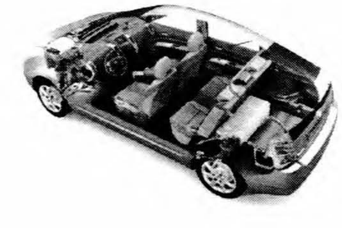

HYBRID ELECTRIC VEHICLE CONTROL: GENERAL CONCEPTS AND A REAL WORLD EXAMPLE

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ABSTRACT

The main objective of this paper is to explain the general concepts and analysis behind hybrid electric vehicle (HEV) control. Systems, components and concepts will be explained in order to illustrate the important position that this research currently plays in the environment of HEVs. Hybrid control strategies will be classified and current research considered in order to forecast future trends in this area. A real world example will also be provided, illustrating the key concepts and discussions of the publication.

Index Terms— Hybrid Control, Hybrid Control Strategies, CHOICE project.

1.INTRODUCTION

The emergence of *Hybrid Electric Vehicles* (HEVs) has opened new doors in the area of automotive research, and the control of HEVs is one area attracting a lot of interest. Due to the range of options possible in HEV control, there have been a variety of concepts developed, making it difficult to give a generic explanation which encloses them all [1].

However, this paper illustrates the general concepts currently involved in the optimisation of HEV control. The common parameters along with the techniques being implemented will be discussed in order to identify the common best practice. Also a description of a novel hybrid control project will be provided; with the objective to show possible parameters which could be taken into account in future HEV control strategies.

The CHOICE (City Hybrid-electric bus with Optimised efficiency using Information and guidance systems for passenger Convenience and vehicle Energy consumption) project has been undertaken in the group to which the authors belong. The aim of this project is to use collected data such as the speed and passenger information in order to optimise the fuel efficiency and reduce the exhaust emissions of the bus [2].

This paper is presented in two main sections. The first part will cover the control in HEV taking into account the elements and possible strategies involved. A real project illustrating the concepts of HEV control (CHOICE) will be explained in the second section.

2.CONTROL IN HEV

It is generally possible to observe whether the outcome of a system is actually what would have been predicted, based on a particular input or demand. If the outcome is different, then a method of control must be implemented in order to provide the necessary corrections and adjustments. The *control system* in a predominantly electrical device such as in an HEV operates in *real time* based upon real events during operation.

Apart from the common tasks that the HEV *control system* has to handle with respect to a normal control system such as safety issues, there are other methods and operations which are worth noting. The *HEV strategy* is the most interesting as it needs to determine which energy source/s need to be used when the car is driven, and the extent to which energy is recovered in braking. The area of

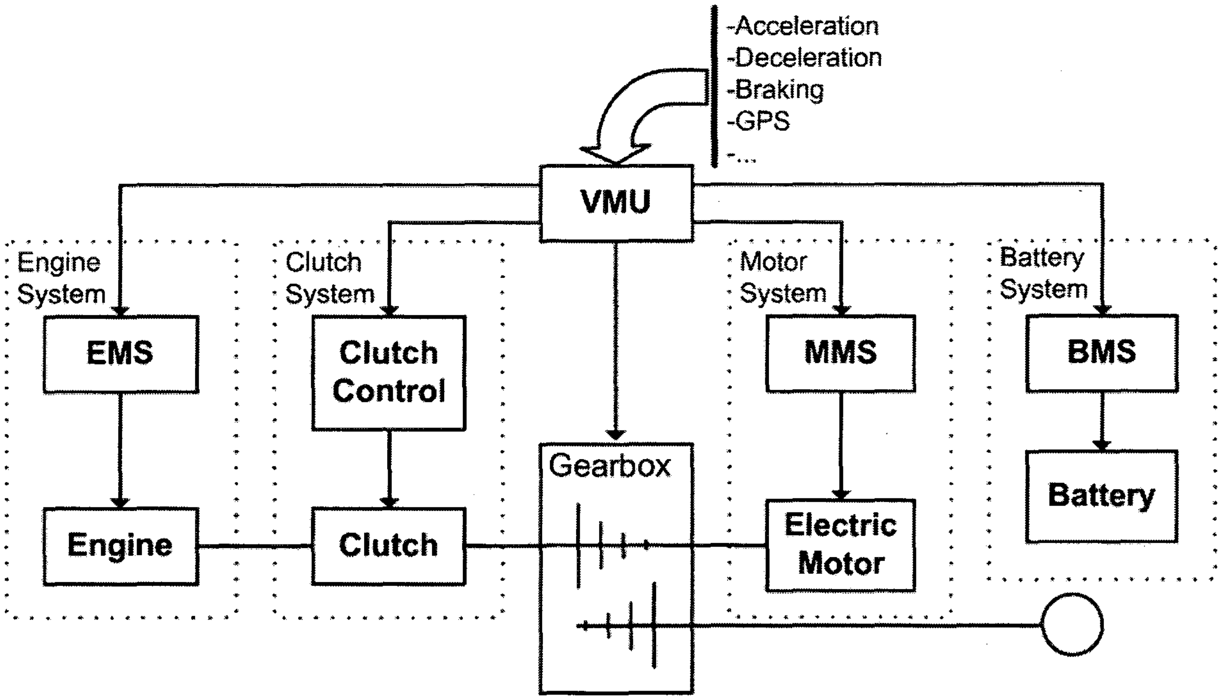

***Figure 1:** General Hev Control Diagram*

HEV control within this paper will primarily be focused on the analysis of the current parallel HEV configurations. In order to cover this area it is important to introduce the following concepts:

2.1.Elements

There are several systems which are involved in the control system of a HEV. Figure 1 illustrates a general interconnecting scheme along with their functional connections. The *Vehicle Management Unit* (VMU) is considered to be the key part of the control system, as it provides high level management of all of the other system components. Each system is responsible for one element, meaning for example the engine, clutch, electric motor and battery are monitored for each system management configuration; explained further in the following subsections. The events or request responses are reported to the VMU which in turn makes an operation decision. The communications between the systems and the VMU are generally realised over a communications bus, typically a *Control Area Network* (CAN).

2.1.1.Vehicle Management Unit(VMU)

The *Vehicle Management Unit* (VMU) is considered to be the *brain* of the vehicle. The VMU collects and processes the necessary data from the other systems including the *Battery Management System* (BMS), *Motor Management System* (MMS) and *Engine Management System* (EMS) in order to decide the best response for each individual event. When the VMU makes a decision, it communicates with the necessary system/s which are responsible for the final execution. Therefore, the VMU implements the control within an HEV, thorugh the systems peripherals which provide data to the VMU and execute its orders.

Essentially, the VMU is responsible for the following tasks [3]:

- As shown in Figure 1, the VMU must detect the basic intentions of the driver. In other words, it must detect acceleration, deceleration, and braking demands in order to regulate them.
- The VMU controls the synchronisation of the system during the gear shifting process.
- In a parallel HEV, although not drawn in Figure 1, the VMU is responsible for the traction drives. This allows for the safe

operation of the drive components, such as the traction battery, by monitoring the system with the VMU. With this, modern-day dependency and reliability can also be achieved for alternative drive configurations.

- The VMU must implement the HEV strategy, as explained above. This strategy governs the choice between electric motor, internal combustion engine (ICE) and a combination of them both depending on the inputs and data requirements of the systems.

Concluding, the VMU, through the implemented embedded software, coordinates the correct working operation of all of the systems in the vehicle and integrates their operation for best effect.

a) BMS Function

A good definition for the *Battery Management System* (BMS) function is a subroutine or system to increase the battery's life, preventing it from facing serious dangers [4]. Also, the BMS function includes an estimation of the battery status. Therefore, the main objectives of the BMS function include:

- Protect the cells or the battery from damage.
- Prolong the life of the battery.
- Maintain the battery in a state in which it can fulfil the functional requirements of the application for which it was specified.
- Estimate the battery cell status in terms of both capacity and ageing.

In contrast, through a number of introduced concepts, it is possible to describe the battery status, the definitions of which are introduced here:

- ***State of Charge* (SOC):** The SOC is the *remaining capacity* of the battery and it represents the energy level remaining for useful work output. SOC is the ratio between the remaining capacity and the initial (rated) capacity of the battery, with this value usually being represented as a percentage.
- ***State of Health* (SOH):** SOH is the current condition of the battery. It can be determined as the remaining lifetime or the percentage degradation from the initial (rated) lifetime of the battery.
- ***State of Function* (SOF):** SOF is a measure of battery to perform vehicle functions, such as starting the engine. SOF is determined by both values for SOH and SOC, once determined the SOF shows what the battery is capable of delivering in vehicle terms. The SOF can provide the relationship between required current and time, whilst taking into account the whole health issues concerned with the battery. With these considerations the VMU can determine how long it can source predetermined current. Obviously, if the demand for current is high, the time will be low and vice versa. The SOF relationship is becoming widely used in the automotive industry due to its clear reporting capability [5].

Basically, the VMU is able to estimate the battery status (SOC, SOH and SOF) from a variety of parameters which are possible to sample. This status will be discussed further in order to take into

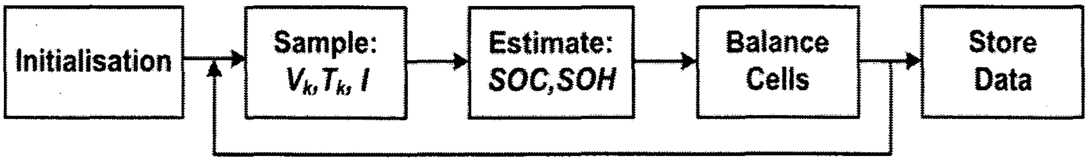

Figure 2: BMS Functional Diagram

account required energy needs or charging of the batteries, depending on the situation.

Figure 2 shows a block diagram of the functional working system of the BMS. Each time the subroutine is restarted, the BMS is initialised to its original settings. The previous load of the last parameter is captured and observed; in order to ensure the system operates as two subtasks. The following sample is an important operation of the BMS which is explained in-depth.

(1) Sample

Over the connection between the BMS and VMU through the CAN bus, the VMU receives a sample of the open circuit voltage and/or the current. Current within a battery system is a common parameter, whereas the voltage needs to be captured for each cell in order to estimate the SOC and SOH. The other parameter of concern is the temperature, which also needs to be sampled in order to protect the battery. The operation of the CAN interface is controlled by the BMS, and is covered in the following section.

(2) Estimated SOC and SOH

The key process in estimating the SOC and SOH is through sampling the previous voltage and current values; this can be achieved through certain techniques. Such options include the working of neural networks or fuzzy logic, both of which are currently attracting a lot of research in order to gain the appropriate knowledge to implement such approaches. Both of these approaches offer an array of flexibilities including the ability to predict future outcomes easily; however their current weaknesses lie within the area of testing [6]. These options are conventional static techniques and they frequently use data recorded within a laboratory environment; applying different cycle tests to a variety of cells to simulate real life conditions. As a result, these experiments produce characteristics such as the relationship between the open circuit voltage and the current to give the SOC and SOH [7].

In order to determine SOC the current must first be integrated in order to measure change in current from battery operation. The fundamental equation in order to use the current integrator technique to estimate the SOC is:

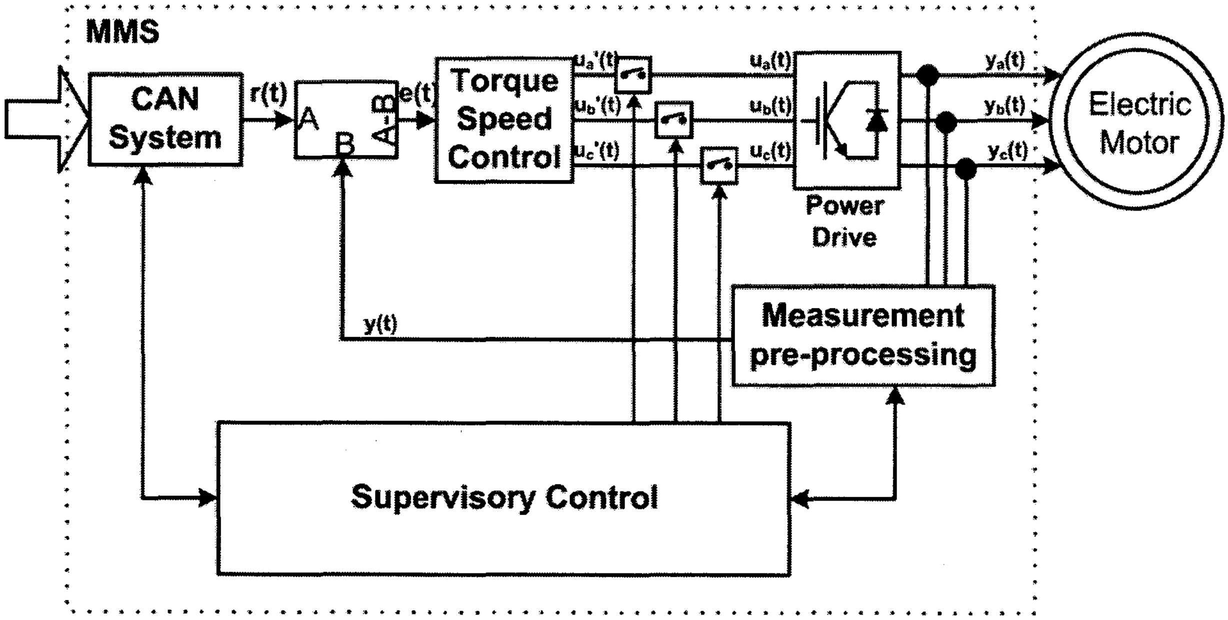

Figure 3: MMS functional diagram

$$SOC = \frac{Current \quad Cell \quad Capacity}{Total \quad Cell \quad Capacity} = $$

$$= \frac{\int_{t_s}^{t_f} Idt}{Total \quad Cell \quad Capacity}$$

Here, t_s is the sample time and I is the current measured from start to finish. The variation in the *Total Cell Capacity* over a measured period of time represents the SOH. The SOH parameter is frequently monitored in order to estimate its changing value with respect to the gradually depleting charge capacity, experienced by the cell. This evaluation also requires the sampled temperature as well. In contrast, the voltage and current are two parameters which can estimate the SOC by themselves, or as a combination.

(3) Balancing the Cells

In many instructions of electrical devices such as CD players or digital cameras, it is advised not to mix new cells (100% SOC) with old ones (e.g. 20% SOC) as this would shorten the useful lifetime of the new cells. For HEV applications this is no exception, and this problem must be controlled by within the BMS system.

The sampled voltage for each cell is determined in order to obtain an estimation of the SOC for each cell. The cells can then be matched in terms of their charge. Although the benefits of this practice are undoubtedly noticeable, there are still issues concerning the cost involved in implementing this into the BMS.

(4) Data Storage

The stored data within the BMS can be used in order to improve the general behaviour of the BMS function; storing the data and creating an historical log for future predictions. For example, the *Kalman* filter application in the SOC, SOH and SOF estimation is an important research area in the BMS environment which requires the collection of such data [8].

b) MMS and EMS Functions

The MMS and EMS functions control the power and energy requirements of the electric motor and the internal combustion engine (ICE). This operation is further controlled by the VMU based on the inputs such as acceleration or braking along with the data from other systems such as the SOC, SOH and SOF of the batteries. Generally, the VMU aims to operate the ICE at its peak efficiency through the EMS function, maximising the advantages for the HEV.

The EMS and MMS functions also report any special event/s to the VMU such as abnormal operation in order to maintain proper working order. As noted previously the communication is performed between the system (MMS or EMS) and the VMU over a communication bus standard such as CAN.

2.1.2. Battery Management System (BMS)

The *Battery Management System* (BMS) exists as a VMU function within the framework of the HEV control system. The BMS includes the necessary electronic devices to monitor the parameters, as previously explained for the BMS functions in the VMU. Depending on the kind of estimation that the BMS is going to execute, the sampling of the voltage and/or current will be necessary. The temperature is also required to be sampled, in order to estimate the SOH.

There are several devices which can sample both the voltage and currents, however only small selections of them are able to work with the high current and voltage levels, due to the difficulty of measuring the dynamic range of current. A *Hall Effect* sensor is generally used to capture the current, whilst an electronic based optocoupler design is an excellent choice to estimate the open circuit voltage for each cell. The advantages of an optocoupler are the high gain and current transfer that the device offers.

There are experts who consider that the BMS should provide conditioning as well. This conditioning process consists of repeatedly charging and deep discharging a battery for the purpose of preventing voltage depression or *memory effect*,

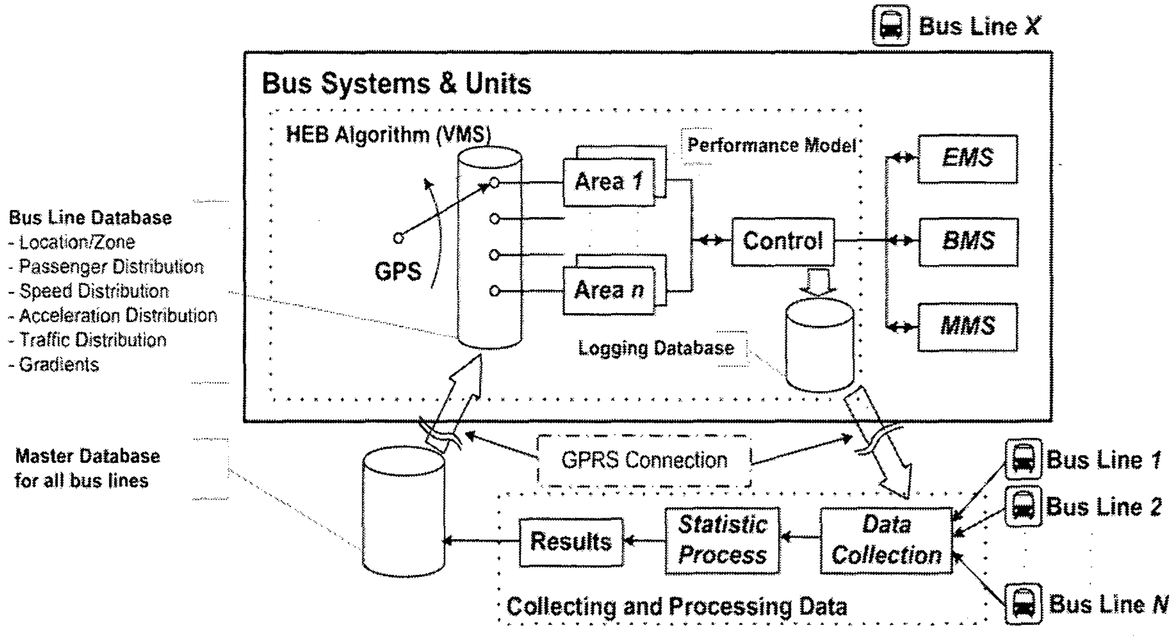

Figure 4: CHOICE Implementation Details

otherwise restoring lost capacity and maintaining a healthy cell balance.

2.1.3.Engine Management System(EMS)

The *Engine Management System* (EMS) (if fitted) is responsible for the fuel injection, ignition and the turbo issues concerned with a conventional engine. The control of the ICE is its main task and obviously it has contact with the VMU in order to report the necessary events. In contrast, the VMU must communicate back driver demands such as acceleration and braking.

In an HEV the VMU may divide the driver's required acceleration demand between the electric motor and ICE, and this is transparent to the EMS.

2.1.4.Motor Management System(MMS)

The objective of the *Motor Management System* (MMS) is to facilitate the electric motor control required by the VMU, and to supervise the correct performance of it [9]. The type of control is always determined by the electric motor type which is usually permanent magnet and synchronous alternating current (AC) in HEVs, to enable smoother operations between levels of the control system.

Figure 3 shows a block diagram with the main functional tasks of the MMS, which are described further below. The *CAN system* is responsible for interpreting between the MMS and VMU and vice versa. Basically, the power demands for the electric motor provided by the VMU is translated to the *r(t)* signal, it also has direct contact with the *Supervisory Control* block to warn the VMU of any abnormal events.

The *Torque Speed Control* is the real control part of the loop, with the objective of supplying the three controls signals necessary for the electric motor, once amplified in both current and voltage for the *Power Drive*. The *Measurement pre-processing* is responsible for two tasks. The first is to retranslate the three control signals ($y_a(t), y_b(t)$ *and* $y_c(t)$) into *y(t),* in order to differentiate the signals which will improve the accuracy within the feedback process. Secondly, to keep in contact with the *Supervisory Control* for safety issues; operating as a switch between the blocks if necessary.

In other words the MMS is undertaking the control of the electric motor when it is operating. The way in which this is achieved is beyond the scope of this publication; however this can be referred to in [10].

2.2.HEV Strategy

The choice of energy source/s for a particular HEV is governed by the HEV strategy of the vehicle. By employing an appropriate strategy, the HEV will gain the most benefits whilst avoiding any decreased performance effects. One area which is monitored and controlled by the HEV strategy is the state of the batteries. It is crucial to keep the batteries in a healthy state in order to protect the complete system from premature deterioration and therefore maintain the efficient working life of the batteries. Therefore, a well designed algorithm could optimise the process, and help to increase the benefits of the HEV application.

The process inputs are the stimulus provided by the driver. For example, if the driver is accelerating strongly, the VMU should use all energy sources. In contrast, if the vehicle is braking, the VMU should use this energy to recharge the batteries. In both cases, a good estimation of the cells status is a key point to decide the extent to charge or discharge the batteries and hence increase their life.

The three key areas under which this research lies fall under the following categories [11]:

- **The use of intelligent control techniques:** *Fuzzy logic* and *Neural Networks* are just two examples within this line of research [12], [13].
- **The use of static optimisation methods:** Basically, the electric energy in an HEV is handled like a fuel in terms of energy cost [14], [15]. This method optimises the proper energy and/or power split between the two energy sources used. As the optimisation of this process requires relatively little computational effort, the emissions can also be reduced by a greater extent as well [16].
- **The use of dynamic optimisation methods:** Generally speaking, these methods use the dynamic nature of the system, in order to realise the optimisation of such with respect to time. In general terms, this technique is far more accurate than the previous static one [17], [18].

2.2.1.New Trends

New trends have begun to see the use of electronic devices such as GPS (Global Positioning System) in order to try and improve the HEV strategy. In fact, there are previous projects developed within the authors' group which support this idea. For example, the *CHOICE* project has the objective to develop a *hybrid electric bus* (HEB), as it may well provide a useful tool for optimising HEV transportation systems and other vehicle systems in general [2]. Factors such as the weather, the speed distribution, the passenger distribution and most obviously the global positioning are being taken into account in the HEV strategy of these buses.

3.A REAL WORLD EXAMPLE: CHOICE PROJECT

The *CHOICE* project is a collaborative project between a number of industrial and academic partners. The overall aim of which is to specify, design, build, test (in a full service environment) and evaluate a diesel series hybrid electric bus (HEB).

The vehicle's energy usage (and hence efficiency and emissions) is to be optimised through advanced engine and battery control techniques, which in turn make use of a range of input information. Additionally, the HEB will make use of current and future telematics technologies to assist in the optimisation of the efficiency. The key targets for the project are:

- Enhanced traffic system information, including clear performance zone switching & route guidance.
- Reduced emissions (exhaust) to Euro 4 (or lower) legislative limits (2006).
- Reduction of fuel consumption and CO_2 emissions by a minimum of 30%.

Therefore, this project should provide a good case study upon which to predict future trends in HEV technology.

3.1.Implementation Details

The most desirable input for the HEV strategy control is an accurate power prediction. If this parameter is forecasted correctly, the HEV control could manage the available energy sources effectively for optimum effect.

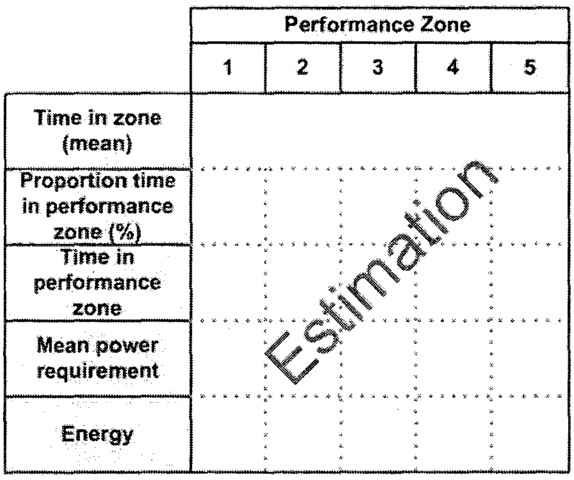

Fig.ure 5: Energy Profile for Traversal of a Geographic Zone

The CHOICE project estimates this power by collecting the necessary data and statistically processing it. This is possible due to the high correlation with the buses behaviour over time for the same route, as there are a number of aspects which will be roughly the same for each individual journey, such as the road surface and average speeds for example.

Figure 4 illustrates a general block diagram of the HEV control strategy developed in these buses. This representation can easily be divided in two sections; 1) *collecting and processing data* and 2) *HEB Algorithm (VMU)*.

3.1.1.Collecting and Processing Data

This first strategic step is developed outside of the bus, in two stages as the *collection of data* and the *statistical processing* of data.

a) Data Collection

The first evaluation to take into account is the determination of the necessary data to get accurate power estimations for the journey. These estimations can be divided into two key classes:

- **Static journey data:** This is data that does not change from journey to journey, such as the roads used, location stops and the gradients of roads.
- **Dynamic journey data:** This is data that relates to the particular journey, and which will not be constant from journey to journey. These can be subdivided in to two subclasses:

  _ *Progression of the journey descriptors*: such as the positioning, speed and acceleration of the bus.

  _ *Events of the journey*: defining the main factors which affect a journey such as weather, passenger loads and levels of traffic.

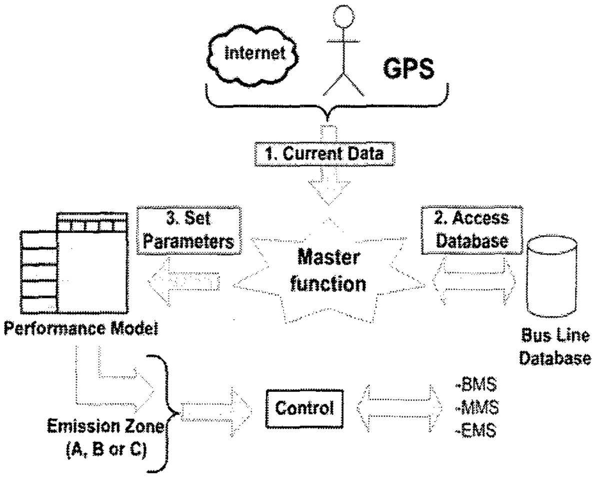

Figure 6: HEB Algorithm: Implementation details

For the first class (static data) the required information was collected using a route survey and maps of the area. This allowed the positions of major road junctions, bus stops, geographic features and speed limits to name but a few to be recorded. This information was then used for route classification purposes.

For the second class (dynamic data), collection was achieved through the use of a portable system (PDA), rather than an onboard or hard-wired system. This provided a greater degree of flexibility as the system could be used on any bus service without the need for costly or time consuming installations of the data collection equipment. Furthermore a fully automated system was not possible as a number of parameters were logged that are not readily available in an automated way, for example the number of passengers getting on and off at a particular stops, the weather and road traffic accidents.

These selections of data are collected for each bus route as there would be slight variances in results for individual routes. However, a number of the static data parameters are the same across the board, which makes the process of control easier to come to optimise (Figure 4).

b) Statistical Processing

When the data had been collected, the statistical analysis was calculated with the aim to estimate both the power and energy required for each situation. Due to the complexity of this process, the *performance zone concept* was introduced. This concept is captured and displayed in table (Figure 5).

In each column, the performance zones are separated to represent the varying bus speeds and the split in power requirements. The definition for each column is as follows;

1. 0 – 5 km/h, Performance Zone 1 (Creep zone): To represent slow moving traffic in a queue for a road junction or regular stop/starts, resulting in low average speeds.

2. 5 – 10 km/h, Performance Zone 2 (Crawl zone): To represent slow moving traffic at a junction as above, but with a steadier slow speed.

3. 10 – 20 km/h, Performance Zone 3 (Low speed zone): Typical inner city driving speeds.

4. 20 – 40 km/h, Performance Zone 4 (Medium speed zone): Typical urban speeds.

5. 40 – 80 km/h, Performance Zone 5 (High speed zone): Typical extra urban speeds.

The rows then go onto show the most important estimated parameters for each journey, (Figure 5). These parameters are processed statistically in order to work out the necessary averages, variances and percentiles; expecting that the correlation between journeys is high. Also, the grid is divided into different areas to classify the order of accuracy required for the differing power requirements between say the city and the motorway environment.

Therefore, the ideal performance model parameters are defined for all for all possible bus routes of the fleet. This obtained information is then stored in a master database. The performance model table for each bus route can then be loaded into the corresponding bus for any given journey.

3.1.2.The HEB Algorithm (VMU)

The HEB control is executed inside the bus VMU as previously discussed. Basically, this software manages the correct operation of a hybrid system; thus providing the best solution for each given situation. In other words, it optimises the fuel consumption and reduces emissions.

In the CHOICE project for example, the control system stored extra data which enabled the choice of the best strategy. This extra data has been described in the previous section and is stored in an internal database which distinguishes between the different bus routes (Figure 4).

Functionally, a master function loads these performance model table parameters whilst taking into account the different inputs, as shown in Figure 6. For example, weather (sun, rain....or fog), passenger distribution (0%, 25%, 50%, 75% or 100%), week day (Monday, Tuesday...or Sunday), time (1h, 2h or 24h) so on and so forth. The working area is fixed by the GPS, and set in a function which searches for the correct performance model table in the bus route database for these introduced parameters.

Depending on the nature of these functional inputs, these parameters can be introduced by internet (e.g. weather, unusual events...), GPS (e.g. current position) or manually (e.g. passengers loads) (Figure 6). Secondly, this function searches the database for the key parameters from the best performance model tables to provide information to the control system.

With the important objective of reducing the emissions especially within the city centre, the bus route has been divided into three types of operating regime; A, B & C. A represents a mandatory zero emission zone, B is ideally zero emission and C has no specific zero emission requirement. This parameter is provided to the control system as well in order to achieve the aim.

The control system based on the performance model tables (power and energy estimations) manages the emissions zones, battery output, electric motor and ICE management in order to establish the best possible solution for any given part of the journey. These control methods are also communicated back to the involved systems. Also, the control system logs a database in this process in order to generate a feedback approach to approve the accuracy of the process at each interaction (Figure 5).

3.1.3.GPRS Connection

To facilitate the connection between the master and the bus route database, the GPRS solution has been implemented for the CHOICE project. The logged database provided by the control system is recollected with this method as well. The advantages of GPRS are that you don't have to waste time on the move by constantly having to dial, whilst still being able to view moving images.

4.CONCLUSION

Undoubtedly, the control methods being introduced for HEV applications are offering advantages to electrical developments currently being implemented by other vehicles. For example, the global positioning and the maps of the software format found in the GPS car systems may be used in order to improve HEV strategies. For example, speed limits, crossroads and roundabouts are some usual parameters which can be obtained from GPS, and may be utilised in future energy and power requirement estimations. The method in which to make these predictions correctly is the key point in being able to improve current HEV systems.

The CHOICE project has been presented as an example of the extra data utilisation required in order to improve current HEV strategies. The research in *CHOICE* has been focused around hybrid electric buses (where the correlations between journeys are higher than those for cars); some of the statistical data and developments may however be useful in future HEV control systems analysis.

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REFERENCES

[1] K. Chau & Y. Wong, «*Overview of Power Management in Hybrid Electric Vehicles*», Energy Conversion & Management, 2002.

[2] S. Baker, P. Jennings & C. Mellors, «*Quantifying Variations in Real-World Drive Cycles for Hybrid Bus Optimization*», SAE Commercial Vehicle Engineering Congress & Exhibition, Chicago, October of 2004.

[3] R. Baddy, C. Renner & C. Amsel «*Concept of charge-sustaining Parallel Hybrid Drive train*», Euroforum-Fachkonferenz für die Automobilindustrie, March of 2001.

[4] C. Andersson, «*Observations on Electric Hybrid Bus Design*», Thesis Lund University, 2001.

[5] Australian Automotive Aftermarket Magazine, «*The future for Batteries*», March 2005.

[6] A. Mukherjee, «*Advances in Battery Management Using Neural Networks and Fuzzy Logic*», School of Electrical and Computer Engineer, Cornell University, Ithaca, 2003.

[7] R. Perez, «*Lead-Acid Batteries*», URL: http://www.homepower.com/, 1987.

[8] G. Plett, «*Kalman-filter SOC estimation for LiPB HEV cells*», 19th Electric Vehicle Symposium, Busan Korea, October of 2002.

[9] E. Bueno, S. Cobreces, F. Espinosa, F. Rodriguez, «*Design of a back-to-back NPC converter Interface for Wind Power Applications*», IEE Proc. Electric Power. Publication accepted.

[10] L. Tolbert, F. Peng, T. Cunnyngham & J. Chiasson, «*Charge Balance Control Schemes for Cascade Multilevel Converter in Hybrid Electric Vehicles*», IEEE transaction on Industrial Electronics, October of 2002.

[11] Ch. Lin, J. Kang, J. W. Grizzle & H. Peng, «*Energy Management Strategy for Parallel Hybrid Electric Truck*», Americal Control Conference, Arlington Virginia, June of 2001.

[12] B. Baumman, G. Washington, B. Glenn & G. Rizzoni, «*Mechatronic Design and Control of Hybrid Electric Vehicles*», IEEE Transactions on Mechatronics, v5 2000.

[13] S. Farrall & R. Jones, «*Energy Management in an Automotive Electric/Heat Engine Hybrid Power train using Fuzzy Decision Making*», International Symposium on Intelligent Control, Chicago 1993.

[14] C. Kim, E. NamGoong & S. Lee, «*Fuel Economy Optimization for Parallel Hybrid Vehicles with CVT*», SAE, 1999.

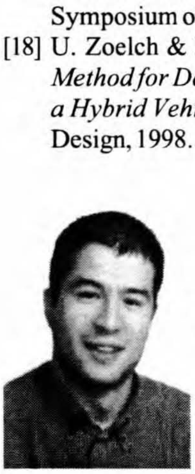
[15] G. Paganelli, G. Ercole, A. Brama, Y. Guzennec & G. Rizzoni, «*A General Formulation for the Instantaneous Control of the Power Split in Charge-Sustaining Hybrid Electric Vehicles*», 5th International Symposium on Advanced Vehicle Control, Ann Arbor, 2000.

[16] V. Johnson, K. Wipke & D. Rausen, «*HEV Control Strategy for Real-Time Optimisation of Fuel Economy and Emissions*», Future Car Congress, April of 2000.

[17] A. Brahma, Y. Guezennec & G. Rizzoni, «*Dynamic Optimization of Mechanical/Electrical Power Flow in Parallel Hybrid Electric Vehicles*», 5th International Symposium on Advanced Vehicle Control, 2000.

[18] U. Zoelch & D. Scroeder, «*Dynamic Optimization Method for Design and Rating of the Components of a Hybrid Vehicle*», International Journal of Vehicle Design, 1998.

AUTHORS



Diego Sánchez-Repila was born in Salamanca (Spain), in 1980. He obtained his Masters degree in Telecommunications Engineering from the University of Alcalá (Spain) in 2004. From 2002 to 2004, he was collaborating as Software Developer in a project supported by the Ministerio de Ciencia y Tecnologia.

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His tasks in WMG are focused in two different projects. On the first, he is working on the ISOLAB project, which has the main aim to develop a battery to meet the electrical power demands of future vehicles, which are able to support alternative installation and packaging strategies. On the other project, he is collaborating on the ECHOES project, which has the goal to use customer evaluation to help set engineering targets for the sounds of new vehicles.

John Edgar William Poxon was born in Chard (England, U.K.), in 1982. He obtained his Bachelors degree in Electronic Engineering from the University of Exeter (U.K.) in 2003. His final year project was to create web-based applications in the area of Communication Systems. This allowed students to work with interactive applets on communication theories online without the need for Matlab®.

His research area is focused within the field of hybrid electric vehicles on the Engineering Doctorate (EngD). His particular interests lie in the analysis of HEV modelling software, identifying possible areas to improve in the design process, and exploring the potential capabilities of high voltage HEVs.

He is a member of the Technology & Information Group (TIG). This is a research team based at the University Of Warwick in the Warwick Manufacturing Group's (WMG) International Manufacturing Centre (IMC). For the last 16 years they have been working closely with the automotive industry on a number of technology issues.

Stephen Baker was born in Manchester (UK) in 1975. He obtained his Bachelors degree in Physics from the University of Birmingham in 1996 which concluded in a final year project investigating the stability of sonoluminescence. This was followed by a Masters Degree in Manufacturing Systems Engineering in 1997 from the same institution. Since 1997 he has been a member of the TIG team (Technology and Information Group) based at the University of Warwick's Warwick Manufacturing Group.

His research interests have principally focused on a number of automotive based problems ranging from the Electromagnetic Compatibility (EMC) issues relating to composite and lightweight vehicles (an EPSRC funded Project), through to journey modelling for hybrid-electric buses (CHOICE Project).

More recently his research has centred on Sound Quality Engineering within the automotive sector. This includes the capture of customer opinion, and how this can be included early in the product design process. During this research he has assisted in the development of the groups product perception laboratories which includes a controlled listening environment and Noise and Vibration Simulator (NoViSim).