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# HYBRID ELECTRIC VEHICLES: COMPONENTS AND ITS WORKING

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***Abstract:*** This study has been undertaken to investigate the determinants of stock returns in Karachi Stock Exchange (KSE) using two assets pricing models the classical Capital Asset Pricing Model and Arbitrage Pricing Theory model. To test the CAPM market return is used and macroeconomic variables are used to test the APT. The macroeconomic variables include inflation, oil prices, interest rate and exchange rate. For the very purpose monthly time series data has been arranged from Jan 2010 to Dec 2014. The analytical framework contains**.**

***Index Terms*** **- Electric vehicle, Battery, IC Engine, Regenerative Braking.**

## I. INTRODUCTION

The first ever HEV was built in 1898, and several automotive companies were selling HEVs in the early 1900s. The production of HEV s did not last the course of time due to significant problems with them. Henry Ford initiated the mass production of combustion engine vehicles; making them widely available and affordable within the $455to $911 price range (375€ to 750€ with prices taken from the current American dollar to Euro conversion rate). In contrast, the price of the less efficient EV s continued to rise. In1912, an electric roadster sold for $1,732 (1,425€), whilst a gasoline car sold for $547 (450€) as illustrated by About Inventors. Another problem was the requirement for smooth coordination between the engine and the motor, which was not possible due to the use of only mechanical controls.

## II. COMPONENTS OF HYBRID ELECTRIC VEHICLE

### Gasoline Engine

The gasoline engine in an HEV is similar to that found in a conventional ICE vehicle.Gasoline engines in HEVs are usually much smaller than ones found in comparable conventional vehicles. Larger engines are primarily heavier, requiring extra energy during accelerations or climbing inclinations; pistons along with other components are heavier in a larger engine, which decreases the efficiency and adds tothe overall weight of the vehicle. The gasoline engine is the primary source of power for the vehicle, and the electric motor is the secondarysource of power. The Toyota Prius for example can operate in stand-alone electric mode at low speeds (usually up to 15 mph) and can offer assistance during heavy acceleration or when a power boost is required. Pollution, loss of hearing, high blood pressure, sleep deprivation, productivity loss, and a general reduction in the quality of life can develop from the noise of traffic. The greatest and most concerning effects do stem from larger vehicles; including buses and trucks. There has been researched into the inclusion of HEV buses, primarily within the US, which has helped to reduce the problem caused by conventional buses. It can be seen that much sickness is caused by the vehicles that people drive [1].

Many governments worldwide have begun to realize that issues such as these need to be prevented. Regulating tighter measures will lead to more efficient and environmentally friendlier vehicles. Honda's HEV s do not have an electric-only mode, unlike the Toyota Prius, though during stops at junctions and at lights the ICE automatically shutsoff, and only starts again the accelerator is pressed. The Honda Civic incorporates Integrated Motor Assist (IMA), which couples both the gasoline engine and the electric motor, to offer boosts in both the performance andfuel economy of the vehicle. Studies have goneon in the development of ICEs for HEVs to further optimize their performance of them; one such study has developed an optimized compressed natural gas (CNG) engine for a hybrid urban bus. Both gasoline and diesel engines do have several advantages over other competitors and alternative technologies. One key issue is that liquid fuels have extremelyhigh energy densities and can achieve a long driving range for a relatively small storage tank. Another factor is that there are fully establishedand functional infrastructures for these fuel types; it would cost billions of euros to make changes to the current infrastructure tointroduce new technology types and alternativefuels. These few advantages alone make it a daunting task for any alternative technology such as fuel cells to be considered for the short and medium-term solution to a more efficient and emissions-free future for transport [2].

### Electric Motors

The electric motor is primarily used to drive HEV s at low speeds, and assist the gasoline engine when additional power is required. The electric motor can even act as a generator and convert energy from the engine or through regenerativebraking into electricity, which is then stored in the battery. This functionality works as the electric motor applies a resistive force to the drivetrain which causes the whee1s to slow down. The energy from the wheels then begins toturn the electric motor, making it operate as a generator, converting this normally wasted energy through coasting and braking into electricity [3].

### Generator

In a series-configured HEV, only the electric motor is connected to the wheels. A series HEV has a separate generator that is coupled with the gasoline engine. The engine/ generator set supplies the electricity required by the batteries, in turn feeding the electric motor. The coupled generator and engine maintain the efficient usage of the battery system during operation [4].

### Energy Storage

### Battery Technologies

The batteries are an integral component within HEVs. Electrical energy can be drawn from the batteries to the electric motor; also this processcan operate in reverse by recapturing energy through regenerative braking. The only time there is a large requirement for electrical energy is during the electric-only mode, the majority of the time the electrical loads are easily managed within the whole vehicular system. Due to the high-cost increment of the battery for energy storage, it is far more cost effective to use the engine as the primary power source for the vehicle at higher loads, rather than increasing the amount of energy storage. Continued efforts must concentrate onimproving the existing battery technologies to make them more efficient, rather than just increasing their sizes to gain a greater output. By improving the current battery technologies which exist, the costs of HEVs willbe kept to a minimum, preventing them from being too high for potential customers to consider displaying the properties regarding the key battery technologies for hybrid applications. The following section will discuss the varieties of battery chemistries available; comparing and contrasting the appropriate types, to determine the most suitable technology for HEV use [5].

Lead-acid (Pb) batteries were invented by Gaston Planté in 1859. Gustavo Trouvé firstused them in a vehicle in France in 1881 by demonstrating their use in a tricyc1e which traveled at 7 mph. Lead acid is still the most commonly used electrical storage technology for electric traction applications today. One of the main factors in choosing Lead-acid is the lowest costing technology compared to that of other battery chemistry types [6].

However, due to their low power densities compared to other lightly higher densities offered by alternative battery types, problems occur when there is a high power required men for their design. Tomeet such high power demands larger battery packs can be constructed, which is not the optimal choice due to the inefficiencies causedby the increased weight and cost of such a development. Lead-acid technologies are not best suited to cold weather conditions becausethe battery is severely affected under low ambient temperatures of anything below 10°C.By exposing this technology to such low temperatures it can have damaging effects by reducing both the effective energy and power densities of the battery. A way in which to enable this technology to work under such conditions would be to have a battery-heating device in operation. A heating device would be able to maintain the temperature of the battery and allow it to operate in this state. Due to their costs, they are currently the most sensible option to use in low-power start/stop systems, which do not require the need to store a vast amount of energy. A simple idle-off system would be an ideal application for this technology. Ifthe requirement is to achieve a significant amount of electric motor assist and regenerative braking, then another battery technology is currently more viable.

Advanced Lead-Acid (Pb), To overcome some of the pitfalls of the conventional lead-acid battery type developers have engaged in new techniques to produce advanced lead-acid batteries. Some of the methods used include improved computer analysis and enhancements to the modeling of the current distribution in the batteries [7]. The authors are members of the Technology & Information Group (TIG); a research group based at the University of Warwick that has been involved in several projects engaged in improving current lead-acid technologies. One project they have been involved with was RHOLAB (Reliable Highly Optimized Lead Acid Battery) [8]. The project aimed to develop a traction battery suitable for use in an HEV such as the Honda Insight. Instead of developing a new typeof battery technology, RHOLAB took the existing lead-acid battery technology and developed it, sothat it could be used in new applications in vehicles of the future. TIG's key contributions were the application of built-in intelligence, module design, case development, and the fabrication of a battery management system (BMS). Buildingon the findings and experience gained during the RHOLAB project the ISOLAB (Installation and Safety Optimized Lead Acid Battery 42V) project followed in its footsteps [9].

The ISOLAB project aims to develop a batterycapable of meeting the electrical power demands of future vehicles, which is also able to support alternative installation and packaging strategies. Research efforts in Lead-acid technologies have helped to improve the grid structure of current configurations. Battery weights have decreased on the whole, which has resulted in lower internal resistance which can achieve better retention of the active plate material.

A specific example of the development of advanced lead-acid batteries is the Valve-Regulated Lead-Acid battery (VRLA). The VRLA battery is the result of a collaborative effort between lead producers, battery manufacturers, and component suppliers formed in 1992; who joined forces as the Advanced Lead-Acid Battery Consortium (ALABC). The key aspiration of the ALABC was to improve the specific energy of these batteries, improving the range per charge. Regardless of the additional improvements, VRLA batteries still have relatively low power, density, and cyclelife. Lead acid still has the potential of being a significant battery technology, and there has been researched into the possible future developments of the chemistry [10].

Nickel-cadmium (Ni/Cd) batteries were first developedin the early 20th century [11]. They are constructed in a cell configuration with a sintered positive nickel electrode and a plastic-bonded cadmium negative electrode. This battery technology has an energy density of approximately 50 Wh/kg and a relatively high power density of 200 W/kg. This technology has sparked interest in the past with EV developers due to its capability to accept high charge and discharge rates. One problem Ni/Cd has is that such charge capabilities require the use of a careful control management system to controlthe battery's temperature, voltage, and time of charge and this adds to the cost and weight of avehicle design. Ni/Cd batteries suffer problems when they are not discharged or recharged fully,as they tend to remember state-of-charge (SOC) extremes, meaning they behave as though they have less capacity. Due to the increased toxicityof nickel-cadmium over lead-acid the technologyis poor in terms of its recyclability. Cadmium products need to be clearly labeled toaware people that they need to be recycled or disposed of properly. If this task is not easily achievable then this must be carried out by a professional. This along with some other problems has inhibited the use of this battery type and has made other battery types a more viable means for HEV applications.

Nickel-metal hydride(NiMH) has become the long-term replacement for nickel-cadmium (Ni/Cd) batteries and has appeared in a selection of EVs that have recently been developed. NiMH batteries' maximum energy density of 70 Wh/kg is 20 Wh/kg greater than that offered by Ni/Cd types; this is a valuable asset as the battery can be of less weight and still achieve the performance requirements of the vehicle. NiMH can cope with over 2,000 cycles of 80% discharges before needing to be replaced whereas Ni/Cd needs to be replaced after a maximum of 2,000 cycles. The other advantage NiMH has over Ni/Cd is the fact it is not cheaper per unit cost (f per kWh), this is without the toxicity problems of Ni/Cd. NiMH batteries have a greater power and energy density than that lead acid types. They have been under development since the 1970s. The energy density of NiMH is roughly twice thatof lead-acid batteries, 70Wh/kg for NiMH compared to 45Wh/kg for lead-acid [12].

Another advantage is that NiMH batteries can befully recharged within about 15 minutes. NiMH batteries are perfectly suited to high-power hybrids and have been the battery choice for REV models released to date, which include the Toyota Prius, Honda Civic, andHonda Insight. The key reasons why NiMH technologies have been used in the development of HEV s rather than lead-acid is they can offer higher energy and power densities, reduced size mass, longer cycle life, and lower cost of ownership [13].

Lithium-Ionbatteries have an even higher energy density than that NiMH batteries. NiMH batteries can offer a respectable 70 Wh/kg, whilst lithium-ion can offer roughly two times that amount ranging between 120-150 Wh/kg. Lithium-ion has a reasonably low maintenance, offering an advantage that most other battery chemistries cannot. There is no memory or scheduled cycling requirements to prolong the overall life of the battery. Despite the obvious advantages of lithium-ion technology, some current drawbacks prevent the technology from replacing other current chemistries.Lithium-Ion is a fragile technology, which requires a protection circuit to maintain the safe operation of the technology type. The inclusion of a protection circuit does however ensure the voltage and current limits remain within their safe limits. Lithium-Ion batteries become susceptible to aging especially when not in use, and are 40 percent more expensive to manufacture than Ni/Cd. Lithium Ion is currently not a fully matured technologyand the chemistry is changing continually. It still requires huge developments in cycle life, durability, and cost, before the chemistry could become commercially viable and be included in HEVs. Lithium- Ion technologies are currently used in manyapplications including laptops; the cycle life of the chemistry type is expected to improve within the near future. Looking at the wider scale, lithium-ion may not be the breakthrough the automotive industry is looking for, which is essentially crucial to be able to reduce the cost of energy storage in HEVs [14].

**Future Energy Storage**

There are several demands for an HEV energy storage system, some of which include: high specific energy and power to be able to achieve range and performance requirements, long cyc1e, and calendar life (comparable to that of the overall life of the vehic1e), quick recharge capabilities, high efficiency, and low cost and maintenance free. Technologies to date which have been deemed suitable for this application are lead-acid batteries, nickel-cadmium batteries, nickel-metal hydride batteries, supercapacitors, flywheels, and hydrogen storage in nanofibres and nanotubes. HEVs energy storage technologies can be split up into three main areas: electrochemical buffers, electrical buffers,and hydrogen storage.

Supercapacitors are more commonly known as Electric Double Layer Capacitors (EDLCs). Energy is stored within a boundary layer that is formed between the interfaces of a conductive electrode and an electrolyte solution. The interface of the electrode/electrolyte has a very small dielectric thickness (a few Angstroms) and combined with a material of high surface area can producea low voltage, high-capacitive, energy storage capacitor. Supercapacitors have low resistance and can therefore offer greater power and efficiency compared to that pulse batteries. They can be produced in large cells, which makes them a suitabletechnology for automotive applications [15].

Supercapacitors have traditionally been createdwith carbon electrodes which when treated canoffer a particularly large surface area of up to 2,000 square meters per gram. These electrodes are typically combined with dilute sulphuric acid electrolytes. The benefits of usingan aqueous acid such as dilute sulphuric acid are that they offer high capacitance and power density. A salt solution, however, can be used instead if there is a higher preference for a greater energy density than power density. Within a supercapacitor cell, the electrolyte is in intimate contact with the electrode of high surface area. The voltage of the cell is limited to just over one volt to avoid any chance of decomposition of the water in the dilute electrolyte to oxygen and hydrogen. The sole use of supercapacitors for the power requirements of an electric vehicle of any form seems to be some years away; due mainly to the considerable development requirements of the technology. Supercapacitors would howeverbe a more than viable means to operate in combination with existing batteries due to theirhigh power densities. Supercapacitors can now offer power densities up to 4 kW/kg, which is 16 times that of the closest battery power density of 250 W/kg for advanced lead-acid types. The combination of the two would work well together as batteries tend to have high specific powers but a much lower power density.

These benefits along with the fact they are relatively inexpensive can be recharged easily (externally or through regenerative braking) and that they require no maintenance because their deterioration over time is far less than that of existing battery technologies; making them a serious consideration when developing such vehicles.

The flywheel energy storage system is a mechanical device that can be regarded as another electrical buffer, which stores kinetic energy within a rapidly rotating wheel rotor. They contain no hazardous chemicals and are not affected by high rises in temperatures, unlike some battery technology types. Flywheels are a technology that has been around for some years, but with performance capability developments, have recently been able to compete with electrical battery storage systems. Current prototype flywheels are considered too large and heavy for small HEV s, although efforts are currently being made into being able to produce new lightweight, high-strength materials. However, due to the level of complexity, and the costs in producing an efficient unit may exc1ude their use in hybrid vehicles altogether.Hydrogen storage technologies are the other key area in future storage options.

Primary Hydrides (the Millennium cell) are based on thereaction between aqueous alkaline sodium borohydride and a high-surface metal catalyst. The reaction within this cell is easily controlled as hydrogen is only produced both the catalyst and reaction solution are in contact. Current limitations are that raw material costs are quite high; however, plans are currently being put into place to recycle the sodium borohydride to make the process cheaper. Although the cost of the materials for this technology is considered high, the principal concern is over both the control and safety of such a solution. To be ableto be considered a practical solution for HEVs, improvements must be made in the possible effects caused by the rise in temperatures, to prevent runaway reactions. Carbon Nanotubes/Fibres research has been active in many institutions including DERA, Loughborough University, North-Eastern University (USA), and Mannesmann (Germany). This technology is still on1y in the research stages but has the potentia1 for very high storage densities. Carbon nanotubes do have a lower energy than that nanofibres. The reaction between hydrogen and ethane/carbon monoxide over a finely divided catalyst bed produces carbon nanofibres. It is during the reaction that hydrogen is absorbed into the catalyst. The exact carbon nanofibre structure is reliant upon the reactant gas and temperature of the catalyst [16].

By exposing carbon nanofibres to hydrogenat high pressures in the region of 120 bar, the absorption of hydrogen occurs. By looking at the possibilities for the short to long-term solution for energy storage systems in vehicles, it can be seen that there are many possible routes in which to move next.

Current electrochemica1 battery options seem to be the optimum choice for current vehicles,but with improvements in the other technology types discussed, there seems as though there will be a shift in the approach to energy storage in the future.

## III. HOW HYBRIDS WORK

### Regenerative Braking

Regenerative braking is an advanced feature in an HEV that allows the electric motor to act as a generator to recapture energy that would once have been lost through heat dissipation and frictional losses. An HEV follows the rules of physics; $F = ma$; Where F is the force being applied, m is the mass (the vehicle mass in this case), and a is theacceleration of the vehicle. In simplified terms, the faster you want an object to accelerate, the more force you have to apply to it. These basic principles relate straight back to the configuration of an HEV. Concentrating on the electric motor first, energy from the battery is applied to the coil windings within the electric motor. A magnetic force is then produced on the rotor of the motor, causing the production of torque on the output shaft. The generated torque is applied to the wheels of the vehicle via the coupled gears and shafts. The wheels then rotate; applying a force to the ground in the process. This force is due to the friction between both the wheels and the ground, enabling the vehicle to move along the surface. The matter of frictional loss not only needs to be considered for conventional vehicles but for HEVs as well. In conventional vehicles, torque isgenerated to move the wheels to drive the vehicle on the road. During driving operations, friction is generated and losses occur. Through applying the brakes, the specially designed material in the brake pads can handle the heat increases through friction applied to the drums and rotors preventing the wheel from turning. A conventional vehicle has frictional losses to move the vehicle and uses friction to stop the vehicle. So the situation can be regarded as a lose/lose situation. When considering the frictional losses within an HEV, there are frictional losses throughout the system. There is the resistance between the electrons of the atoms moving in the wires between the electric motor and the battery,and through the electric motor itself [17,18].

Produced magnetic fields incur friction in the metal laminations making up the magnetic circuit with the electric motor. There is mechanical friction between every mechanical moving part of the system, including gears, chains, and bearings. As mentioned previously the by-product of friction is heat, and the higher the frictional force the greater the resultant heat. The consequence of the sum of the frictional losses determines the overall efficiency of the vehicle. The efficiency of HEVs isgreater than that of conventional vehicles in the respect that HEVs can reclaim energy that would once have been lost through regenerative braking. The inertia of the vehicle is the fundamental factor in being able to reclaim the energy back into the batteries.

Instead of using the full potential of the brakes of the vehicle, HEVs allow the linkages back to the electric motor such as the drive shafts, andgears transfer the torque from the wheels backto the electric motor shaft. Electric motors can transfer electrical energy into mechanical energy and back again, and in both cases can be achieved very efficiently. How electricity is reproduced is through the magnets on the shaft of the motor moving past the electric coils of the stator in the motor,passing the magnetic fields of the magnets through the coils. Electrical energy is then fed back into the battery, in tum charging up the hybrid battery pack. There are two forms of regenerative braking which are parallel regen and series regen; this is not related to parallel and series-configured HEVs.

The forms are dependent on how many wheels are being used to reclaim the energy. The most common approach in vehicles is that the front wheels are the only wheels reclaiming energy. Energy is still lost in this case through the back wheels as before through minor heat dissipation unless they are somehow connected back to the electric motor. The otherkey determinant factor is the battery state-of-charge (SOC) and how hard the energy is being driven back into the battery. Overall, the regenerative braking process is highly advantageous as it eliminates the need for a large, on-board electrical generating system, like the ones which have appeared on most parallel hybrid gasoline-electric drivetrains.

### Planetary Gear Set

The Battery Management System (BMS) can be regarded as the brains of a hybrid system, but it is the planetary gear set that manages the physical interaction between the engine, electric motor, and additional generator. The planetary gear set is a feature that appears only in parallel configured HEVs; it is not practical for use in a series configuration due to the coupling of the ICE and the electric motor/s in the parallel configured HEV. The planetary gear seamlessly harnesses and transmits power from the electric motor (high-speed), thus enabling a more compact and powerful motor. This results in much longer life, fewer frictional losses, and quieter driving [19].

**Continuously Variable Transmission (CVT)**

The Continuously Variable Transmission (CVT)further enhances the performance of a parallel configured HEV. A CVT offers the same potential as a parallel HEV, offering increased fuel economy and minimizing emissions in the process. The combination of thetwo is therefore a sensible and advantageous option to employ [20].

Unlike conventional vehicles which have a fixedgear ratio typically offering 4 to 6 gear options, the CVT in an HEV allows for an infinite numberof transmission gear ratios within the limits of the device. This is advantageous as it maximizes the efficiency of the powertrain whilst allowing the driver to have a much smoother ride, thanks primarily to jolt-free acceleration. The main reason behind moving from manual to CVT is so that theengine will always operate at its optimum regimeand throttle positions, whilst adapting to the varying road conditions and power demands.

Currently, conventional vehicles do not make useof CVT, one reason for this is that its belt-driven orientation limits its application with vehicles of engine sizes over 1.2 liters; making manyconventional vehicles incompatible with this transmission type. Other disadvantages includeits large size and weight. However, developments are aiming to decrease these effects and make CVT a more viable means of transmission for all vehicle types in the future.

**Integrated Motor Assist (IMA)**

The Integrated Motor Assist (IMA) system owesmuch of its remarkable performance to the application of numerous technologies developed over the last four decades. Honda, for example, has used their knowledge in lean-burn combustion, low-emissions, variable valvetiming, high-efficiency motors, regenerative braking, and nickel-metal hydride battery to their advantage in developing the IMA system for its Insight model. They aimed to make the world's most fuel-efficient gasoline-powered automobile. Honda optimized the performance of each of the technologies withinits knowledge base to create an efficient, lightweight, and compact hybrid drive system. The advantage of such a system is that it is easyfor customers to use, and requires no changes in lifestyle either. The key part of the IMA system is the intelligent power unit (IPU), which controls the flow of electricity to and from the motor, and controls the storage of the electrical energy in the battery pack. During deceleration and braking, the electric motor acts as a generator, to recharge the battery pack. More than 95 percent of the energy generated during the braking cycle is recovered for storage in the batteries. The IMA in the Honda Insight boats an impressive 24 percent improvement in efficiency, which also combines with the fact that the Insight also meets California's stringent Ultra-Low EmissionsVehicle (ULEV) standard. Another advantage of the IMA system is its capabilities for long-range driving. The Insight can travel over 600 miles; all on a single tank of gasoline (10.6 gallons) [21].

**BATTERY MANAGEMENT SYSTEM (BMS)**

The primary goal of the Battery Management System (BMS) is to increase the cell life of the batteries in an HEV. More commonly referred to as the Electronic Control Unit (ECU), it managesthe power flow between the generator, battery,and electric motor. By keeping a constant monitor over various driving conditions, the BMS allows the transmission to gain optimal power and fuel consumption from the power train. The BMS manages the interaction between the battery and the electric motor, optimizing the movements between both in the process [22].

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