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A Study on Battery Operated Electric Vehicle Technology destined for Industrial Manufacturers

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ABSTRACT: In a world where energy conservation and environmental protection are growing concerns, the development of electric vehicle technology has taken on an accelerated speed. The 1990's are likely to be the decade in which the long-sought practical, economical electric vehicles will begin to be realized. This paper provides an overview of present status and future trends in electric vehicle technology, with emphasis on the impact of rapid development of electric motors, power electronics, microelectronics, and new materials. Comparisons are made among various electric drive systems and various battery systems. The market size of electric vehicles in the coming years and the potential electric vehicle impacts are discussed.

KEYWORDS: EV, Electrcal Porpulsion, Motos, Energy, PWM, Battery, FOC.

I. INTRODUCTION

Electric vehicles (EV's) have been around since before the turn of the century. They were very popular and sold reasonably well until about 1918. However, the use of EV's for transportation ruled out as the gasoline powered internal combustion engine (ICE) continued to improve. By 1933, the number of EV's was reduced to nearly zero because the EV was slower and more expensive than its ICE counterpart. The shortcomings which caused the EV to lose its early competitive edge have not yet been totally overcome. Significant advances in power electronics and microelectronics have been utilized to make EV power trains that provide performance competitive with ICE power trains. Although there have been no similar advances in battery energy storage, the evolution of materials and production technologies provide means to achieve the optimistic battery system goals.

Significant factors which encourage the recovery of EV's are energy cost, energy independence, and environmental protection. Because of the upcoming shortage of gasoline products, their cost and limitations in supply have encouraged people to look at EV's as a possible alternative mode of transportation. As electricity can be generated from many alternate energy resources, EV's are the ultimate flexible fuel vehicle. Moreover, they are generally recharged when power utilities have excess energy available. The major reasons for the rebirth of interest in EV's are environmental considerations that electricity is superior to gasoline. EV's can dramatically reduce air pollution in congested urban areas. Particularly energy efficient in urban stop-and go traffic, the EV produces no emissions at the point of use. Thus EV's meet the national energy strategy to seek for an energy future that would be secure, efficient, and environmentally sound.

Due to the growing concern for air quality and the possible consequences of the greenhouse effect, some cities have set aside emission-free zones and have enforced stricter emissions regulations encouraging the promotion of EV's. The outlook for EV's has shifted dramatically in the 1990's; major automotive manufacturers have launched aggressive programs to develop electric vehicles for commercialization, power utilities have launched infrastructure programs for EV's, intense electric vehicle R&D conducted by government agencies, academic institutions, and related industries are actively pursued. The overall goal of EV development is to produce commercially viable EV's over the long term, this means EV's must provide the range, performance, personal comfort, safe, trouble-free operation currently available with the ICE counterparts and at a competitive price. Table 1 or Fig:1 shows the present realistic performance goal of four

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different types of EV's. In this context, the development of high performance, low-cost, reliable and safe batteries is very essential. In addition, the development of a high power density, high-efficiency, integrated electric propulsion system and the development of efficient auxiliary power units for a hybrid power train will make significant contribution. In the long term, fuel cell battery vehicle will offer the greater promise for a transportation system that produces nearly zero emissions, full performance, and unlimited range.

Table 1 Realistic Performance Goals

	Passenger Car	Van	Minibus	Urban Bus
Range (km)	120–250	100–150	140–200	150–300
Max. speed (km/h)	100–120	80–100	80	70
Continuos speed (km/h)	100	80	60	60
Grade ability (%)	30	20–25	15–20	12–15
Acceleration 0 to 50 km/h (s)	7–10	10–15	12–18	15–20

Fig 1: Realistic View

For the presently available EV's, the capital outlay of the EV is about 1.5-3 times the capital outlay of the ICEV. However, the routine maintenance cost of the EV is only about half that of its ICEV equivalent. The difference of fuel cost between EV and ICEV depends on the costs of gasoline/diesel, electricity, and annual mileage.

II. SYSTEM TECHNOLOGY

The EV system is an integration of vehicle body, electric propulsion, energy storage battery, and energy management. The technologies involved are diversified, which include electrical and electronic engineering, mechanical and automotive engineering, and chemical engineering. The philosophy and architecture of the system are of prime consideration. System integration and optimization enables perfect matching among subsystems, bearing in mind that the components used in EV are working in mobile and severe temperature conditions.

Capital importance is energy management in EV systems that controls and regulates the energy flow within the vehicle with the aim of using the energy from the batteries as economically as possible and making the recharging of batteries as convenient and efficient as possible. Based on the concept of multi-energy system, the batteries can be normally charged up at night or quickly charged up in a short period of time using a dedicated super quick charger. During deceleration, battery charging can be performed through regenerative braking. The batteries can also be charged by solar energy using solar cells embedded in the vehicle roof. Low heat load windshield and glazing should be selected to reduce the solar heat load, and hence to reduce the power required for air conditioning. Because the energy and power densities of storage batteries are so much smaller than that of fuel for ICE, a larger number of batteries must be used to assure a certain level of power performance. However, mounting a large number of batteries on a vehicle requires various types of tradeoffs. For instance, it reduces interior space and luggage space; the resulting increase in vehicle weight sacrifices acceleration and other areas of performance; the cost of the vehicle also rises.

III. BODY TECHNOLOGY

The consistent weight-saving design of EV's is very important, which directly affects the performance of EV's. The EV body is of a hybrid design, possibly consisting of supporting aluminum structure, which is light and very rigid, and a plastic outer skin. The EV suspension is purposely designed to attain simplicity and very light weight. Low drag coefficient body design can effectively reduce aerodynamic resistance of the body. In general, it is more difficult to reduce the drag coefficient as the vehicle length is shortened. However, the aerodynamic resistance can still be reduced through a good balance among the following features: tapering off the front and rear ends; flat under floor design and adoption of an undercover; optimization of airflow around the front and rear windows; use of rear spats; provision for airflow streaks along the front and rear tires; and slanted front nose design. Low rolling resistance tires are particularly effective in reducing running resistance at low and medium driving speeds and play an important role in extending the

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range of EV's in city driving. This has been achieved through the use of a newly developed blended tire polymer, together with an increase in tire pressure. Figure 2 shows the cross section of low rolling resistance tire.

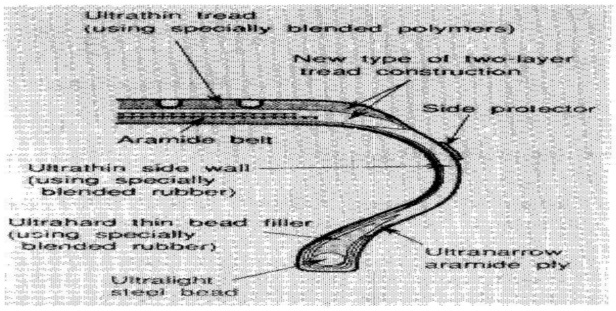

Fig 2. Cross section of low rolling resistance tyre

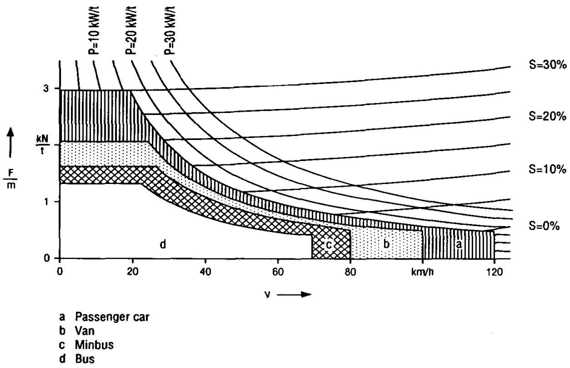

Fig. 3. Tractive force-speed diagram.

IV. ELECTRICAL PROPULSION TECHNOLOGY

Electric propulsion **or** the power train is the heart of EV. The selection of preferred power train features and packaging options has to be carried out at the system level, examining the likely product impacts of many system tradeoffs. The basic consideration of power train configuration includes: **1)** single **or** multiple motor drive, **2)** single **or** multiple speed transmission, 3) system voltage, 4) types of motor, converter, and controller, and their maximum voltage and current capabilities, *5)* motor torque-speed characteristic and its maximum torque and speed capabilities, ***6)*** type of battery and its energy and power capabilities, 7) battery charger and charging scheme, and **8)** maximum torque and gear ratio of the transaxle.

Electric propulsion technology comprises three major areas contro1, power electronics, and motor. From a functional point of view, the controller which depends mainly on the control technique and hardware implementation provides proper control signals to the power electronic part. The signals are amplified via a driver to turn on/off proper power devices of the converter. The function of the converter is to transfer and regulate with high efficiency the power from the main supply to the motor. Figure **3** shows the minimum power per weight for the different types of EV's in a tractive force diagram**.** Here the tractive force is referred to a vehicle mass of one ton for better comparison. The torque-speed characteristic of the electric drive is divided into constant torque region and constant power region for starting / climbing and cruising, respectively. It can be seen that for a bigger vehicle the required specific torque, power, and continuous speed are smaller. It should be noted that in the past, some EV's did not meet these specifications; as a result, the maximum speed and grade ability **of** the EV's were not comparable to those of the ICEV in city and highway traffic. Energy system and management is an important aspect in EV design. Figure 4 shows the energy system and block diagram.

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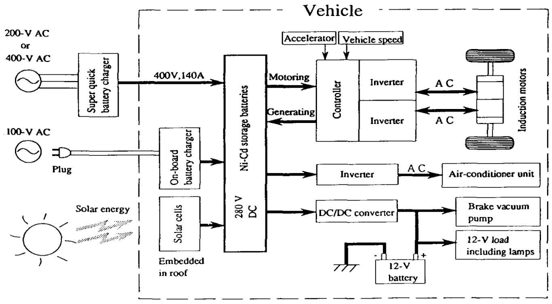

Fig 4: Multiple Energy System

A. EVOLUTION OF MOTORS

In past decades, dc variable-speed drives were commonly used for EV's. With the advent of advanced power electronic devices and converters, powerful microelectronic products, new materials and motor topologies, and modem control algorithms, ac drives offer several definite advantages over their dc counterparts-namely, high efficiency, high power density, efficient regenerative braking, robustness, reliability, and almost no maintenance. AC motors can be classified into sinusoidal-fed motors and rectangular-fed motors. Classical induction motors and synchronous motors, which are fed by sinusoidal supplies, produce essentially constant instantaneous torque and can run without using electronic controllers. By replacing the field windings with permanent magnets (PM's), classical synchronous motors immediately become PM synchronous motors (PMSM's). Two basic classifications of PMSM's are the surface-mounted type where the magnets are mounted in the magnetic outside of the rotor, and the interior mounted type where the magnets are mounted inside the magnetic structure of the rotor. Because of buried magnet installation, interior PMSM's are robust and thus permit higher operating speed. The small effective air gap and strong armature reaction effect in this class of motors permit operation in constant-torque region as well as in field weakening constant-power region up to a high speed such that the motor can be used for EV applications.
Since the interaction between rectangular current and rectangular magnet field may produce a larger torque than that produced by the interaction between sinusoidal current and sinusoidal magnetic field at the same peak current and voltage, a considerable amount of research and development effort is being expanded in that direction. By inverting the classical PM dc commutator motor, the PM brushless dc motor (BDCM) is formed. The BDCM has a very high power density and recently has been used for EV applications.

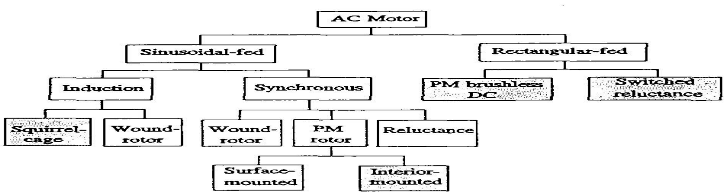

Fig 5: Classification of AC motors

Another rectangular-fed motor is the switched reluctance motor (SRM), which cannot be derived from any of the classical motors. The classification of the aforementioned ac motors is illustrated in Fig. 5, where the shaded types have been accepted for EV applications.

B. EVOLUTION OF POWER ELECTRONICS

Power devices are at the heart of power electronic circuits. In the last few years, device technology has made tremendous progress. Among the new devices are the high-power bipolar-junction transistor (BJT), the power MOS field-effect transistor (MOSFET), the gate turnoff (GTO) thyristor, the insulated-gate bipolar transistor (IGBT) also called a conductivity-modulated field-effect transistor (COMET), and the MOS-controlled thyristor (MCT). Also important are the static-induction transistor (SIT), and its cousin, the static-induction thyristor (SITH).

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Of these, the IGBT which combines bipolar and MOSFET features possesses definite advantages over the BJT such as: high-impedance voltage-controlled gate which results in a dramatic reduction in gate power and thus permits an effective circuit integration of a gate driver, and substantially shorter switching time which allows reduced switching losses and increases PWM switching frequency. The SIT is a high-power high-frequency device and is essentially the solid-state version of a triode vacuum tube. The reliability, noise and radiation hardness of SIT are claimed to be superior to MOSFET's. The newly introduced MCT is so unique that it combines relatively high switching speeds with the potential for high voltage and current ratings.

Another aspect of power converters, in addition to circuit topology, is pulse width modulation (PWM) control. The PWM research activity over the last few years has focused on harmonic suppression, better utilization of the dc link voltage, suitability for real-time and microcontroller-based implementation, and fluctuation of the dc link or battery voltage. Very recently, the interest has shifted to the PWM schemes for the resonant dc link converters and high frequency resonant ac link conversion systems.

C. EVOLUTION OF CONTROL

In drive systems, it is desired that the machine flux be regulated to provide better utilization of the machine. A requirement for maximum possible transient dynamics is to operate the motor at its rated flux level. The variable voltage variable frequency **(VVVF)** control adopted for the open loop regulation of machine flux has been extensively used in industry. Although the performance can be improved using slip compensation, the closed-loop control is necessary when the desired accuracy is independent of the converter motor unit and load torque, and the desired dynamic behavior is rapid. The features determining the selection of the control strategy are illustrated in Table 3, where the disadvantage of the open-loop cases is that their accuracy -is dependent on the converter-motor unit and load torque, and their dynamics are slow.
High-performance drives require very rapid dynamics and precise regulation. To achieve this, the emerging consensus **is** to use the field-oriented control **(FOC).** Field **ori**entation is a technique that provides a method of decoupling the two components of stator current: one producing the airgap flux and the other producing the torque. Therefore, it provides independent control of torque and flux, which is similar to a separately excited dc motor. Figure 6 shows the structure **of FOC** of an induction motor for **EV's.** Due to the rotor resistance dramatic changes with operating temperature, considerable amount of research has been directed to develop parameter adaptation schemes for optimum decoupling of **FOC.**

Adaptive control, including self-tuning control (STC) and model-referencing adaptive control (MRAC), has been applied in electric drive systems. In STC, the controller parameters are tuned to adapt to the plant parameter variations. The identification block tracks the changes in system parameters. This information is used to update the controller parameters through controller adaptation to guarantee a desired closed-loop performance. In MRAC, the output response is forced to track the response of a reference model irrespective of plant parameters variations. The controller parameters are adjusted to give a desired closed-loop performance. This adjustment is based on an adaptation algorithm that utilizes the difference between the reference model output and the plant output as its input. Variable structure control (VSC) using the sliding mode has recently been introduced into the field of controlled electric drive systems to compete with the former two adaptive control schemes. With the sliding mode, the control system can be designed to provide parameter-insensitive features, prescribed error dynamics, and simplicity in implementation. By using a set of switching control laws, the drive system is forced to follow a predefined trajectory in the phase plane irrespective of plant parameter variation.
The emerging technologies such as neural networks, fuzzy logic, and expert systems have recently been applied in various controllers. In such systems, the controller could possible interpret the dynamics of the system operation, then self-learn and self-adjust accordingly. Systems incorporating artificial intelligence could permit diagnosis and correction of faults in a complex system to supplant the need for human intervention. Microcomputers, microprocessors, microcontrollers, and digital signal processors have had a tremendous impact on electric motor drives. They enable implementation of sophisticated and complex algorithms for control and protection. Microcomputers are used where flexibility is required. Microprocessors have been used for signal processing. The emergence of powerful microprocessors such as the Motorola 68020 and 68030, Intel 80386 and 80486 allows high-resolution signal processing and is useful in high-performance drives using modem control theories. Single chip microcontrollers such as

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the Intel 8096 and 80196 possessing all necessary components of microcomputers have found universal acceptance for dedicated jobs. Digital signal processors such as the TI TMS32020 and TMS32030 can provide high-speed computation, and these are likely to play an increasingly important role in future embedded control implementations. The emerging microelectronics technologies such as the application-specific integrated circuit (ASIC) chips and transputers provide the opportunity to implement very sophisticated algorithms for high-performance drives.

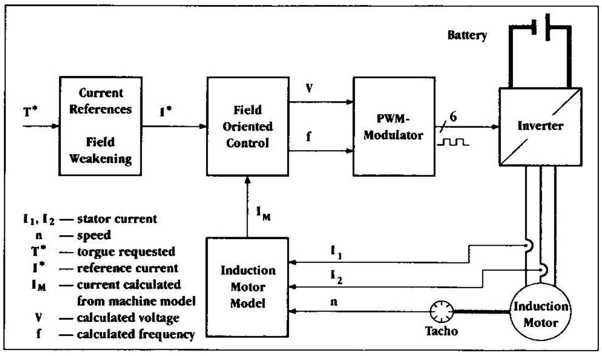

Fig. 6. Structure of the field-oriented control.

Table 3 Features of Control Strategy

Control Strategy	Accuracy	Dynamic Behavior
Open loop	dependent	very slow
Open loop with internal loop	dependent	slow
Closed loop with internal loop	independent	rapid
Closed loop with internal loops	independent	very rapid

V. BATTERY TECHNOLOGY

Until now, the only commercially available and full-grown battery technology suitable for EV's has been lead-acid, and though modem versions may last longer and cost somewhat less than those at the turn of the century, the performance and range afforded by lead-acid batteries have not improved much. The benchmark lead-acid batteries of today will last for about 30 thousand miles with deep discharging cycles. The life cycle of today's lead-acid batteries is about 750. Their energy density and peak power density at 50% depth-of-discharge are 33 Wh/kg and 93 W/kg, respectively. However, most of the advanced batteries offer significantly greater performance over lead-acid in terms of energy, power, and operating life.

Recently, nickel-based battery systems have received heightened interest. In general, the advantages of the aqueous, room-temperature batteries such as nickel-iron (Ni-Fe), nickel cadmium (Ni-Cd), and nickel-metal hydride (Ni-MH) are high peak power and demonstrated high energy density under practical EV conditions. However, nickel-based systems are fundamentally different from one another. Characteristics like material toxicity, ability for sealed operation, energy density, cycle life, power, etc., all impact the final selection of one system over the other.

Analysis **of** Ni-Fe batteries requires caution. In general, the energy density is of about 50 Wh/kg, the cycle life is of about 300 cycles, the peak power density is of about 100 W/kg, and the system requires excessive maintenance. The energy efficiency is so poor that up to 50% overcharge may be required. While watering systems have been designed, there are concerns over safe removal of hydrogen and oxygen, especially at the high required degree of overcharge. Ni-Cd batteries have achieved *55* Wh/kg energy density by changing from seal to vented operation, using a new structure for the nickel hydroxide electrode, and increasing the utilization of the cadmium electrode. The peak power density is over 190 W/kg. However, the short life cycle is still a concern Of course, performance issues aside, Ni-Cd batteries have a fundamental deficiency that surely must disqualify them as a rational solution to an environment pollution problem-they represent an unacceptable environmental hazard due to the toxic nature of cadmium.

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Ni-MH batteries provide a near-term, realistic EV battery for widespread application. They have the energy density of 54 Wh/kg, peak power density of 174 W/kg and relatively long life. Ni-MH batteries use environmentally safe materials, and are totally sealed for maintenance-free operation. They are tolerant **to** overcharge and over discharge, making them well suited for series operation. One of the key advantages of Ni-MH batteries is the elimination of cadmium from the negative electrode and indeed from the entire cell.

VI. AUXILIARY TECHNOLOGY

EV's are 'at the brink of entering the commercial market. To succeed in a highly competitive market, special attention should be paid and arrangements made to provide the customers with convenient and comfortable environment. For the convenience, the battery state-of-charge indicator should be very similar to the conventional fuel gauge while the battery charger should work automatically, reliably, and efficiently. **For** comfort, the EV should be equipped with heaters for winter use, and if used in humid **or** hot climate, air conditioning is indispensable.

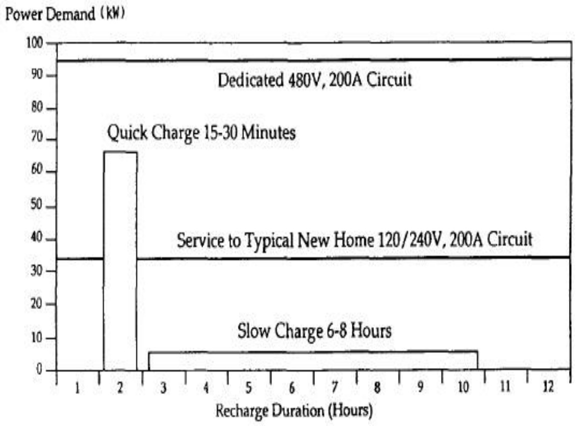

Fig 7: Recharge Power Demand

Microcontroller-based battery state-of-charge indicators for EV's have been developed. The indicator is based on the measurement of ampere-hour, while the current density, temperature, intermittent discharge, and the ageing factor are taken into account. Intelligent battery chargers for EV's, both plugging type and inductive type, have also been developed, which allow for efficient charging of quality batteries by adjusting continually the charge rate to match the ability of batteries to accept charge. Figure 7 shows the comparison of power demand between quick charge and slow charge based on recharge for 30 kWh, or 120 km at 0.25 kWh/km. It can be seen that from the power utility point of view, quick charge may not be desirable, since it would cause high peak demand and hence the present household supply system would have to be reformed. Incentive-based electricity billing system may be employed to encourage people to recharge during off-peak periods, while quick charge would be suitable for emergency purposes at dedicated service stations. The charging infrastructure and the impact of EV's on power systems are important issues. The perturbations caused by chargers including harmonics, reactive power, and EM1 should be closely investigated.

VII. CONCLUSIONS

The EV technology, including system, body, electric propulsion, battery, and auxiliary, has been reviewed. Comparing the technologies of latest EV's, it can be found that ac motor drives with advanced power converter and controller, as well as advanced batteries are increasingly being accepted. The concepts of consistent weight-saving design, consistent energy-saving design, and optimum safety are generally adopted for latest EV's. Legislation spurs the EV market. Standardization and infrastructure are essential for promotion of the EV. It is clear that EV is a clean, energy-efficient urban transportation alternative.

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