to the fundamental flow of future vehicles: “internal combustion engine vehicles (ICV) → HEV → plug-in hybrid electric vehicles (PHEV) → Pure EV.” This scenario validates my assertion (made more than 10 years ago) pertaining to the requirement of employing the aforementioned flow.

Fig. 1. Plug-in Hybrid Electric Vehicle.

Fig. 1. shows a PHEV. On a given day, PHEV users can commute from their homes to their offices by utilizing night-time electricity, which was used when the vehicles were charged at the homes of the users; once at their offices, the users can charge the vehicle batteries from the electric consents at their offices. As a result, they can utilize day-time electricity during the reverse commute from their offices to their homes. Consequently, PHEVs following this procedure will perform in a manner similar to pure EVs; this familiarizes users with the pure EV environment. In the scenario of excess daytime electricity, which is a possibility in the near future, the above-mentioned situation will also be beneficial for electric power companies.

PHEVs will lead to a progressive reduction in daily gasoline usage, consequently eliminating the requirement of gasoline engines and complicated hybrid control systems; this will reduce both the purchase price and the maintenance costs of the vehicle. The huge market established by PHEV will be changed to pure EVs. In such a scenario, supercapacitors will be used to perform the functions currently performed by high performance batteries.

II . EVs DRIVEN ONLY BY SUPERCAPACITORS

Supercapacitors (EDLCs: Electric Double Layer Capacitors), occasionally referred to as physical batteries, have the following remarkable advantages as compared to conventional batteries: (1) long operating life (a supercapacitor can be charged and discharged for an average of approximately one million times); (2) extremely high power density; (3) use of environmentally friendly materials; and (4) feature of energy level estimation from terminal voltages.

For their operation, EVs require charging and discharging multiple times a day; this necessitates that their power sources have a long life and low charging time. Therefore, EDLCs are significantly more suitable for applications as power sources in EV in comparison with conventional batteries; this is because the functioning of EDLCs, unlike conventional batteries, is not based on chemical reactions. However, EDLCs have low energy density, although they have high power density. Currently, the EDLC energy density is equivalent to lead-acid batteries, i.e., approximately 1/10 of recent Li-Ion batteries. Improvements for increasing the energy density of EDLCs will require a significant time period; however, the present energy density should probably be sufficient for satisfactory operation of EVs.

Fig. 2. C-COMS Driven Only by Supercapacitors.

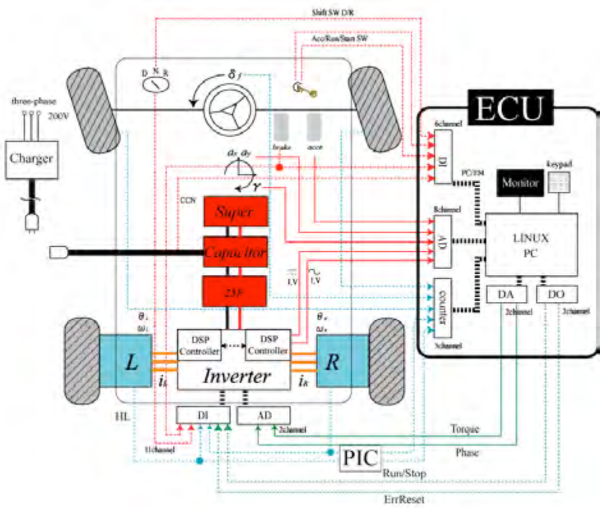

Fig. 3. Control System Configuration of C-COMS1.

C-COMS 1 shown in Fig. 2 has 21 EDLC modules (approximately 100 V, 100 F in total) connected to the inverters directly, and it operates between 50 V and 100 V. The inverter input voltage need not be constant. This implementation considers the fact that large inverters that drive electric trains are designed to operate under as much as 200% voltage variation. When we employ the capacitors between 50 V and 100 V, we can use greater than 75% of the charged energy; this is not possible in the case of conventional batteries. Moreover, the charging time of these capacitors is very short. This enables EDLC-operated EVs to function for greater than 20 min for a 30 s charging.

The vehicle control system of C-COMS 1 is shown in Fig. 3. A Linux PC is used to compute the reference torque for the inverter on the basis of the velocity of each tire, the steering wheel angle, the acceleration of the vehicle, and the yaw rate. C-COMS 2 shown in Fig. 2 has two direct-driven inwheel motors, and it is used for various motion control experiments; these experiments validate our hypothesis that EVs have remarkable advantages over ICVs.

The concept of these “Capacitor Cars” was actually realized by buses in Shanghai; these buses provide a stable operation, as shown in Figs. 4 and 5. In China, they plan to make 200 buses of this type until the Exposition to be held in Shanghai in 2010. This system would be extremely suitable for bus transport in most big cities of the world.

Electric consents have become ubiquitous in recent times. Further, there exists an accessible charge infrastructure. Train-like EVs based on frequent recharge can be presently realized; however, their realization is hindered by the large battery requirement. In such a scenario, we can redefine range as the distance from the infrastructure at which we do not feel any significant difference in our comfort level.

Fig. 4. Capacitor-operated Bus in Shanghai.

Fig. 5. Illustration of Charging an EV at a Bus-stop (Charging Duration: less than 30 s).

III . Motion Control of EVs

The advantages of EVs are similar to those of electric motors. ICVs cannot realize the following three essential aspects:

(1) Quick Torque Response of Motors

The torque response of electric motors is 100 times faster than that of engines. Cars do not require energy if they move only in a horizontal direction. Most losses are a result of the friction between the tire and road surface. By applying adhesion control quickly to reduce motor torque against the micro-scale tire slip, the tire would circumvent the problem of friction losses.

UOT March II is shown in Figs. 6 and 7; Figs. 8 and 9 show the results of experiments performed using UOT March II. Please peruse the provided references for a detailed description of the results; these results indicate that the mechanical characteristics can be altered using electrical control. The reasons for this alteration have not yet been identified. Using UOT March II we can achieve the same performance as current vehicles for half the width of tires and double the fuel efficiency. The most important advantage of these EVs is motion control.

Fig. 6. UOT Electric March II.

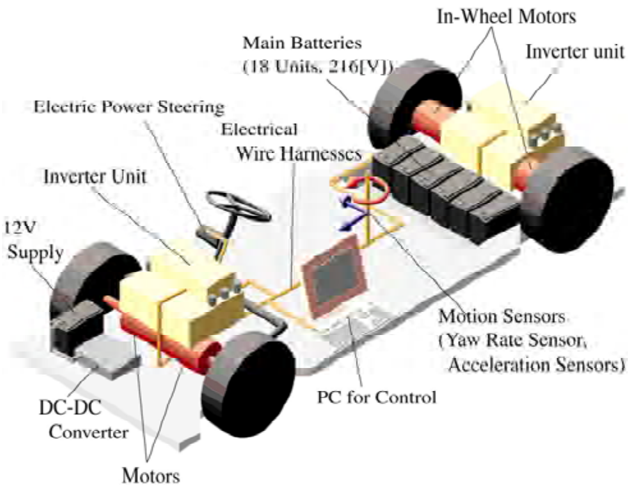

Fig. 7. Configuration of UOT March II.

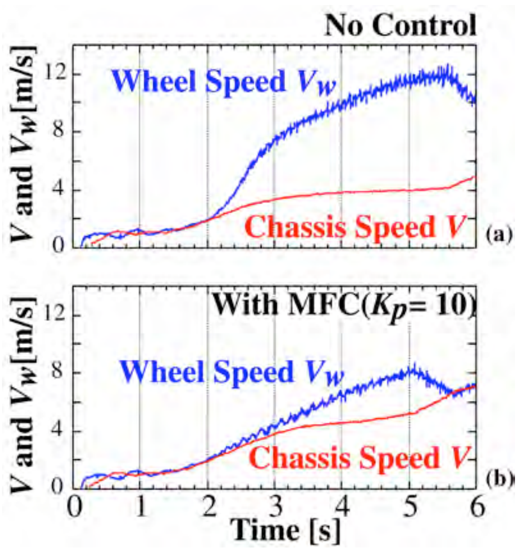

Fig. 8. Adhesion Control.

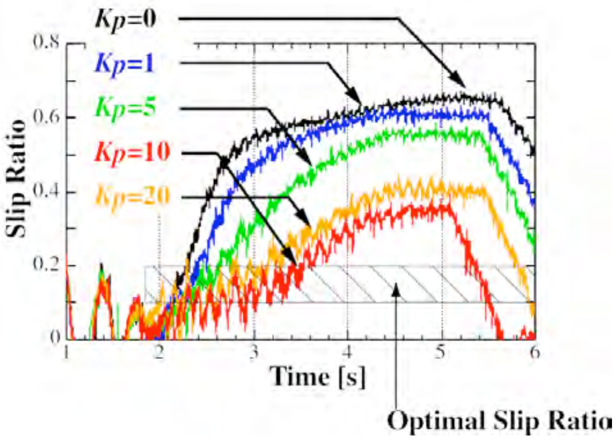

Fig. 9. Variation of Mechanical Characteristics on the basis of Electric Control.

(2) Distributed Motor Installation

A single EV motor can be divided into 4 and installed into the wheels of the EV without any significant cost increase, which is not the case with cars. Further, EVs provide a great advantage in high-performance motion control such as Direct Yaw Control (DYC). Motors can easily generate seamless positive and negative torques. It is completely different from conventional 4WD or 4WS, which are based on driving force distribution using differential gear.

(3) Tractable Motor Torque

The motor torque can be easily determined from motor current. In contrast, engines exhibit considerable nonlinearity; as a result, the model description in this case is quite difficult. In case of EVs, we can estimate the force transferred from the tire to the road by using the driving force observer. This realizes effective road surface condition estimation. For example, the car can now inform the driver, "We have entered a snowy road." Consequently, running sensors can be implemented in every car; this will significantly improve driving safety.

IV. Wireless Power Transfer System

In the near future, energy storage and supply technologies to moving objects will be very important. Wireless power transfer systems capable of operating at 10-500 kHz, 13.56 MHz, and 2.45 GHz are being developed.

Wireless power transfer will be accessible much sooner than we expect; in these power transfer systems, capacitors will play a very important role as the buffer device, instead of batteries. This will reduce the dependency on gasoline stations, thereby reducing the costs involved in the charging of gasoline-operated vehicles in the future, as shown in Fig. 10.

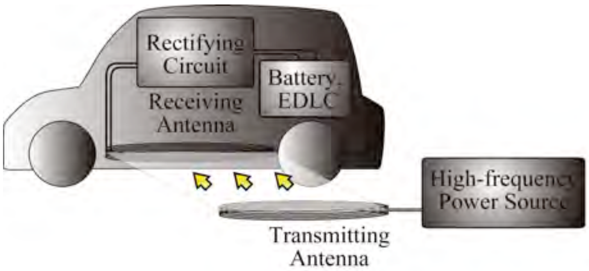

Fig. 10. Wireless Power Transfer System.

Fig. 11. Experiment of Wireless Power Transfer at Hori Lab.

(a) Gap Variation

(b) Antenna Displacement

Fig. 12. Robustness of Wireless Power Transfer System against Gap Variation and Antenna Displacement.

Fig. 11 shows our recent experimental results of wireless power transfer. Here, we use approximately 10 MHz frequency. The energy transfer efficiency between the two antennas is over 90%. Fig. 12 shows good robustness of this system against gap variation and antenna displacement.

Capacitors are made of environment friendly materials. This feature will assume increased importance in the future. For example, the use of a permanent magnet for high temperature operation of electric motors is precarious from the viewpoint of resource availability. Fuel Cell Vehicles (FCVs) are no longer a viable choice as they use 100 g Pt per vehicle. FCVs should reset their targets from large and long-range vehicles to small and short-range vehicles.

The realization of future vehicles driven by electricity received from a power network is a strong possibility; motion control will be a very important feature in this realization. We are now standing at a very important point in history from the perspective of revolutionizing our daily commutation.

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