ABSTRACT

An advanced electric drive controller for a high power starter-generator subsystem based on a series DC machine is presented. The machine is belt-coupled to a diesel engine in a series-parallel 2×2 HEV. The DC electric drive is developed for engine starting, generating and motoring. Computer simulations are performed for tuning the controller parameters, and for selecting proper inverter rating of the starter-generator drive. The drive controller is implemented in hardware using Lab Instruments Drive Technology with algorithm software fixed point digital signal processor (DSP) and a high resolution current sensing board to achieve the best torque regulation at various load conditions. The DC starter-generator has been tested in both motoring (engine starting) and generating modes with the starter-generator mounted in the vehicle.

For the propulsion motor drive, three phase induction motor driven by a three-phase PWM inverter has been considered. The three phase induction motor drive cannot deliver high static and dynamic performance without the correct parameter values in the controller. Computer simulations showed the correct parameter variation effects on the performance of an induction motor drive used in an electric vehicle. A novel algorithm software mode observer based induction motor controller with on-line parameter adaptation is then presented. Software in the-loop (SIL) and hardware-in-the-loop (HIL) simulations have been performed for induction motor with electric vehicle load to verify the performance of the new algorithm as well as to tune the control parameters. For the HIL simulation, the controller was implemented in SIL based control hardware, and a electrical motor model was implemented in software. The new on-line parameter adaptation algorithm has been tested experimentally on three phase induction machine for a proof-of-concept demonstration. The developed algorithm for the three phase induction motor couple to dc motor provides fast convergence of parameters, rapid response characteristics of the drive, and accurate tracking of the control command for the three phase induction motor drive. These performance features are highly desirable for the propulsion motor in HEVs and EVs.

ABSTRAK

Satu kenderaan elektrik hibrid (HEV) motor aruhan tiga fasa pasangan untuk dc enjin dan pembakaran dalaman (IC) laluan enjin. Satu pengawal kenderaan yang penyeliaan menghasilkan perintah kawalan itu untuk subsistem dalam motor aruhan tiga fasa berdasarkan pemandu permintaan dan kelajuan kenderaan. Kecekapan bahan api dan pengeluaran daripada pembakaran dalaman (IC) enjin bergantung penggunaan subsistem dalam kedua-dua lorong-lorong penghantaran kuasa. Mejar subsistem dalam penghantaran kuasa elektrik laluan (EPTP) adakah jalan-jalan penggerak yang lari sama ada dalam menjana mod atau dalam memandu mod untuk proses aliran kuasa antara sumber dan roda-roda itu. Dalam penyelidikan ini, dua pemanduan bermotor maju subsistem dengan meningkat alat-alat kawalan telah direka bentuk dan dibangunkan untuk satu HEV motor aruhan tiga fasa pasangan untuk dc enjin. Dua subsistem adalah pemula penjana pacu elektrik dan pemanduan bermotor pendorongan. Sumbangan penyelidikan ini akan membolehkan penggunaan cekap HEV automotif.

Satu pengawal pacu elektrik yang maju untuk kuasa tinggi pemula penjana subsistem didasarkan satu siri mesin DC dibentangkan. Mesin adalah tali pinggang digandingkan untuk enjin diesel dalam satu siri selari 2×2 HEV. Pacu elektrik DC dibangunkan untuk permulaan enjin, menjana dan memandu. Simulasi komputer dipersembahkan untuk menala pengawal parameter, dan untuk memilih sesuai penyongsang penarafan pemula penjana memandu. Pengawal pacuan dilaksanakan dalam perkakasan menggunakan LAB INSTRUMENTS DRIVE TECHNOLOGY activeasma titik tetap pemproses isyarat digital (DSP) dan satu arus peleraian tinggi lembaga penderiaan bagi mencapai kilas terbaik peraturan di syarat-syarat muatan pelbagai. DC pemula penjana telah diuji dalam kedua-dua memandu (permulaan enjin) dan menjana cara dengan pemula penjana dipelekap dalam kenderaan.

Untuk pemanduan bermotor pendorongan, motor aruhan tiga fasa didorong oleh satu PWM tiga fasa penyongsang telah dipertimbangkan. induksi Tiga fasa pemanduan bermotor tidak boleh menyampaikan prestasi statik tinggi dan dinamik tanpa nilai-nilai parameter betul itu dalam pengawal. Simulasi komputer menunjukkan ubahan parameter itu kesan-kesan pada prestasi satu pemanduan bermotor induksi digunakan dalam satu kenderaan elektrik. Sebuah novel Lucas-Nuller Asma dan pctrain pemerhati mod pengawal motor aruhan berasas dengan penyesuaian parameter dalam talian kemudiannya dikemukakan. Perisian dalam itu gelung (SIL) dan perkakasan dalam itu gelung (HIL) simulasi-simulasi telah dipersembahkan untuk satu motor aruhan kuasa tinggi dengan beban kenderaan elektrik untuk mengesahkan prestasi Lucas yang baru mod Nuller pemerhati penyesuaian parameter berasas algoritma serta untuk menalakan kawalan parameter. Untuk simulasi HIL, pengawal itu telah dilaksana dalam PLC berpangkalan perkakasan kawalan, dan satu model enjin yang maya telah dilaksana dalam perisian. Parameter dalam talian baru algoritma penyesuaian telah diuji secara eksperimen sedang tiga fasa mesin induksi untuk satu bukti bagi konsep demonstrasi. Algoritma maju menyediakan berpuasa penumpuan parameter, ciri-ciri respons cepat pacuan, dan penjejakan tepat bagi perintah kawalan untuk induksi tiga fasa pemanduan bermotor. Ciri-ciri perlakuan ini adalah amat elok untuk enjin pendorongan dalam HEVs dan EVs.

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CHAPTER 1

INTRODUCTION

Nowadays the air pollution and economical issues are the major driving forces in developing electric vehicles (EVs). Hybrid electric vehicle (HEV) is one of the most promising alternatives to a conventional engine-powered vehicle by offering a clean, efficient and environmentally friendly urban transportation system (Abdalla, Abdelnassir,2005). However, how much the hybrid vehicle is better than the conventional one depends heavily on its control strategy.

The most advanced control algorithms for a motor drive require a good knowledge of the machine analytical model. A motor drive cannot deliver good performance without having the correct machine parameters in the controller. Especially in HEV applications, incorrect machine parameters in the controller of the propulsion motor make a significant difference in vehicle performance. Therefore, the primary focus of this dissertation will be machine parameter estimation for efficient use of a propulsion motor (Ambroˇziˇc, et al., 2004). The control algorithm and motor drive selection for a high power starter/generator of an HEV will also be addressed in this research.

In Laboratory TATIUC the already developed digital signal processors (DSPs) in motor control applications has allowed electrical machines to deliver their highest performance in terms of torque-speed characteristics and dynamic behaviour. Now complex control algorithms can be implemented, and these algorithms can be optimized considering efficiency and desired dynamic and static response (A.Aradadi, et al., 2007). The performance of a starter dc motor or main propulsion type subsystem in an electric or hybrid electric vehicle depends on the efficiency performance and robustness of the motor drives including the controller. In addition, the energy storage system of electric or hybrid electric vehicle must have sufficient capacity to supply enough power and energy to the three phase electric motors couple dc motor of different subsystems so that the machines can operate at full capacity.

1.1 HYBRID ELECTRIC VEHICLES

A hybrid electric vehicle (HEV) combines at least two sources of propulsion, one of them being electric. Hybrid power production options include spark ignition engines, compression ignition direct engines, gas turbines, and fuel cells. The primary options for energy storage include batteries, ultra capacitors, and flywheels. Hybridization of the automotive attempts to combine the low emissions of electric automobiles with the extended range of gasoline engines (A.Aradadi, et al., 2004). A hybrid electric vehicle (HEV) decreases the fuel economy and increases the emissions of the system when compared to a vehicle functioning only on a gasoline engine. The greatest benefit of the gasoline engine is the high energy density of gasoline (A. Kocalmis, 2005), on the order of 12,000 Wh/kg, in contrast with the much lower energy density of batteries, on the order of 500 Wh/kg. This allows the much greater range of vehicles run on gasoline engines. The benefits of electric motors include high torque at low speeds, the absence of on-board emissions, and regenerative braking. Traditionally, there are two ways to configure the system, series or parallel.

Hybrid electric vehicles attempt to combine the best of both conventionally powered internal combustion engine vehicles and electric vehicles. Hybrid electric vehicles can circumvent the range limitation of electric vehicles by using liquid fuels which over 100 times the energy density of current battery technology. Automobiles are an integral part of our everyday life (A. Farrokh Payam R. Yazdanpanah, 2006). Unfortunately, most automobiles use fossil fuels such as gasoline and diesel. Consequently, internal combustion (IC) engines release carbon monoxide, nitrogen oxides, carbon dioxide and hydrocarbons to the environment. The chemicals cause air pollution, acid rain, and build up of greenhouse gases in the atmosphere.

Electric vehicles (EV) powered by alternative energy provide the means for clean, efficient and environmentally friendly transportation. In EVs, an electric motor is the only propulsion unit, and power is supplied from a battery pack. Hybrid electric vehicles (HEV) that use both electric machines and an internal combustion (IC) engine for propulsion produce less emission as well as cause less air pollution than conventional automobiles (A. Tenconi, et al., 2004). The IC engine used in an HEV is, of course, downsized compared to an equivalent IC engine vehicle. Electric vehicles first came to the market in the middle of 19th century, even before gasoline powered vehicles (A. Arkkio, 2004). In the year 1900, 38% of the vehicles sold were electric powered. The invention of the starter motor for IC engines, improvement in engine technology, and availability of gasoline and inconvenience of battery charging challenged the existence of electric vehicles. However, during the last decade, motivated by concern over pollution and a future energy crisis, government and major automotive industries embarked on a number of initiatives to bring commercial EVs and HEVs into the market.

The architecture and component selection of Automotive of an HEV depends on vehicle architecture. The existing architectures for HEVs fall under the categories of series, parallel and series-parallel (A. Rahide, 2000). In series hybrid vehicle architecture, the IC engine acts as a prime mover to drive an (A. T. de Almeida,et al, 2002) electric generator, but never delivers power directly to the wheels. The electric generator provides power to the propulsion motor through an energy storage link. In parallel hybrid architecture, two energy sources provide propulsion power. A parallel hybrid automotive blends the power of the IC engine and the electric motor mechanically (A. T. de Almeida, et al., 2001.) with both sources supplying power to the wheels in parallel. The series-parallel architecture is a mix of series and parallel hybrid automotive. Combining the advantages of series and parallel improves the performance and increases the fuel efficiency.

1.1.1 Series Configuration

In a series configuration, the gasoline engine is connected via a generator to the electric motor, and only the electric motor provides power to the wheels. Torque produced by the gasoline engine generates electric energy in the generator, which is stored in the battery for use by the motor. In this system, the gasoline engine often runs continually in its zone of highest efficiency or lowest emissions, eliminating transient operation of the engine (A. Emadi, et al., 2005.). Numerous types of control strategies are being employed with series configuration. The gasoline engine can be controlled to optimize either fuel consumption or emissions production(A . P. Walker, 2004). Design of the generator-motor system takes into consideration whether or not the car will be “charge-dependent” or “self-sustaining”(A. Simpson, 2006). A charge-dependent car relies on external electric input whereas a self-sustaining car does not. The charge-dependent car, thus very similar to a pure electric vehicle, releases fewer emissions; but the self sustaining car demonstrates a longer running range. Of the two, the self-sustaining car requires a generator of a larger capacity and the charge-dependent car requires a battery of a larger capacity. There are a number of other factors to be taken into consideration in the design and control of series hybrid electric vehicles (A. Pesaran, 2006). The engine does not have to run consistently throughout a driving cycle; thus, the number of times that an engine is started over the cycle is an important variable in influencing the production of emissions (A. Rajagopalan, 2002; G. Washington , 2002). Another factor is the relation of the battery’s state-of-charge and the traction motor output to the input from the gasoline engine. In a “thermostat” strategy, the gasoline engine runs at a single power level; it is started when the battery’s state-of-charge reaches a designated minimum and stops when the state-of charge has reached an upper set point (A. M. Trzynadlowski, 2001). In a “power-follower” strategy, the gasoline engine follows the immediate demands of the motor output, and the battery’s state-of-charge remains constant (A. Derdiyok, et al., 2002). Because this strategy matches the engine’s torque to the motor torque second-by second, bypassing the need to store the torque in the batteries, battery losses are reduced, increasing fuel economy .

1.1.2 Parallel Configuration

In a parallel configuration, either the gasoline engine or the electric motor, or both can supply torque directly to the wheels. As a general principle, the electric motor is used for starting and low vehicle speeds, and the gasoline engine provides the power for steady-state operation (A.A., E. Monmasson, et al., 2005). This configuration presents the designer with an even greater number of design options than the series configuration. Control and control strategy are thus very important. Control systems function primarily to match the drive train with the driving conditions. Some principles are common to most parallel control systems. For example, the gasoline engine is never allowed to idle. When the vehicle is stopped or when it is decelerating, the engine is shut off. Only the electric motor provides torque for all slow-moving operations (A. Brooker, et al., 2002). A minimum vehicle speed is usually set to govern the entrance of the gasoline engine. Both the gasoline engine and the electric motor are used together for operations that demand high torque. Regenerative braking is employed (A. K. Jain,2006; S. Mathapati, 2006). A number of factors vary among designs. Designers must choose a minimum speed below which the gasoline engine is turned off. They also determine a minimum operating torque as a function of engine speed for the gasoline engine (A. Trentin, 2006; P. Zanchetta , 2006). If the torque required to meet the trace, which is the instantaneous torque demand on the vehicle, falls beneath this mark, the excess torque is used to drive the motor as a generator, recharging the batteries. A parallel-configured hybrid can run the gasoline engine in a number of ways; the gasoline engine can be used to meet the trace, it can be used only for steady-state operation, or there can be an intermediate control strategy.

1.2 ELECTRIC MACHINES

Electric machines demonstrate a number of features that are desirable for application to personal transportation. Electric motors have very high drive train efficiency, at least 90%. They also produce high torque at low speeds, a feature which has many applications in the varied driving conditions and needs for quick acceleration of personal transportation (B. Ozpineci et, al., 2006). Electric machines can be categorized as DC and AC types. Prior to 1980s, DC motors were widely used in industries and in a number of prototype electric vehicles due to their developed technology and ease of control (Baumann B, et al., 2000). DC machines offer flexible torque speed control and wide speed range operation, which is desired for an HEV propulsion motor (Boulter, et al, 2004). DC machines are simple to control, but they have low power to weight ratio, low efficiency, and require brush and commutator maintenance.

During the last three decades, AC machines have slowly replaced the DC machines due to the size and maintenance requirements of the latter. Recent electric and hybrid electric vehicles use AC machines both for propulsion and starter-generator applications. The types of AC machines used for these and other automotive applications are induction, permanent magnet and switched reluctance machines (B. Kou, 2005; L. Li et, 2005). These AC machines will be discussed in the following paragraphs.

1.2.1 Induction Machines

The stator is identical to a stator of a synchronous machine: three phases, P poles, sinusoidal mmf and flux distribution, and synchronous speed. In induction motors, the stator carries the field (C. Lascu, et al., 2004). The rotor is much different; in induction motors, the rotor is an iron cylinder with large embedded conductors, which are shorted to allow the free flow of current. The stator flux induces the ac current in the each the rotor conductors, and an ac voltage is induced in the rotor to drive the currents. The currents in the conductor produce a magnetic.

Induction machine technology is a mature technology with extensive research and development activities over the past 100 years. Recent development in digital signal processor and advanced vector control algorithm allow controlling an induction machine like a DC machine without the maintenance requirements (C. Gherasim, J. Van den Keybus, 2004). Induction motors are considered as workhorses of the industry because of their low cost, robustness and reliability. Induction machines are used in electric and hybrid electric vehicle applications because they are rugged, lower-cost, operate over wide speed range, and are capable of operating at high speed (C. D. Rakopoulos, 2004). The size of the induction machine is smaller than that of a separately excited DC machine for similar power rating. The induction machine is the most mature technology among the commutator fewer motor drives. There are two types of induction machines: squirrel cage and wound rotor (CASADEI, D, et al., 2001). In squirrel cage machines, the rotor winding consists of short-circuited copper or aluminium bars with ends welded to copper rings known as end rings. In wound rotor induction machines, the rotor windings are brought to the outside with the help of slip rings so that the rotor resistance can be varied by adding external resistance. Squirrel cage induction machines are of greater interest for industries as well as for EVs and HEVs. Instant high power and high torque capability of induction machine have made it an attractive candidate for the propulsion system of EV and HEV. The three-phase stator windings in an induction machine are displaced by 120° (electrical) in space along the stator circumference(Choi, Tayoung Gabriel, 2008; C. Lascu, et al., 2000). If three-phase voltages are applied to the stator, the stator magnetic field will cut the rotor conductors, and will induce voltages in the rotor bars (Casadei., et al, 2002). The induced voltages will cause rotor currents to flow in the rotor circuit, since the rotor is short-circuited. The rotor current will interact with the air gap field to produce torque. As a result the rotor will start rotating in the direction of the rotating field. The difference between the rotor speed and the stator flux synchronous speed is the slip speed by which the rotor is slipping from the stator magnetic.

1.2.2 Machines used for starter/generators

Electric machines are classified according to the mechanism of establishing the rotating field in the stator and the rotor. Rotating stator fields in electrical machines are generated using electrical excitation (Chan C, Chau K, 2001). In addition, a field at the rotor must also be created, i.e. the rotor has to be magnetically oriented in order to make it spin. Different solutions exist to produce the rotor field:

- The rotor's field can be induced from the stator, because of the rotor's structure (as in the induction machine)
- The rotor can be electrically excited so that it would create a magnetic field with a constant orientation (as in the synchronous machine)
- The shape of the rotor can induce reluctance variations in the stator (as in the switched reluctance machine)
- The rotor can be permanently magnetized with permanent magnets (as in the PM machines).

The conventional induction and synchronous machines have certain disadvantages: in the case of synchronous machines, the need for an electric source to energize the rotor leads to a less efficient system. In addition, electrical losses will occur if mechanical connectors, such as rings and brushes, are used to provide the rotor with the DC excitation (C. Gherasim, J. Van den Keybus, 2004). These elements will also suffer from mechanical aging, which makes them less reliable. As for induction machines, part of the current in the stator must serve to magnetize the rotor, and therefore does not contribute to the production of torque, which will reduce the efficiency (Chen, Qi, 2007). One criterion of good operation is the smoothness of the rotation of the rotor; the switched reluctance motor is prone to high torque ripple, which makes it a bad candidate for applications that require smooth operation. The motors with permanent magnets are the most efficient because they don't require an external field excitation (Choi, Tayoung Gabriel, 2008). In this category of motors, two main motors emerge: the Permanent Magnet Synchronous Machine (PMSM) and the Permanent Magnet Brushless Direct Current machine (PM-BLDC). PMSMs have been sinusoidal back-EMF, while PM-BLDC machines have trapezoidal back-EMF.

One of the machines mentioned can be used for the starter/generator application (C. Lascu, et al., 2000). The researchers in selected an induction machine for a three-phase 4kW starter/generator for the ease of manufacture and cost. The induction motors have good efficiency and smooth torque, and have been widely studied and used, which gives them an advantage(CRC press Taylor & Francis Group, 2005). However, the rotor losses and the cooling of the rotor are a concern for the induction machine.

Switched reluctance machines are attractive because of their simple design, and fault-tolerance capability in the face of switch failures. However, their study and development are still in an early stage and their use in current industrial applications is still limited. Finally, PM machines are attractive because these machines have the great advantage of having the highest efficiency (D.Anderson and Judi Anderson, 2005). The cost is an impediment due to the use of expensive permanent magnets. The permanent magnets are also vulnerable to elevated temperatures.

In (D.Anderson and Judi Anderson, 2005), another type of permanent magnet electric motor, known as a double-stator electric machine, is used to develop a starter/generator application. The interest of this research was to develop a motor drive that would be compact, have a high starting torque and a wide speed range when operated as a generator. The general idea is to have, from the centre of the motor to the outside, first a stator, then the rotor, and finally the second stator. The rotor is made of permanent magnets, while the stators have windings (D.Casadei and G.Serra, 2002). A finite element analysis was conducted, and prototypes were built; they showed improvements over the level and the shape of the voltage generated by this special kind of motor. The best improvements were made possible by adjusting the pitch displacement of the two stators (D.A. Staton, et al., 2005). The latter factor was also considered in order to obtain attractive values of average torque and torque ripple. The electric machine chosen for the Akron hybrid vehicle starter/generator is a PM-BLDC machine. The selection was based on both the availability of a 20kW PM BLDC machine and the technical advantage of this machine for the intended application (E. Semail, X.Kestelyn, 2004). The review of PM Brushless Machines and their control will be presented in this chapter.

1.2.3 Switched reluctance machines

Switched reluctance (SR) machines are also gaining attention in HEV applications. They are inexpensive, reliable, have high fault tolerance, and weigh less than other machines of comparable power outputs (Eun-Chul Shin, et al., 2003). High torque-inertia ratio is an advantage for the SR machines. The SR motor is a doubly salient and singly excited reluctance machine with independent phase windings on the stator (E. Nordlund, 2005). The stator winding is comprised of a set of concentrated winding coils. The rotor structure is very simple without any windings or magnets, and is made of magnetic steel laminations. Two major problems associated with SR machines are the acoustic noise and significant torque ripples .

The SR machine is excited by a sequence of current pulses applied to each phase, and the energized phases cause the rotor to rotate in the motoring mode. The SR machine operates on the principle of varying reluctance (E. Nordlund, 2005). The reluctance is minimum (inductance is maximum) when stator and rotor poles are in the aligned position, and maximum when the poles are unaligned. A stator phase is energized when the reluctance for the respective phase is maximum (E. C. Lovelace, T. M. Jahns, et al., 2004). The adjacent rotor pole-pair gets attracted toward the energized stator to minimize the reluctance of the magnetic path. When the reluctance is minimized, the next stator phase is energized. As a result, torque is developed in the direction of rotation.

1.3 RESEARCH MOTIVATION

The increased complexity of vehicle control and vital data communication in a HEV require a careful and thorough testing of the vehicle controller and its coordination with various subsystems. Testing of a vehicle controller in a HEV is essential before it is used to run a real vehicle based on both economic and safety grounds (Faiz J, et al., 2003). A Hardware-in-Loop (HIL) simulation platform enables on-the-bench testing of a vehicle controller to be employed in a HEV.

A HIL simulation setup provides the necessary bridge between offline simulations and real time implementation of a vehicle controller. Most of the research work done earlier demonstrates many offline studies done on a vehicle model (Fang Lin Luo, Hock Guan Yeo, 2000). The path between the offline simulations and real world implementation needs many factors to be considered. In a HIL simulation setup, offline simulations are modified to run in real time, and the hurdles in real time implementation of a HEV controller can be seen earlier in the design process. The importance and utility of this technology motivated the development a HIL setup to be used for HEV controller testing University of Akron. Arkon model is a HEV design competition with headline sponsorship from General Motors (GM), and the United States Department of Energy (USDOE) (F, 2001; Faiz J, Sharifian M.B.B, 2001). The primary objective was to reengineer a GM Chevrolet Equinox into a fuel efficient, environment friendly HEV while maintaining the performance of a stock vehicle.

1.4 RESEARCH OBJECTIVES

The primary objective of this research is to develop advanced control s for the motor drive, theInduction motor couples to dc motor. To know and Record the data parameter trategy of the Transient or steady state system. And how to collect data in steady state condition , the data parameter are torque, mechanical power, armature voltage, armature current, apparent power ,active power , reactive power, slip , power factor and efficiency vs speed . For data transient system are torque, speed, power, current vs time. And shows the wiring diagram of induction motor and how to collect data in transient condition, for the first time experiment use only Induction motor and the second time experiment use Induction motor coupled to DC motor. The following research objectives are set forth:

The simulation is used testing the maximum driving range at a constant speed 35 mph(mile per hour) for Conventional Hybrid System compare to the Proposed HEV.

The simulation is used testing the maximum driving range at Up-hill grade-ability for Conventional HEV(only induction motor) compare Proposed HEV(Induction motor coupled dc motor) .

The simulation is used for testing the maximum driving range at Down-hill grade-ability for Conventional HEV(only induction motor) compare Proposed HEV(Induction motor coupled dc motor).

Development of a new observer based on-line parameter estimation algorithm for induction motor couple dc motor drive drives, which is simple, easy to implement and able to overcome the difficulties of existing methods.

1.5 RESEARCH CONTRIBUTIONS

The primary objective of this dissertation is to investigate and fine control solutions to derivability problems that arise due to the intrinsic characteristics of hybrid-electric vehicle cars and the control strategies that manage them. In accordance with this objective, the first contribution of this research is the development and experimental validation of an through-the-road parallel HEV model with the purpose of predicting low-to-mid frequency vehicle dynamic behavior that has the impact on longitudinal drivability (Feng Chai et, al., 2005). Throughout the course of this thesis, simplified versions of this model are used for the design of control algorithms.

The second contribution is made in the area of HEV control design. Despite the presence of considerable research effort on fuel economy optimization, these works rarely consider the derivability effects of the actions taken by the energy management controllers (G.-J. Su, et al., 2006). This thesis attempts to address this limitation. One of the findings of this research is the importance and difficulty of maintaining good derivability in a HEV that uses a multi-mode control architecture because of the need for proper utilization of the engine start-stop and couple function. This observation motivated the study in the area of control of systems with mode-switching induced transients (G.-J. Su and J. S. Hsu, 2004). The beginnings of a mathematical approach are presented to address the problem of achieving seamless mode transitions in a special class of switched dynamical systems. The proposed framework is applied to a HEV drive line control problem during the transition from electric only to hybrid mode.

The third contribution is simulation programs are used to present the results since no road test results are available for a hybrid vehicle. There also has been no research on computer simulations as they are applied in this thesis (Głowacz Z, ZdrojewskiA, 2005). However, the results of these simulations may give an approximate idea about the performance of the Induction motor couple to dc motor in the hybrid vehicle (Głowacz Z, 2000). The idea may be applied if any manufacturer is interested in producing this hybrid vehicle in the future.

The interface mimics the in-vehicle communications. A schematic representation of a HIL simulation platform is given in Figure 1.1. The RTS may consist of a single node or many nodes based on the complexity of the vehicle model. The vehicle subsystems like ICE, Electrical Motor and generator can run on different nodes communicating on a CAN network (G. Buja and M. Kazmierkowski, 2004). The nodes are interfaced to an Electronic Control Unit (ECU). The ECU may be a production ECU.

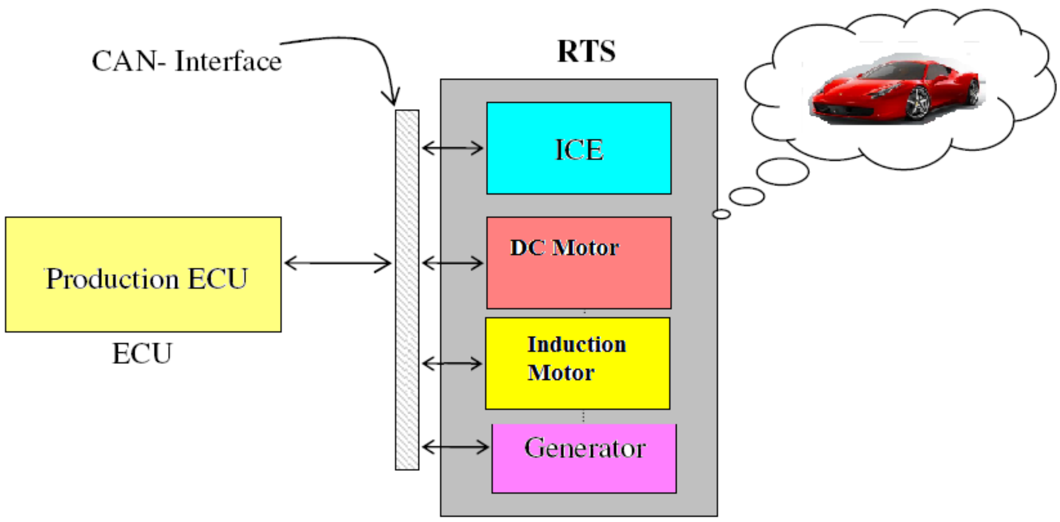

Figure 1.1: Concept of Hardware in Loop Simulation

In this work , the capability of using a single modeling and simulation tool (Matlab/Simulink) from the design stage to a prototyping stage is demonstrated. The Matlab/Simulink models of HEV obtained using Car Systems Analysis Toolkit (CSAT) is presented. CSAT is vehicle modeling and simulation software provided by the TATIUC Labs.

In a HEV, the operation of the propulsion system and other subsystems is controlled by a vehicle control strategy. A basic vehicle control strategy has been developed and added to the existing control libraries in CSAT for future development and testing. The model of a HEV controller is checked by running a Software-in-Loop (SIL) simulation to validate the initial sizing of the components, and also to ensure that the vehicle performance is satisfactory (G. Escobar, et al., 2003). The vehicle controller is further tested in real time on the HIL simulation setup, and it is demonstrated that the HEV meets initial design requirements. The HIL simulation setup built is scalable and can be easily upgraded depending on the requirements of the real time simulation. This is not like the earlier systems where it was customized for a particular application or a project (GRABOWSKI, P. Z. et al., 2000). The real time code obtained from a vehicle model in Matlab/Simulink is run on a RedHawk Real Time Operating System (RTOS) provided by Concurrent Computer Corporation. The various tools for real time simulation of the vehicle model are presented and explained (Honda, et al., 1998). Versatility of the HIL simulation setup is demonstrated by real time simulation of a vehicular subsystem (Electric Motor Drive). The intricacies and the changes in the offline model when implemented in real time are demonstrated (H. Samsul Bachri M, 2007). To demonstrate the scalability of the HIL setup, additional computation nodes were included, and the setup was used to demonstrate distributed simulation of a vehicle and its subsystems (Hamid A.Toliyat and Huangsheng XU, 2000). The HIL simulation setup can be used effectively in future years and tied up into the ongoing automotive research at The University of Malaysia Pahang a turn key system.

1.6 SCOPE OF THE THESIS.

The objective of this thesis is to investigate on the development of an advanced induction motor couple to dc motor based HEV system. Important issues related to modeling, design and control of an HEV system will be presented, including:

Wide speed range field oriented control of an induction motor couple to dc motor;

Modeling and design of a power circuit of HEV;

High current power HEV circuit design example, discussing issues such as power module integration, filtering components and safety operation management.

1.7 THESIS ORGANIZATION

The dissertation introduction addressed the research trends in the area of motor drives for HEVs. A brief description of the hybrid electric vehicle drive automotive followed by a presentation of different electric machines that are used in HEV power automotive subsystems was presented. The research motivation and objectives were then explained in detail.

Chapter two describes the architecture, components selection and sizing of the motor drive subsystems for the electric power transmission path, and highlights the issues with these subsystems that have motivated this research.

Chapter three presents the mathematical model for Series Parallel HEV, drive structure, and modelling of an advanced induction motor couple to dc motor drives that have been selected for the HEV under consideration. A literature review on existing parameter estimation methods to improve the performance of propulsion motor drive system is also presented.

Chapter four is presented the simulation Results, that employed control strategy method such a parallel hybrid electric control strategy. The simulation results cover IM couple to DCM average SUV and Full Size SUV.

Chapter five describes the experiment laboratory and analysis calculation of three phase induction motor couple to dc motor, including software-in-the-loop simulation results in experiment method of the induction Motor drive couple to dc motor in HEV Itis. presented.

Chapter six concludes and future work this thesis, and presents future research topics related to the Couple induction motor to dc motor in application subsystems of an HEV/EV

CHAPTER 2

BACKGROUND

This chapter briefly describes the various HEV architectures and introduces the series parallel 2x2 HEV and electric power transmission part. The propulsion power in a hybrid electric vehicle (HEV) comes from one or more traction electric motors and an internal combustion engine. The propulsion power is transmitted to wheels through either the mechanical power transmission path (MPTP) or the electric power transmission path (EPTP), or the combination of the two (Harry L. Husted, 2003). The stages in the development process of a vehicle control system, Software-in-Loop simulation and Hardware-in-Loop simulation are explained. The advantages of using Hardware-in-Loop (HIL) simulation for vehicle controller testing are described as well.

2.1 ELECTRIC POWER TRANSMISSION PATH

2.1.1. Electrical Components

The advancements in conventional vehicles provide some improvement in a vehicle performance and fuel economy, but long term benefits in terms of reducing the dependency on oil and the emissions from ICE vehicles cannot be achieved without a more drastic change. An interim technology and solution for this are a hybrid electric vehicle (HEV). Figure 2.1 shows the electrical components in the Automotive of the series-parallel hybrid electric vehicle. One electric machine (labeled as “Generator”) is coupled with the engine and can be operated as a generator as well as a motor.

During generation, the power through the generator can be used to charge the energy storage using a bidirectional inverter, or to deliver energy directly to the propulsion motor through the DC bus. The generator can also be operated as a motor during engine starting and torque boosting (Idris, et al., 2000). The energy storage system will absorb or deliver power depending on the system state of charge and driving conditions. The propulsion motor can also capture regenerative energy during vehicle braking.

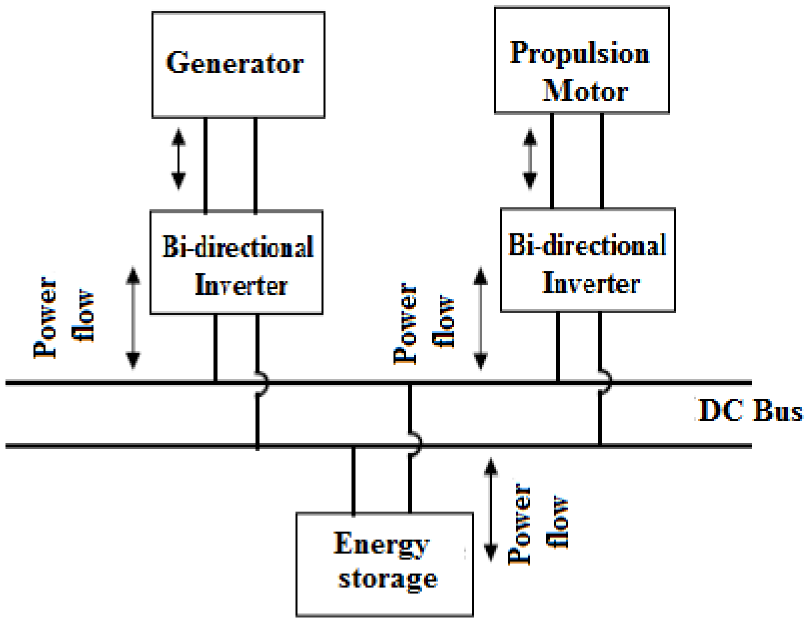

Figure 2.1: Electrical Components of a Series-Parallel Hybrid Electric Vehicle

The fuel efficiency and the run-time of the IC engine in a hybrid electric vehicle depend on the efficient use of the electrical components. The components need to be selected with a suitable torque-speed operating envelope that will deliver the desired vehicle performance (I. J. Albert, et al., 2004). The physical size of the components is also critical, since they need to be properly packaged and mounted within the vehicle.

2.1.2 Electric machines for HEV

The starter-generator and propulsion motor in the EPTP uses high power electric machines. These electric machines need to have the motoring and generating capability, high power density, high efficiency, and high starting torque over a wide speed range to meet performance specifications (I. Arise., et al, 2004). Any one of the three machine drives, induction, PM or SR, can meet the requirements of a starter-generator and propulsion system when designed accordingly. The selection depends on the subtle features of the machines and their power, electronic drives and the availability in the desired time-frame.

The plot of an electric machine torque-speed characteristic is shown in Figure 2.2. The motor delivers rated torque (Tr) up to the rated speed or base speed? Base where the motor reaches its rated power condition. In the constant power region, the motor can operate at speeds higher than the rated condition but the delivered torque decreases (I. Husain, 2003). The natural characteristics' region can be used to extend the operating region of certain motors. The power electronics based motor drive enables electric motor operation at any point within the envelope. In HEV applications, transmission gears are used to match the higher speed of the electric motor with the lower speed of the wheels.

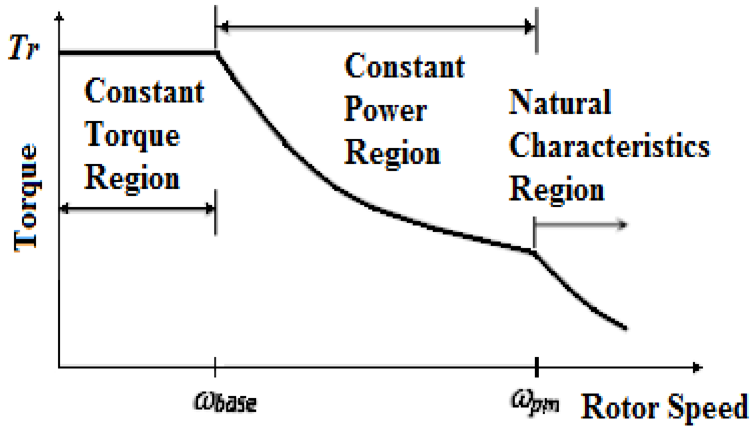

Figure 2.2: Electric Motor Torque-Speed Envelope

2.1.3 Internal Combution Engines.

Four-stroke gasoline/patrol engines and diesel engines are both used in HEV applications. The selection of an IC engine for an HEV application is based on maximum power and torque output, brake specific fuel consumption, emissions, efficiency and driving performance (J. Habibi, S. Vaez-Zadeh, 2005). The engine is sized to supply efficient power to overcome the road load comprised of aerodynamic drag, rolling resistance and roadway grade during the charge sustaining mode of operation.

The ignition in gasoline engines is initiated by a spark plug, whereas diesel engines require only compression of fuel to start combustion. Compression ignition engines with turbocharger operate more efficiently than spark ignition engines because of higher compression ratio and high combustion temperature (J.E. Naranjo, et al., 2004). Turbocharging and supercharging to increase the power output of the compression ignition engines allowing further size and weight reduction (J. Marshaus, 2004). Moreover, diesel engines use less fuel when idling.

The cranking torque and speed of the IC engine define the size of the starter motor. The starting torque of the engine depends on the compression ratio. The diesel engines have compression ratios of 14:1 to 23:1, whereas the gasoline engines used in conventional vehicles have compression ratios of 7.5:1 to

10.5:1(Jin-Qiang Yang, Jin Huang, 2004). Because of the high compression ratio, the diesel engine requires more starting torque compared to a gasoline engine of the same size. Diesel engines with sizes ranging from 1 6L. to 2L require starting torque from 80Nm to 100Nm at speeds of 800rpm to 1200rpm (Jia-Qiang Yang, Jin Huang, 2005).

2.2 HEV ARCHITECTURES

There are several HEV architectures, each with its distinct design and operating characteristics. HEVs usually fall into one of the following categories like Series HEV, Parallel HEV, Split HEV, and Series-Parallel 2x2 HEV, based on the arrangement and operation of the propulsion systems in the vehicle.

2.2.1 Series Hybrid Architecture

Series HEV is the simplest HEV architectures. Series' hybrid architectures employ an ICE coupled to a generator, which supplies electric power to an onboard energy storage device such as a battery and to an EM that serves as the propulsion system.

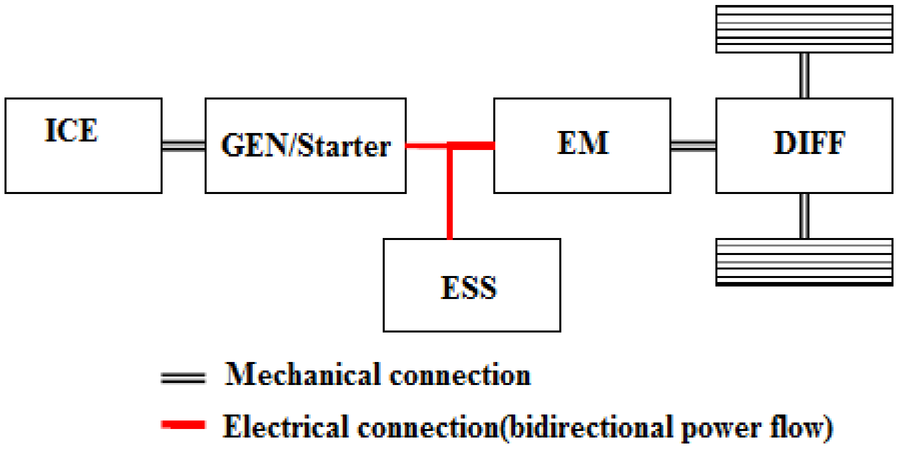

Figure 2.3: Series HEV Architecture

The EM drives the wheels through a differential (DIFF).A schematic representation of a series HEV is given in Figure 2.3. For simplicity gear coupling associated between the ICE and generator (GEN) is not shown. By controlling the GEN operating point, the ICE is operated in its most efficient operating range (J.Pedra,2004). In a series HEV there is no mechanical transmission and the performance characteristics are governed by the EM and energy storage assembly. The generator is also used as a starter to start the ICE.

2.2.2 Parallel Hybrid Architecture.

Parallel hybrid architectures use a single electric machine, which draws current from an energy storage device to provide mechanical assistance to the ICE. The parallel systems are best suited to low-power vehicles where the EM and the ICE are operated together to enhance the overall performance (Jae Sub Ko, 2006). The simplest is the one in which the EM and ICE are on the same shaft. The Honda Insight and Honda Civic Hybrid are examples of production HEVs with similar parallel architectures.

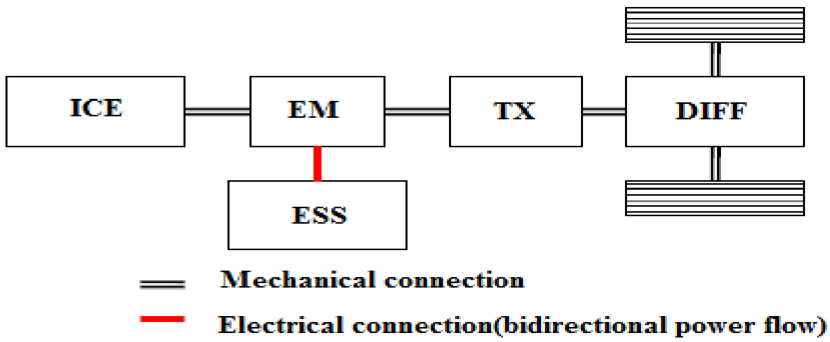

Figure 2.4: Parallel Pre-transmission HEV Architecture.

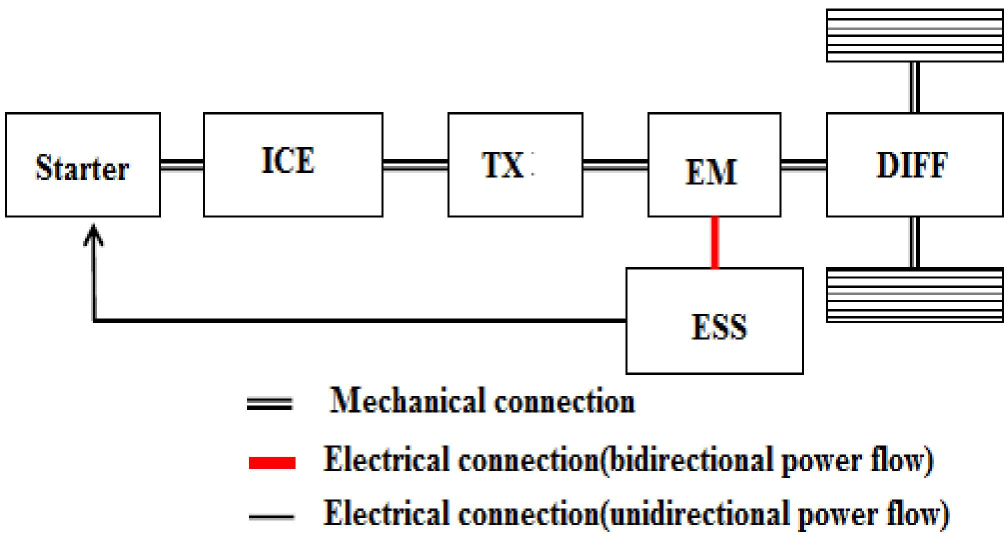

Figure 2.5: Parallel Post-Transmission HEV Architecture

There are three variations of a parallel HEV based on the position of the EM in the drive machines. In parallel pre-transmission HEV the EM is coupled to the ICE shaft before the transmission and in a parallel post-transmission HEV, the EM is coupled to the ICE shaft after the transmission (TX) (Jussi Puranen, 2006). The layouts of the parallel pre-transmission HEV and post transmission HEV are given in Figure 2.4 and Figure 2.5 respectively.

A variant of the parallel HEV is the parallel 2x2 where the ICE shaft is separated from the EM. The ICE drives the front axle and the EM drives the rear axle (James Larminie, et al., 2003). A small starter motor is mounted on the ICE shaft for starting purposes. A schematic is shown in Figure 2.6. The rear drive motor is capable of regenerating. This is also called parallel ‘through the road’ architecture.

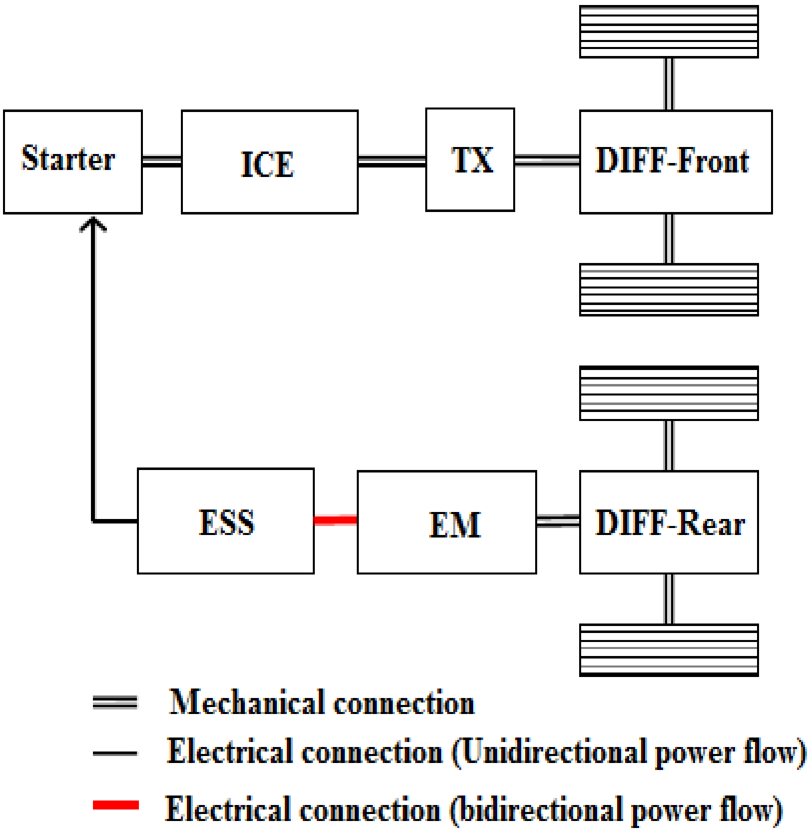

Figure 2.6 : Parallel 2x2 HEV Architecture

2.2.3 Split Hybrid Architecture

The power split configuration is a blend of series and parallel designs. The split architecture uses a planetary gear set in which the ICE drives the planet carrier gear (C). The ring gear (R) is coupled to a Motor/Generator (MG) and to a differential, and the sun gear (S) is coupled to a Starter/Alternator (SA). The power split provides a mechanical path from the ICE to the vehicle’s wheels. In addition, the planetary gear set allows the effective gear ratio between the ICE and the output shaft to be continuously varied, similar to a Continuously Variable Transmission (CVT) (J. Anderson, and C. D. Anderson, 2005). This gives the flexibility of operating the ICE independent of vehicle speed. A schematic layout of a HEV with split architecture is given in Figure 2.7. The drawback of this architecture is the complex control involved.

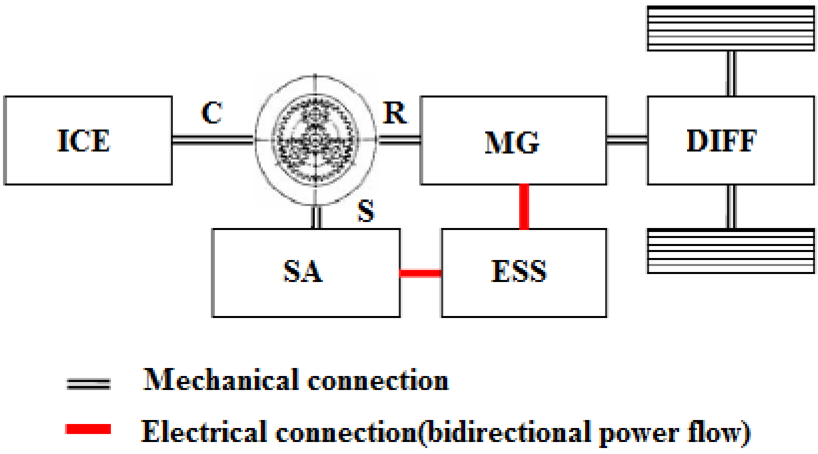

Figure 2.7: Split HEV Architecture

2.2.4 Series - Parallel 2x2 HEV Architecture

To blend the features of controlling the ICE operating point seen in a series architecture and excellent performance seen in a parallel architecture a unique architecture named series-parallel 2x2 was introduced(J. Gonder and T. Markel, 2007). The series-parallel 2x2 architecture gives an additional degree of freedom in operating the ICE. A correctly sized electric machine operating as a generator coupled to the ICE improves fuel economy ratings over the parallel 2x2 by operating the ICE in an optimal efficiency zone (J.M. Miller, 2004). A schematic layout of the series-parallel 2x2 architecture used in the Akron Challenge X HEV is given in Figure 2.8. This architecture is relatively more complicated, involving an additional mechanical link when compared to a series' hybrid HEV, and also an additional generator coupled to the ICE shaft compared to a parallel 2x2 HEV. More information on the various HEV architectures can be obtained in (J. Gonder and A. Simpson, 2007) .

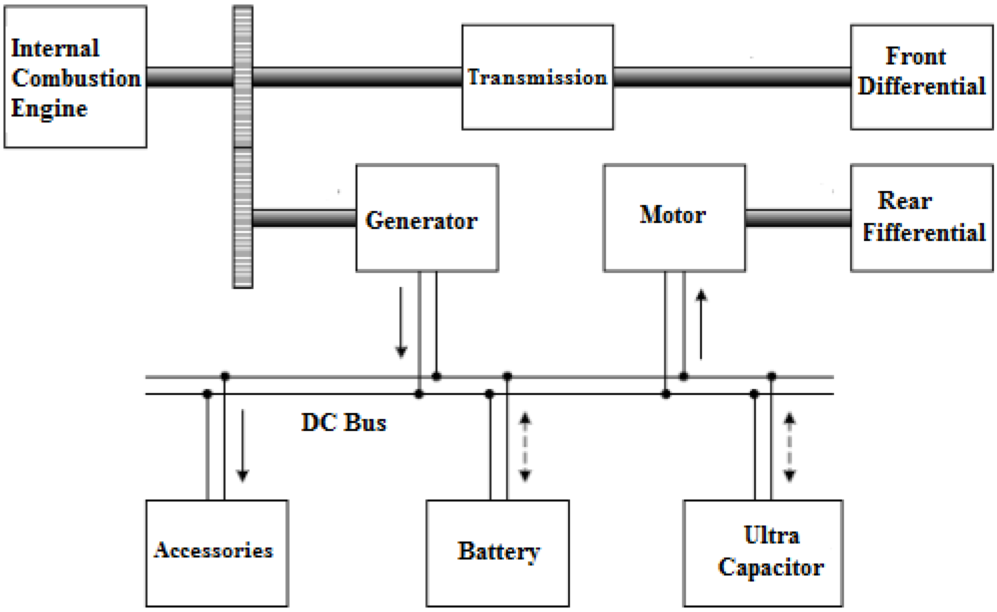

Figure 2.8: The University of Akron HEV Architecture Model.

2.3 VEHICLE CONTROLLER: DEVELOPMENT AND TESTING

Before installed in a vehicle, the vehicle controller is developed and tested using two classes of configurations namely SIL configurations and HIL configurations. This section explains the various steps that can be carried out in each of these configurations. This also gives an overview of how the HIL setup built is tied into the development process (Jeon S, et al., 2001).

2.3.1 Software-in-Loop Configurations

In these configurations, the controller and the plant are modeled and simulated using software at a graphical level or code level, to evaluate the performance of a vehicle (a controller and chosen powertrain) (Johnson V, et al., 2000). The most straightforward type of Software-in-Loop simulation is depicted in Figure 2.9. In this set up, known as Model-in-Loop (MIL) Simulation, offline simulations of the HEV (plant and controller) are run on a single computational node. The simulations may be done on a non-real time platform like Windows XP (Microsoft) or GNU Linux (Free Software Foundation) (J. Cross, P. Viarouge, 2002). Every subsystem in the vehicle model is programmed using the same software. The software coding may be accomplished using graphical tools like Simulink. Typically, a MIL simulation does not involve any real time code.