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Chair of Mechanosystem Components

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STUDY ON MODELING AND CONTROL OF DUAL CLUTCH TRANSMISSION FOR HYBRID VEHICLES

MSc thesis

The author applies for

The academic degree

Master of Science in Mechatronics engineering

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AUTHOR'S DECLARATION

I declare that I have written this graduation thesis independently.

These materials have not been submitted for any academic degree.

All the works of other authors used in this thesis have been referenced.

The thesis was completed under Professor Vu Trieu Minh supervision

"11th May" 2016

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The thesis complies with the requirements for graduation theses.

"18th May" 2016

Supervisor: Professor Vu Trieu Minh

Signature:

Accepted for defense.

Chairman of the defence committee.................................

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Signature.............................

TUT Department of Mechatronics
Chair of Mechanosystem Components

MASTER'S THESIS SHEET OF TASK'S

Year 2016 semester (Spring)

Student: Moustafa Ahmed Abdelmalek Abouelkheir, a144752
Curricula: MAHM02/13
Specialty: Mechatronics
Supervisor: Professor, Head of Mechanosystem Components, Vu Trieu Minh

MASTER'S THESIS TOPIC:
(In English) "Study on Modeling and control of Dual Clutch Transmission for Hybrid Vehicle"
(In Estonian) "Uuring hübriidsõidukite topel tsiduriga käigukasti modelleerimise ja juhtimise kohta"

Assignments to be completed and the schedule for their completion:

Nr	**Description of tasks**	**Timetable**
1.	**Discussing dual clutch transmission architecture generally, its benefits, cons and pros, different applications used in several models like Getrag's dual transmission "6HDT200", Volkswagen's "DSG", the history before "DSG", and why the automotive industry seeks to have such kind of transmission?**	**Week 5 – 6**
2.	**General information about the case study, I chose to implement this comparative analysis, how we will proceed with the simulation later.**	**Week 7**
3.	**Modeling and simulation of dual clutch transmission and automatic transmission, comparing the performance for each architecture using MATLAB and Simulink.**	**Week 8 – 9 – 10**
4.	**Stating the working scenarios motor1 alone; engine alone; motor1+engine; motor2 alone; motor2+engine; motor1+motor2+engine, demonstrating and clarifying the results.**	**Week 11 – 12**
5.	**Conclusion, Future work and Abstract.**	**Week 13**

Solved engineering and economic problems: The objective of this research is to discuss how well the dual clutch transmission will be beneficial, in terms of environmental effect, cost and performance for hybrid cars. Using a six speed-Dual clutch transmission by simulation using MATLAB and Simulink, implement the working scenarios occur in the hybrid vehicles in different amount of loads and torque, in terms of strengths, weaknesses, functionality, fuel consumption and performance.
Language: English.

Application is filed not later than **12/02/2016**
Deadline for submitting the thesis 01/06/2016

Student Moustafa Ahmed Abdelmalek Abouelkheir/Signature .... /date**: 08/02/2016**

Supervisor Vu Trieu Minh/Signature Minh /date: **Feb 10th, 2016**.

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EESSÕNA

Esiteks tahan tänada ülikooli, et andsite mulle võimaluse osaleda Mehhatroonika Master õppekava ja pakub mulle võimalust suurendada oma praktilisi teadmisi see uuenduslik programm ja doktoritöö teemade valik erinevaid kohapeal, eriti selle huvitavam doktoritöö teadusuuringute teema, mida ma tegin oma doktoritöö teadus.

Rakenduslikuks doktoritöö on pühendatud mitmele isikule kõigepealt Professor Mart Tamre, Mehhatroonika osakonnajuhataja, kes oli toetav ja abivalmis varem mööda kaks aastat, intervjuu, ta tegi minuga enne ma nõustuti programm, annab mulle võimaluse sulanduvad töökeskkonna osakond, siiani. Ma tahan ka tänada minu järelevaataja, Professor Vu Trieu Minh, juhataja Mehhanosüsteemide komponentide õppetool, kes oli toetav, arutame ja valides teema teadusuuringud seni esimene samm, sest ta siiralt pakkus mulle võimaluse on suur panus samaväärsust käesoleva uurimistöö doktoritöö tehes. Ma tahan tänada ka Steve Miller, Priyanka Gotika, Kevin Oshiro ja Ryan Chladny jooksul MATLAB Inc meeskonna näitlikustamise videod mis oli põhjalik, uuenduslik ja toetav minu magistritöö teadustöös.

Viimane, kuid mitte vähem, ma tahan tänada minu pere, kes olid selle vahe-eesmärk ja põhjus jätkan rakenduslikuks doktoritöö, hoolimata raskustest; nad toetavad mind vaimselt ja iga võimaliku aspekt.

1. INTRODUCTION

1.1 Motivation

As devised in the monthly energy review, conducted in February 2016 by United States Energy Information Administration [1], 4,829 metric tons of carbon dioxide was emitted only in 2015 because of petroleum substances, gasoline and fuel residual only represented 22.1% of the whole substances effect. In 2015 United Nations Climate Change Conference, held in Paris, “The Paris Protocol - A blueprint for tackling global climate change beyond 2020” was conducted. In annex 1, it was declared that emissions, Greenhouse Gases including carbon dioxide, reached a critical limit in China and United States of America, with over 12000 and 6000 million tons of CO_2 equivalent, which delivers an enormously huge impact on the environment [2].

Continuously fluctuated oil prices and consumption, emissions of Carbon Dioxide and other Greenhouse Gases, represent great, inevitable threats to the whole planet, regarding population and current cost-demanding needs of people. Several actions had been taken to prevent the petroleum policies devised by the petroleum exporting countries, including decreasing the crude oil output. As shown in figure 1.1, the oil demand will be higher than the oil production in the coming 40 years, according to projections done by Energy Information Administration in United States [3].

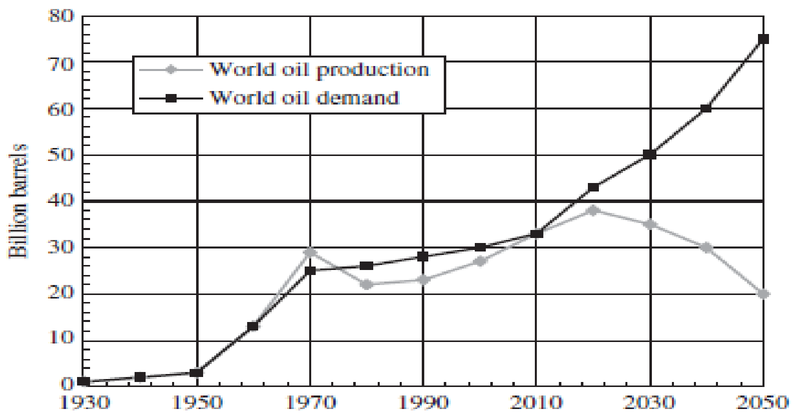

Figure 1.1. World oil demand and depletion history and projections [3]

Moreover, several meetings and conferences, held to address global warming crisis, laid stress on reducing greenhouse gases. However, current measures, which had been taken all over the past century until now, was so hard to overcome with the technologies using petroleum substances like transportation facilities and automotive industry, generally.

In this current challenging situation, new technologies have to be provided and developed to decrease the usage of petroleum and other greenhouse gases in automotive industry and to be more dependent on other renewable resources, like electrical power in particular. Automotive experts, as a result, started to search for ways to reduce the automotive industry contribution in the population and global warming crisis via developing Hybrid Vehicle technologies, which get the most benefit of using electrical power as a renewable resource, and in the same time, provide efficient, reliable and sustainable performance that suits all sectors of automotive facilities' consumers. It became essential to search for the better transmission, as it is one of the core parts of a vehicle, which can fulfil the performance, Fuel-Economy and environment-friendly requirements.

This thesis research has the same purpose and objective, with the new technologies offered in how different powertrains are used in a car, it is needed to continuously investigate and discuss in more detailed manner, comprehensively, and provided by experiments and simulations, which kind of transmission architecture can achieve both fuel consumption and performance efficiency. Therefore, it is necessary to clarify and demonstrate all aspects; it may be present in the choice for transmission architecture, provide results from modeling and simulation techniques.

1.2 Overview on the topic, tasks and previous researches

The idea behind using Hybrid Vehicles, or in other words, using electric power in cars, arose in the time of oil crisis back in 1973. Then, the Electric and Hybrid Vehicle Research, Development, and Demonstration Act was introduced in United States, recommending the use of EVs (Electric Vehicles) to reduce the oil dependency, according to the current crisis, the world suffers from [3]. The need to find another source to propel vehicles became bigger than any time before and Electric Vehicles became a favorite option for customers. However, the development and innovation were not in a high level to fulfil the same performance, as the Conventional Vehicles had [4]. In late 90's, Japanese manufactures conducted many researches to develop a sustainable, thoroughgoing types of Hybrid Vehicle. The aim was to produce mass-produced Hybrid Vehicle types, with highly efficient batteries, motors, inverters, and DC-DC converters. In addition, what was important, how a reliable control system can be devised to control the switching modes and the connections between the electrical part and the conventional mechanical part of the vehicle [5].

Several transmission architectures are considered in Hybrid Vehicles, whether Manual Transmission, Automatic Transmission, Dual Clutch Transmission or Continuously Variable Transmission. Several types of Hybrid vehicles are considered, as well, as Series, Parallel, or Series-Parallel Hybrid cars. Several control methods were applied in Hybrid Vehicles to guarantee smooth shifting, durability and efficiency, as Stateflow, fuzzy logic, and mode predictive control methods.

Previous researches investigated the performance of Dual Clutch Transmission in Hybrid Vehicles using specific configuration, different control methods, and drive cycles. In [6], UDDS (Urban Dynamometer Driving Schedule) and HWFET (Highway Fuel Economy Test) were used to evaluate efficiency simulation results using supervisory control runs at different modes, demonstrated by flowcharts. In [7], US06 HWY (Supplemental Federal Test Procedure) and UK BUS drive cycles were used to examine the Hybrid Electric Vehicle model's performance with a Stateflow control method. While in [8] [9], fuzzy control method was applied for optimizing the operational efficiency for Hybrid Vehicles. In [10], an optimal line pressure control algorithm was proposed for the Fuel-Economy improvement of an Automatic Transmission-based parallel Hybrid Electric Vehicle. In [11], modelling and simulation study on Series-Parallel type of Hybrid Vehicles was conducted and a control scheme, using flowchart and Stateflow approach, was presented. In [12], a control strategy for the Series-Parallel Hybrid Vehicle was developed, depending on the speed and the power required for driving the vehicle and the State-of-Charge (SOC) of the battery. In [13], kinematics and dynamics of Dual Clutch Transmission is investigated with a detailed analysis and simulation results to compare the effect of different synchronizer models on transmission and vehicle dynamics.

In this thesis research, the main features of Dual Clutch Transmission inside Hybrid Electric Vehicle, along with a Series-Parallel Hybrid Vehicle model, and Dual Clutch Transmission gearbox in Conventional Vehicle, developed, presented and modeled and simulated using MATLAB and Simulink. To verify the validity of the presented model, a comparative study is elucidated between the simulation results of the three models. Both Hybrid Electric Vehicle models will be controlled using Stateflow control method with a mode logic; deciding different working modes, and engine, motor, and generator status, with the vehicle speed, State of Charge, engine speed and brake signal as inputs. Simulations are done with (Federal Test Procedure), (New York City Cycle), (Highway Fuel Economy Test) and (Extra Urban Driving Cycle) to investigate the performance of the models. The second part is to propose a Hybrid Dual Clutch Transmission Vehicle model and investigate its performance using the same drive cycles mentioned above and compare it with the previous models. The significance of this research is to compare between Conventional Vehicles and Hybrid Vehicles in terms of fuel consumption and performance efficiency and show what is more effective and economical to be used. Moreover, one of the purposes is to present Dual Clutch Transmission, as an effective option to be used in Hybrid Vehicles in a wider perspective in automotive industry through presenting a Hybrid Vehicle with a Dual Clutch Transmission.

The thesis will be divided into ten chapters. Chapter 1 includes introduction, overview on the topic, tasks and previous researches. Chapter 2 includes literature review about the main classification, components and functionality of transmission architectures and hybrid systems. Chapter 3 includes the modeling of the Dual Clutch Transmission in Conventional Vehicles, and Chapter 4 includes Series-Parallel Hybrid Vehicle architecture and control system, modes and components' controllers. Chapter 5 includes the proposed Hybrid Vehicle model, which contains Dual Clutch Transmission Chapter 6 includes simulations, and representing results for all models. Moreover, discussion and notes on the results obtained is presented. Chapter 7 includes conclusion and discussion, and Chapter 8 includes summary and future work. References are withdrawn in the end of the thesis in Chapter 9. Appendices are stated in Chapter 10.

2. LITERATURE REVIEW

2.1 Transmission architectures

With the new technologies offered in how you use different powertrains in a car, it is needed to do many researches and continuous investigation to discuss in more detailed manner, comprehensively, and provided by experiments and simulations, which kind of transmission architecture can achieve both fuel consumption and performance efficiency. Worldwide, it has been an important aim towards developing a transmission system that transfers the torque coming from the engine to the rest of vehicle drivetrain, as optimum as possible and with high efficiency. The different types or architectures developed until now offers a great variety economically, also in terms of providing comfort and prosperity to the driver, with no compromising on the overall performance, such as Manual Transmission, Automatic Transmission, Dual Clutch Transmission, and Continuously Variable Transmission. The main type, which still has the major margin among production rates, is Manual Transmission. However, Automatic Transmission started to gain much more dominance in the market of North America [14].

As shown in figure 2.1, Dual Clutch Transmission started to get more familiar to the market in Western Europe countries over the past six years and it is expected to grow more in that market, as the technology offers efficient and reliable transmission architecture, as it will be discussed next.

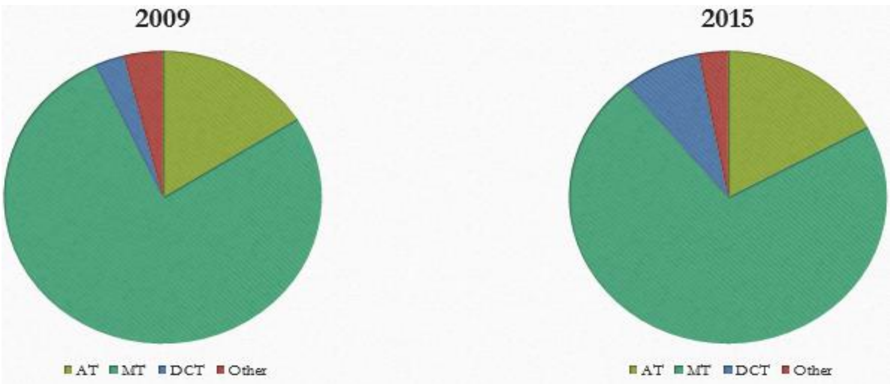

Figure 2.1. The split in 2009 and split in 2015 are compared in Western Europe [14]

2.1.1 Automatic & Manual Transmission architectures

Manual Transmission is still used widely, because of its cost economy and reliability. Moreover, Fuel-Economy is a milestone to base your vehicle transmission choice on. Manual Transmission basically based on changing gear ratio using a clutch pedal, unlike the Automatic Transmission, which uses planetary gears and torque converter to do this task. Manual Transmission has two shafts for the torque and input power and the other shaft for transmitting the torque and the power to the wheels, its efficiency is high and reaches 96% [15].

After Manual Transmission became a preferable choice for consumers, as in Mercedes-Benz C class Six-Speed Manual Transmission, shown in figure 2.2, who care about fuel and cost economy, compromising with the comfort, especially in over-crowded cities, and safety, recently. It was a compromise against the older Automatic Transmission architecture, intake manifold pressures were used to shift the gear, but newly developed versions of Automatic Transmission can now do the job. Modern developed Automatic Transmission, as in Mercedes-Benz C350, shown in figure 2.3, has more gears than the Manual Transmission based cars, which can achieve the transmission of power to the wheels with less number of revolutions [16].

It was explained in [19], as it uses electronically controlled valves activated through solenoids, the shift schedules are pre-determined in the transmission controllers, which achieve fast Transmission with less power losses than the older ones. Therefore, Automatic Transmission started to gain much more ground, especially in North America, as shown in figure 2.2. However, Manual Transmission in countries, which care more about cost economy and buying a cheaper vehicle, still has the biggest portion of transmission architectures used in automotive industry.

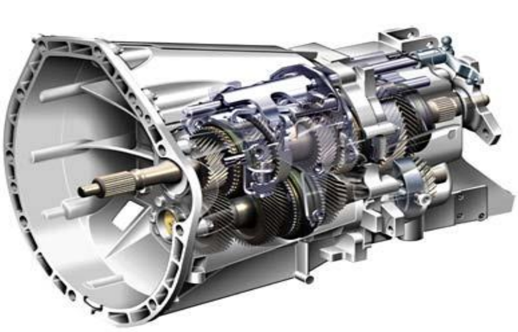 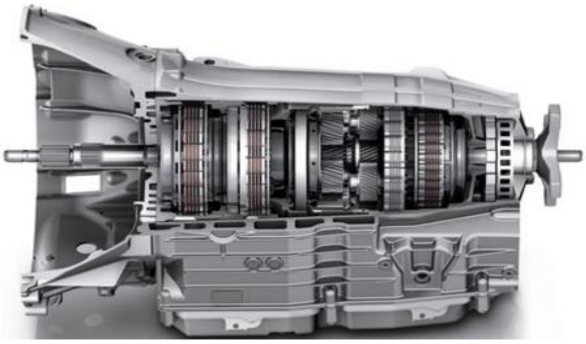

Figure 2.2. On the left represents Mercedes-Benz C-class sport coupe’s Six-speed Manual Transmission [17], figure 2.3. On the right, represents Mercedes-Benz C350’s seven-speed Automatic Transmission [18]

2.1.2 Dual Clutch Transmission architecture

Some developments occurred to find an alternative between Manual and Automatic Transmission architectures, which led to Automated Manual Transmission. As discussed in [20], Automated Manual Transmission enables engagement of engine and wheels by automatically controlled clutch using hydraulic actuators, in order to gain the flexibility and eliminate the problems, which the less-skilled drivers face in switching the gear selector and engaging the right gear according to the right speed. Despite the previously mentioned advantages, the lack of having a smoothly operated transmission without shift shocks and badly transmitted torque led to a failure in marketing and gaining the customers’ satisfaction. In those circumstances, Dual Clutch Transmission arose as an optimum solution for the previously mentioned problems, to provide a smoothly transmission operation and response, and efficiency.

Worldwide, Dual Clutch Transmission is highly integrated into automotive industry for its unique effectiveness, in terms of cost and fuel efficiency. Dual Clutch Transmission, as a transmission architecture, as shown in figure 2.5, uses two Clutches, without having a clutch pedal, acting independently. The transmission is controlled by sophisticated electronics, solenoids and hydraulics. In other words, gear-shifting is automatically controlled, while its actual construction is two parallel Manual Transmissions. The two clutches are alternatively engaged to produce different speed arrangements, and through the controlling of clutch engagement condition, the power transmitted through the whole system [21]. It is considered that Dual Clutch Transmission has much more sensitivity to input torque, compared to the Conventional Automatic Transmission, which uses torque converter, as the torque converter is not present in this transmission architecture [22].

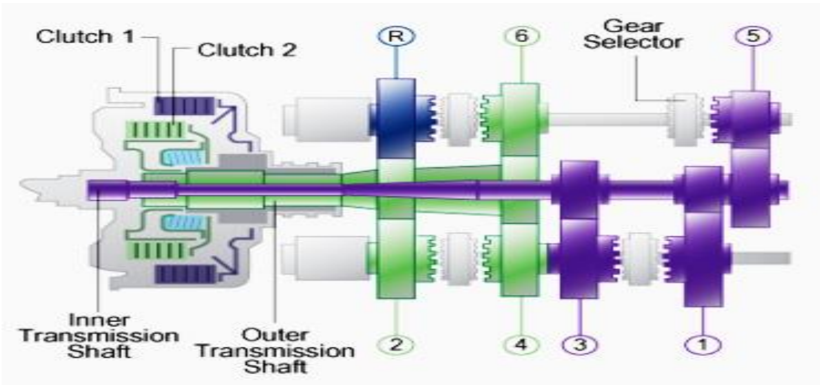

Figure 2.5. Six-speed Dual Clutch Transmission [23]

Several transmission suppliers, as Getrag, FEV GmbH and BorgWarner, designed Dual Clutch Transmission architectures and they began recently to have their presence in the automotive market. Volkswagen uses Getrag’s DSG (Direct Shift Gearbox), as shown in figure 2.6. Moreover, 6DCT250 dry Clutch is used in Renault EDC, as well as, Ford Focus and Volvo V70 are examples of several vehicles uses the Dual Clutch Transmission, manufactured by Getrag [24] [25].

Figure 2.6. VW/Audi’s DSG [26]

2.1.3 Continuously Variable Transmission

It is a recently developed transmission architecture and the engine with this transmission works in its most efficient region according to the continuously gear ratio change. The disadvantages, which can be seen, as discussed in [15], high pressure required to be available for the two sets of pulleys, the transmission consists of, as shown in figure 2.7, consumes more energy during operation. It costs higher than the conventional transmission architectures, and the efficiency is lower than Manual Transmission.

Figure 2.7. Nissan HR15DE engine with Xtronic CVT [27]

2.1.4 Summary

Several comparisons was devised in Fuel-Economy performance between Dual Clutch Transmission, Continuously Variable Transmission, Automatic Transmission and Manual Transmission. Honda proposed a comparison based on its current available data [28], as shown in table 1. Bernd Matthes in [29] proposed a comparison regarding the same topic, he stated that for small engines, Continuously Variable Transmission is better than Automatic Transmission, and the opposite is right. For large displacement engines, Dual Clutch Transmission is better in Fuel-Economy than Manual Transmission.

Table 2.1. Comparison between transmissions by Honda, using its database [28]

Factors	Relative performance
Mechanical efficiency	DCT > AT > CVT
Ratio flexibility	CVT > DCT = AT
Performance	CVT = DCT > AT

Based on the previous information and what is mentioned in chapter 1, Dual Clutch Transmission is chosen for performing the study proposed in this thesis.

2.2 HEV architectures and types

The name “Hybrid” came from “mixing” concept, as the mechanical powered source, which is the Internal Combustion Engine (ICE), and the electrical powered sources, are combined in the same architecture to provide power and torque to the wheels with several ways, which will be discussed in the coming sections.

There are two main types according to the propulsion, Hybrid Electric Vehicles and Plug-in Hybrid Electric Vehicles (PHEVs). Hybrid Electric Vehicles can be characterized as it maintains the liquid fuel as the main source of energy coming from the internal combustion engine, the regenerative braking is done as a main key point offered by the electrical power source, which is the electric motor, to reduce the fuel used in such operation. In the same time, electric mode selected in controlling this type of vehicle architectures offers a unique way to propel the vehicle via the electric motor, which is needed in some cases. Plug-in Hybrid Electric Vehicles uses an additional fuel source, which is the battery placed inside, contains the electricity to offer the variety to propel the vehicle with another cheaper source and reduce fuel used [3].

According to its mechanical, powertrain and the way power and torque supplied through the vehicle system, Hybrid Vehicles generally can be classified to three main types, series, parallel and series-parallel. Mi C., et al. discussed in [3] the differences between those three types and presented their different working combinations, Pels T. et al. in [30], classified Hybrid Electric

Vehicles in terms of powertrain functionality and related the three types, mentioned earlier, to their classifications. Based on that, in the coming sections, those three types are presented briefly.

2.2.1 Series HEV configuration

Series Hybrid Electric Vehicle is an architecture, which features the Internal Combustion Engine as the primary energy source. Propelling the vehicle with mechanical power out from the fuel used, a generator is used to convert this mechanical power to electricity. According to the mode, which is assigned to the vehicle, this electricity can be provided from the engine or the battery or both combined to the electrical motor. Fuel-Economy is at its best in this mode, flexibility and simple controlling method are also guaranteed [3]. Combinations of working principles for this configuration are battery alone, standstill, combined, engine only, and regenerative braking [31]. Series configuration, as shown in figure 2.8, is suitable for heavy-loaded trucks, because of transmission elimination is increasing the efficiency of the whole vehicle.

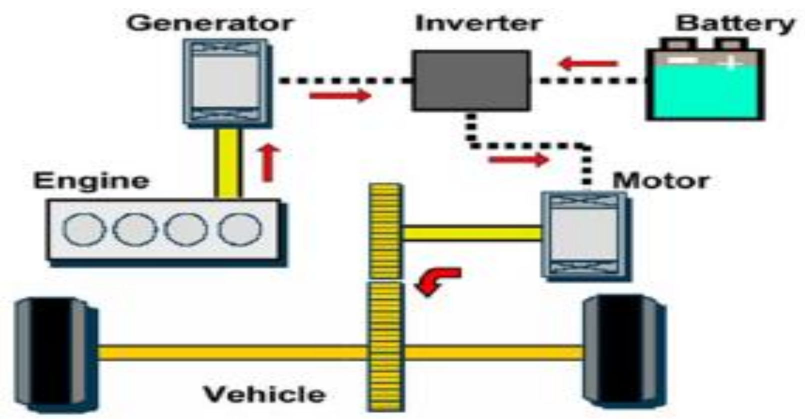

Figure 2.8. Series HEV configuration [32]

2.2.2 Parallel HEV configuration

Unlike the series configuration, the Internal Combustion Engine is not the primary source and the electric motor joins it to provide the power to wheels. The efficiency is high due to the low losses in power transmission. However, the mechanical transmission architecture is complex in return. Moreover, the design for this configuration is so compact because of the absence of the generator, that is because the engine has the ability to recharge the battery during the drive cycle part, which occurs within the city, as electric motor can be used alone to propel the vehicle [3] [32]. As mentioned, the ability to use both engine and electric motor simultaneously with direct connection to the wheels will lower the energy losses, besides the usage of Electric motor as a generator during the "regenerative braking" process. Parallel Hybrid Vehicles can be also classified into Pre-Transmission, Post-Transmission Parallel Hybrid Vehicles, depending on the position of the mechanical Transmission relatively to Internal Combustion Engine and electric motor; between the torque coupler and the wheels, and between the torque coupler and the engine, respectively. Combinations of working principles for this configuration are motor alone, standstill, combined, engine only, power-split, and regenerative braking [31]. Parallel configuration is used widely in automotive industry, as shown in figure 2.9, in Honda Accord, Civic and Ford Escape [32].

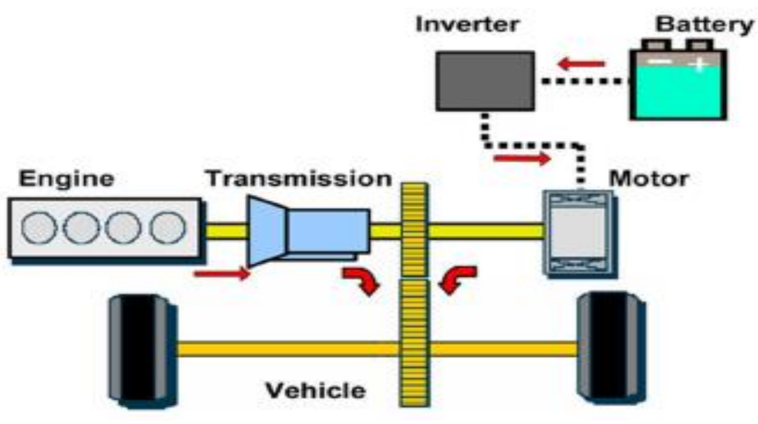

Figure 2.9. Parallel HEV configuration [32]

2.2.3 Series-Parallel configuration

Series-Parallel configuration is a configuration, which combine the advantages of both previous configurations and can be characterized by providing the necessary power flow for driving the wheels from the engine, and if needed, the electrical power provided by the electrical path, devised by the planetary gear used in the configuration, together [6] [33]. The typical components integrated in this configuration is an Internal Combustion Engine and two Electrical Motors; which offers many varieties in the combinations of working principles, as it will be discussed. Mechanical link is added to drive the engine directly and a second motor is added to act as a generator in charging the battery in case of low State of Charge occurs [3]. The main disadvantages are combinations of working principles are Low Power Mode, High Power Mode, Very High Power Mode, Charging sub-modes, and Braking Mode. Series-Parallel configuration, as shown in figure 2.10, is used in Toyota Prius, as a common example of application, and it achieved a great contribution among other configurations. It uses planetary gear set to achieve Continuously Variable Transmission. In this case, the Conventional Transmission is not needed [3]. However, its complexity made it more expensive than parallel and series configurations.

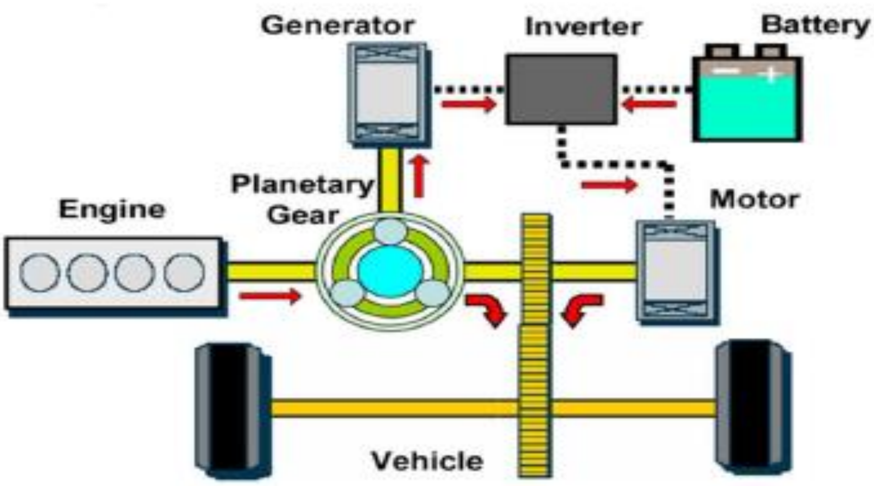

Figure 2.10. Series-Parallel Configuration [32]

2.2.4 Plug-in Hybrid Electric Vehicle

An interesting alternative to the Hybrid Electric Vehicle architecture, which can offer the ability to charge the vehicle through a plug in cable, is offering a flexible option regarding the energy storage system. The need to provide an intelligent, reliable energy control system is vital, besides the modes depending on the main advantage Plug-in Hybrid Electric Vehicle offers, which is the possibility to drive the Vehicle on the battery more time than the conventional Hybrid Electric Vehicle. It can be concluded that the size of the battery used in the Plug-in Hybrid Electric Vehicle will determine how long the vehicle will take to recharge and other constrains regarding the Fuel-Economy and the ratings it can offer to decrease the dependency on the fuel to drive the vehicle. Large battery pack has its pros and cons, as it is a compromise between the time and the economic benefits obtained by using such vehicle model.

Architecture wise, Plug-in Hybrid Vehicles has series, parallel architectures. In series architecture, the generator is used to charge the battery or the motor in the main powertrain; it is also connected to the Internal Combustion Engine. In parallel configuration, the design is more complex, as the motor and the engine, as in the conventional Hybrid Vehicle, both can drive the vehicle. Moreover, the battery pack, which must be large to provide longer time of driving the vehicle in electric mode and to fulfil the power demand by the vehicle, is recommended, in figure 2.11, a series architecture of series architecture of a Plug-in Hybrid Electric Vehicle [3].

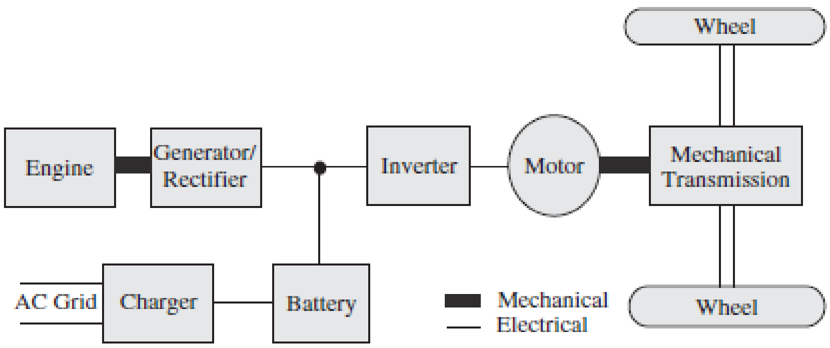

Figure 2.11. Series architecture of PHEV [3]

2.2.5 Summary

What Hybrid Electric Vehicles offer is a relief from using gasoline-fueled based vehicles, by offering a new option to combine a pollution-free power source, which is the electrical power. Adding to that, the Fuel-Economy, performance and different operating modes provided by Hybrid Electric Vehicles enhance its contribution in the automotive market, as stated in study done by EDTA (Electric Drive Transportation Association) in United States [34], indicating the gradual increase in this particular automotive field. However, there are some doubts regarding the price of such technology, but it is predicted to have this balance in the near future.

After clarifying the Hybrid Electric Vehicles' different architectures configurations, the chosen configuration in this thesis is the Series-Parallel configuration, which can make the vehicle performance and its Fuel-Economy better than the Conventional Vehicles. The directly influencing factors in choosing an architecture are the quality of the components, the connections, control methods and modes.

The components, which it is taken into consideration regarding its quality, are the electric motor, and the power electronics involved in the electrical system of the Hybrid Electrical Vehicle. The second component is the storage system, which directly refer the development process into the battery; its volume, life cycle and fidelity. The third is how the heat is controlled throughout this complex system. The fourth is the control method, whether it is a fuzzy control system, a model predictive system, or a Stateflow method. In chapter 4 and 5, it is discussed, in details, the model of the Hybrid Electric Vehicle, the control method and different controllers used inside the model.

3. MODELING OF DUAL CLUTCH TRANSMISSION IN CONVENTIONAL VEHICHLES

3.1 Previous contributions and brief introduction to the model

Many researchers investigated several aspects, regarding the modeling of Dual Clutch Transmission. Galvagno E., et al in [13] discussed the dynamic and kinematic model of a Dual Clutch Transmission, considering different configurations, description of gear-shifting and simulation results. Moreover, Oh J.J. et al. discussed in [20] the estimation of the torque transmitted through each clutch of the Dual Clutch Transmission with a designed individual clutch torque estimator. In addition, Maloney P. et al. in [35] investigated an optimizing performance technique for a Dual Clutch Transmission powertrain using a MATLAB/Simulink model-based design.

In the model presented, there will be a detailed explanation to four main sections of the model. The first is the main conventional driveline analysis, the second is the internal combustion engine; the third is the Dual Clutch Transmission. Within the third section, different components of the transmission will be discussed and explained; Synchronizers, differential, Friction Clutch, and transmission controller and finally, the fourth is vehicle dynamics.

3.1.1 Main conventional drivetrain analysis

As shown in figure 3.1, Dual Clutch Transmission working principle can be explained as it consists of two main clutches and each clutch is connected to a set of gears, odd and even. In the case mentioned here, odd and even gears are connected to clutch 1 and 2 respectively. Therefore, for example, in case of moving from standing still position to an accelerating behavior, after the second gear is selected, there will be no power loss during shifting between gears. The main characteristic that differs Dual Clutch Transmission than any other transmission architecture is the ability to preselect the next gear used based on the predicted vehicle speed.

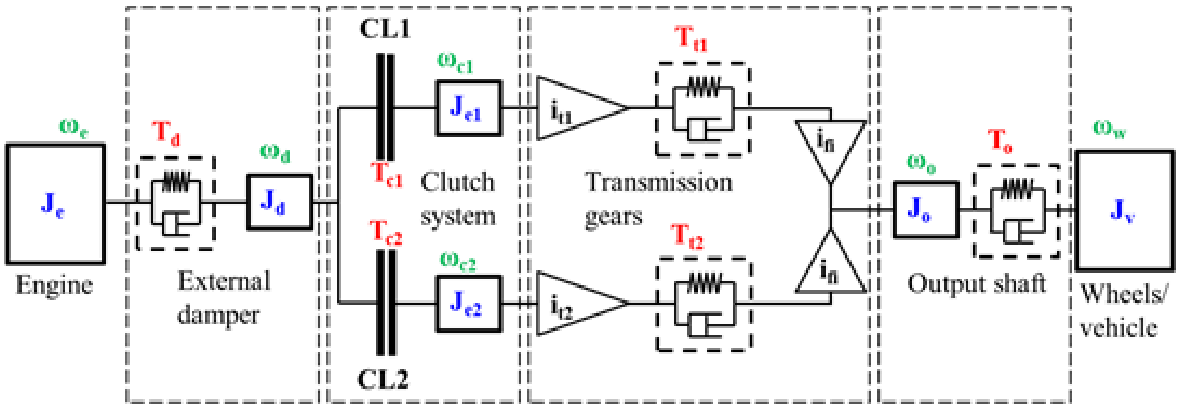

Figure 3.1. Powertrain model including Dual Clutch Transmission [35]

Based on modeling criteria discussed in [7] [20] [35], in order to obtain a balanced driveline, the model can be represented using the following equations:

$$J'_e \dot{\omega_e} = T_e - T_d \tag{3.1}$$

Where J'_e - Engine inertia

$\dot{\omega_e}$ - Engine speed

T_e - Net Engine torque

T_d – External Damper torque.

The previous equation is the torque balance equation for the whole driveline.

$$J_d \dot{\omega_d} = T_d - T_{c1} - T_{c2} \tag{3.2}$$

Where J_d – External damper inertia.

$\dot{\omega_d}$ – External damper speed.

T_{c1}- Clutch 1 torque.

T_{c2}- Clutch 2 torque.

The damper output torque can be represented directly from the engine torque.

$$J_{e1}\,\dot{\omega}_{c1}=T_{c1}+T_{c2}(i_{t2}/i_{t1})-(T_0/i_{t1}) \tag{3.3}$$

Where J_{e1} – Effective torque inertia from Clutch 1 perspective.

$\dot{\omega}_{c1}$ – Clutch 1 speed

T_0 – Output shaft torque

i_{t1} – Transmission gear ratio for shaft 1

i_{t2} - Transmission gear ratio for shaft 2

Dynamics of transfer shaft is determined by the previous equation.

The same equation is applied to Clutch 2, as follows:

$$J_{e2}\,\dot{\omega}_{c2}=T_{c1}(i_{t1}/i_{t2})+T_{c2}-(T_0/i_{t2}) \tag{3.4}$$

Where J_{e2} – Effective torque inertia from Clutch 2 perspective.

$\dot{\omega}_{c2}$ – Clutch 2 speed.

The torque equation for vehicle dynamics is described, as follows:

$$J_v\,\dot{\omega}_v=T_o i_{f1}-T_v \tag{3.5}$$

Where J_v – Vehicle inertia.

$\dot{\omega}_v$ – Wheel speed.

T_v – Vehicle resistance torque.

i_{f1} – Final reduction gear ratio for shaft 1.

The torque equation for each dynamic part in the driveline model is described, as follows:

$$T_e = f(\alpha_{th}, \omega_e) \tag{3.6}$$

$$T_d = k_d(\theta_e - \theta_d) + b_d(\omega_e - \omega_d) \tag{3.7}$$

$T_{c1} = F_{n1}C_{c1}\mu sgn(\omega_d - \omega_{c1})$ (3.8)

$T_{c2} = F_{n2}C_{c2}\mu sgn(\omega_d - \omega_{c2})$ (3.9)

$T_0 = k_0((\theta_{c1}/i_{t1}) - (i_{f1}\ \theta_w)) + b_0((\omega_{c1}/i_{t1}) - (i_{f1}\ \omega_w))$ (3.10)

Where θ – Shaft angle

k - Torsional stiffness

b - Torsional damping coefficient

$T_v = rF_v = r(F_r + F_g + F_a + ma) = r[mg(C_0 + C_1 v_{dc}) + 0.5\rho C_d A_f v_{dc}^2 + Mgsin\theta$ (3.11)

Where F_v - Total Force Demand.

r - Wheel Radius.

F_r - Rolling Resistive Force.

F_g - Gravitational Force.

F_a - Aerodynamic Force.

m - Vehicle Mass in kg.

C_0 - Constant Rolling Coefficient between Tire and Road.

C_1 - 1st order Rolling Coefficient between Tire and Road.

v_{dc} – Drive Cycle Speed.

ρ – Air Density.

C_d – Aerodynamic Coefficient.

A_f – Frontal Area of the Vehicle.

The following equation determines the output shaft dynamics:

$J_0\ \dot{\omega_0} = i_{f1}\ T_{t1} + i_{f1}\ T_{t2} - T_0$ (3.12)

Where J_0 – Output shaft inertia

$\dot{\omega_0}$ – Output shaft speed.

T_{t1} – Shaft 1 torque.

T_{t2} – Shaft 2 torque.

In the same way; output shaft torque represented, Torque of each shaft can be described as follows:

$$T_{t1} = k_{t1}((\theta_{c1}/i_{t1}) - (i_{f1}\ \theta_0)) + b_{t1}((\omega_{c1}/i_{t1}) - (i_{f1}\ \omega_0)) \tag{3.13}$$

$$T_{t2} = k_{t2}((\theta_{c2}/i_{t2}) - (i_{f2}\ \theta_0)) + b_{t2}((\omega_{c2}/i_{t2}) - (i_{f2}\ \omega_0)) \tag{3.14}$$

Each Clutch torque has to be calculated via the following system of equations, according to its status, referring to equations (3.8) and (3.9):

$T_{c1} = 0$ (Disengaged)

$$T_{c1}=F_{n1}C_{c1}\mu sgn(\omega_d - \omega_{c1}) \text{ (Slipping)} \tag{3.15}$$

$$T_{c1}=T_d - T_{c2} - J_d\dot{\omega_d} \text{ (Engaged)} \tag{3.16}$$

$T_{c2} = 0$ (Disengaged)

$$T_{c2}=F_{n2}C_{c2}\mu sgn(\omega_d - \omega_{c2}) \text{ (Slipping)} \tag{3.17}$$

$$T_{c2}=T_d - T_{c1} - J_d\dot{\omega_d}] \text{ (Engaged)} \tag{3.18}$$

3.1.2 Internal Combustion Engine

The main power source, which propels the vehicle using liquid fuel. The internal combustion engine is a spark-ignition type, which is modeled by specifying the demanded torque as a fraction of maximum torque possible. Therefore, it can be said that the torque of the engine is simply a function of drive cycle speed (v_{dc}), which will be used in testing, and the driver signal distinguished by the pedal. A system level model was used in Simulink environment [36], as it is simple to assign engine type, maximum power, and maximum speed and stall speed.

3.1.3 Dual Clutch Transmission architecture

Dual Clutch Transmission was presented in SimDriveline [36], as shown in figure 3.2, as it contains two main clutches with set of odd and even gears connected to each one of them both. Gear ratio, as discussed in subdivision (3.2.1), is determined, based on the torques and motion of base and follower axes, and it can be given by a simplified equation for simulation purposes, as follows:

$$G_{fb}=T_f/T_b=\omega_b/\omega_f \tag{3.19}$$

Where T_f – Follower torque.

T_b – Base torque.

ω_b - Base angular velocity

ω_f - Follower angular velocity

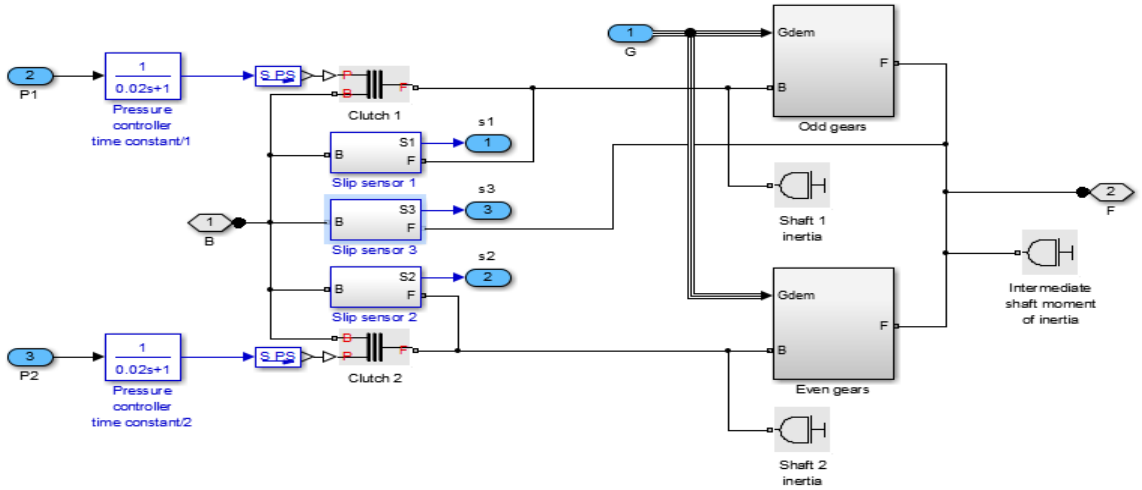

Figure 3.2. Dual Clutch Transmission model in Simulink

Different components of the transmission will be discussed and explained in the following sub-clauses; they are Synchronizers, Friction Clutch, and Transmission Controller. All are developed in SimDriveline, which make it thoroughgoing and guarantees the fidelity of the model.

Friction Clutch

The friction clutch is the responsible part for transferring the torque between the two axes [7]. It is modeled in SimDriveline, as a dog clutch with rectangular teeth. It is defined by three different operating states.

1-Engaged but slipping: $T_{transfered} = C\mu(\Delta\omega)P$ (3.20)

2-Unengaged: $T_{transfered} = 0$

3-Locked: $T_{transfered} = T$

Synchronizers

Synchronizers used to adopt the clutch models in the SimDriveline environment. The assumption made for simplifying the model is that synchronizers are not explicitly modeled as the dog clutches have the torque transmission model parameter set to Friction Clutch approximation. Engaging is not necessary done by lining up the teeth of the clutch.

Transmission Controller

The Transmission Controller of Dual Clutch Transmission consists of shift state controller, which preselects the gear according to the current and desired vehicle speed, which can be characterized by gearshift schedule.

3.1.4 Vehicle Dynamics

It is developed via SimDriveline models, which vehicle parameters can be specified and taken into consideration easily. Volkswagen Golf R was chosen and all the specifications required for the vehicle model parameters are found in appendix 1.

4. HYBIRD VEHICLE MODEL

4.1 Previous contributions and brief introduction to the model

Several previous researches was focusing in how to model and control Series-Parallel Hybrid Electric Vehicle architecture. Yaohua L. et al. discussed and built using MATLAB/Simulink environment a Series-Parallel Hybrid Electric Vehicle and testify the effectiveness of the model in [11]. While in [32], Liu J. et al. discussed the Toyota Hybrid System, which is a power-split planetary gear system, and developed the dynamic model of that system to examine its behavior compared to the experimental results on Toyota Prius. In [12], Zhao H. et al. studied the behavior of Series-Parallel Hybrid powertrain and used stateflow control method to compare energy characteristics of various powertrain configurations, including series Plug-in Hybrid Electric Vehicle and Conventional Vehicles. Xiong W. et al. discussed in [38] design approaches of the Series-Parallel Hybrid Electric propulsion system and investigated the Fuel-Economy of the Hybrid bus under the city transit bus-driving cycle.

In this research, the Series-Parallel Hybrid Vehicle architecture with a planetary gear is chosen for comparison with the Dual Clutch Transmission in Conventional Vehicles [7] [33] [37]. The configuration will be discussed in three main subdivisions. First subdivision will contain detailed explanation and modeling of the main component of the configuration, the second subdivision will contain the description of the controllers used inside the model, and finally the third subdivision will contain detailed explanation of the control modes.

4.2 Hybrid Electric Vehicle model

The sketch of the HEV model is shown in figure 4.1. It consists of several main components; ICE (Internal Combustion Engine), Electric motor, DC-DC converter, battery, and Vehicle Dynamics. Each component will be discussed separately.

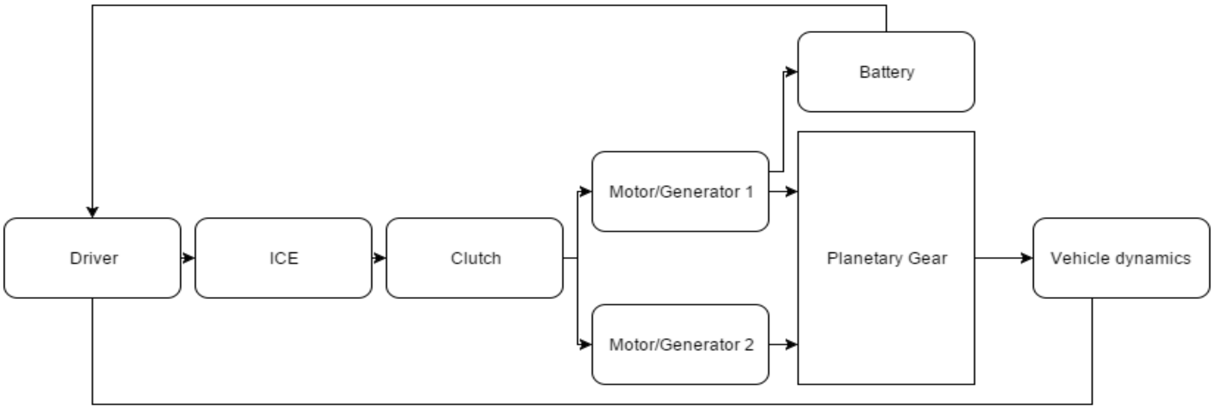

Figure 4.1. Hybrid Electric Vehicle model

4.2.1 Driving Cycle and Driver

Driving cycle is acting as the first input to the driver, which can be characterized by the acceleration and velocity profile as function of time. Driving cycles can be downloaded directly from the internet, as there are several standard driving cycles to test different powertrains using distinguished driving styles.

As discussed in chapter 3, equation (3.11) calculates the forces affect the driver behavior are Gravitational Force, Aerodynamic force, Rolling Resistive force. They all can be summed to provide the total force demanded to know the torque required by the driver, but we have to add the PI controller parameters to the equation to be as follows:

$$T_v = rF_v = r(F_r + F_g + F_a + ma)$$

$$= r[mg(C_0 + C_1 v_{dc}) + 0.5\rho C_d A_f v_{dc}^2 + Mg\sin\theta + K_p \Delta v + K_i \int \Delta v dt \qquad (4.1)$$

$$\Delta v = v_{dc} - v_{actual} \qquad (4.2)$$

Where K_p – Proportional gain

K_i – Integral gain

4.2.2 Internal Combustion Engine

SimDriveline was used to present the engine. It is a spark-ignition type, as in the Dual Clutch Transmission model, which is modeled by specifying the demanded torque as a fraction of maximum torque possible. Equation (4.3) shows how dependent the engine torque on the drive cycle and the throttle signal.

$$T_{engine} = f(v_{dc}, \text{throttle signal}) \quad (4.3)$$

4.2.3 Electric Motor and DC-DC converter

In this case, the DC-DC converter is used to boost the voltage from the battery to the volts value required in the DC network, which is used to drive the motor. The motor is modeled using SimElectronics and DC-DC converter was modeled using SimScape. The motor is a servomotor model with closed-loop torque control, and has the connections to the mechanical part and the electrical part of the Hybrid Electric Vehicle.

4.2.4 Battery

Using Simscape model and conditions listed below, the battery model is a basic generic battery, which can be described with equation (4.4), which describes the relationship between the voltage and the remaining charge, which provides an approximation to what happens inside the real battery [36]:

$$V = V_0*[1-(\alpha(1-x)/(1-\beta(1-x)))] \quad (4.4)$$

Where x - The ratio of the ampere-hours left to the number of ampere-hours, AH, for which the battery is rated

α, β - Constants calculated to provide a reciprocal relationship between voltage and remaining charge.

V_0 - The voltage when the battery is fully charged.

Two conditions are satisfied by constants α and β:

- The battery voltage is zero when the charge is zero, that is, when $x = 0$.
- Satisfying a user-defined data point [*AH1*, *V1*] ($x = AH1/AH$).
  Where *AH1* – Parameter value and the charge when the battery voltage is $V1 < V\_nominal$

The nominal voltage is the voltage at the output in case of fully charged battery. The battery also is a function of State of Charge, which will be discussed in mode logic description in the second subdivision.

4.2.5 Planetary Gear

Planetary gear is used in the Hybrid Electric Vehicle architecture to perform the power-split functionality between the mechanical link and the electrical link. It consists of carrier, ring, planet and sun gears. In SimDriveline, gear meshing and viscous bearing losses can be added and parameterized. The principle of the planetary gear is to replace the traditional Automatic Transmission in Hybrid Electric Vehicles and the connections in the model presented are as follows. The internal combustion engine is connected to the carrier; the first motor/generator is connected to the ring gear and so is the final drive, and finally the second motor/generator is connected to the sun gear.

The equation used to describe the torque-speed relationships is in (4.5):

$$\omega_e = (N_r/(N_r+N_s))\omega_m+(N_s/(N_r+N_s))\omega_g \qquad (4.5)$$

Where ω_e – Engine Speed

ω_m – Motor Speed

ω_g – Generator Speed

N_r – Tooth number of ring gear

N_s – Tooth number of sun gear

Toyota Prius is one example of vehicles using this principle, and according to a study done by Toyota in [38], it claims that the Planetary Gear Set has no clutch surfaces and therefore should be more reliable than any Automatic Transmission. As the planetary gear set has a fixed gear ratio, unlike the conventional Automatic Transmission that uses clutches, where parts slide against each other with friction and resulting heat and wear.

4.2.6 Vehicle Dynamics

SimDriveline was used to develop a standard system based model, where the parameters of the chosen vehicle can be assigned. The parameters of the chosen vehicle are available in appendix 1. Parameters needed are the vehicle mass, vehicle frontal area, vehicle aerodynamic drag coefficient, tire radius, and final drive ratio.

4.3 Controllers

The main control method used inside the presented model is Stateflow method. The Hybrid Electric Vehicle control structure is as shown in figure 4.2. The main controller has three main inputs and three other main outputs. The first input is the electrical system main characteristic, which is the State of Charge, the second input is the vehicle speed, and the third is the engine speed. On the other hand, the first output is the motor torque required to be assigned to the electrical system block coming from the motor controller output, the second output is the generator torque required to be assigned to the electrical system block coming from the generator controller output. Finally, the third output is the throttle signal coming from the output of the engine speed controller. In the coming clauses, controllers will be discussed and explained separately.

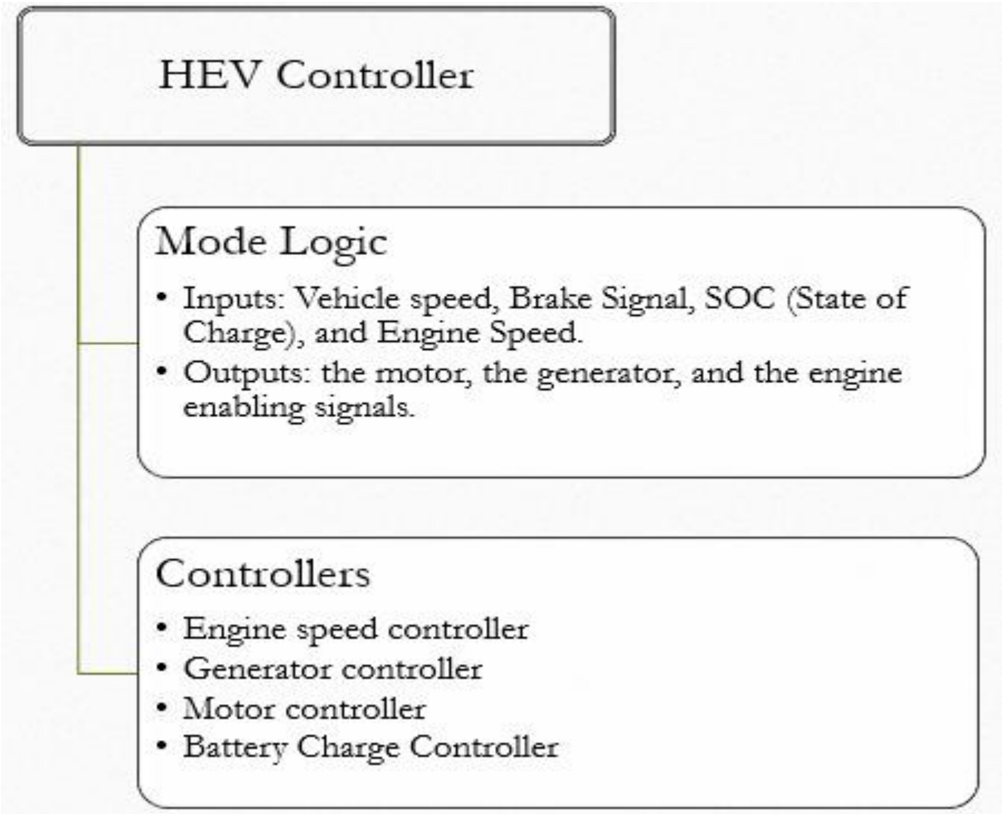

Figure 4.2. Hybrid Electric Vehicle Control Structure

4.3.1 Engine Speed Controller

PI controller is used, the throttle output value determined by three input parameters, the control command coming from the mode logic block, engine speed demand, and actual engine speed. The idle speed is 800 rpm, and if the speed demand is below than this number, it will be automatically set to zero.

4.3.2 Generator Controller

This controller is a PI controller, the generator torque output required is controlled by five different input parameters; first is the enabling signal comes from mode logic block, second is the engine speed demanded, third is the motor speed demanded, and then the obtained torque demanded from the battery and finally the generator speed. The maximum volts allowed is 5 volts, which is equivalent to 10000 rpm.

4.3.3 Motor Controller

PI controller is used; the motor torque required is controlled by three input parameters. First, the enabling signal from the mode logic block, and then the motor speed demanded, and finally the actual speed of the motor. The maximum volts allowed is 5 volts, which is equivalent to 6500 rpm.

4.3.4 Battery Charge Controller

The battery charge controller is responsible for providing the generator torque demanded to lunch the generator in case it has the order to be activated in the mode logic. The input signals used to provide that characteristic is the engine speed and the State of Charge.

4.3.5 Mode Logic and states

As mentioned before, Hybrid Electric Vehicle model is controlled via Stateflow control method, where states, the action taken within those states and how the vehicle can perform the transitions between all the states. Transitions in the Stateflow architecture is dependent on a certain Mode Logic and states; each has a specific condition to work with.

The inputs for the mode logic block are four parameters; vehicle speed, brake input, SOC (State of Charge), and engine speed. These inputs are implemented to figure out which state, the vehicle has to be assigned to, and then it decides, whether the motor, the generator or the engine. In the coming sub clauses, different states of the vehicle will be explained [33] [36].

Low Power Mode

When the vehicle is in motion in the very beginning of the driving cycle, the generator is used to start the engine, as a starter motor. At low speed, it is considerable that electrical driving mode is in charge to handle low speeds requirements. Therefore, the electric motor is used to drive the vehicle. This mode can be also named as a motor alone mode. This state can be reached when the speed is not exceeding the threshold speed and the state of charge is above the minimum level.

High Power Mode

In the high power mode, it is devised that the engine is enabled in order to drive the vehicle and charge the battery, as well.

Very High Power Mode

In the very high power mode, besides enabling the engine to drive the vehicle, the motor is enabled to drive the vehicle even faster; on the other hand, the generator is disabled. That criteria guarantees all the torque produced to accelerate without any losses to the generator. The maximum speed that was specified in the start mode has to be exceeded in order to switch to this mode.

Charging

There are several sub-modes to charge the battery; according to several different situations of the vehicle. The first is the Charge-Cruise Mode, when the state of charge is lower than the minimum value, permitted by the Stateflow control conditions, the vehicle then can use the generator to charge the battery from the excess power delivered by the engine. That occurs in the same time with the engine and the motor enabled to provide a stable drive cycle.

The second is (No-Charge) Cruise Mode, where the state of charge is higher than the minimum value assigned by the Stateflow control conditions, and then the generator is not used in this case, unlike the previous sub-mode. The engine and the motor still drives the vehicle. The third is Stop-to-Charge Mode, where the engine is not used to drive the vehicle, as no power is permitted to the rest of the drivetrain. However, the engine is used to propel the battery, in case of reaching a lower value of charge than the minimum State of Charge assigned.

Braking Mode

In this mode, it is required to enable the motor in order to perform the regenerative braking process to charge the battery and conventional vehicle braking is used in addition, if needed.

Transitions between Modes

To change between modes, the main parameters that have to be taken into consideration are the current speed, the old speed and the state of charge. Transition from Low Power Mode to High Power Mode is done when engine speed exceeds the rpm value assigned to the signal, which enables the engine and vice versa. Transition from Very High Power Mode to the Cruise Charging or No Charging sub-modes is done when the state of charge is above 30% and the speed required is above 0.998 of the old speed and below 1.002 of the old speed. Transition within the charging modes is happening, when the State of Charge >99.9% and the opposite is applicable, when State of Charge <30%.

The full Mode Logic block is as shown in figure 4.3. Old speed is the main function used inside the block. “EngOnRPM” refers to the engine speed, which assign the enabling signal to the engine.

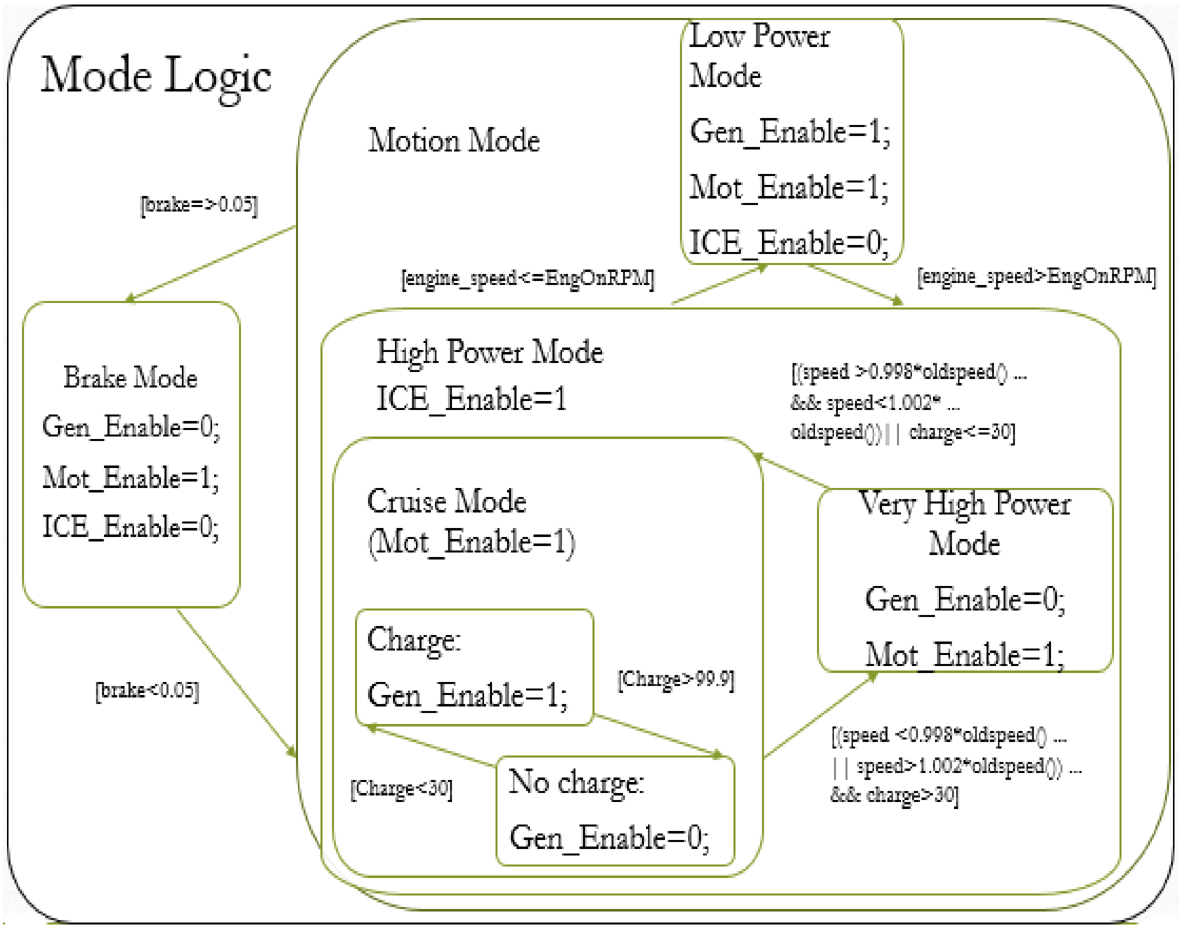

Figure 4.3. Mode Logic Block

5. PROPOSED HDCT VEHICLE MODEL

In this chapter, a Hybrid Electric Vehicle model with a Dual Clutch Transmission architecture is proposed. The Hybrid Electric Vehicle model configuration, as shown in figure 5.1, consists of several components. First is the drive signal, then internal combustion engine, two Electrical motors; each is connected to odd and even gears of the Dual Clutch Transmission, and finally the vehicle dynamics. The main Hybrid Electric Vehicle model, apart from the Dual Clutch Transmission, is quite similar to the previous Hybrid Electric Vehicle model presented in the previously mentioned model in Chapter 4.2, including the mode logic. Moreover, in order to clarify the connections properly, every component will be discussed separately in the coming sub-divisions.

Previous researches investigated and proposed Dual Clutch Transmission architecture in Hybrid Vehicles. Upendra K. discussed and proposed a Dual Clutch Transmission for Plug-in Hybrid Electric Vehicle model in [6]. In [7], Joshi A., et al. investigated the modeling and simulation of a Hybrid Vehicle powertrain with a Dual Clutch Transmission. In [40], Song Z., et al. proposed energy management strategy, along with a Dual Clutch Transmission in a Plug-in Hybrid Electric Vehicle using MATLAB/Simulink environment.

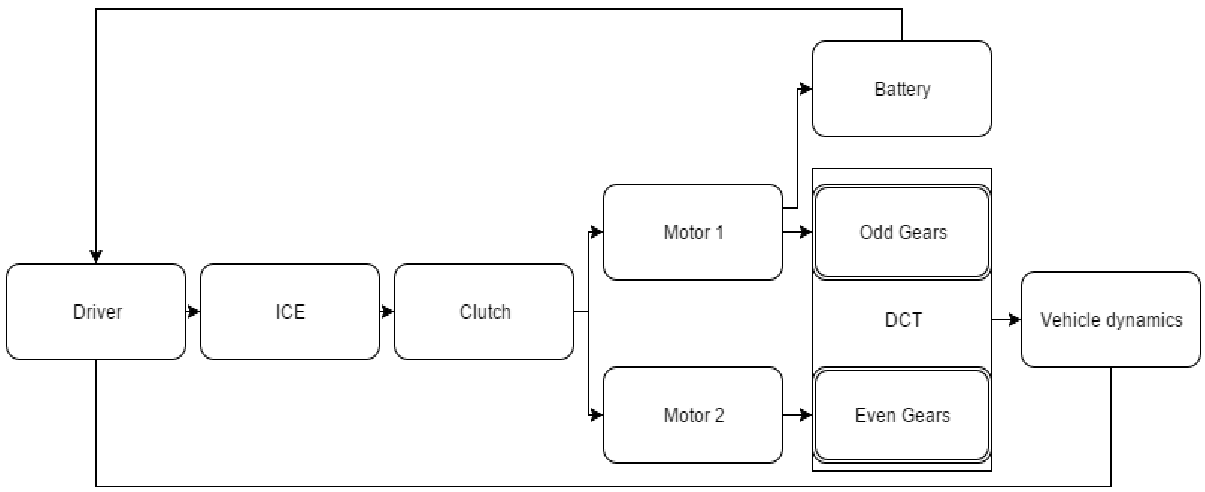

Figure 5.1. Hybrid Electric Vehicle model including Dual Clutch Transmission

5.1 Drive Signal

The drive signal is a function of the throttle, as a drive cycle, which can be characterized by the acceleration and velocity profile as function of time. The four driving cycles used in testing is the Federal Test Procedure, New York City Cycle, Highway Fuel Economy Test, and Extra Urban Driving Cycle [38].

5.2 Internal combustion Engine

It is the main power source with liquid fuel to drive the vehicle. It is modeled simply in SimDriveline as a spark-ignition engine; with maximum power, maximum speed and stall speed can be parameterized.

5.3 Dual Clutch Transmission architecture

The Dual Clutch Transmission presented in this model is modeled via SimDriveline, it consists of two clutches; each clutch has a set of gears. The gear ratio is discussed in details chapter 3.2.1, and equation (3.19) is explaining the relation between torques and angular speeds of the base and follower axes with the gear ratio.

The main structure of the Dual Clutch Transmission are similar to the structure withdrawn in chapter 3.2.3. In brief, it consists of Friction Clutches, Synchronizers, and Transmission Controller. Friction Clutches are modeled as dog clutches with rectangular teeth and equation (3.20) describes their operating states. On the other hand, Synchronizers are modeled with the aid of SimDriveline environment also, the Transmission Controller is different from the controller used in the previously mentioned configuration in chapter 3.2.3.; it will be discussed separately in the coming sub-division.

5.3.1 Transmission Controller

In this model, the Transmission Controller block mainly has several inputs and outputs; the main inputs in this model are the vehicle speed, the internal combustion engine speed, the clutch slipping sensor signal, and the command (drive cycle) speed, and the main outputs are the gear, pressure and torque demanded, which are used to drive the transmission.

The Transmission Controller consists of three main components, first is the shift state block, which is modeled via Stateflow control method, the main inputs, which determines the shift state are the engine and vehicle speed, slipping condition of the clutch and the driver action. Each gear has its own state according to the current speed and the throttle. The second main component the clutch pressure control and the gearshift demands blocks, which control the pressure for each clutch and then deliver the pressure demanded to determine the gear demanded according to the current vehicle situation. Figure 5.2 shows the Transmission Controller's blocks.

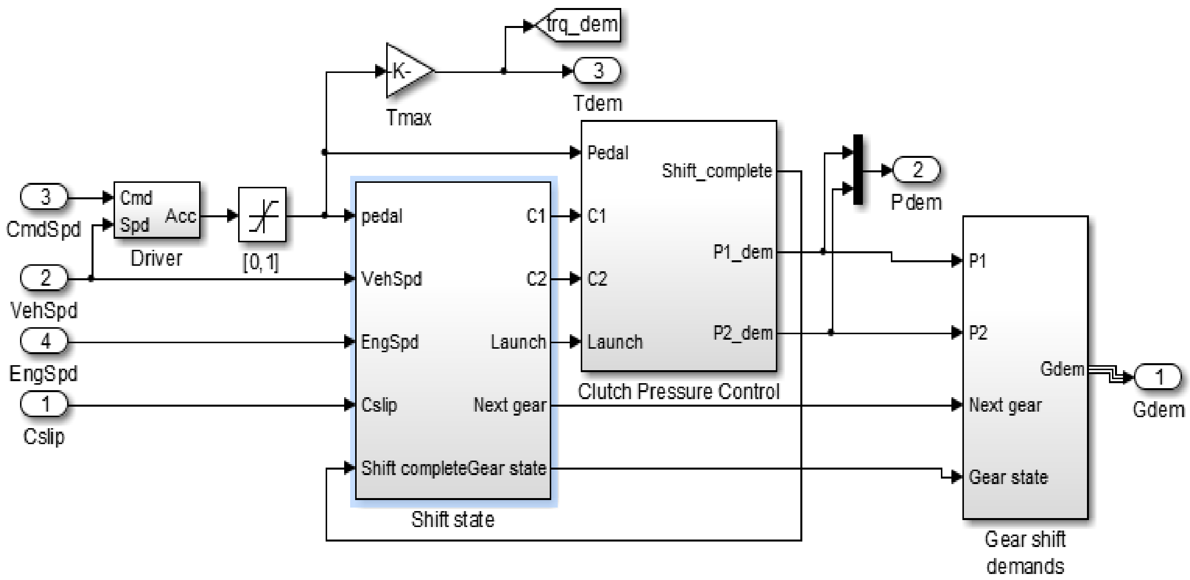

Figure 5.2. Transmission Controller of Dual Clutch Transmission

5.4 DC-DC converter

DC-DC converter is used to boost the voltage to the value assigned in the DC network to drive the motor. The output voltage required is 500 volts. The DC-DC converter has a mask, where different parameters can be assigned, as the proportional and integral gains of controlling the bass voltage, and resistance, load dependent losses in Ohms.

5.5 Electric motors

Mainly the electric motor is modeled using SimElectronics. Servomotor is used to represent the motor model and returning to description in Simulink, the output torque required is tracking the torque reference value demanded with a certain time constant. The model itself has a mechanical and an electrical connection; the servomotor must be connected also to a DC supply, and there are different parameters that can be assigned inside the model, as the torque control time constant, maximum torque values, and rotor damping etc.

5.6 Battery

The battery used inside the model is a simple generic model, as discussed in chapter 4.2.4, which it can be used to assign several parameters as nominal voltage, internal resistance, Ampere-Hour rating, initial charge and etc., according to the equation (4.4).

5.7 Vehicle Dynamics

For developing vehicle dynamics for the current model, SimDriveline models are used and the vehicle chosen for testing is Ford Escape. Entering the parameters into the vehicle model is simple and in Appendix 2, the parameters of the vehicle chosen, required for testing, are stated.

6. SIMULATIONS AND RESULTS

In order to perform tests to compare the fuel efficiency and the performance between three different architectures, it is needed to use a reference drive cycle to see how reliable, good and applicable a model can be, and how the model can be improved to get better matching results. The three models discussed here are Series-Parallel Hybrid Electric Vehicle, Conventional Dual Clutch Transmission Vehicle and Hybrid Electric Vehicle with a Dual Clutch Transmission in order to investigate the performance of the using different drive cycles.

The drive cycles used in the tests performed on the three models have to be chosen in a wide range of driving behaviors, in order to test the model in different positions and situations. Four different drive cycles are used; they are conducted in USA and Europe, Federal Test Procedure, New York City Cycle, Extra Urban Driving Cycle and Highway Fuel Economy Test. The driving cycle generally is a fixed schedule of vehicle operation, which are defined in terms of Vehicle speed and gear selection as a function of time [38].

Federal Test Procedure is one of the tests acknowledged by EPA (Environmental Protection Agency) in USA; it is devised, along with New York City Cycle, as low speed urban driving cycle tests. Extra Urban Driving Cycle is an EU legislative cycles used for approval of Hybrid Electric Vehicles; it was designed to propose an aggressive and high speed driving modes mainly in European cities [38]. Moreover, the Highway Fuel Economy Test is a chassis dynamometer-driving schedule developed for light-duty vehicles to determine the Fuel-Economy performance [41].

In the coming sub-divisions, the comparison between the three models will be presented; along with each drive cycle is withdrawn. Fuel-Economy performance, vehicles speed, State of Charge and gear-shifting for the three models will be presented in the coming sub-divisions. The discussion about each of the presented figures will be withdrawn in chapter 7.

6.1 Speed Performance and Fuel-Economy

6.1.1 Federal Test Procedure (FTP75, Cold Start)

As mentioned in the previous division, Federal Test Procedure is designed to fulfil the driving modes of low speed urban conditions [38]. The reference speed of FTP75 is shown in figure 6.1.

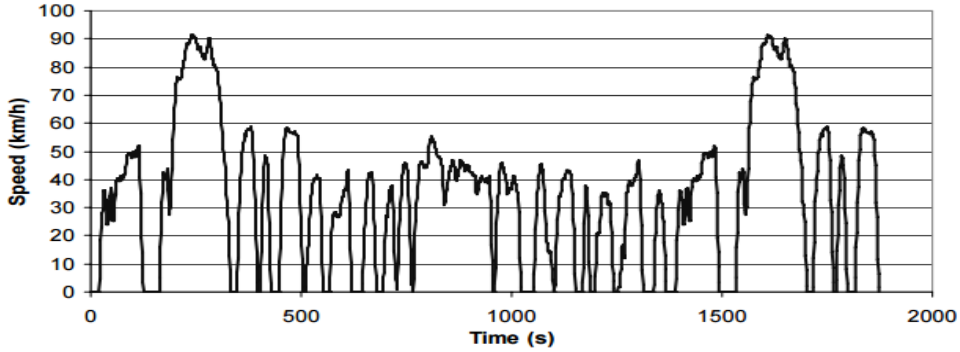

Figure 6.1. FTP75 Drive Cycle

In figures 6.2, 6.3, 6.4, 6.5, and 6.6, it is shown Dual Clutch Transmission Conventional Vehicle, Hybrid Electric Vehicle and Hybrid Electric Vehicle with Dual Clutch Transmission in terms of (Speed Performance – Fuel Flow – Fuel Use). Finally, the comparison between the models in Fuel-Economy, and comparison between the three models and reference speed, respectively, are withdrawn.

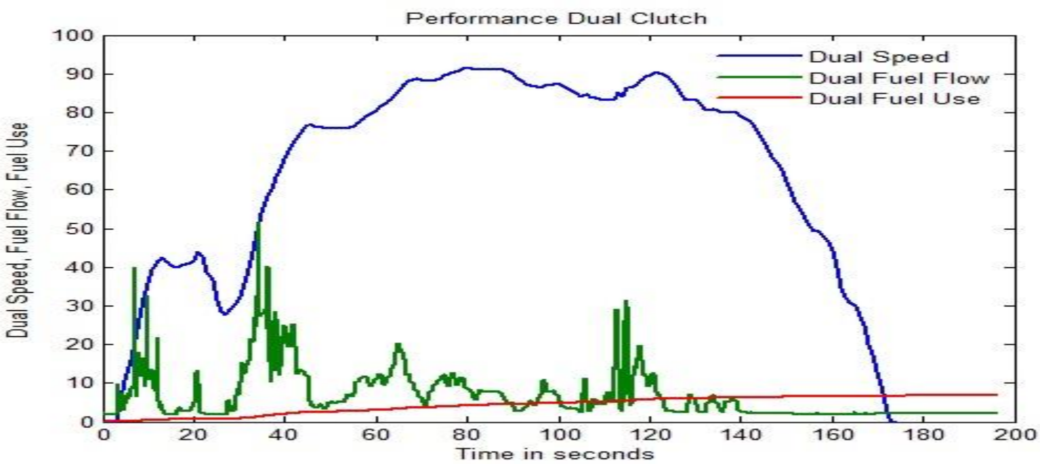

Figure 6.2. Dual Clutch Transmission Conventional Vehicle's (Performance – Fuel Flow – Fuel Use) (FTP75, Cold Start)

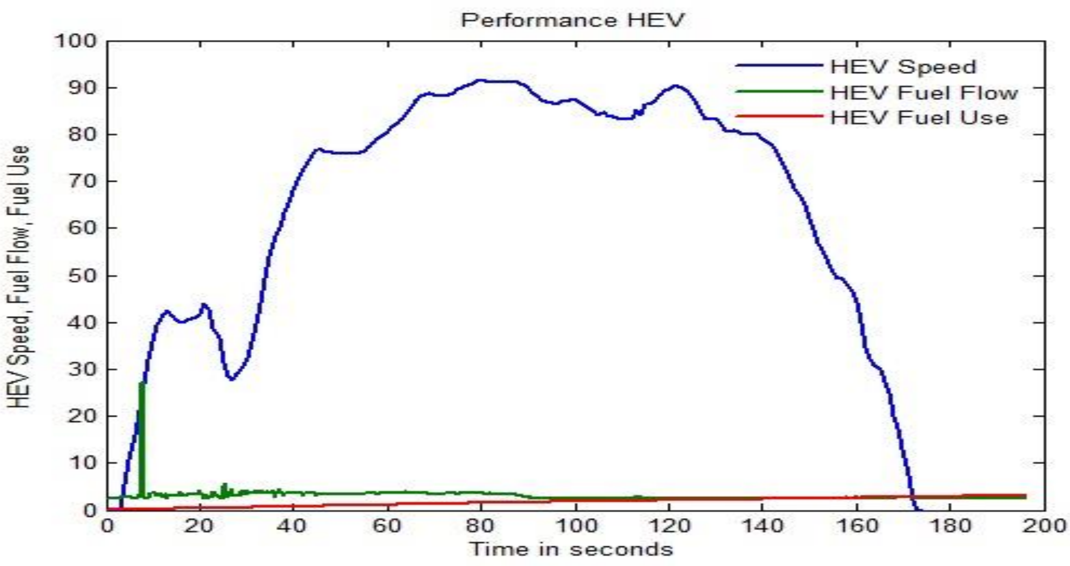

Figure 6.3. Hybrid Electric Vehicle (Performance – Fuel Flow – Fuel Use) (FTP75, Cold Start)

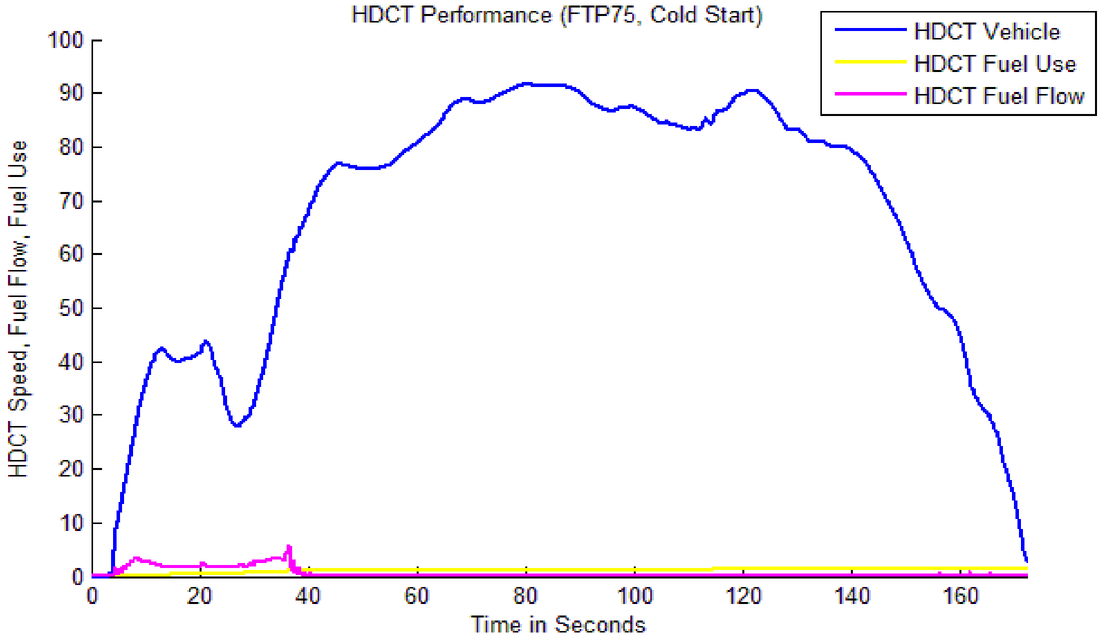

Figure 6.4. Hybrid Electric Vehicle with Dual Clutch Transmission (Performance – Fuel Flow – Fuel Use) (FTP75, Cold Start)

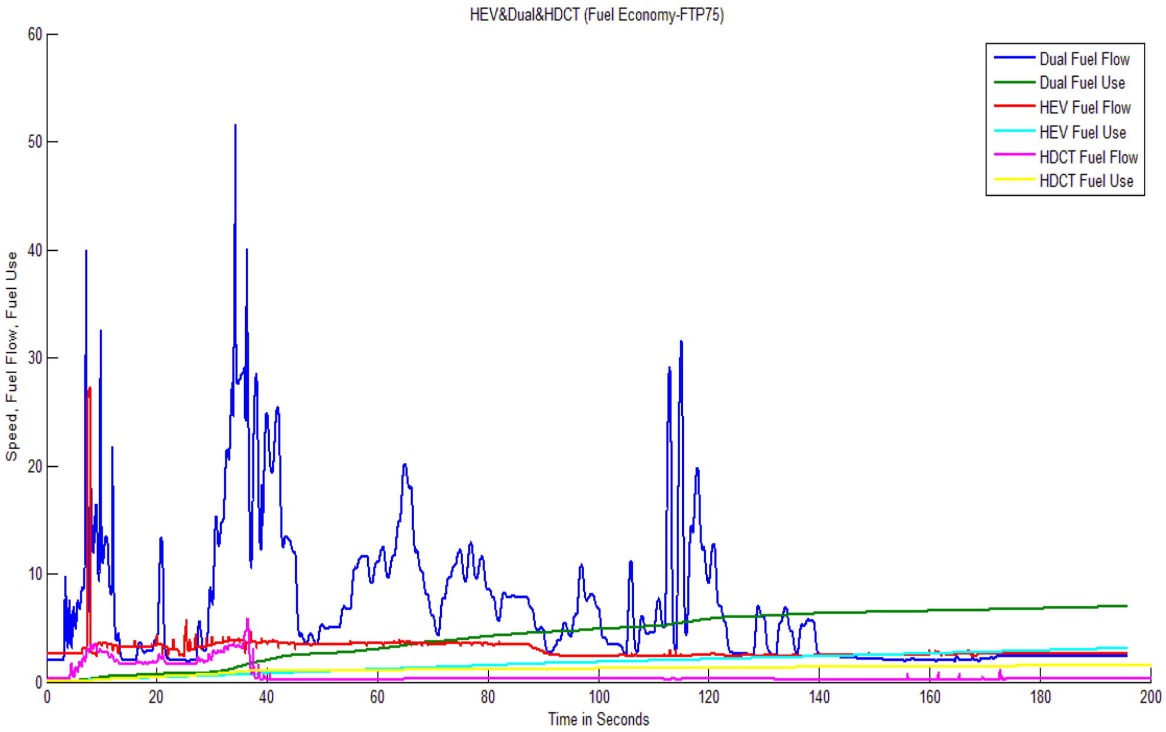

Figure 6.5. Comparison between the models in Fuel-Economy (FTP75, Cold Start)

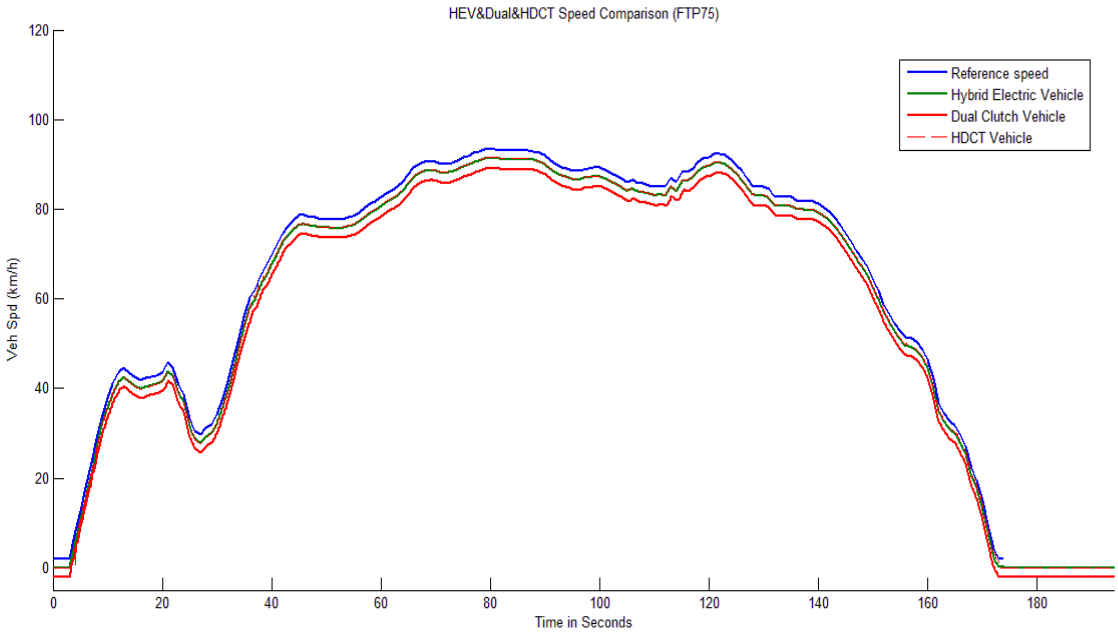

Figure 6.6. Comparison between the models and reference speed (FTP75, Cold Start)

6.1.2 New York City Cycle (NYCC)

New York City Cycle is one of the driving cycles conducted in the United States for low speed urban driving conditions [38]; it is shown in figure 6.7.

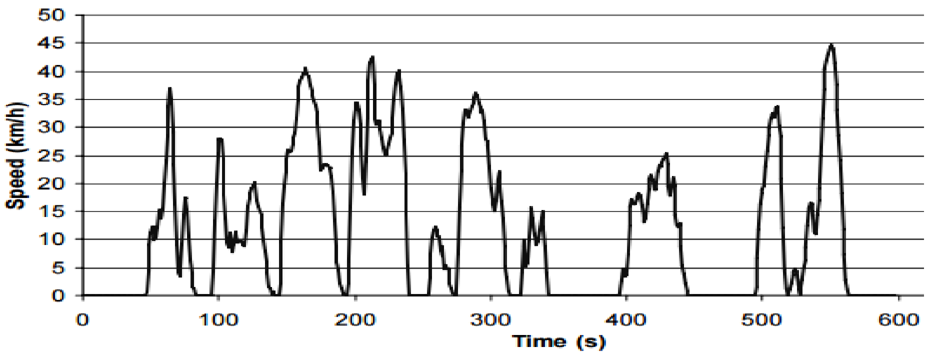

Figure 6.7. NYCC Drive Cycle

In figures 6.8, 6.9, 6.10, 6.11, and 6.12, it is shown Dual Clutch Transmission Conventional Vehicle, Hybrid Electric Vehicle and Hybrid Electric Vehicle with Dual Clutch Transmission in terms of (Speed Performance – Fuel Flow – Fuel Use). Finally, the comparison between the models in Fuel-Economy, and comparison between the three models and reference speed, respectively, are withdrawn.

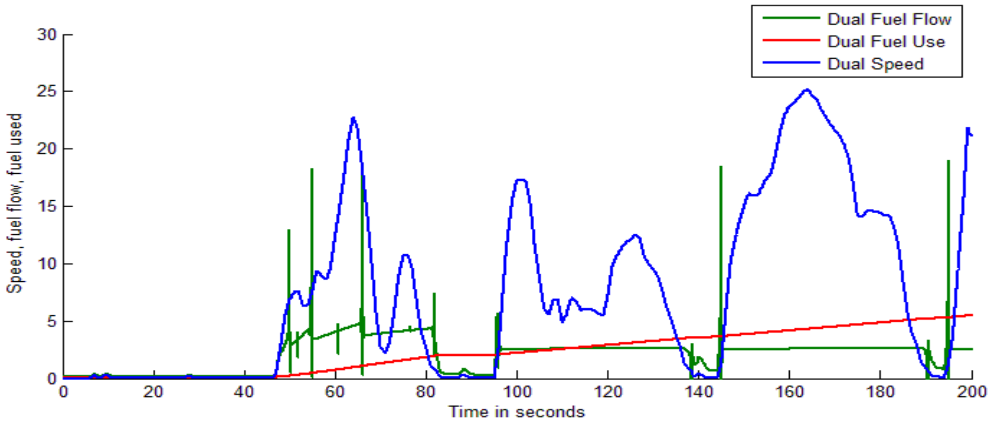

Figure 6.8. Dual Clutch Transmission Conventional Vehicle's (Performance – Fuel Flow – Fuel Use) (NYCC)

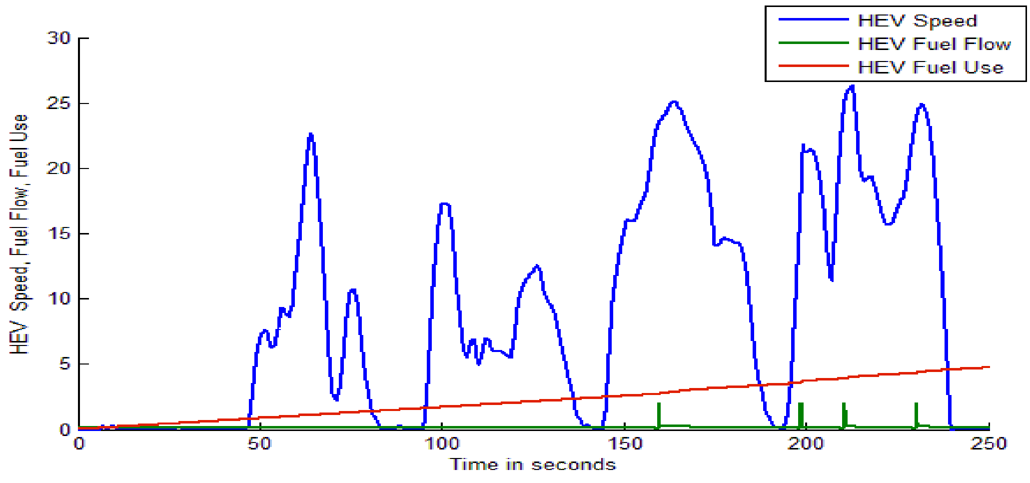

Figure 6.9. Hybrid Electric Vehicle (Performance – Fuel Flow – Fuel Use) (NYCC)

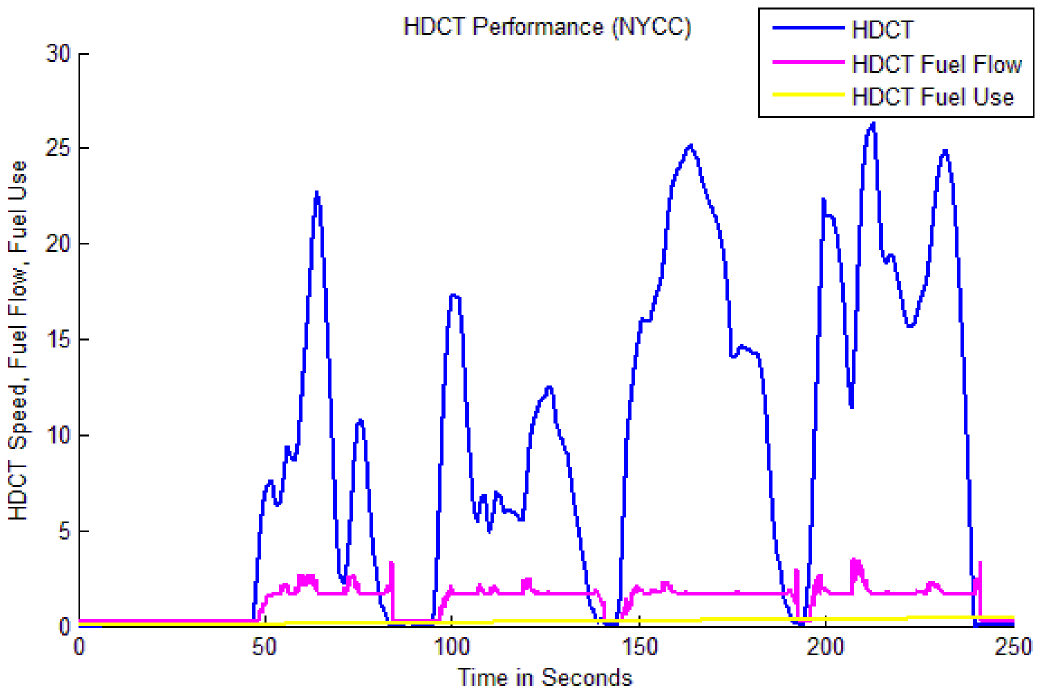

Figure 6.10. Hybrid Electric Vehicle with Dual Clutch Transmission (Performance – Fuel Flow – Fuel Use) (NYCC)

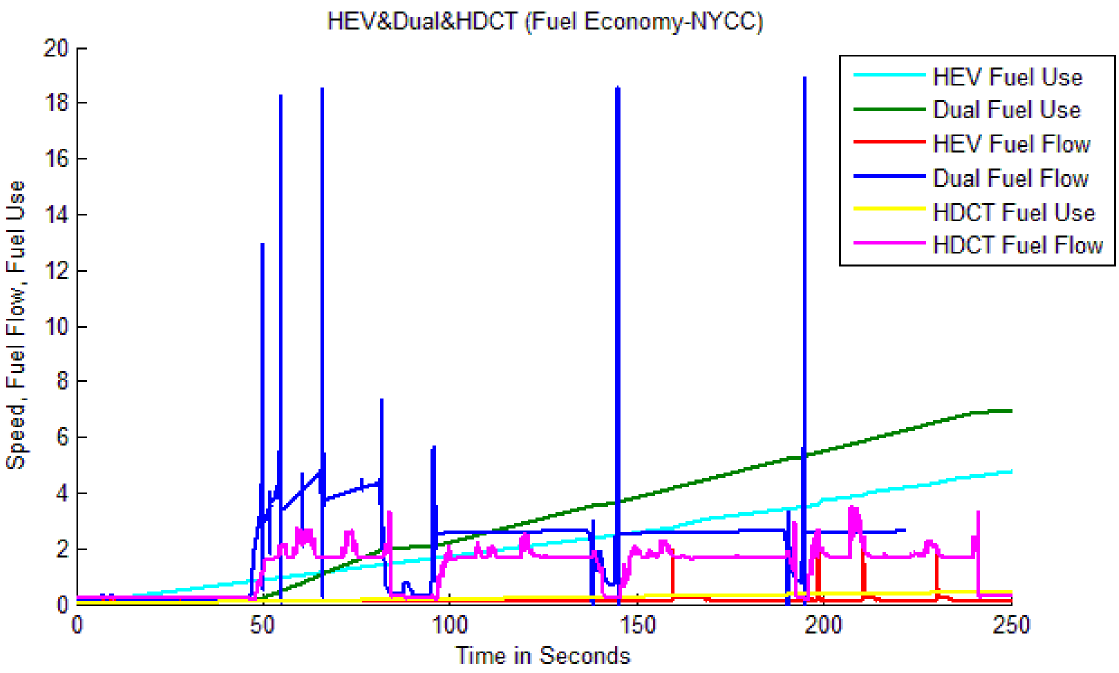

Figure 6.11. Comparison between the models in Fuel-Economy (NYCC)

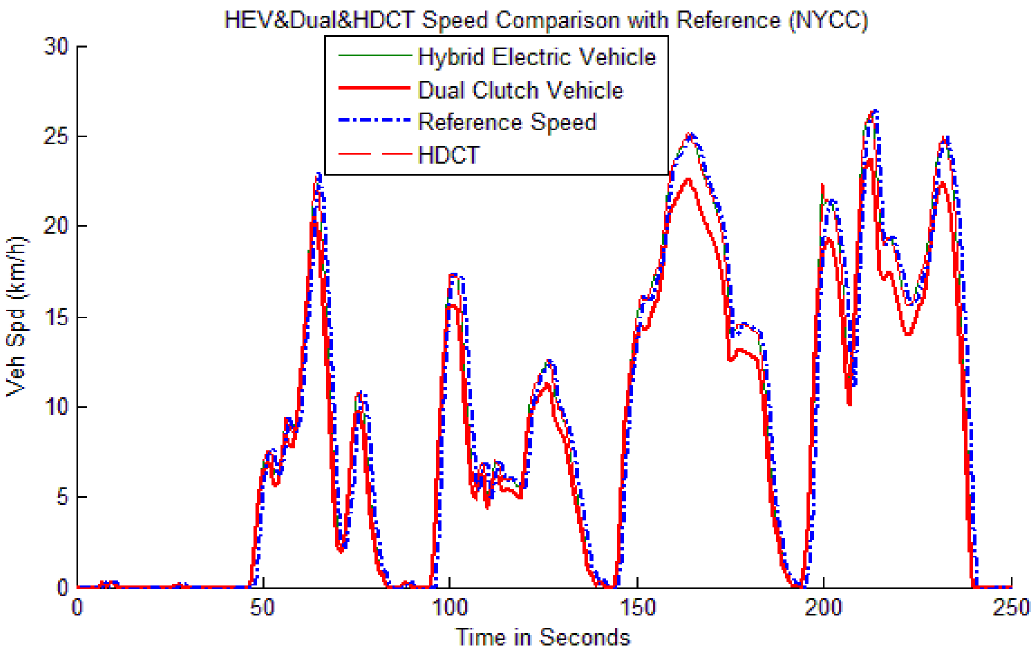

Figure 6.12. Comparison between the models and reference speed (NYCC)

6.1.3 Highway Fuel-Economy Test

It is a drive cycle that was developed for light-duty vehicles to investigate the speed performance and Fuel-Economy [38]; it is shown in figure 6.13.

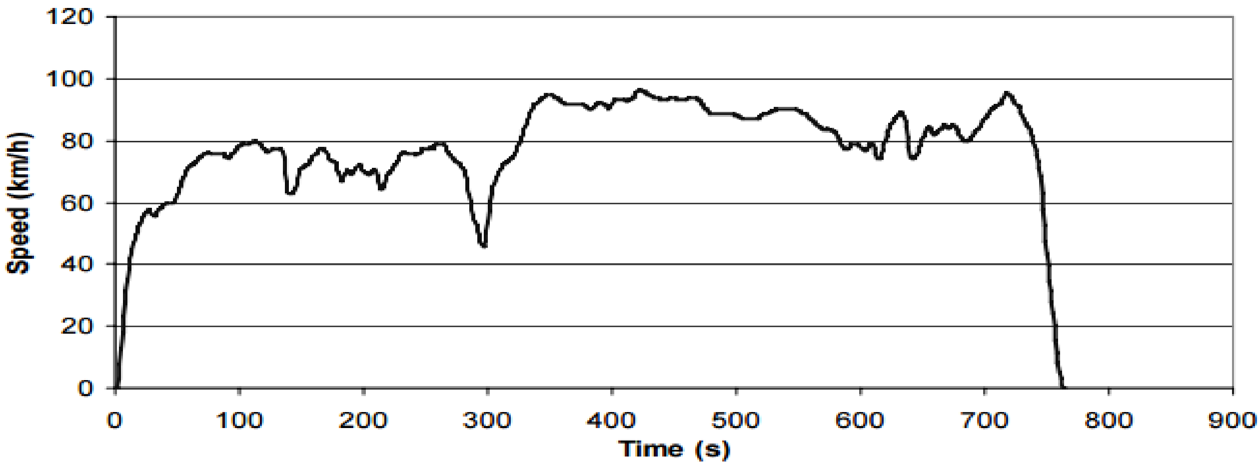

Figure 6.13. Highway Fuel Economy Test Drive Cycle

In figures 6.14, 6.15, 6.16, 6.17, and 6.18, it is shown Dual Clutch Transmission Conventional Vehicle, Hybrid Electric Vehicle and Hybrid Electric Vehicle with Dual Clutch Transmission in terms of (Speed Performance – Fuel Flow – Fuel Use). Finally, the comparison between the models in Fuel-Economy, and comparison between the three models and reference speed, respectively, are withdrawn.

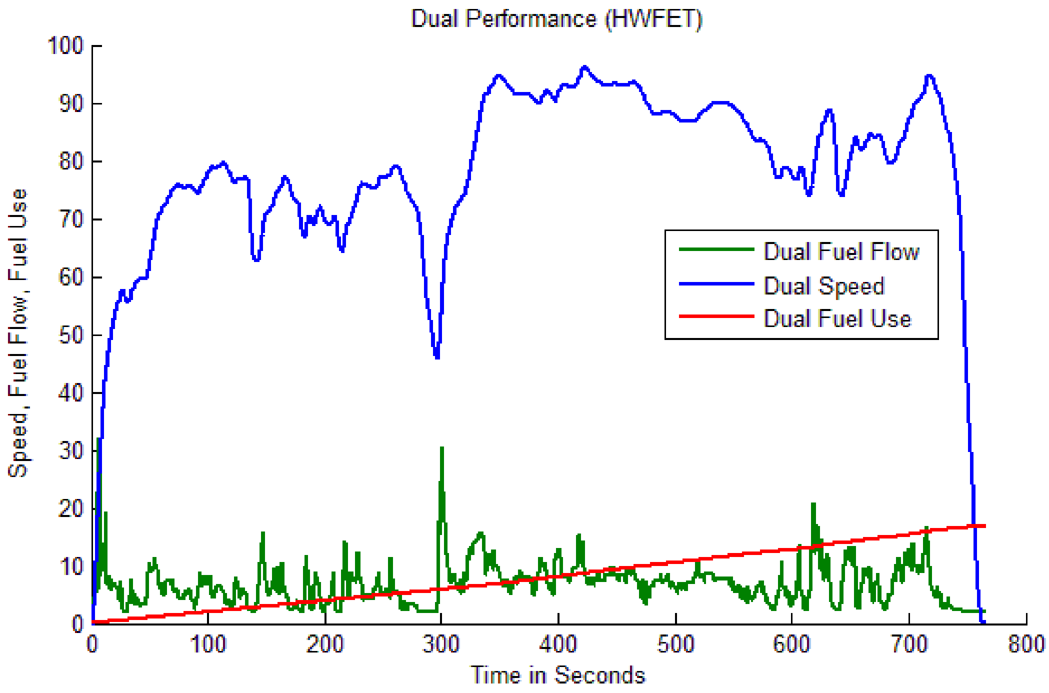

Figure 6.14. Dual Clutch Transmission Conventional Vehicle's (Performance – Fuel Flow – Fuel Use) (HWFET)

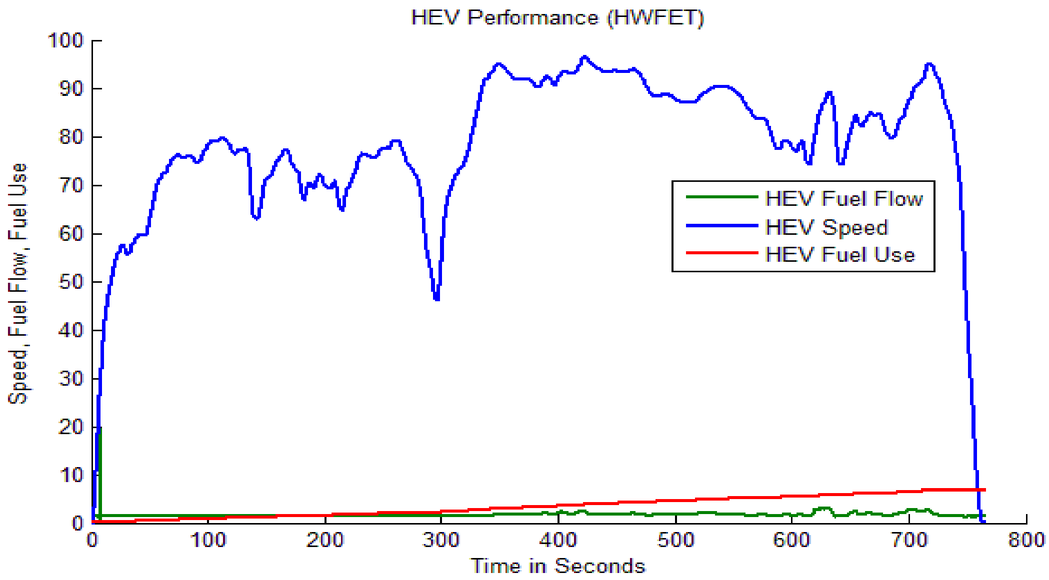

Figure 6.15. Hybrid Electric Vehicle (Performance – Fuel Flow – Fuel Use) (HWFET)

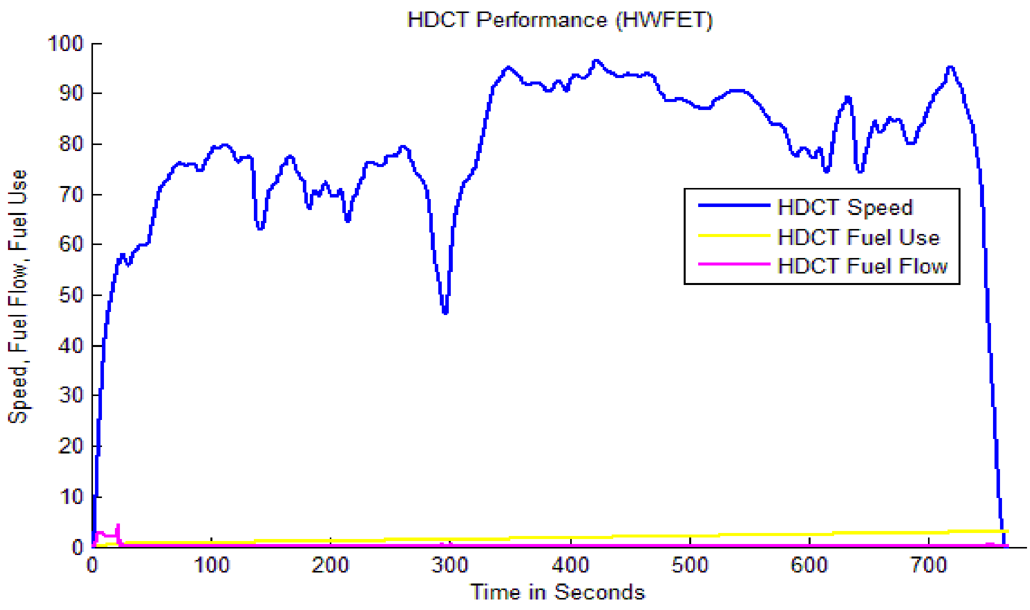

Figure 6.16. Hybrid Electric Vehicle with Dual Clutch Transmission (Performance – Fuel Flow – Fuel Use) (HWFET)

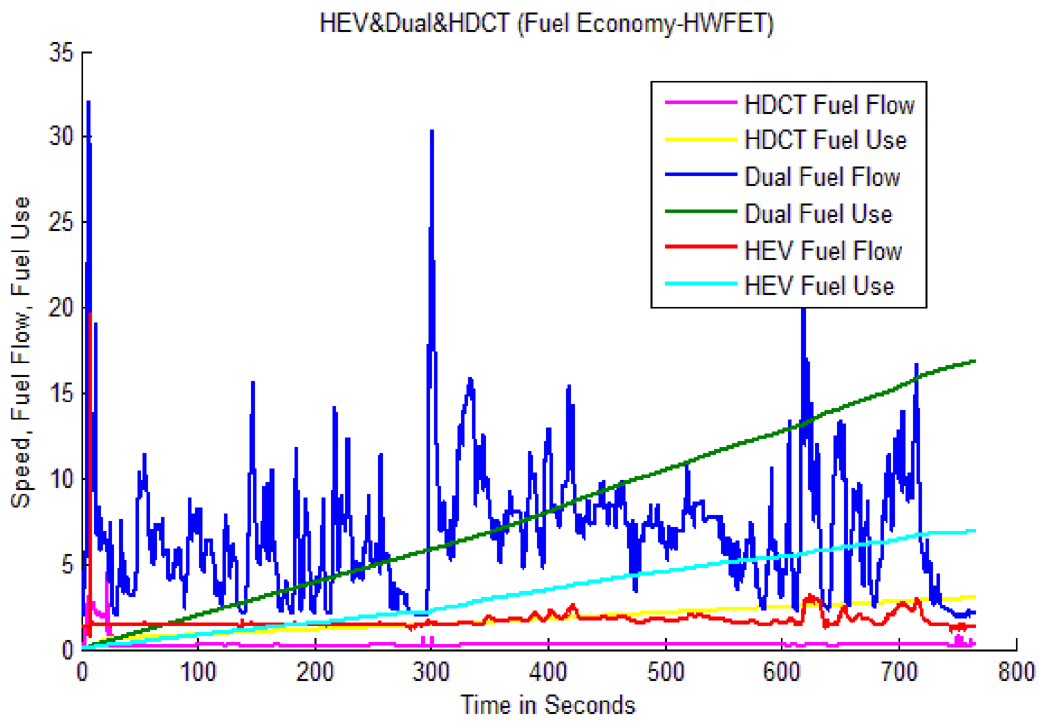

Figure 6.17. Comparison between the models in Fuel-Economy (HWFET)

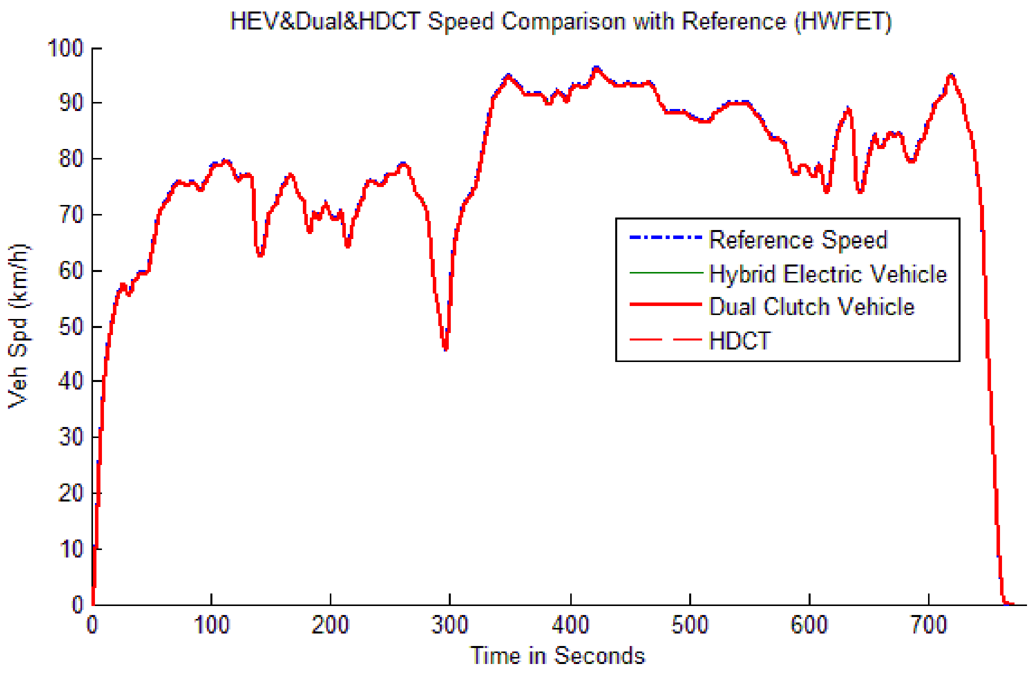

Figure 6.18. Comparison between the models and reference speed (HWFET)

6.1.4 Extra Urban Driving Cycle

Extra Urban Driving Cycle is one of the standard driving cycles, applied in Europe. The test here, as the previous tests, simulated driving behavior according to the characteristics of each cycle [38]. It is shown in figure 6.19.

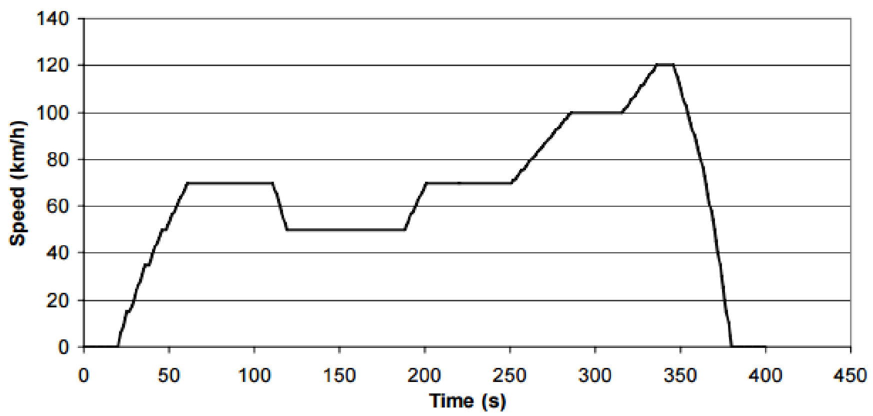

Figure 6.19. EUDC Drive Cycle

In figures 6.20, 6.21, 6.22, 6.23, and 6.24, it is shown Dual Clutch Transmission Conventional Vehicle, Hybrid Electric Vehicle and Hybrid Electric Vehicle with Dual Clutch Transmission in terms of (Speed Performance – Fuel Flow – Fuel Use). Finally, the comparison between the models in Fuel-Economy, and comparison between the three models and reference speed, respectively, are withdrawn.

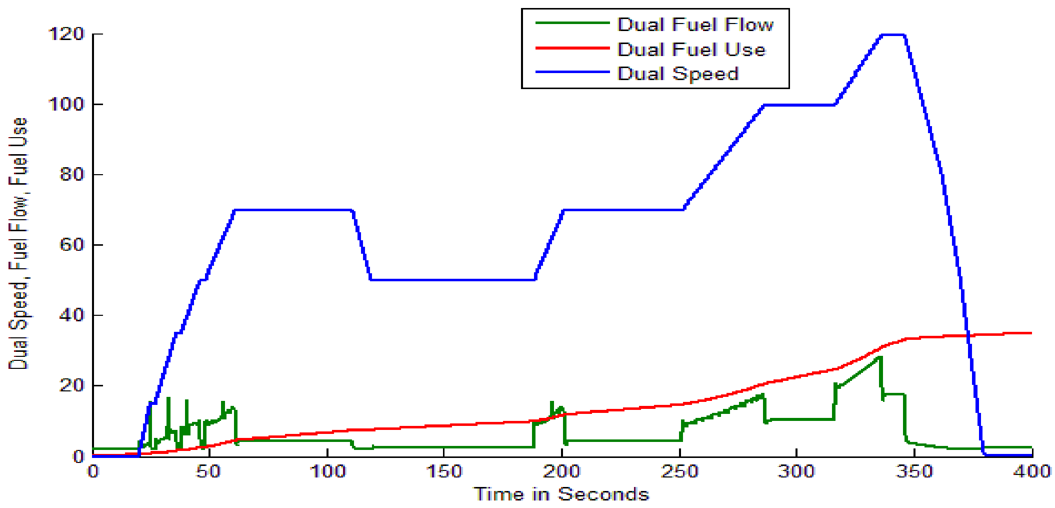

Figure 6.20. Dual Clutch Transmission Conventional Vehicle's (Performance – Fuel Flow – Fuel Use) (EUDC)

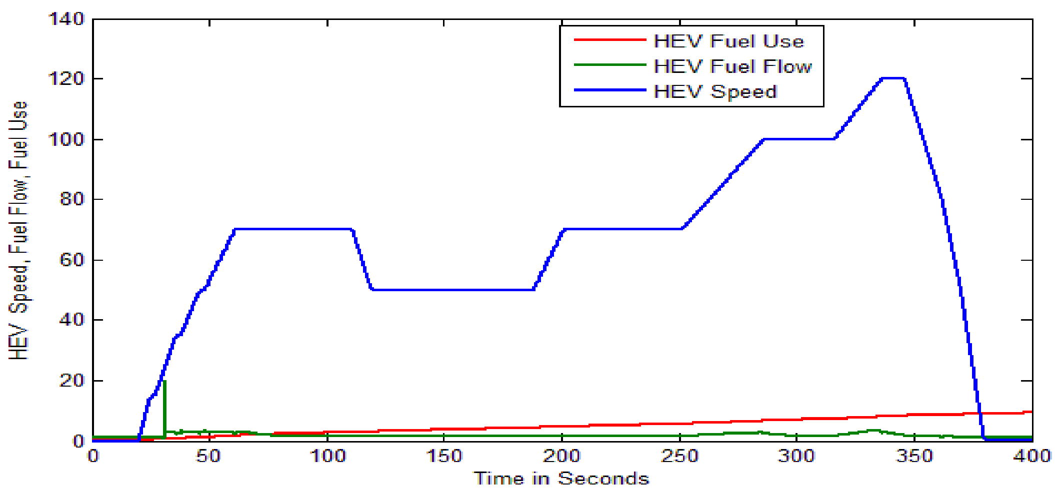

Figure 6.21. Hybrid Electric Vehicle (Performance – Fuel Flow – Fuel Use) (EUDC)

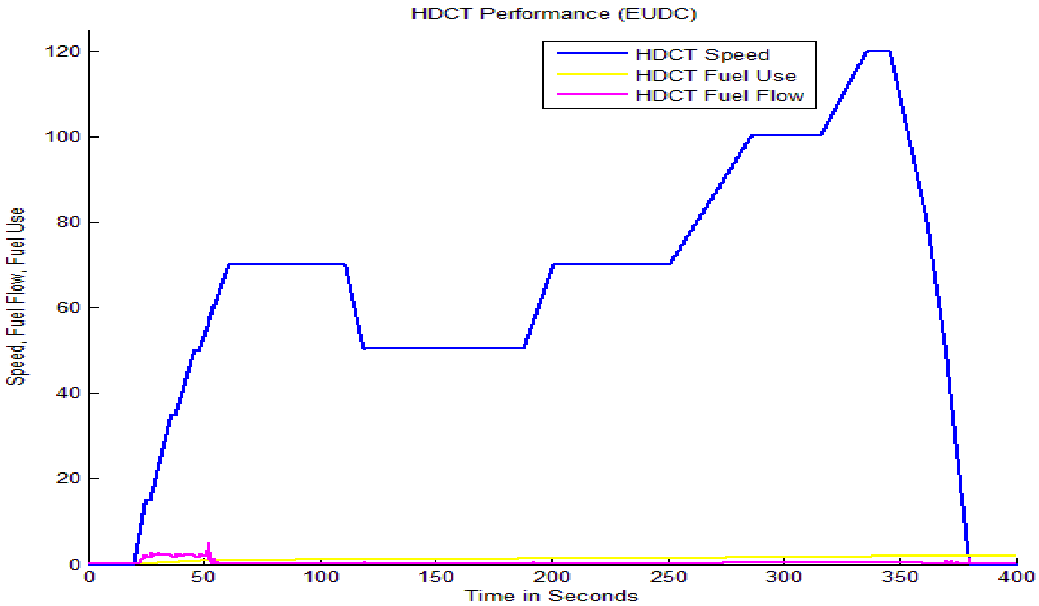

Figure 6.22. Hybrid Electric Vehicle with Dual Clutch Transmission (Performance – Fuel Flow – Fuel Use) (EUDC)

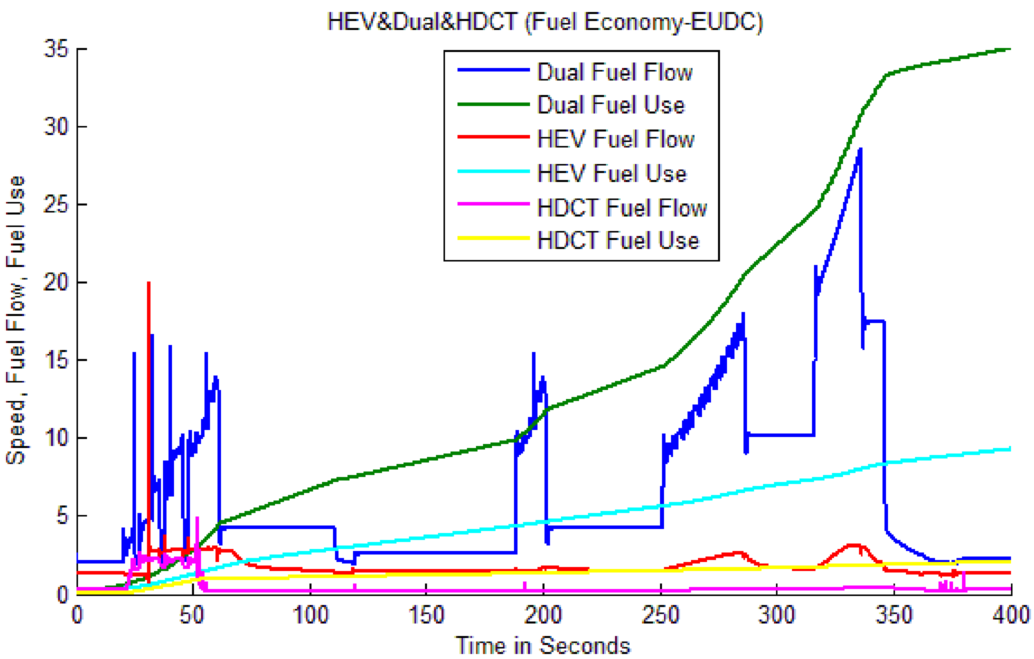

Figure 6.23. Comparison between the models in Fuel-Economy (EUDC)

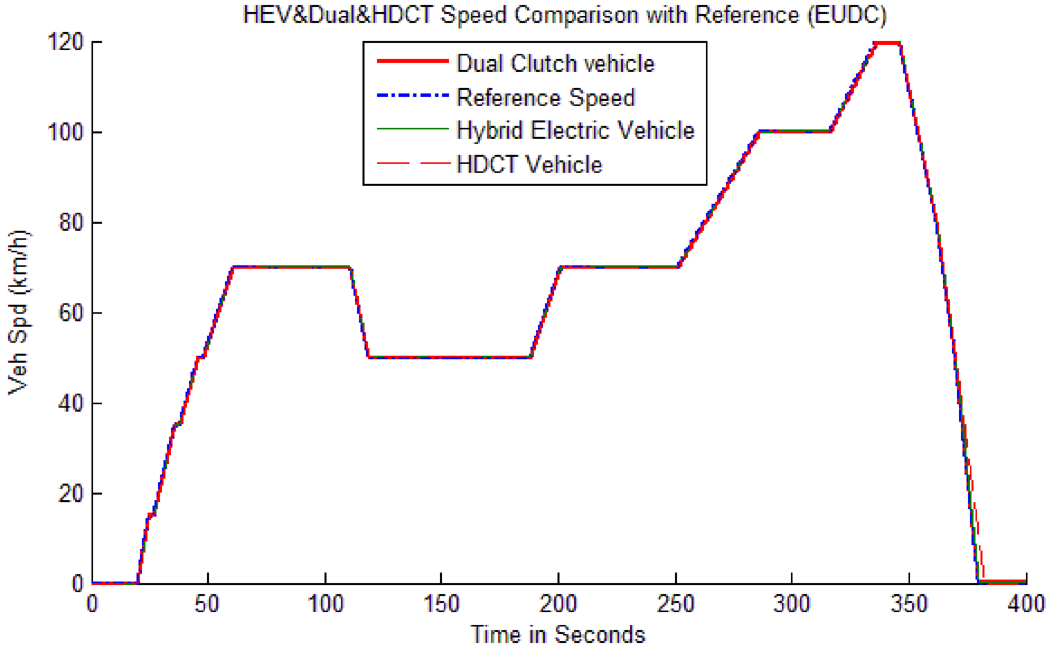

Figure 6.24. Comparison between the models and reference speed (EUDC)

6.2 Gear-shifting & State of Charge

One of the most important aspects to compare between the Dual Clutch Transmission Conventional and Hybrid Vehicles in terms of the time, which each vehicle could take to perform the gear-shifting process and how flexible and fast, each vehicle can change gears to follow the assigned drive cycle used as a reference.

As mentioned previously, whether it is for the Dual Clutch Transmission Conventional Vehicles or Hybrid Vehicles, the odd and even gear sets are connected by shafts to the transmission block. The dog clutches are the parts responsible for allowing the transmission to preselect the next gear, to which the transmission will shift; those clutches are controlled by signals from the control system used in each vehicle. The main benefit, Hybrid Electric Vehicle type has, is the variety of the operating modes assigned by the controller, which includes the usage of the electric motor to drive the vehicle in the beginning of the drive cycle, which is devised in crowded city driving. Therefore, the electric motor will be used and the gear-shifting will be limited to the first gear, which is used until the speed of 50 km/h in the model presented. In case of excessive loading requirements, the internal combustion engine has to be activated along with the motor to fulfil them, so the gear-shifting happens in milliseconds to the higher gears, according to the vehicle speed. In the following figures 6.25, 6.26, 6.27, 6.28, 6.29 and 6.30, gear-shifting status for the two models are presented and in chapter 7, more discussion on the comparison and results will be withdrawn.

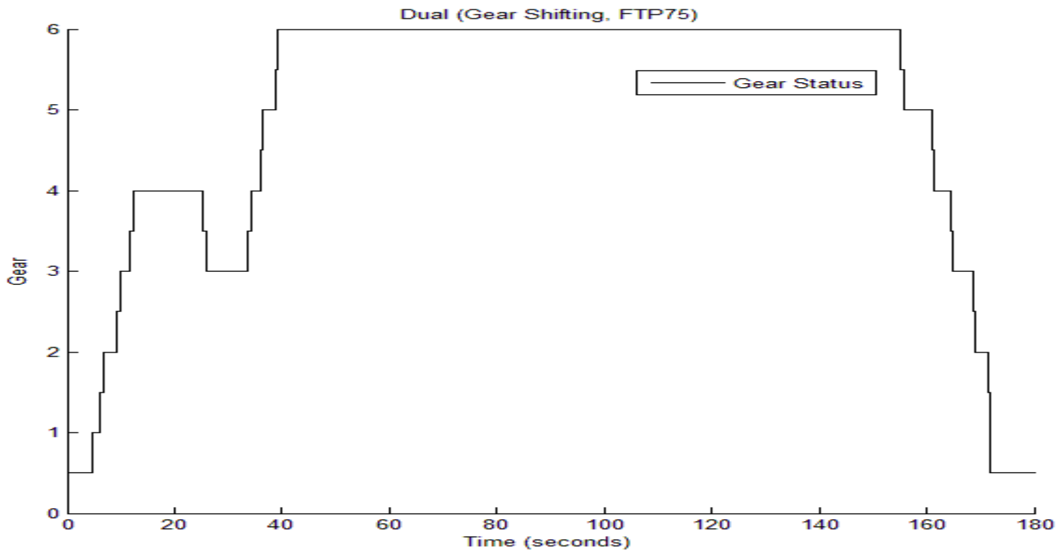

Figure 6.25. Gear-shifting for Dual Clutch Transmission Conventional Vehicle (FTP75, Cold Start)

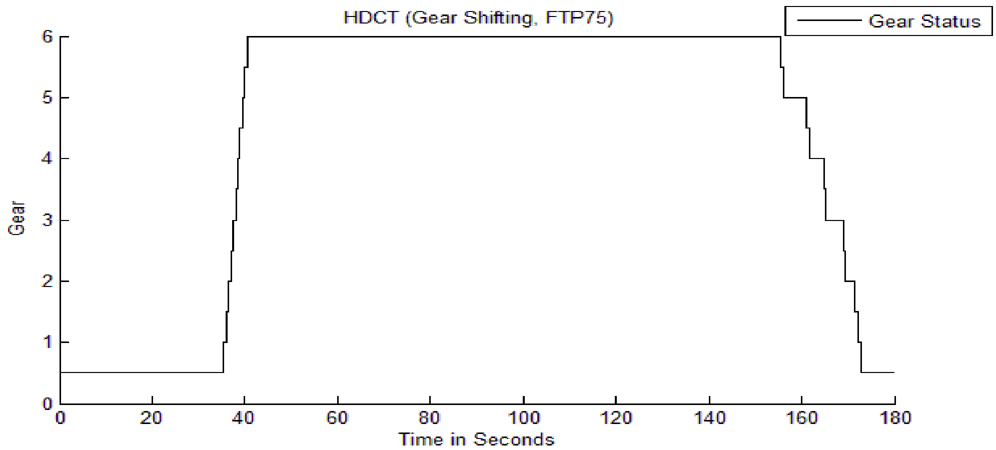

Figure 6.26. Gear-shifting for Dual Clutch Transmission Hybrid Vehicle (FTP75, Cold Start)

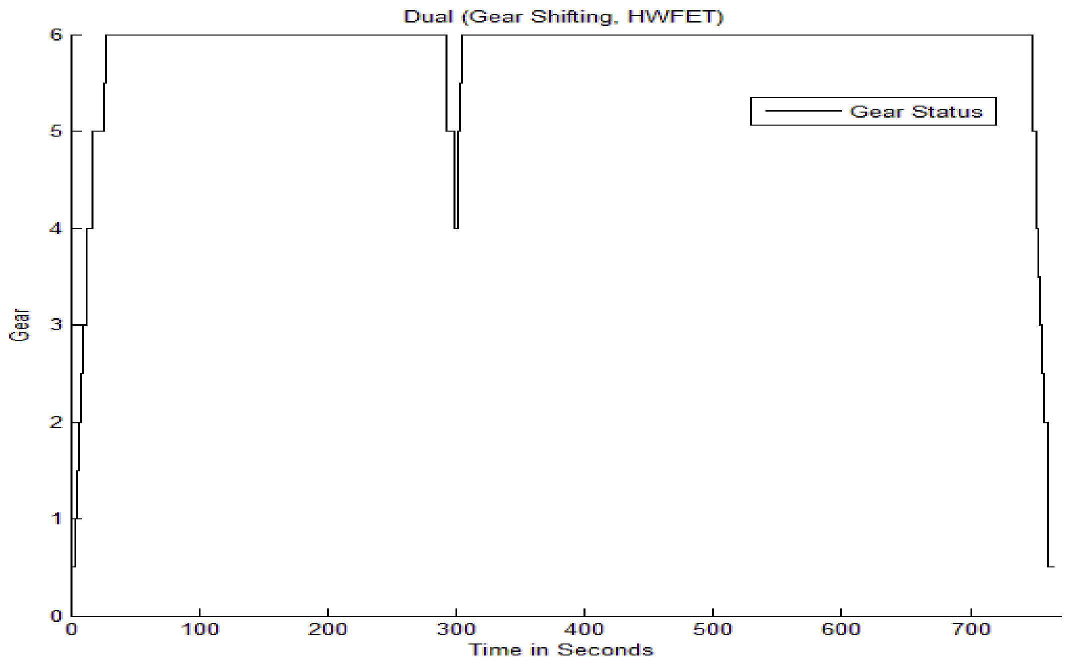

Figure 6.27. Gear-shifting for Dual Clutch Transmission Conventional Vehicle (HWFET)

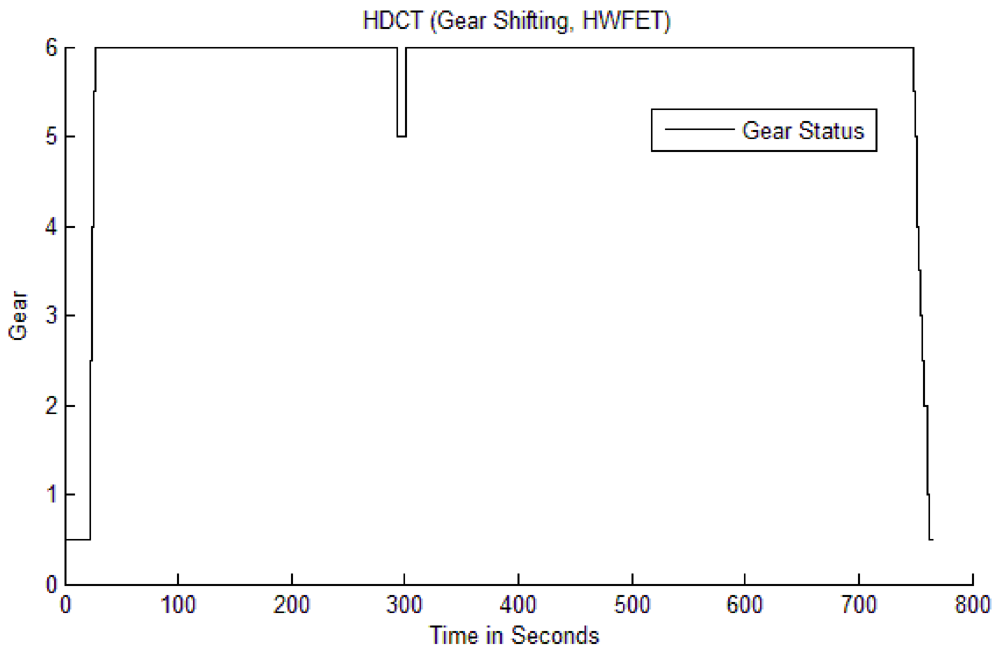

Figure 6.28. Gear-shifting for Dual Clutch Transmission Hybrid Vehicle (HWFET)

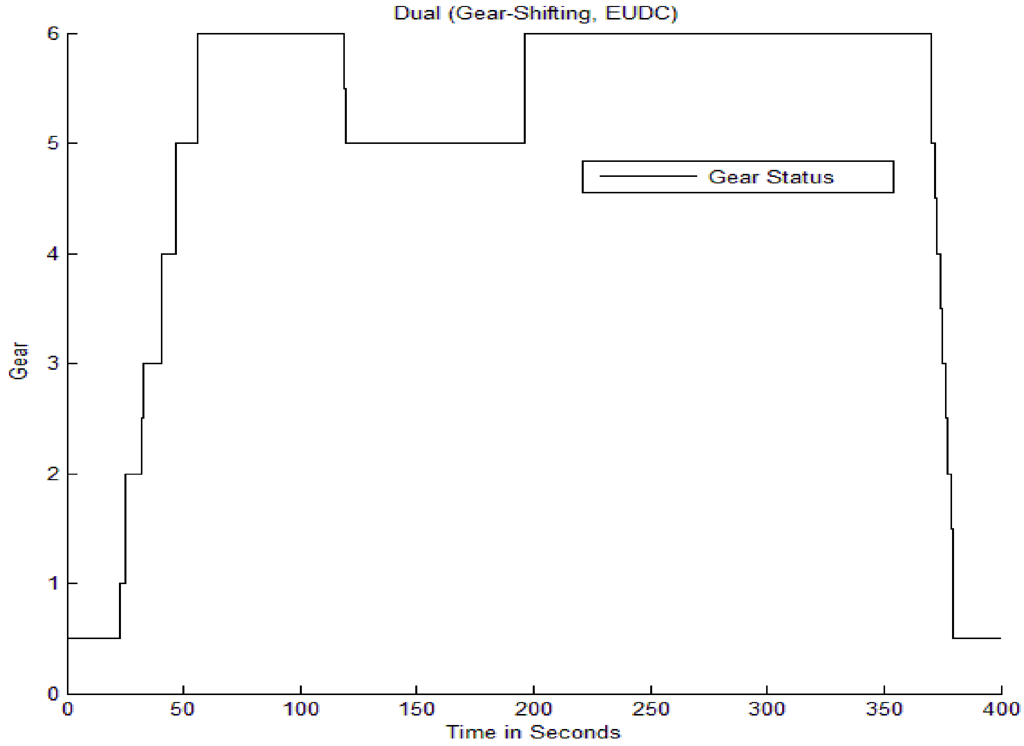

Figure 6.29. Gear-shifting for Dual Clutch Transmission Conventional Vehicle (EUDC)

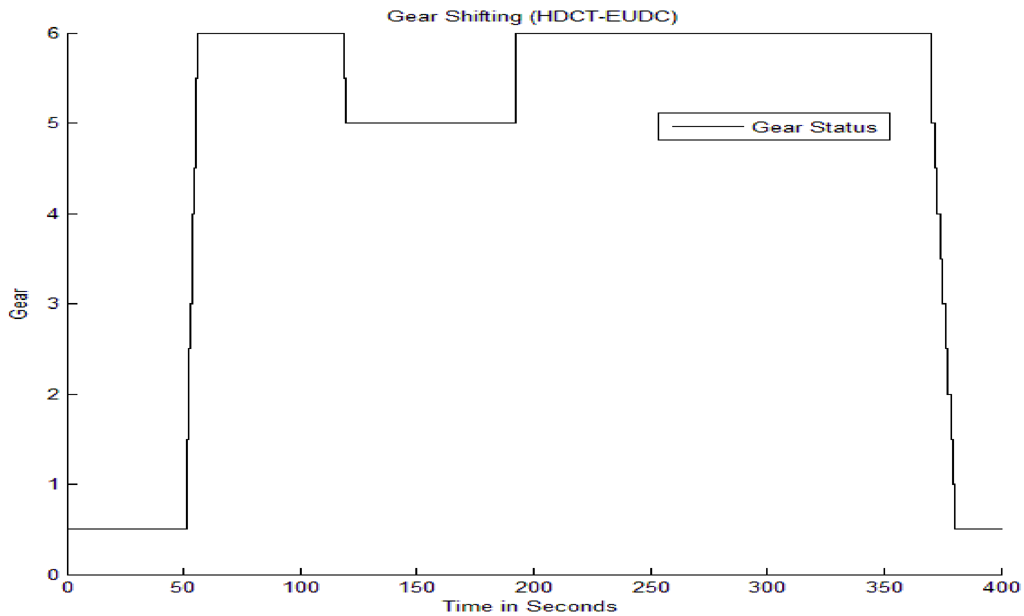

Figure 6.30. Gear-shifting for Dual Clutch Transmission Hybrid Vehicle (EUDC)

The important parameter that has a big influence in investigating and comparing the performance of Hybrid Electric Vehicle and Hybrid Electric Vehicle with Dual Clutch Transmission is the state of charge. In figures 6.31., 6.32., and 6.33., comparison between the mentioned two model, in terms of state of charge for the same drive cycle. The state of charge is one of the main factors of controlling the behavior of the vehicle according to the limits assigned in the battery controller. Maintaining the state of charge level is important in order to provide an efficient and robust driving behavior, along with adjusting the control system and the modes to retain the original desired value. In chapter 7, the discussion on the results obtained will be withdrawn to investigate the reasons behind those behaviors.

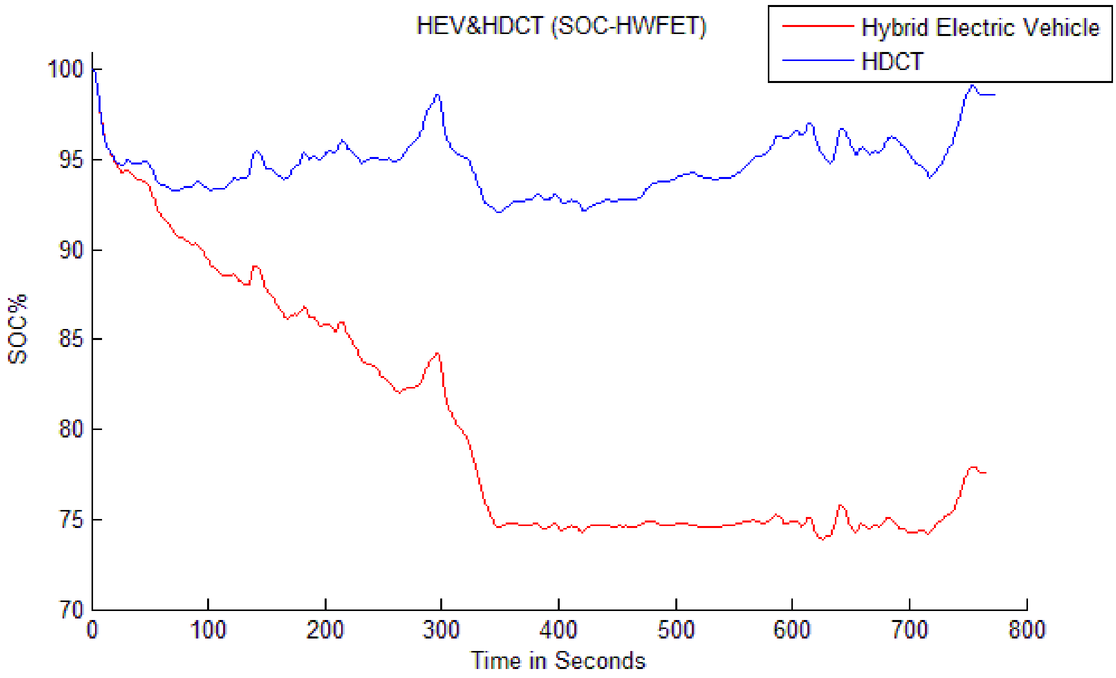

Figure 6.31. State of Charge comparison for HDCTV and HEV (HWFET)

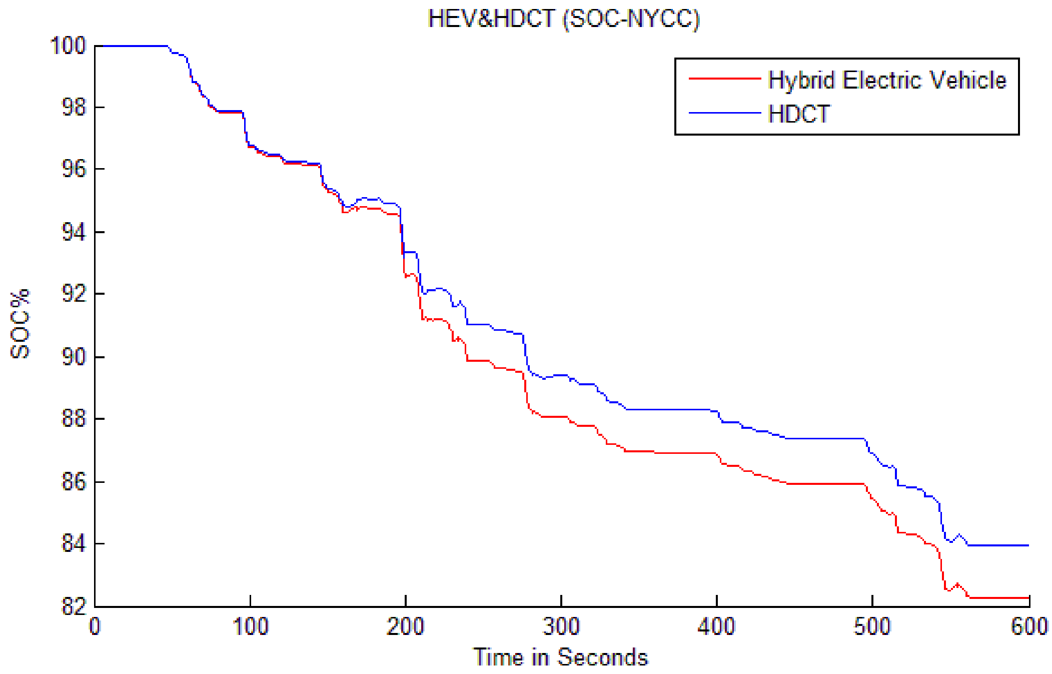

Figure 6.32. State of Charge comparison for HDCTV and HEV (NYCC)

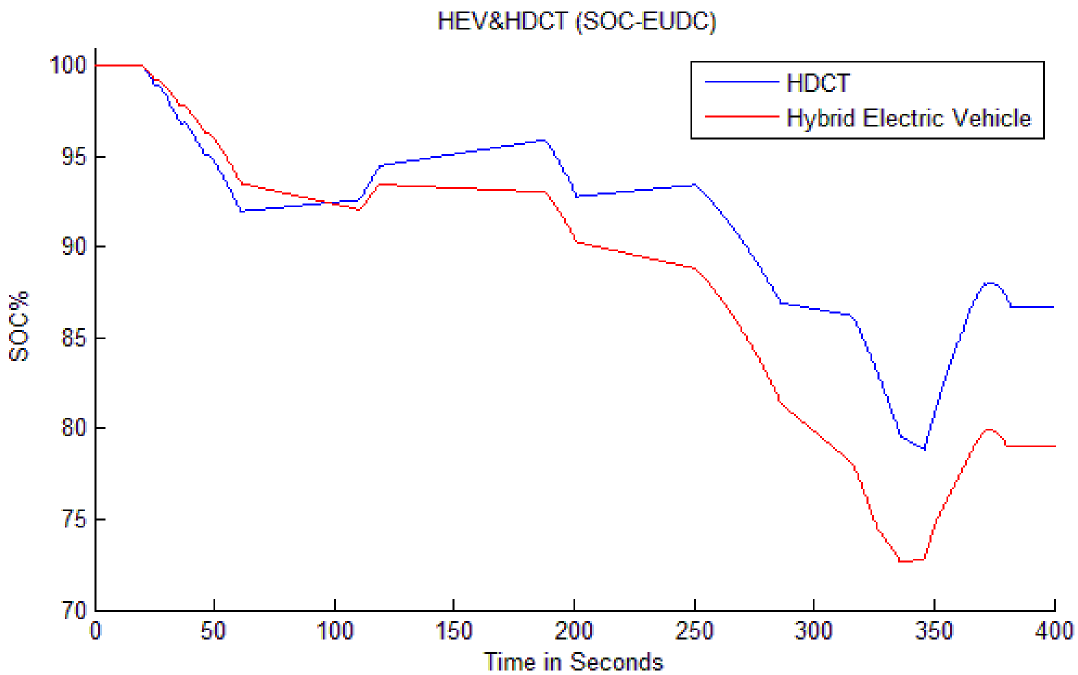

Figure 6.33. State of Charge comparison for HDCTV and HEV (EUDC)

7. DISCUSSION AND CONCLUSION

In this first division of this chapter, discussion upon the simulation results in chapter 6 is withdrawn and in the second one, conclusion will be stated.

7.1 Discussion about the comparison between HDCTV, HEV and DCTV

In the previous chapter, tests were done on the three models discussed in this thesis, Series-Parallel Hybrid Electric Vehicle, Conventional Dual Clutch Transmission Vehicle, and Hybrid Electric Vehicle with Dual Clutch Transmission. They were performed using four standard drive cycles; Federal Test Procedure, New York City Cycle, Extra Urban Driving Cycle and Highway Fuel Economy Test. The purpose was to investigate the performance of both models. Moreover, the Fuel-Economy and fuel consumption rates, which will affect the comparison between both models. Regarding the speed performance, as shown in figures 7.1, 7.2, 7.3, and 7.4, the results were acceptable, as there is a slight difference between the obtained and original drive cycle performance for the three models. However, the Hybrid Electric Vehicle with Dual Clutch Transmission model is better than the two other models in matching the referenced drive cycle.

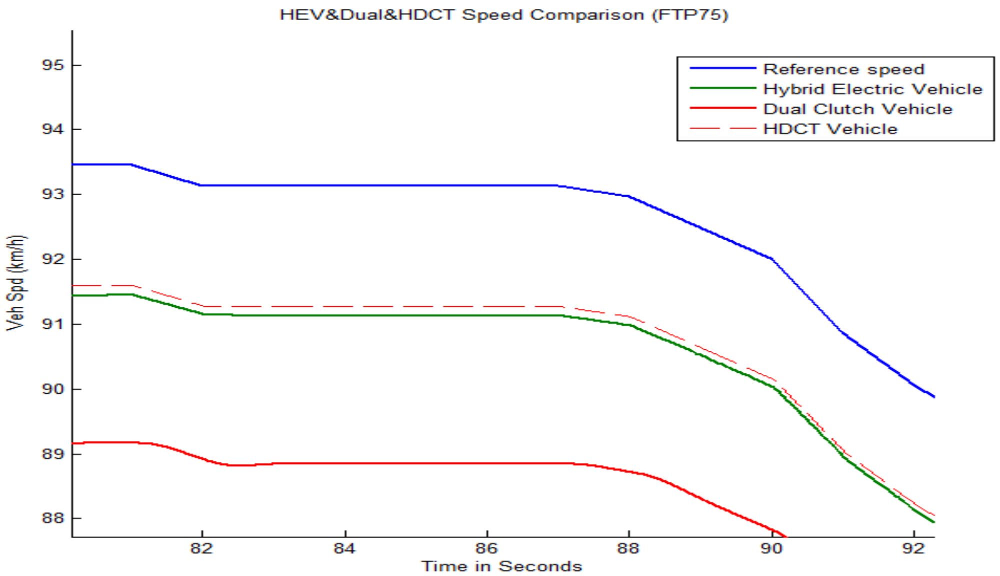

Figure 7.1. Chosen section of comparison between the three models, as (FTP75, Cold Start) is the reference drive cycle

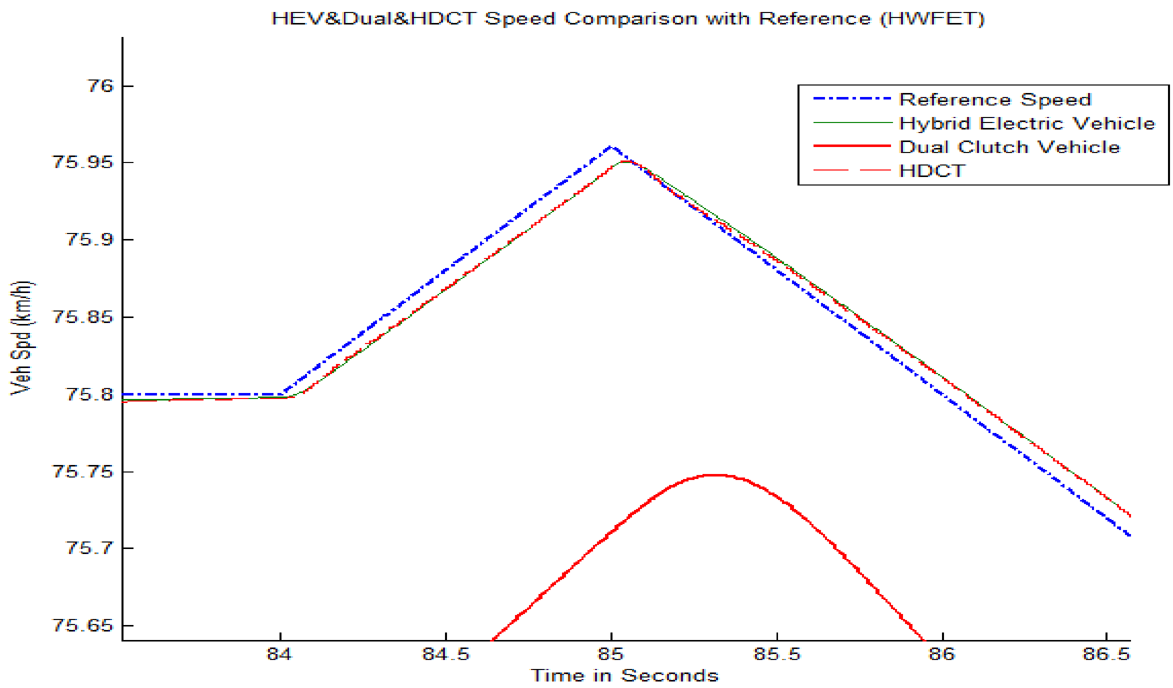

Figure 7.2. Chosen section of comparison between the three models, as (HWFET) is the reference drive cycle

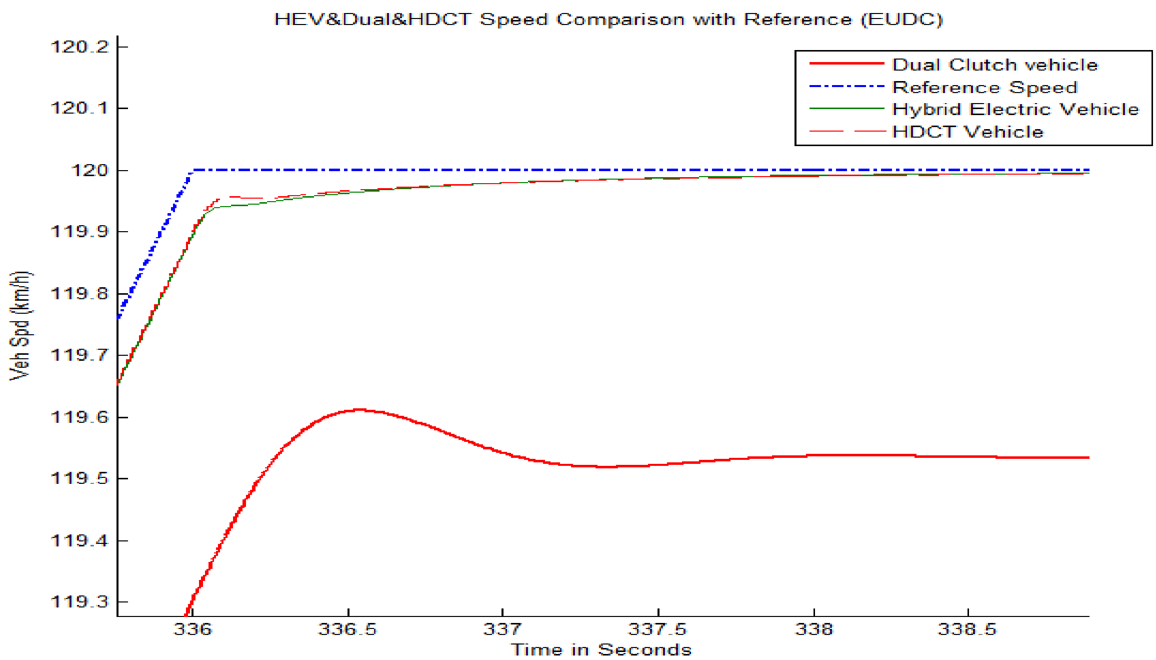

Figure 7.3. Chosen section of comparison between the three models, as (EUDC) is the reference drive cycle

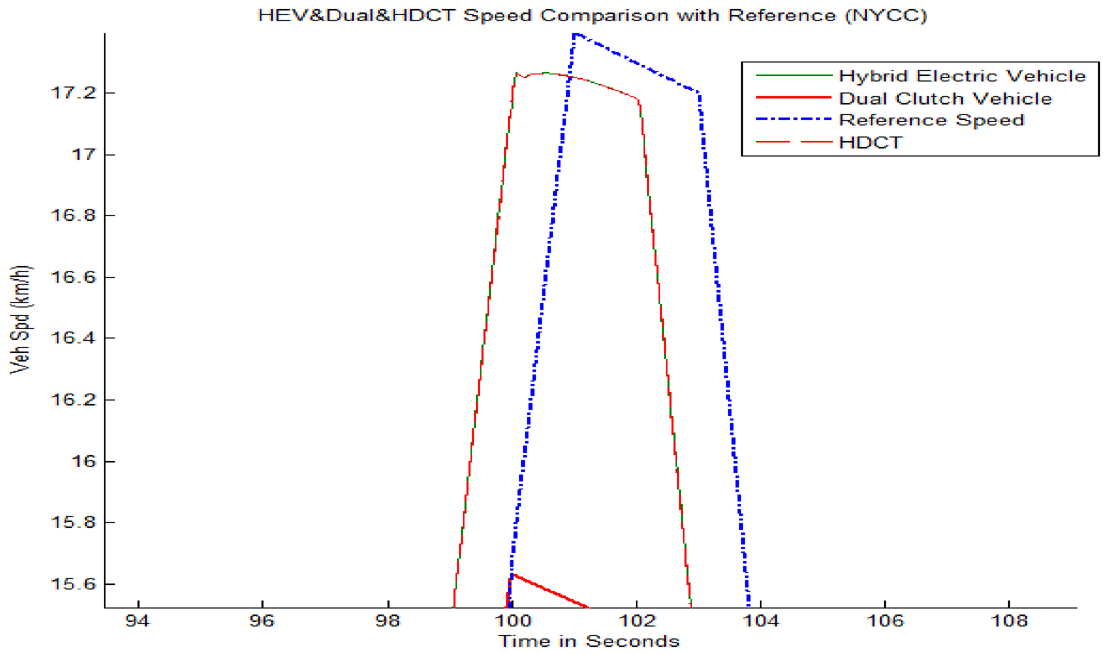

Figure 7.4. Chosen section of comparison between the three models, as (NYCC) is the reference drive cycle

Table 7.1 shows the comparison between the fuel consumption in the three models. The comparison is done via the number of kilometers run using one liter of fuel. The Fuel-Economy is better in case of Hybrid Electric Vehicle with Dual Clutch Transmission than the other two models. That is due to compact size of the Dual Clutch Transmission inside the Hybrid Electric Vehicle model. Moreover, the regenerative braking process, which improves the Fuel-Economy efficiency, as it uses the electric motor to implement it without the need for conventional braking process using the engine. It was discussed in [44] by Wu G. et al., that the smaller and more compact the components of the model, the more Fuel-Economy results you will achieve.

Table 7.1. Fuel consumption comparison

Drive Cycle	Fuel Consumption (HDCTV/HEV/DCTV)
FTP75	(14.201/10.2/7.503) (km/L)
NYCC	(10.32/9.979/7.248) (km/L)
HWFET	(55.01/22.02/13.39) (km/L)
EUDC	(33.04/23.56/19.82) (km/L)

Regarding the comparison, between the Hybrid Electric Vehicle with Dual Clutch Transmission and Hybrid Electric Vehicle without Dual Clutch Transmission, in terms of state of charge level, it is obvious that the first one is much more efficient and meets better levels than the second does. It is devised that the losses, which caused inside the Hybrid Electric Vehicle model without the Dual Clutch Transmission by the two motors inside the design in the power-split architecture. Varied gear ratio, according to the connections offered by Dual Clutch Transmission inside the Hybrid Electric Vehicle, is allowing the motor to work in its ultimate efficiency according to the transmission controller characteristics. Therefore, the battery is depleted quicker in case of the power-split architecture without Dual Clutch Transmission.

A gear-shifting behavior comparison between Dual Clutch Transmission inside Hybrid and Conventional architectures is shown in figures 7.5., 7.6., and 7.7. for several drive cycles. As discussed in [43], the gearshift in hybrid vehicles is depending on the torque commands coming from the internal combustion engine and the motor, which are eliminated to let the dog clutches inside the Dual Clutch Transmission to disengage. Then, the Transmission Control unit is responsible for shifting into the next gear position according to the signals coming from the speed controls of the engine or the motors, as mentioned in subdivision 5.3.1. The first priority is to achieve the minimum time possible to perform the gear-shifting process.

On the other hand, the Conventional Vehicle; it can be seen that the gear shifts are done earlier from the first gear along to the higher gears, and that is because the primary and only source of propulsion is the internal combustion engine, therefore there is no variety in propelling the vehicle as in Hybrid Electric Vehicle configuration.

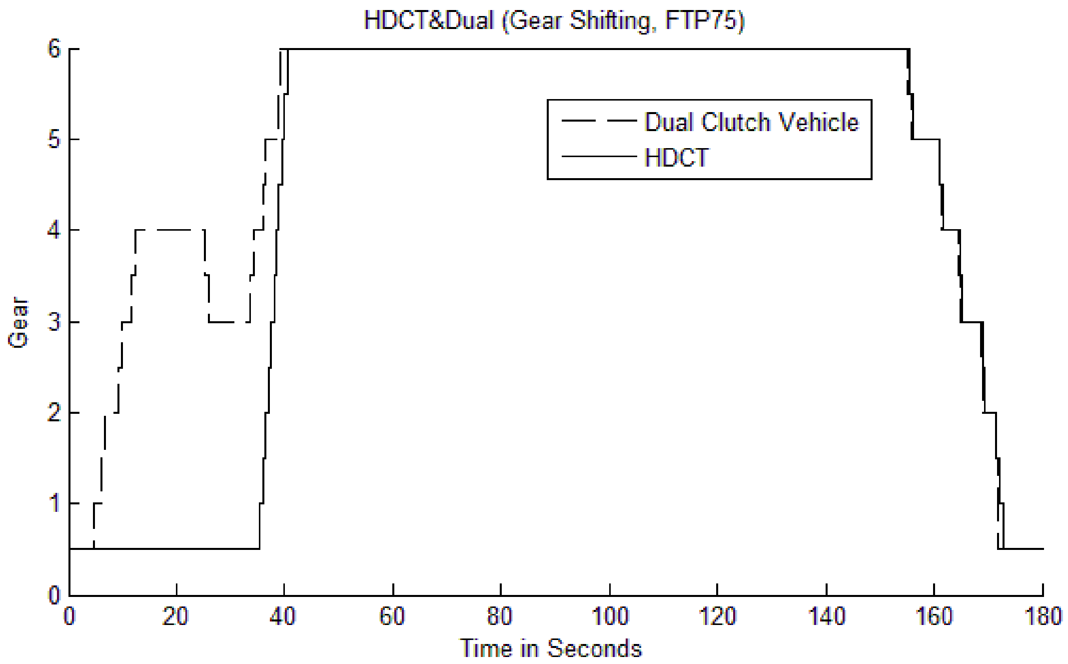

Figure 7.5. Gear Status comparison between HDCT&DCVT (FTP75, Cold Start)

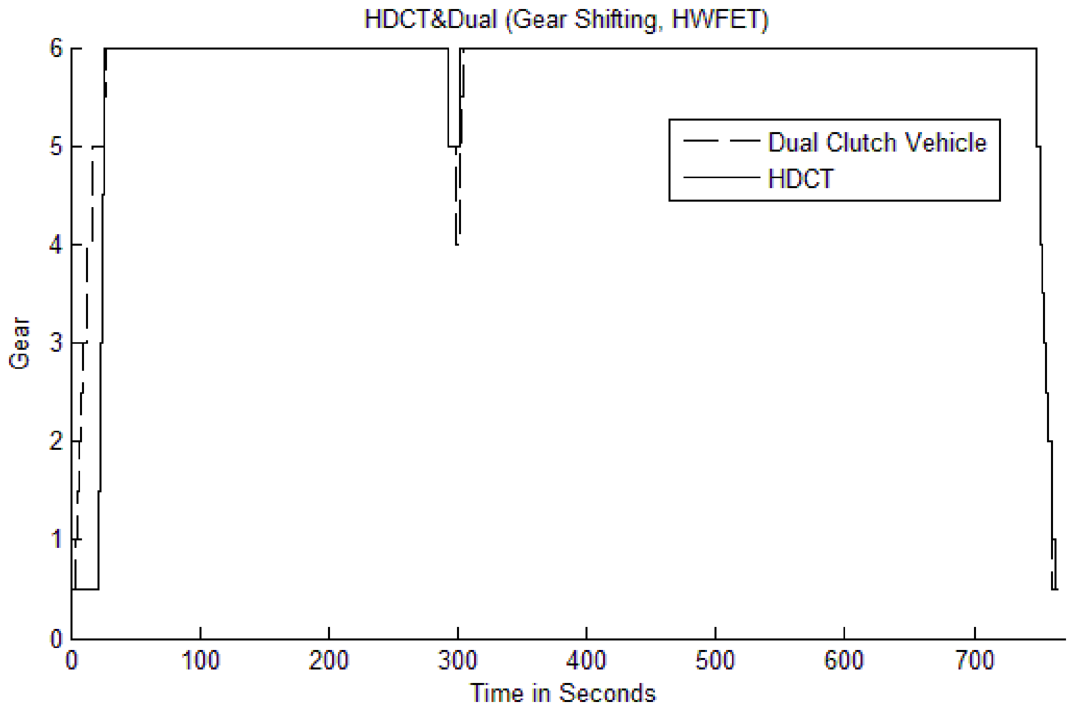

Figure 7.6. Gear Status comparison between HDCT&DCVT (HWFET)

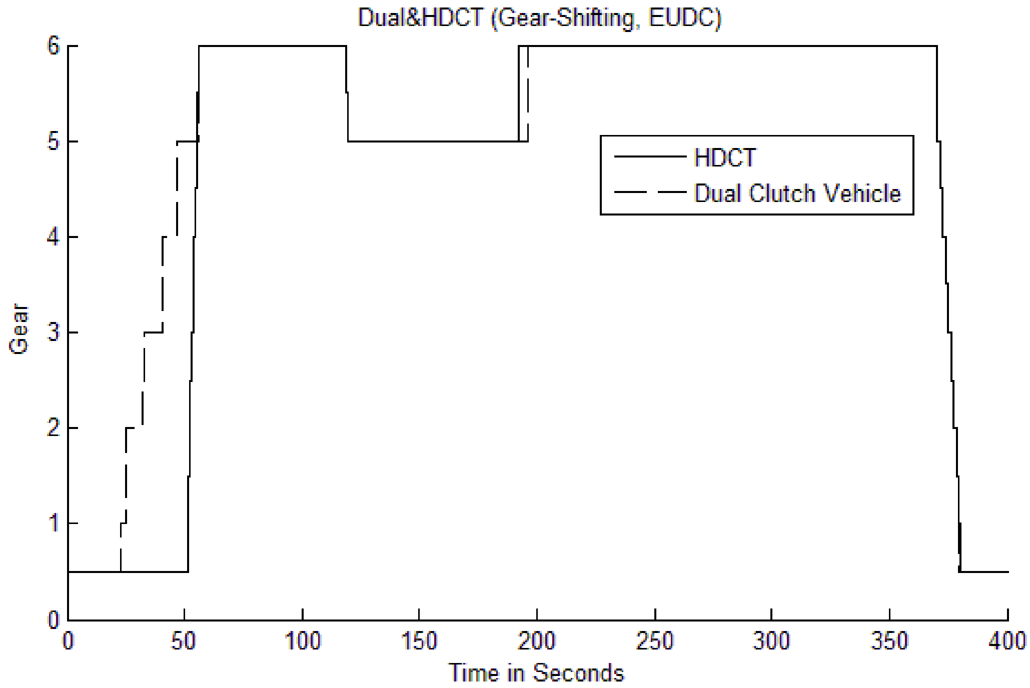

Figure 7.7. Gear Status comparison between HDCT&DCVT (EUDC)

7.2 Conclusion

After the comparison between Hybrid Vehicle model with and without Dual Clutch Transmission and Dual Clutch Transmission Conventional Vehicle model, it is obvious that the Hybrid Electric Vehicle with Dual Clutch Transmission model is performing better than the other two models, in terms of following the reference speed of drive cycle, in the Fuel-Economy and state of charge perspectives. Moreover, the results obtained in this thesis is compatible and meeting the results obtained in [6] and [7].

The core of using a Dual Clutch Transmission inside Hybrid architecture in automotive industry is obviously successful in different aspects and it is showing reliability, effectiveness and economy-friendly conditions. Series-parallel (Power-Split) configuration for Hybrid Electric Vehicle architecture shows great flexibility in moving between the Electrical and the mechanical power links, and with having Dual Clutch Transmission, more Fuel-Economy and robust gear-shifting performance will be achieved. The fuel used in case of Dual Clutch

Transmission inside Hybrid architecture was 73.97% of the fuel used in the Hybrid Electric Vehicle architecture without Dual Clutch Transmission and Dual Clutch Transmission Conventional Vehicle for New York City Cycle.

Moreover, for Federal Test Procedure, Highway Fuel Economy Test and Extra Urban Driving Cycle, it was 71.82%, 40.02%, and 71.30%, respectively, for the same distance, which means that using Dual Clutch Transmission inside Hybrid architecture is more efficient and suitable, especially, in the crowded cities and high traffic situations. In addition, the Hybrid Electric Vehicle with Dual Clutch Transmission model is showing consistency, and the state of charge and gearshift status was appropriate according to the mode logic used in controlling the Hybrid Electric Vehicle.

Regenerative braking system used in the Hybrid Vehicle architecture saves the energy used to decelerate the vehicle, therefore, the energy amount required for braking and low-speed increases in the electrical mode without the engine friction presence, which consumes energy.

For more reliable simulation results, there are several actions can be taken in order to save energy, obtain the most efficient conditions, the vehicle can work in, and to achieve the most economic-friendly situation for the consumer.

First, the appropriate choose of architecture according to the routes and the daily driving behavior taken by the consumer. Second, the size of the internal combustion engine, which influences the fuel consumption and choosing the appropriate type of engine for most efficient propulsion. Third, the level of detail inside the Hybrid Electric Vehicle architecture. It is affecting the price and according to a study performed by Simpson A. et al. the battery and the control of State of Charge, besides the size of the engine and its type are key factors in selecting the Hybrid Electric Vehicle [39]. Finally, operating the internal combustion engine in its economic region is also vital to be managed in an optimal control structure.

8. KOKKUVÕTE JA EDASINE TÖÖ

Käesolevas diplomitöö uuringus käsitleti kolme autotööstuse struktuuri: topeltsiduriga käigukastiga seeria-paralleelstruktuuriga hübriidelektrisõiduk, topeltsiduriga käigukastiga võimsuslahutusega hübriidelektrisõiduk ja topeltsiduriga käigukastiga tavapärane sõiduk. 1. peatükk, sissejuhatus, käsitleb põhiteemat, uuringu põhjuseid, ülevaadet teemaga seotud varasematest panustest ja uuringutest ning põhipunkte, mida diplomitöö käsitleb. 2. peatükis antakse üksikasjalik ülevaade käigukastide struktuuridest, hübriidsõidukite erinevatest struktuuridest ning iga alajaotuse lõpus esitatakse alajaotuse kokkuvõte. 3. peatükis käsitletakse topeltsiduriga käigukastiga tavapärast sõidukimudelit, esmalt erinevaid varasemaid panuseid ja mudeli ülevaadet, seejärel selgitatakse topeltsiduriga käigukastiga tavapärase sõiduki mudelit ning seejärel topeltsiduri struktuuri erinevaid komponente, kasutades keskkondi SimDriveline ja MATLAB.

4. peatükis selgitatakse seeria-paralleelstruktuuriga hübriidelektrisõidukeid, kasutades võimsuslahutuse kontseptsiooni koos planetaarmehhanismiga. Esmalt antakse ülevaade varasematest panustest ja praegusest mudelist, seejärel selgitatakse juhtrežiime ja sõiduki komponente. 5. peatükis selgitatakse hübriidelektrisõiduki mudelit, mis hõlmab kaht elektrimootorit ja topeltsiduriga käigukasti. 6. peatükis esitatakse katsed, mis tehti kolme eelmainitud mudeliga, kasutades nelja standardset sõidutsüklit, samuti esitatakse simulatsioonitulemused, mille eesmärk oli uurida kiirusvõimeid ja kütusetõhusust. 7. peatükis esitatakse simulatsioonitulemustel põhinev arutelu: selgitatakse erinevusi kolme mudeli jõudluse, kütusekulu, käiguvahetuse ja laadimise oleku vahel. Lõpetuseks arutatakse 8. peatükis esitatud mudelite arenduse ja edasise töö võimalusi.

Simulatsioonitulemused olid rahuldavad ja, nagu varem mainitud, vastasid sama teema kohta hiljuti läbiviidud uuringute tulemustele. Kuid edasine eesmärk on mudelite modifitseerimine ja häälestamine, et saavutada sõidutsüklites paremini ühtivad tulemused. Peale selle annab mudelite katsetamine erinevates sõidutsüklites aimu praeguste mudelite nõrkadest kohtadest, et saaks ehitada paremad juhtseadised ja komponendid. Praeguste tulemuste põhjal saab arutleda uuringute üle parema kütusetõhususe saavutamiseks, töötades välja innovaatilised ja põhjalikud strateegiad.

Paljudes eelnevates uuringutes on viidud läbi erinevaid katseid, nagu mitme käigukastistruktuuri väljatöötamine erinevates hübriidelektrisõidukite arhitektuurides, et vaadelda ja uurida, kui mõjuv võiks olla nendevaheline võrdlus seoses jõudluse ja kütusetõhususega. Kuid parema jõudluse saavutamiseks on vaja välja töötada palju kompaktsemad mootorid ja käigukastid. Osas [40] viidi topeltsiduriga käigukastiga laetava hübriidelektrisõidukiga läbi energiahaldusuuring, mis põhines kütusetõhususel, kasutades keskkonda MATLAB/Simulink, milles modelleeriti kõik mudelis olevad komponendid.

Osas [45] töötati välja 7-käiguline topeltsiduriga käigukast tehnoloogia SPORT HYBRID i-DCD jaoks ja selgitati, kui olulised on sõiduelamuse suurendamiseks ning kütusetõhususe tagamiseks kompaktsus ja energiahaldus.

Lisaks on automaatkäigukasti ja hübriidsõiduki struktuuris oleva topeltsiduriga käigukasti edasine võrdlus samm edasi selge nägemuse saamisel topeltsiduriga käigukasti kasutamise tõhususe ja mõju kohta hübriidstruktuuris, olenemata sellest, kas see ühendab mõlema mudeli eeliseid või mitte. Seda saab teha, võrreldes käigukaste erinevates sõidutsüklites. Järgmises etapis saab läbi viia HIL-katse koos edasiste katsetega, kasutades muid sõidutsükleid, et saada reaalsemad ja täpsemad tulemused, mis võivad mudelite jaoks olla usaldusväärne kinnitus

9. SUMMARY AND FUTURE WORK

In this thesis research, three different automotive architectures were discussed, Series-Parallel Hybrid Electric Vehicle with Dual Clutch Transmission, Power-Split Hybrid Electric Vehicle without Dual Clutch Transmission and Conventional Vehicle with Dual Clutch Transmission architecture. In Chapter 1, introduction was withdrawn to the main topic, the motivation behind the research, overview on the previous contributions and researches related to the topic, the main points, which would be covered in the thesis. Then in chapter 2, detailed review over the Transmission architectures, the Hybrid Vehicles several architectures, and summary of each subdivision in its end. In chapter 3, Dual Clutch Transmission in Conventional Vehicle model was discussed, first with different previous contributions and overview on the model, then explaining the Conventional Vehicle model containing the Dual Clutch Transmission, then presenting different components of the Dual Clutch architecture with the help of SimDriveline and MATLAB environment.

In Chapter 4, Hybrid Electric Vehicle with Series-Parallel architecture using Power-Split concept with planetary gear was explained, first with previous contributions and overview of the current model, then explaining in details the control modes and the component of the vehicle. In chapter 5, Hybrid Electric Vehicle model including two Electric Motors, and Dual Clutch Transmission was developed. In Chapter 6, the tests performed on the three models were presented using four standard drive cycles, and simulation results was withdrawn, in order to investigate the speed performance and fuel efficiency. In chapter 7, discussion upon the presented simulation results was withdrawn; the differences between the three models' performances, fuel consumption, gear-shifting and state of charge were clarified. Finally, in chapter 8, it is needed to discuss the possibilities of future work and development to the current model cases.

The simulation results were satisfying and as mentioned before, it met the results of recent studies in the same perspectives. However, the future objective is modifying, and tuning within the models to have better, matching results with the drive cycles. Moreover, testing the models with more different drive cycles will give indications about the weak points of the current models, in order to have better designed controllers and components. Study on more Fuel-Economy achievement by devising innovative and thoroughgoing strategies can be discussed according to the current results.

Many previous researches did several experiments, including developing several transmission architectures inside different Hybrid Electric Vehicles' architectures in order to examine and investigate how influential the comparison between them in terms of performance and fuel efficiency will be. However, the development of much more compact designs of motors, transmissions and engines is vital to have a better performance. In [40], energy management study was performed on a Dual Clutch Transmission based Plug-in Hybrid Electric Vehicle, with respect to vehicle Fuel-Economy, using MATLAB/Simulink environment to model all the components inside that model.

In [45], 7-speed Dual Clutch Transmission for SPORT HYBRID i-DCD was developed and explained in details, how important and vital the compactness and the energy management for enhancing the driving experience and fuel efficiency.

In addition, future comparison of Automatic and Dual Clutch Transmission inside Hybrid Vehicle architecture is a step towards having a concrete image and vision about the effectiveness and the influence of the transmission inside the Hybrid architecture can be, whether it will combine the advantages of both models or not. This can be done by comparison between them using different drive cycles. In the next step, HIL testing can be performed, along with further tests using other drive cycles to provide much more realistic, accurate results, which can be a reliable verification of the models.

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11. APPENDENCES

Appendix 1

Vehicle	Volkswagen Golf R
Mass	1515 kg
Frontal Area	3.1 m^2
Tire Radius	0.4572 m
Drag Coefficient	0.32
Final Drive Ratio	4.24

Appendix 2

Vehicle	Ford Escape
Mass	1500 kg
Frontal Area	3.63 m^2
Tire Radius	0.3 m
Drag Coefficient	0.36
Final Drive Ratio	3.92