ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

MODELLING, VALIDATION AND INTEGRATION OF STOP/START SYSTEM FOR 1,5L DİESEL ENGİNE

M.Sc. THESIS

Abdulehad ÖZDEMİR

Department of Mechatronics Engineering

Mechatronics Engineering Programme

Thesis Advisor: Prof. Dr. Ata MUĞAN

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

STOP/START SİSTEMİNİN MODELLENMESİ, DOĞRULANMASI VE 1.5 L DİZEL MOTORA ENTEGRASYONU

YÜKSEK LİSANS TEZİ

Abdulehad ÖZDEMİR
(518111001)

Mekatronik Mühendisliği Anabilim Dalı

Mekatronik Mühendisliği Programı

Tez Danışmanı: Prof. Dr. Ata MUĞAN

MAYIS 2013

Abdulehad Özdemir, a **M.Sc.** student of ITU **Institute of / Graduate School of Science Engineering and Technology** student ID **518111001**, successfully defended the **thesis/dissertation** entitled "**MODELLING, VALIDATION AND INTEGRATION OF STOP/START SYSTEM FOR 1.5 L DIESEL ENGINE**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Prof. Dr. Ata Muğan** Istanbul Technical University	....
Jury Members :	**Prof. Dr. Şeniz Ertuğrul Fıçıcı** Istanbul Technical University	....
	Doç. Dr. Serdar Barış Istanbul University	....

Date of Submission : 26 April 2013
Date of Defense : 3 June 2013

To my family,

FOREWORD

I am really greatful to my advisor, Prof. Dr. Ata Mugan for his guidence in my thesis. I am also greatful to Ford Otosan, the owner of the project. I would like to acknowledge Yigit Koyuncuoğlu who provided support for the thesis. Special thanks to my family for their encouragement and support.

April 2013

Abdulehad Özdemir
(Mechanical Engineer)

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ABBREVIATIONS

ABS	:Antilock Braking System
ADS	:Assisted Direct Start
AT	:Automatic Transmission
BCM	:Body Control Module
CoM	:Change of Mind
DTC	:Diagnostic Trouble Code
e	:Axis Misalignment
ECU	:Electronic Control Module
ERR	:Engine Run Request
ESP	:Electronic Stability Program
FB	:Vehicle Acceleration Force
FE	:Fuel Economy
FL	:Aerodynamic Force
FR	:Rolling Resistance
Fst	:Inclination Force
FT	:Tractive Force
FTP	:Federal Test Procedure
Fx	:Wheel force
Fz	:Road reaction force
HS	:High Speed
ICE	:Internal Combustion Engine
JT	:Wheel inertia
MT	:Manual Transmission
$\mathbf{m_w}$	:Mass of the of the wheel
NEDC	:New European Drive Cycle
PWM	:Pulse Width Modulation
S/S	:Stop Start
SAE	:Society of Automotive Engineers
SID	:Stop-in-Drive
SIG	:Stop-in-Gear
SIN	:Stop-in-Neutral
$\mathbf{W_T}$	:Wheel torque
v	:Vehicle speed
VQM	:Voltage Quality Module
X	:Reaction force of the vehicle
Z	:Vehicle weight force

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STOP/START SYSTEM INTEGRATION TO 1.5L DIESEL ENGINE, SYSTEM MODELLING AND VALIDATION

SUMMARY

Because of high fuel prices and related emission regulations, electric and hybrid vehicles become more important nowadays. For electric vehicles, it is difficult to establish a market presence in near future due to range and price handicaps. At the present time, hybrid and micro-hybrid systems became widespread due to fuel economy benefit and environmental concerns. Micro-Hybrid systems such as Regenerative Braking and Stop/Start system are commonly used in automotive industry. Stop/Start system automatically shuts down and restarts the internal combustion engine to reduce the amount of time that the engine spends in idling, thereby reducing fuel consumption and emissions.

Stop start system is in relationship with other vehicle systems. In addition, subsystems in the S/S system are in relationship with each other. There are inputs to the S/S system from other vehicle systems and the S/S subsystems are in relationship with each other. Stop/Start system requires some special components regarding to their functionality and durability. Most important components for Stop/Start system are enhanced battery, enhanced starter motor, voltage quality module, gear neutral sensor and bi-directional crankshaft position sensor.

The calibrators have constraints because of safety and driver comfort. Scheduler calibration provides safety and comfort for the S/S events. The subsystems such as gear neutral sensing subsystem, restraints subsystem, pedals subsystem, brakes subsystem, steering subsystem, power supply subsystem, engine cranking subsystem, base engine subsystem, locking subsystem, climate control subsystem, engine control module, central electrical module were inspected for control algorithm. The outputs of the S/S system was defined as the stop inhibition, engine run request, system-induced automatic restarts, stop abortion, start inhibitor, stall recovery and S/S deselection, S/S deactivation.

For Performance & Emission tests, an engine dynomometer was used. For emission and fuel consumption model, engine-mapping data is used. The NEDC is used for certification tests. The NEDC is a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars.

The mathematical model was developed which allows to have an idea about fuel consumption and S/S system benefit. Fuel consumption and CO_2 emission model contains base map selection submodel, engine torque calculation, engine speed calculation, the S/S system submodel, CO_2 emission calculation. This simulation was used to calculate approximate fuel consumption data. Finally, simulation results indicate the fuel consumption benefit of the S/S system is 0.165 l/100 km, which was measured as 0.16l /100km.

STOP/START SİSTEMİNİN MODELLENMESİ, DOĞRULANMASI VE 1,5L DİZEL MOTORA ENTEGRASYONU

ÖZET

Otomatik Stop/Start sistemi ile aracın rölantide beklediği kısımlarda içten yanmalı motoru durdurarak yakıt tasarrufu sağlanır. Böylece içten yanmalı motoru rölantide tutmak için püskürtülen yakıttan tasarruf edilmiş olur. Stop/Start sistemi için farklı stratejiler de mevcuttur. Otomatik şanzımanlı araçlarda motorun otomatik olarak durması için aracın duruyor olması ve kullanıcının fren pedalına basıyor olması gerekmektedir. Kullanıcı fren pedalını bırakınca motor otomatik olarak başlatılmaktadır. Manuel vitesli araçlarda iki farklı strateji kullanılmaktadır. Viteste durdurma stratejisinde motorun durdurulması için aracın duruyor olması ve depriyajın basılı olması gerekmektedir. Aracın viteste olup olmaması bu strateji için önemli değildir. Kullanıcı depriyaj pedalını bırakmaya başladığı anda motor otomatik olarak çalıştırılır. Bu projede kullanılan yöntem ise boş viteste durdurma stratejisidir. Bu strateji ile motorun otomatik durdurulabilmesi için aracın duruyor olması, boş vitesin seçilmiş olması ve debriyaj pedalının basılı olmaması gerekmektedir.

Stop/Start sistemi araçta dayanım ve işlevsellik yönünden bazı özel bileşenler gerektirir. Bunlar güçlendirilmiş marş motoru, güçlendirilmiş akü, gerilim kalite modülü, vites konum sensörü ve çift yönlü krank mili pozisyon sensörü olarak listelenebilir. Güçlendirilmiş marş motoru ve güçlendirilmiş batarya sistemleri motorun çok fazla sayıda dur kalk yapmasına olanak sağlar. Konvensiyonel bir marş motoru ve akü 40.000-50.000 kez marş yaparken, güçlendirilmiş marş motoru ve akü ile bu sayı 200.000'in üzerine çıkarılmıştır. Bu proje kapsamında hazırlanan kalibrasyon ile bu sistemler test edilmiş ve 230.000 olan marş yapma hedefi başarılmıştır. Gerilim kalite modülü sürücü ve yolcu konforu için önemli bir sistemdir. Otomatik marş esnasında marş motoru aküden çok fazla akım çektiği için akü gerilimi anlık olarak düşer. Bu da radyo, silecekler, farlar gibi sistemlerin anlık olarak durmasına sebep olabalir. Bu durumun önüne geçmek için bir DC/DC dönüştürücü gibi çalışan gerilim kalite modülü kullanılır. Bu modül otomatik marş sırasında gerilim seviyesini istenen değerde tutarak kullanıcının daha az etkilenmesini sağlar. Vites konum sensörü PWM çıkış veren bir sensördür. Çalışma prensibi manyetik alan ölçümüne dayalıdır. Vites kutusu üzerinde bulunur. Tek vitesler ve geri viteste %20 civarı PWM çıkış alınırken, çift viteslerde %80 civarı PWM çıkış alınır. Vites boşta olduğunda ise %50 civarı bir PWM çıkış alınır. Alt ve üst limit değerleri kalibre edilerek hangi aralıkta vitesin boşta olduğu kalibrasyoncu tarafından belirlenir. Bu değerler bileşenlere ve vites kutusuna göre değişebilir. Çift yönlü krank mili pozisyon sensörü, motorun durması esnasındaki krankın çift yönlü hareketini algılamak için kullanılır. Bu sensör motorun dönüş yönü ve dönme miktarı hakkında bilgi verir. Böylece motor durduğunda piston konumları tam olarak bilinmiş olur.

Stop/Start sisteminde güvenlik ve konfor açısndan kalibrasyoncular için sınır şartları vardır. Stop/Start sistemi bir çok sistem ile ilişki içindedir. Stop/Start sisteminin alt sistemleri boş vites algılama sistemi, sürücü varlığı algılama sistemi, pedal sistemi, fren sistemi, direksiyon sistemi, güç kaynağı sistemi, motor kontrol modülü, klima kontrol sistemi ve kullanıcı-makina arayüzü olarak listelenebilir. Bu sistemler tek tek incelenip güvenlik ve konfor göz önüne alınarak Stop/Start sistemi kontrol algoritması oluşturulmuştur. Boş vites algılama sistemi, algılayıcıdan gelen çıkışa göre vitesin boşta olup olmadığını algılayan sistemdir. Sürücü varlığını algılamak için emniyet kemerinin takılı olup olmadığı ve sürücü kapısının durumu incelenir. Güvenlik açısından sürücü araçta değilken otomatik start yapılmamalıdır. Pedal sistemi, gaz ve depriyaj pedalının konumunu algılayıp buna göre Stop/Start sisteminin davranışını belirler. Gaz pedalı veya debriyaj pedalı basılı ise motor durdurulmaz. Fren sistemi güvenlik açısından önemlidir. Fren vakumu referans değerin altına düşerse Stop/Start sistemi engellenir ve motor duruyorsa otomatik olarak çalıştırılır. Referans fren vakum değeri sistem bileşenlerine göre girilir. Direksiyondan gelen sinyaller ile manevra yapılıp yapılmadığı kontrol edilir. Eğer direksiyon torku referans değerden büyükse motorun durdurulmasına izin verilmez. Bazı ağır ticari araçlarda direksiyon açısı da göz önüne alınır. Direksiyon açısı referans değerden büyük ise motor durdurulmaz. Akü şarj seviyesi de Stop/Start sistemi için göz önüne alınır. Akü şarj seviyesi için de referans değerler vardır. Klima, termal konfor için önemli bir sistemdir. Stop/Start sistemine klima kontrol sisteminden gelen girişe göre Stop/Start özelliği devre dışı bırakılabilir. Klimanın açık olduğu süre boyunca sistemin devre dışı bırakılabileceği gibi evaparatör sıcaklığı ve hedef sıcaklık değeri de göz önüne alınabilir. Kullanıcı arayüzü ise sistem hakkında bilgi vermek ya da sürücüye direktif vermek için kullanılır.

Performans ve emisyon testleri için motor dinamometresi kullanılmıştır. Motor dinamometresinde farklı çalışma noktaları taranarak motor haritası oluşturulmuştur. Bu haritalardan yakıt miktarı haritası, oluşturulan modelde look-up tablo olarak kullanılmıştır. Motor dinamometresinde haritalar oluşturulurken motorun tüm hız ve tork haritası taranmıştır. Buna karşılık gelen yakıt değerleri kaydedilmiştir.

Yakıt tüketimi ve karbondioksit emisyon modelinde NEDC (Yeni Avrupa Sürüş Çevrimi) giriş olarak verilmiştir. Yeni Avrupa Sürüş Çevrimi şehir içi ve otoban olmak üzere çeşitli kısımlardan oluşur.

Stop/Start sisteminin yakıt ekonomisi faydasını hesaplamak için bir model oluşturulmuştur. Modelin girişleri araç hızı, vites ve motor soğutma suyu sıcaklığıdır. Yakıt tüketimi modeli motor hızı, motor torku, baz harita seçimi gibi alt modelleri içermektedir. Araç hızından motor hızına geçmek için aks oranı, yuvarlanma yarıçapı, vites oranı değerleri kullanılmıştır. Motor torku hesabı için aracın hareket denklemleri yazılmıştır. Buradan sürtünme kuvvetleri, hava direnci kuvveti ve atalet kuvvetleri hesaplanmıştır. Araca etkiyen toplam kuvvet, yuvarlanma yarıçapı, aks oranı ve vites oranı kullanılarak motor momenti elde edilmiştir.

Dizel motorlarda enjeksiyon için genellikle farklı baz haritalar kullanılır. Bu haritalar motor suyu sıcaklığı ve araç hızına göre değişmektedir. Oluşturulan modelde araç hızı ve motor suyu sıcaklığına göre soğuk, ılık, sıcak yavaş ve sıcak hızlı olmak üzere 4 adet baz yakıt enjeksiyon haritası kullanılmıştır. Hesaplanan motor momenti, motor hızı ve seçilen baz haritaya göre enjeksiyon miktarı bulunmuştur. Tüm çevrim boyunca ayrık olarak hesaplanan yakıt miktarı entegre edilerek toplam yakıt miktarı bulunuştur. Strok başına enjeksiyondan toplam enjeksiyon miktarına geçmek için yapılan hesaplamalar bu kısımda anlatılmıştır.

Dizel yakıt belli bir kimyasal forma sahip değildir. $C_{12}H_{23}$ olarak kabul edilebilir. Bu kabul ile kimyasal tepkime dizel yakıtın tam yandığı varsayılarak yazılmış, kimyasala tepkime denkleştirilmiş ve giren yakıt miktarına göre çıkan karbondioksit hesaplanmıştır.

Modelde edilen sonuçlar test araçları ile şasi dinamometresinde elde edilen sonuçlar ile karşılaştırılmıştır. Şasi dinamometresinde ilk prototip araçlar ile Stop/Start özelliği açık ve kapalı testler yapılmıştır.

Oluşturulan model ile Stop/Start sisteminin yakıt tüketimine ve karbondioksit emisyonuna faydası incelenmiştir. Simulasyonda Stop/Start'ın yakıt tüketimine faydası 0.165 litre/100km olarak hesaplanırken yapılan testlerde bu değer 0.16 litre/100km olarak ölçülmüştür.

1. INTRODUCTION

The major challenges currently faced by the automotive industry such as the increasing fuel prices and the regulations on pollutant and CO2 emissions motivate the research and development of hybrid electric vehicles[1]. Because of high fuel prices and emission regulations, electric and hybrid vehicles become more important nowadays. For electric vehicles, it is difficult to establish a market presence in near future due to range and price handicaps. At the present time, hybrid and micro-hybrid systems became widespread due to fuel economy benefit and environmental concerns. Micro-Hybrid systems such as Regenerative Braking and Stop/Start system are commonly used systems in automotive industry.

Stop/Start system automatically shuts down and restarts the internal combustion engine to reduce the amount of time that the engine spends in idling, thereby reducing fuel consumption and emissions. This is most advantageous for vehicles, which spend significant amounts of time waiting at traffic lights or frequently come to a stop in traffic jams. Road vehicles with stop/start system are being produced by most of the automotive companies such as Ford, Citroen, BMW, Toyota, Renault, Mazda, Honda, Fiat Group, Volvo, Mahindra & Mahindra, Tata Motors, Opel, Kia, Hyundai, Volkswagen[2].

In addition, there is confusion about terminology. Stop/Start system takes part in literature as Stop/Start or Start/Stop. In this thesis, terminology used as Stop/Start because an auto start can be performed only after an auto stop. Stop/Start system is not mandatory for the first start. Due to these reasons, the terminology Stop/Start is used as the name of the feature that automatically stops the engine while idling for fuel economy benefit.

1.1 Stop/Start System

Stop/Start function is designed to improve fuel economy by automatically stopping the internal combustion engine (ICE), during idle phases when it is not required for motor power, and then restarting it when required.

Automatic engine stop and restart is affected by state machine-based control logic referred to as the start-stop scheduler, which is typically hosted within the engine control module (ECM) in the form of a software plug-in module. The scheduler is connected to a number of vehicle and powertrain signals, sensors and switches and schedules (decides) when to shut down and when to restart the engine, based on the particular stop/start strategy employed. Stop/start strategies can broadly be categorized as stop-in-neutral (SIN) and stop-in-gear (SIG) for manual transmissions; and stop-in-drive (SID) for automatic and auto-shift manual transmissions [3].

Figure 1.1 : A picture of ford fusion's cluster during a stop/start event [4].

Stop-in-neutral is a stop/start strategy applicable to manual transmissions. SIN logic stops the engine (subject to inhibitors) whenever the vehicle is stationary AND neutral is selected AND the clutch has been fully released. The engine is restarted on clutch pedal press in neutral [3].

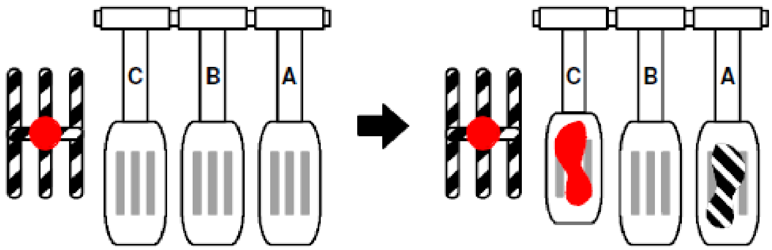

Figure 1.2 : SIN strategy.

Stop start system is in relationship with other vehicle systems. In addition, subsystems under S/S system are in relationship with each other. As seen below, there are inputs to S/S system from other vehicle systems and S/S system subsystems are in relationship with each other.

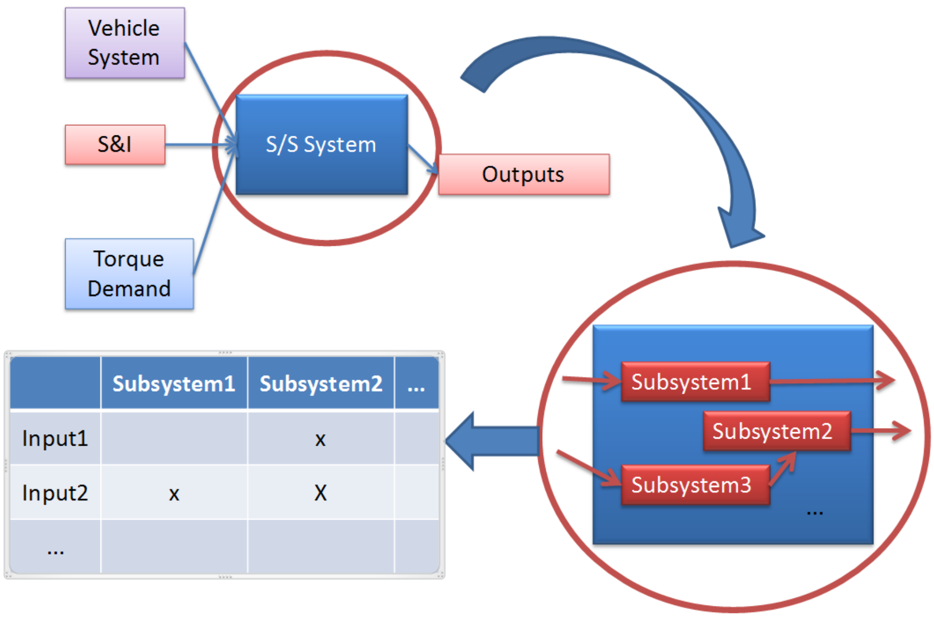

Figure 1.3 : S/S system chart.

The inputs to S/S system and S/S system subsystems can be listed as;

- Gear neutral sensing subsystem
- Restraints subsystem
- Pedals subsystem
- Brakes subsystem
- Steering subsystem

- Power supply subsystem
- Engine cranking subsystem
- Base engine subsystem
- Locking subsystem
- HMI subsystem
- Climate control subsystem
- Engine control module
- Central electrical module
- HS, MS CAN and LIN

As stated before, the S/S system is used for fuel economy(FE). For New Europen Driving Cycle (NEDC), the idle phases are shown below where the S/S can provide advantage in terms of FE.

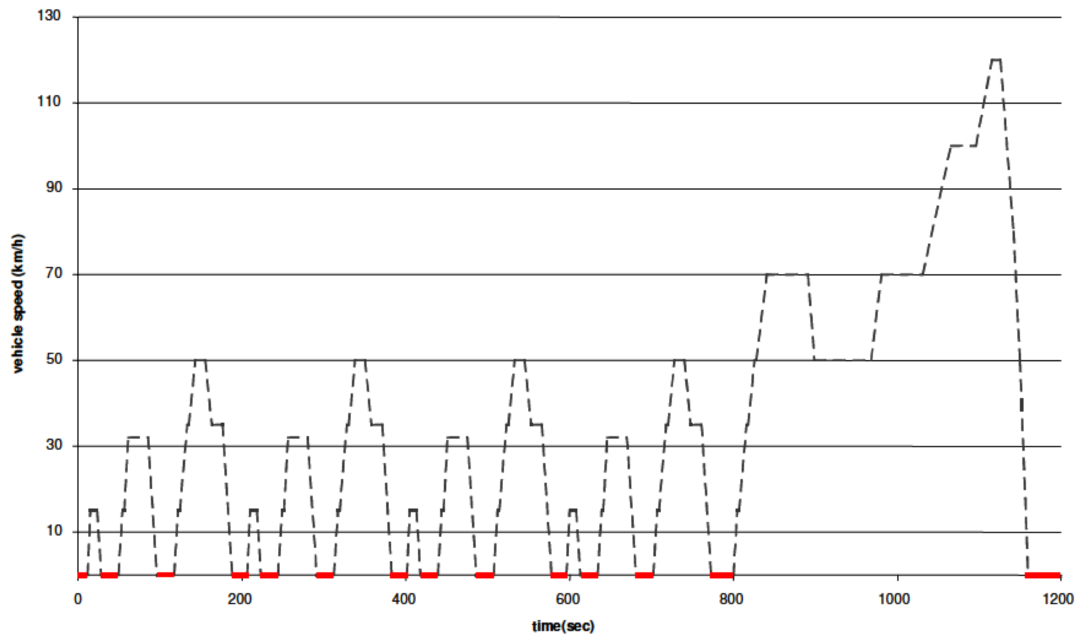

Figure 1.4 : Idle phases of NEDC cycle.

The S/S system outputs will be discussed with reasons at section 3. Brief explanations for the S/S system subfunctions can be found below.

System induced automatic start can only be performed when the driver is deemed to be present. If the scheduler is not certain that the driver is still in position (e.g. because the driver's door is opened), it will prompt the driver to press a pedal to confirm his presence [3].

Stall recovery is an additional 'surprise and delight' feature available with stop/start, and is active even if stop/start itself is deselected or is inhibited. If the clutch pedal is released very quickly after a restart is triggered; then, the logic will abort cranking to mitigate the risk of unintended vehicle movement [3].

With stop abortion or Change of mind (CoM) feature, if a restart trigger is received immediately after the engine starts to shut-down; then, it may be possible to recover the engine by resuming fuelling. Change of mind strategy depends on the engine speed while shutting down. Stop abortion can be performed in different ways such as asisted and unassisted. The figure below shows the difference between stop abortion strategies and behavior of the strategy.

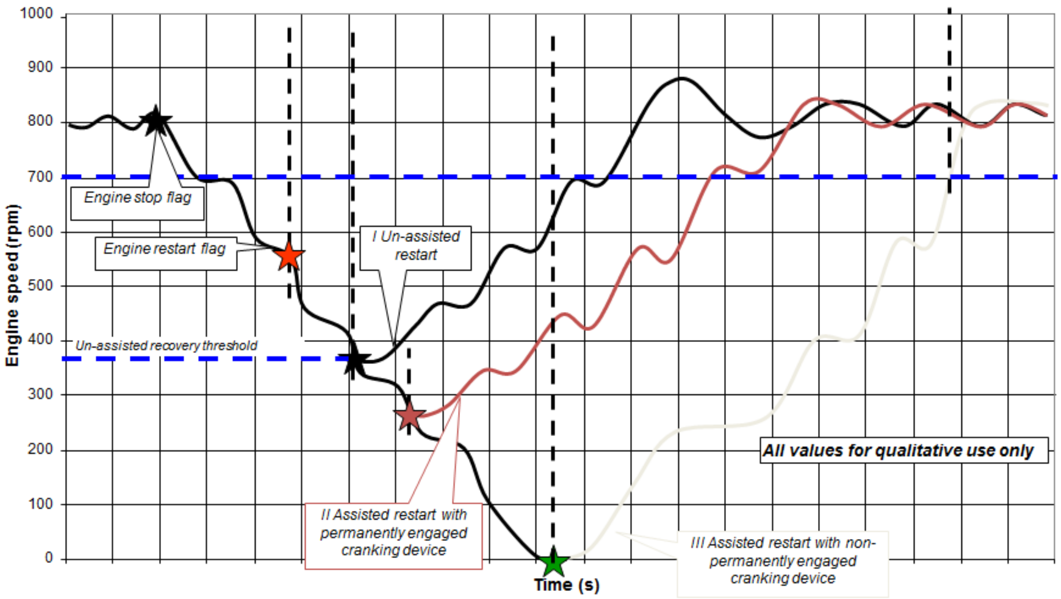

Figure 1.5 : Change of mind feature [3].

Detailed information about the S/S system subfunctions were given thereinafter.

1.2 Literature Review

About the S/S system, there are several academic studies in literature. These studies are mainly based on fuel economy benefits of the S/S system, fast start optimisation and components which are being used by S/S system.

According to [5], the S/S system includes a study about starter/alternator system driven by a standard multi-ribbed Vbelt. In this study, a chassis dynometer was used to demonstrate fuel economy benefit of the S/S system. It is indicated by the authors the testing demonstrated 5.3% improvement in city cycle and found approximately 4% improvement in highway cycle by micro-hybrid systems [5].

Details are given below about mechanical integration.

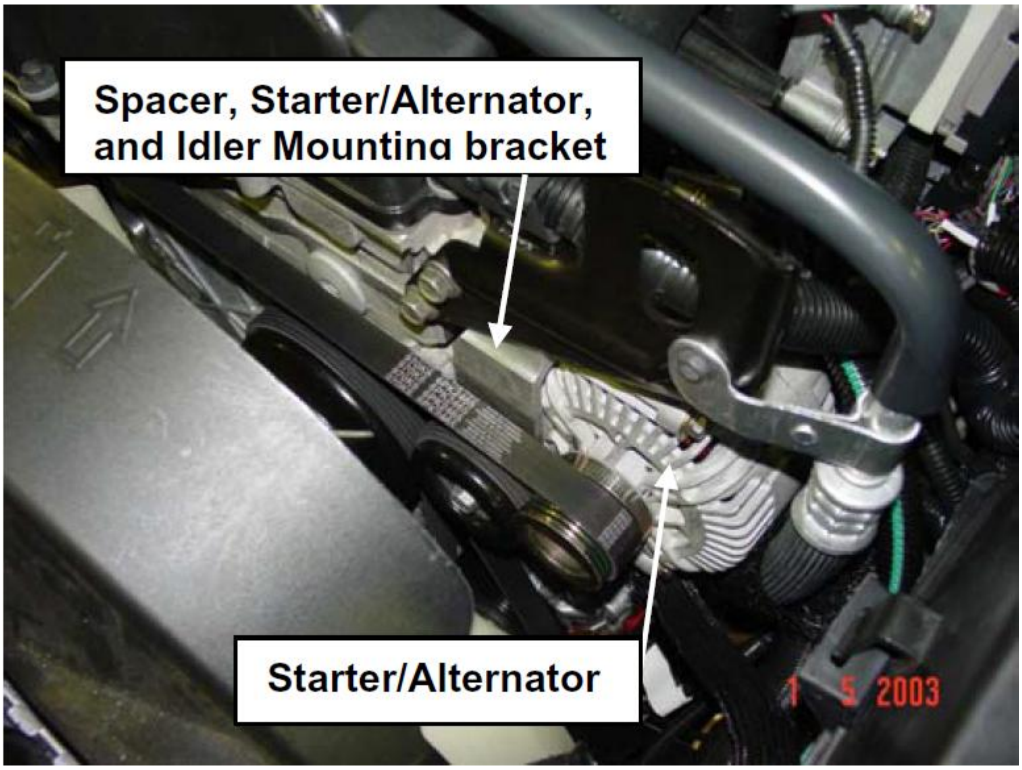

Figure 1.6 : Installation of starter/alternator and fead components [5].

Briefly control strategy development is explained. The FTP cycle is used for emission measurement. The objective of this work was to generate fuel economy and tailpipe emissions data from both the baseline and the modified vehicle [5]. The vehicle was driven on a chassis dynamometer using the above described drive cycles to generate measured emissions with calculated fuel economy for each cycle based on a carbon balance procedure. The chassis dynamometer was set up using the vehicle cost down results obtained during the project [5].

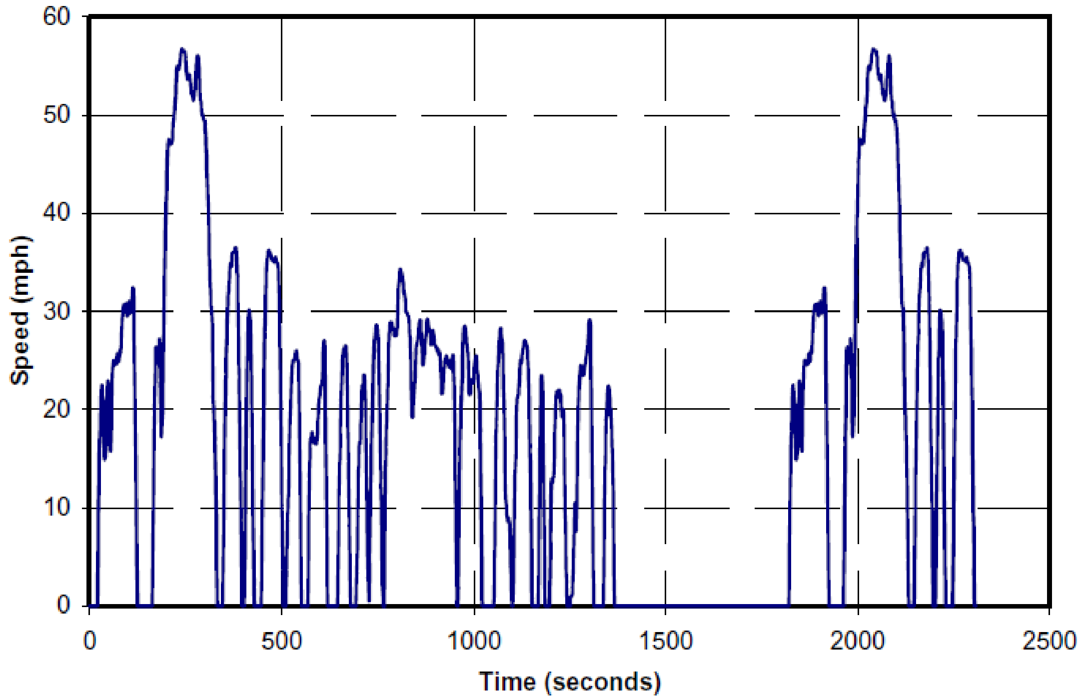

Figure 1.7 : The FTP city cycle [5].

An engine stop/start system was developed which allows transparent stop/start functionality. The improvments in terms of fuel economy;

- 5.3% in city cycle
- 4.0% on the highway cycle
- 4.8% combined [5].

A project was undertaken to demonstrate an engine S/S system at idle system utilizing a 12 volt Belt driven Starter Generator (BSG) in [6].

According to Prucka, the engine control development was divided into 3 main categories: stop/start enable logic, stop/start sequencing, and emissions control [6]. The stop/start enable logic would sample the appropriate sensors and calculations to determine if conditions were appropriate for an engine shutdown and the ensuing engine restart [6]. The stop/start sequencing was used to coordinate all of the actuators required to perform the stop/start event including the throttle position, spark advance, fuel injected, auxiliary transmission pump and the BSG. The emissions control modifications were focused on trims to the start and post-start fuel and spark delivery to minimize emissions during the stop/start event [6].

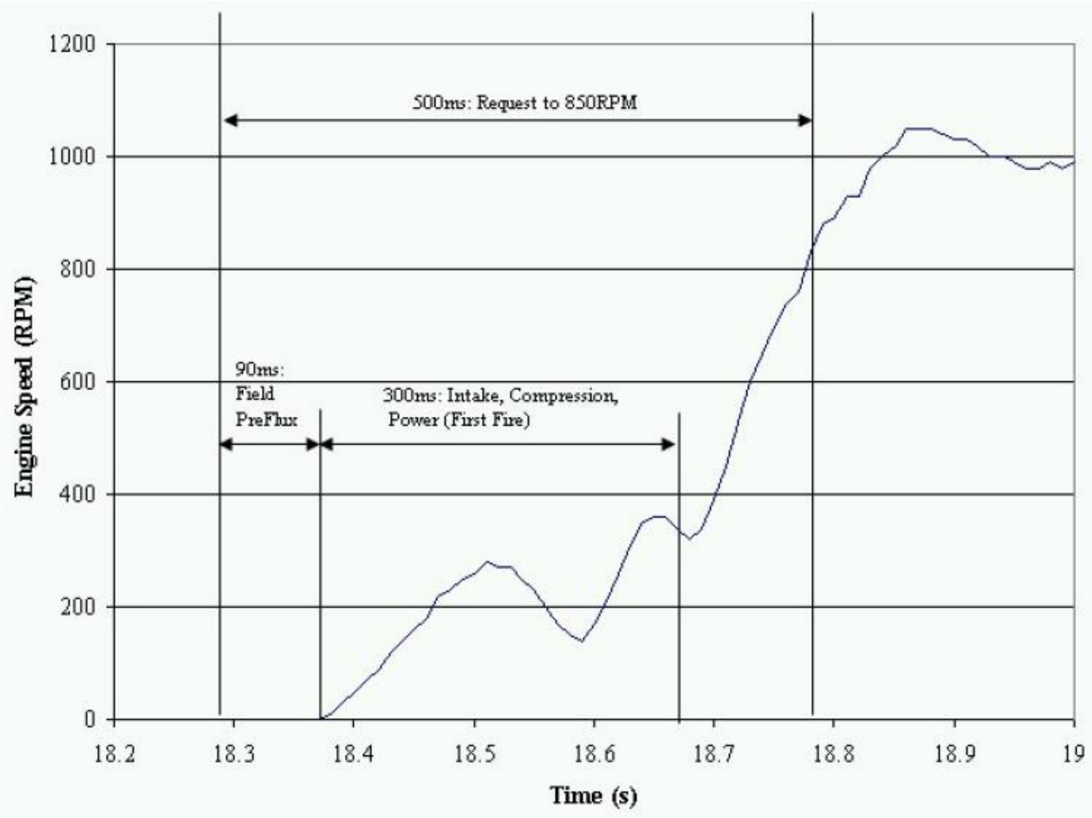

Figure 1.8 : Engine Restart Time [6].

As seen in above figure, engine restart profile is inspected. In this technical paper, an initial fuel economy desktop estimate was performed using a carbon analysis methodology in which CO_2 is set to zero during the warm idle periods of the FTP cycle [6]. The simulation predicted a 4.5% maximum benefit for the demonstration vehicle. However, this result does not account for the electrical energy required to power the equipments such as the brake lamps, auxiliary transmission pump, fuel pump, oxygen sensor heaters etc. [6]. This is somewhat offset by the fact that the BSG is more efficient in generation than a traditional alternator [6]. The simulation's final projected benefit on the FTP cycle is 2.8% for the demonstration vehicle [6]. To confirm the estimates, several FTP test cycles were performed on the vehicle, with and without engine stop/start active to determine the actual emissions impact and fuel economy benefit. The results are as follows [6]:

Combined FE	: +2. 6 %
NMHC (g/mile)	: -0. 001
CO (g/mile)	: -0. 1
NOx (g/mile)	:+0. 003

As can be seen in above given numbers, the tailpipe emissions on this LEV emissions systems equipped vehicle are basically unchanged to meet one of the primary program goals. It was expected that NOx emissions would increase due to the increased amount of fresh air pumped to the catalyst during shutdown [6].

Another paper quantifies the CO_2 potential of Free-Wheeling for various driving conditions and for common emission test cycles [7]. Vehicle simulations as well as vehicle measurements have been carried out in order to derive fundamental requirements for the vehicle system, engine, starter system, auxiliaries, electric power net and transmission [7].

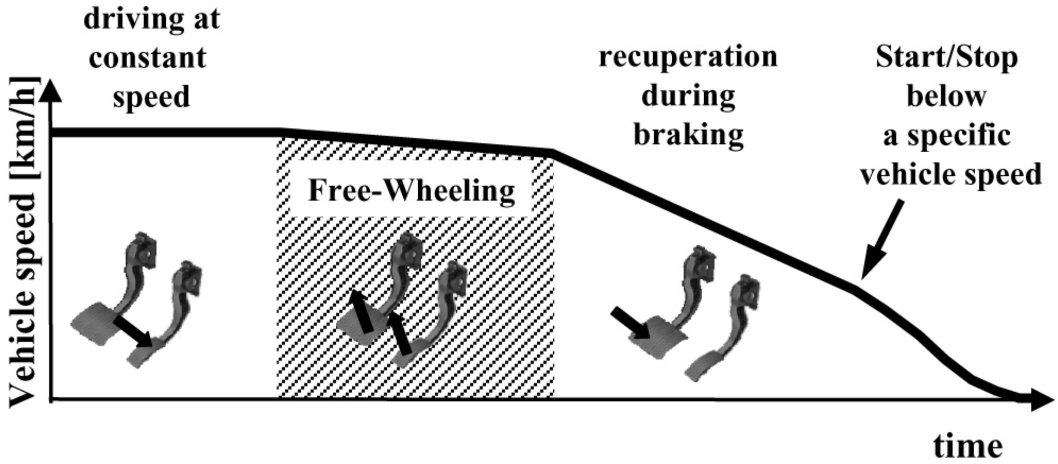

Figure 1.9 : Free wheeling [7].

Free-Wheeling represents the next logical step after the S/S, eliminating the combustion engine's drag torque. Economic driving is rewarded during coasting conditions by a significantly increased rolling distance, and during road testing with a focus on economic driving, the fuel economy benefit of Free-Wheeling in combination with the S/S was more than 10% in comparison with state-of-the-art S/S [7]. As opposed to Free-Wheeling Idling, which requires hardly any changes in the vehicle system, Free-Wheeling Engine-Off entails changes for the power net architecture, increases load cycles for the engine's starter system and increases the need for handling the Change-of-Mind situation adequately by the starter and engine system [7]. Strategies have been developed to keep these increased requirements for the starter motor within limits, so that technology steps from state-of-the-art pinion gear starter motors to belt-driven starter motors or electric motors mounted to the crankshaft can be avoided. For comfort reasons, however, this technology step would be beneficial [7].

The research indicates that for a vehicle with 1470kg, 1.6L Diesel engine fuel economy benefit of the S/S system would be around 4.1% for the NEDC cycle [7].

According to Robinette and Powell, optimization of the engine startup is reported for a multitude of powertrain configurations, including transverse and longitudinal arrangements with manual, automatic and dual clutch transmissions. Details are provided on the level of hardware and calibration necessary to satisfy a set of prescribed performance metrics, particularly seat track vibration and smooth vehicle launch [8]. A correlated lumped parameter modeling methodology is used to determine engine startup profiles, starter hardware and intake cam park position requirements based upon vehicle level response to the startup event [8].

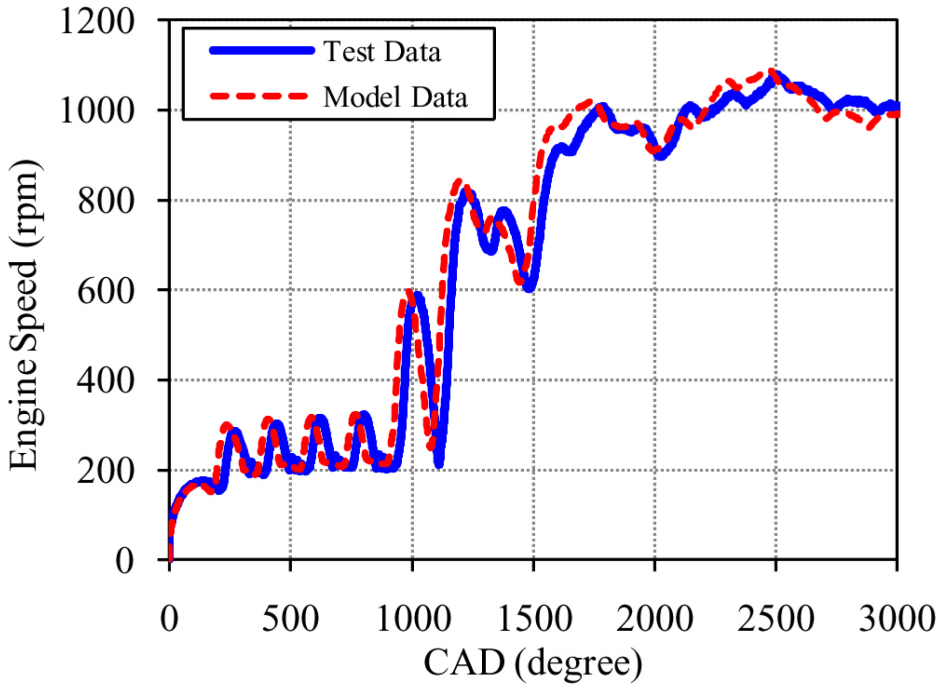

Figure 1.10 : Model correlation for L4 PFI engine [8].

According to [9], fuel consumption is improved if idling-stop is kept for more than about 7 seconds[9]. This study includes idling frequencies for different driving cycles [9].

The S/S system is also applicable to high duty vehicles such as buses. Fuel consumption of a city bus can be reduced to 45.42 l/100km from 52.53 l/100km with the S/S system [10].

Fonscea and et al, presents measurements of CO_2 emission and efficiency of the S/S technology on a diesel vehicle in urban traffic. Two four-wheel-drive diesel vehicles with on-board exhaust emission and vehicle activity measurement systems were tested in two urban driving circuits representative of downtown Madrid [11]. Finally, it is indicated by authors that the three methods have been used to study the influence of the S/S on a four-wheel-drive diesel vehicle, measurement of average CO_2 emissions, modal statistical analysis and energy emission factor, show a significant reduction in CO_2 emissions in actual urban traffic is achieved which is up to 20% at an average speed of 15.5 km/h [11]. The reduction could be partly attributed to changes in the engine and partly to zero idling emissions [11]. In addition, modal statistical analysis explains the variability observed in the CO_2 emissions found in actual traffic flows. Finally, the energy emission factor analysis confirms that CO_2 emission reduction is due to better global energy efficiency of the vehicle with the S/S system [11].

1.3 Purpose of Thesis

This project gives information about the S/S system integration to 1.5L Diesel engine. From control and calibration engineering point of view, control algorithm development, fast start optimization and fuel economy benefit is important topics for the S/S system. The aim of this project is to develop of a generic control algorithm for the S/S system and prediction of fuel consumption. For early phases of a project, it may not be possible to have a test vehicle for fuel economy comparisons. This project gives a simple model for fuel economy and CO_2 calculations a for given test cycle.

1.4 Outline of Thesis

The thesis includes the following parts; introduction, literature overview, system components and integration, control algorithm development, fuel economy and CO_2 benefit modelling.

In introduction part, the necessity of the S/S system explained and general information about the S/S system are given. In literature overview, about similar studies, important points are discussed with details.

In the S/S components and system integration section, components used by the S/S system were introduced. The working principles of componenets especially bi-directional crankshaft sensor, enhanced starter motor, enhanced battery, gear neutral sensor and voltage quality model are explained.

System inputs and outputs were defined in the S/S system control algorithm development section. The subsystems such as, gear neutral sensing subsystem, restraints subsystem, pedals subsystem, brakes subsystem, steering subsystem, power supply subsystem, engine cranking subsystem, base engine subsystem, locking subsystem, HMI subsystem, climate control subsystem, engine control module, central electrical module, HS, MS CAN and LIN are inspected for control algorithm.

A vehicle model is developed in fuel consumption and CO_2 modelling section. The fuel economy and CO_2 benefit of the S/S system are discussed in this section. Simulation results and test data are comparised.

Finally, in conclusion and recommendations section, the results and further works are briefly discussed.

2. SYSTEM COMPONENTS AND SYSTEM INTEGRATION

In this section, general information is given for the components and systems which is used by the S/S system or in relationship with the S/S system. The S/S system requires some special components regarding to their functionality and durability. Most important components for the S/S system are enhanced battery, enhanced starter motor, voltage quality module, gear neutral sensor and bi-directional crankshaft position sensor.

Figure 2.1 : Stop/Start system components [12].

2.1 Enhanced Starter Motor and Enhanced Battery

Start-stop places huge demand on the batteries as it requires starting a car many times during cruise. In comparison to conventional batteries, the battery used for the S/S application must have the primary function as ability to start engine high number of times and ability to have limited or extended engine off periods. Nonetheless, major battery manufactures have already pinpointed this issue and have come up with new developments of their own. For example, ‘Varta Batteries’ have come up with products like ‘start-stop Battery’ based on ‘Enhanced Flooded Battery’ (EFB) technology and 'start-stop Plus Battery' based on 'Absorbent Glass Mat' (AGM) technology, specifically designed for the S/S system applications in vehicles and it is predicted 70% of all new vehicles to feature the S/S technology by 2015 in Europe. Another manufacturer 'Exide technologies' have also developed battery products well suited for the S/S technology based on 'Enhanced Cycling Mat' (ECM) technology [13].

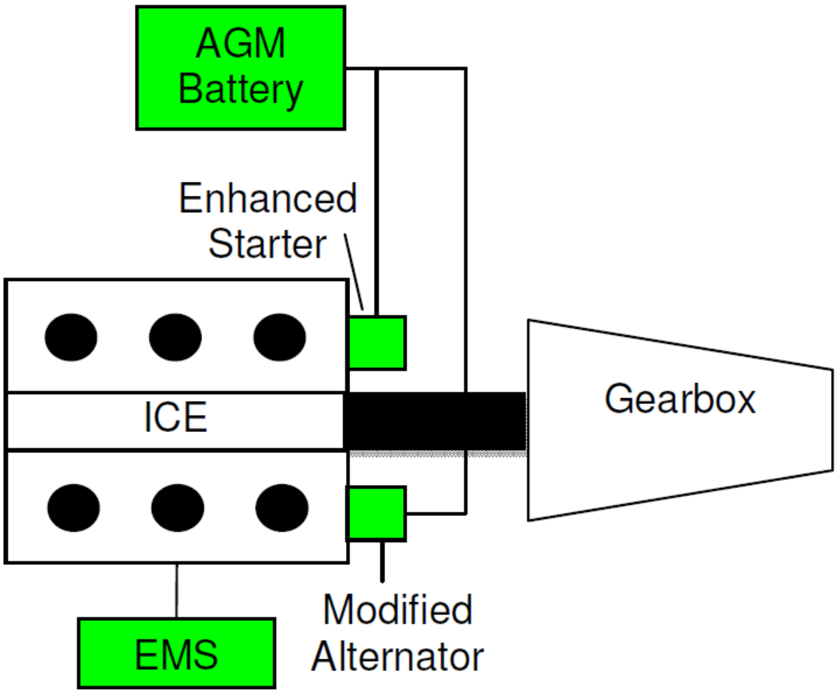

Figure 2.2 : System schematics with a starter motor [13]

The number of starting operations to be performed by a starter motor in a vehicle with the S/S technology has increased considerably in compared with that of a conventional vehicle. Greater design strength such as strengthening of bearings subjected to heavy loading, improvement of planetary gear mechanism, strengthening of pinion-engaging mechanics, optimization of commutator for longer life, has enabled these starter motors to survive frequent starts throughout the lifetime of the vehicle without suffering damage [13].

Figure 2.3 : Bosch Enhanced Starter Motor [14].

Enhanced starter S/S system consists of a modified starter to meet the requirements of multiple starts in compared with a conventional starter. The system also consists of a modified generator for recuperation [13].

2.2 Voltage Quality Module

During a conventional engine start, a voltage dip occurs because a large current is drawn by the starter motor. Electronic and electrical modules are allowed to reset during a conventional start and diagnostic fault codes are masked for this event. For the S/S vehicles to avoid from such an event like this, Voltage Quality Module(VQM) is used.

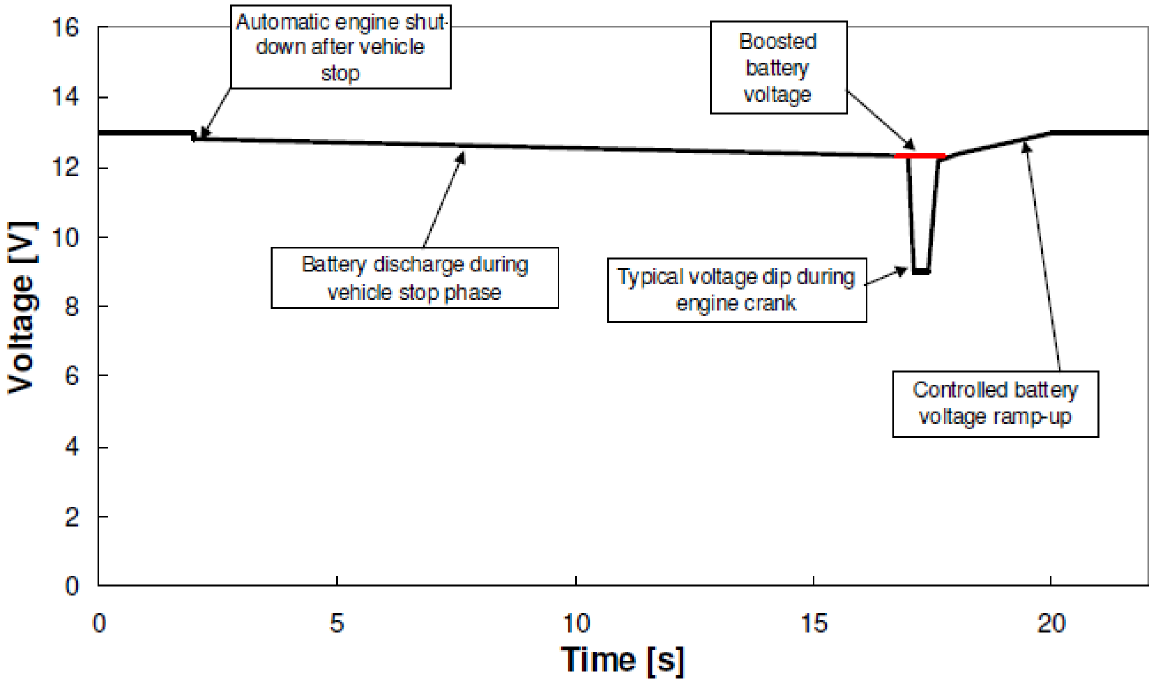

Figure 2.4 : Battery voltage during cranking.

The VQM stabilises the voltage output around 12V. With the stabilised loads, electric power consumers such as the radio, navigation, cluster, illumination continue without a performance trade during a fast start.

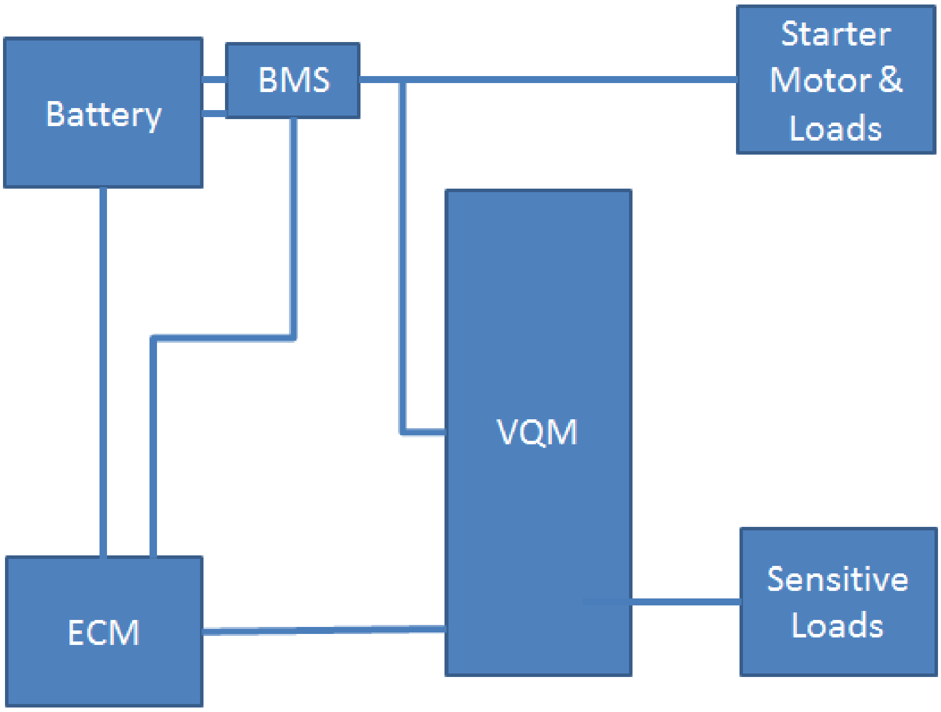

Figure 2.5 : Connection diagram for the VQM.

2.3 Gear Neutral Sensor

The gear neutral sensor is used to determine when the neutral gear is selected. Figure below illustrates the position of the sensor and magnet. The change in the magnetic field is detected by the sensor and converted into PWM signal.

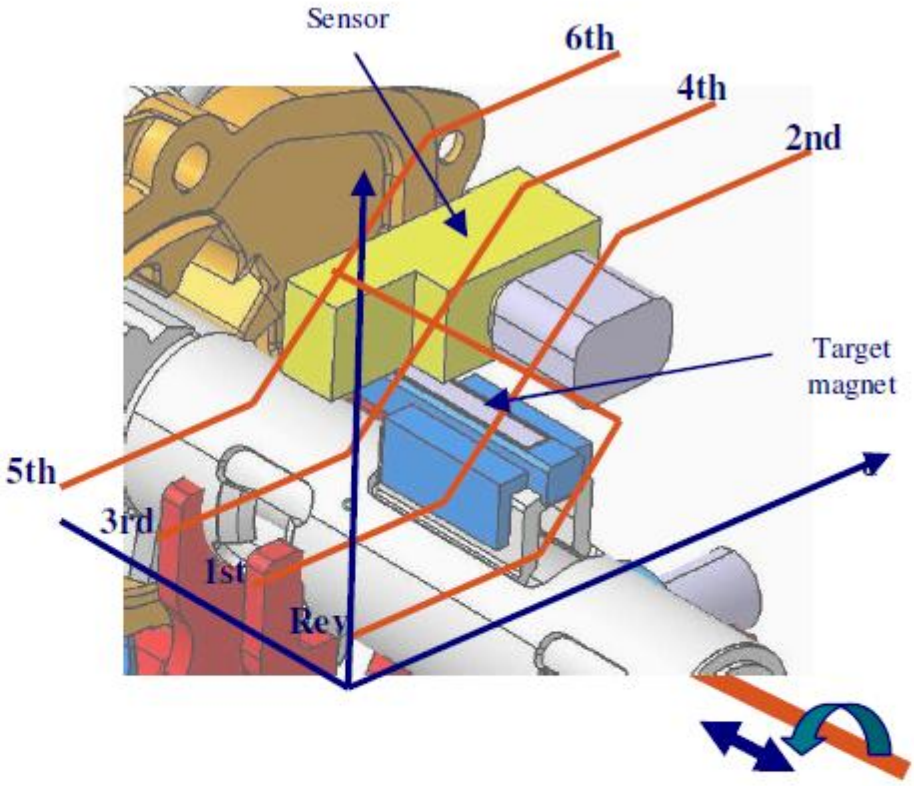

Figure 2.6 : Gear Neutral Sensor

The sensor output given below is under the low threshold for odd gears and over the upper threshold for even gears. Regarding to its position in the gearbox, the rear gear behaves as an even gear or odd gear.

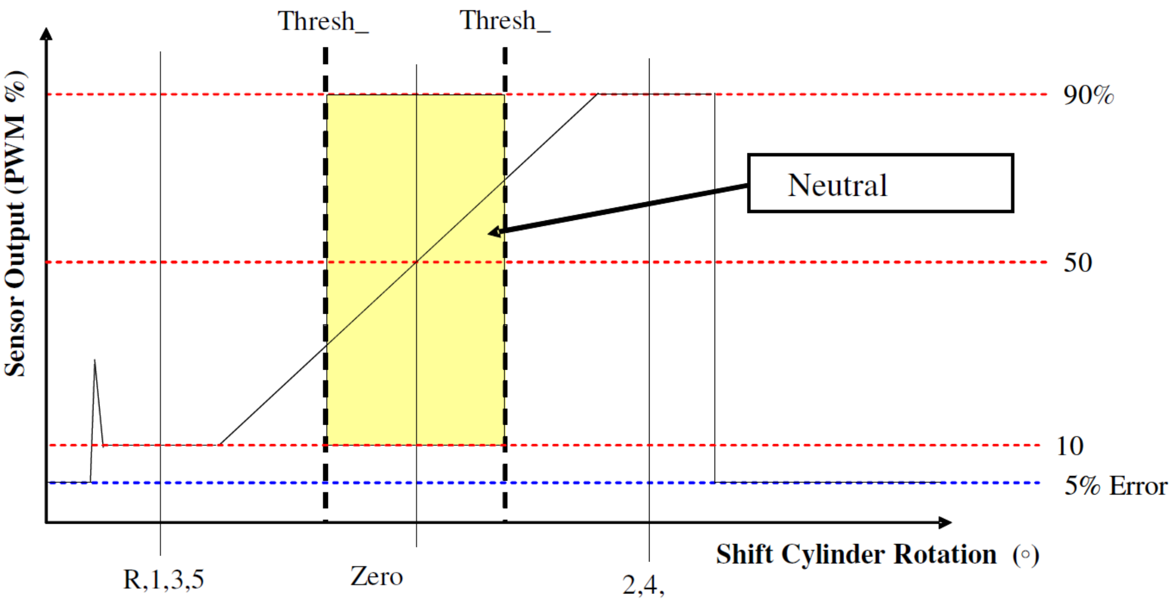

Figure 2.7 : Gear Neutral Sensor Output [3].

The output of the sensor is used as an input of the S/S system for control algorithm development. The neutral gear must be selected for stop in neutral systems. Sensor output is around %50 when neutral the gear is selected. Thresholds can be calibrated regarding to sensor behavior and mechanical design of the gearbox.

2.4 Bi-Directional Crankshaft Position Sensor

The crankshat position sensor is used to determine the crankshaft position. Directional crankshaft position sensors provide information about the rotation and direction. The magnetic pattern of the trigger wheel provides a magnetic field for the crankshaft sensor.

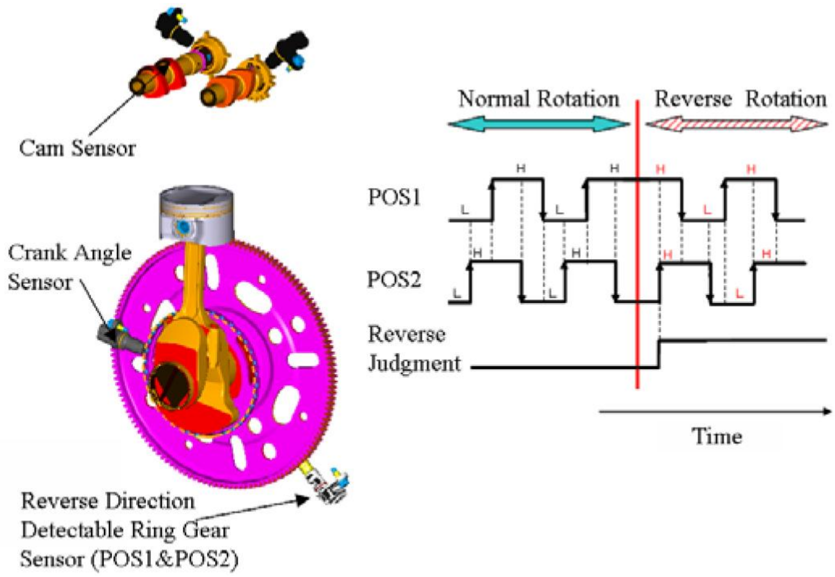

Figure 2.8 : Crank angle sensor system [15].

Using a quadrature sensor of the hall type, it is possible to determine the direction of the rotation from a toothed wheel [16]. At the chip level and at the automotive volumes, a quadrature sensor which has two hall sensor elements has higher costs than a single hall sensor [16].There are 60-2 teethes on the trigger wheel. The crank sensor can differentiate the output regarding to the rotation direction. Falling edges of the output shows the rotation and duration of the output gives the direction of the rotation.

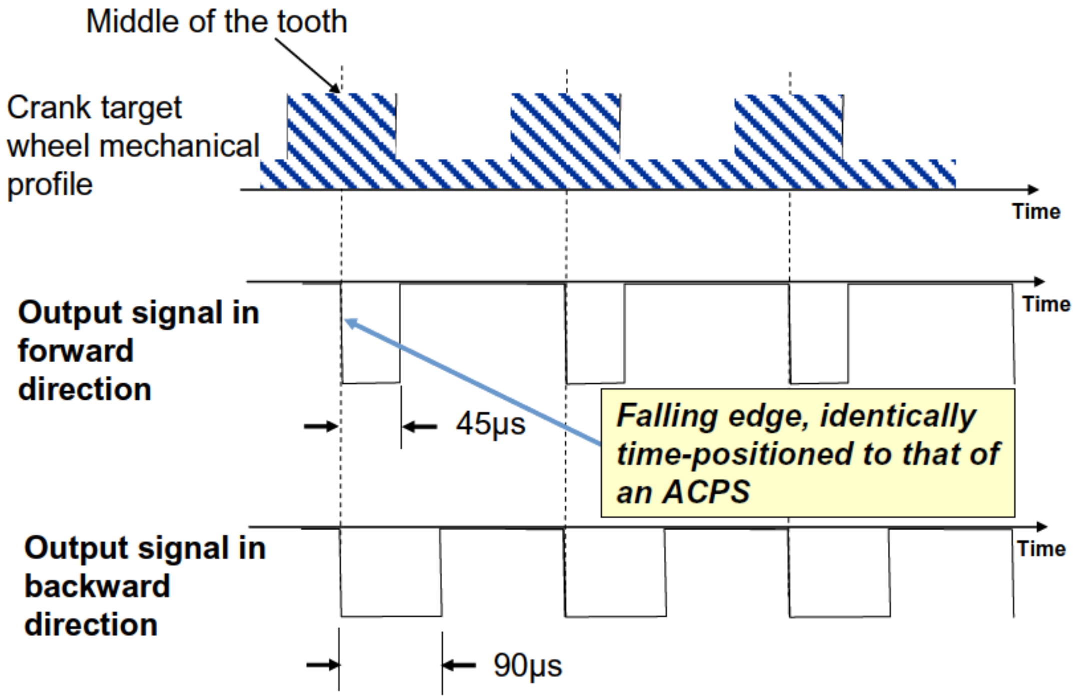

Figure 2.9 : Directional Crankshaft Position Sensor Output [17].

3. STOP/START SYSTEM CONTROL ALGORITHM

3.1 System Inputs and Outputs

The S/S system is in relationship with most of the vehicle systems. There are inputs to the S/S system from;

- Gear neutral sensing subsystem
- Restraints subsystem
- Pedals subsystem
- Brakes subsystem
- Steering subsystem
- Power supply subsystem
- Engine cranking subsystem
- Base engine subsystem
- Locking subsystem
- HMI subsystem
- Climate control subsystem
- Engine control module
- Central electrical module

Effects of the inputs on the outputs are described in the scheduler model. In the boundary diagram given in Figure 3.1, the signals are shown in green, sensor inputs are shown in red and driver inputs are shown in blue. As seen in the boundary diagram there are too many inputs to the system and there are too much subsystem interactions.

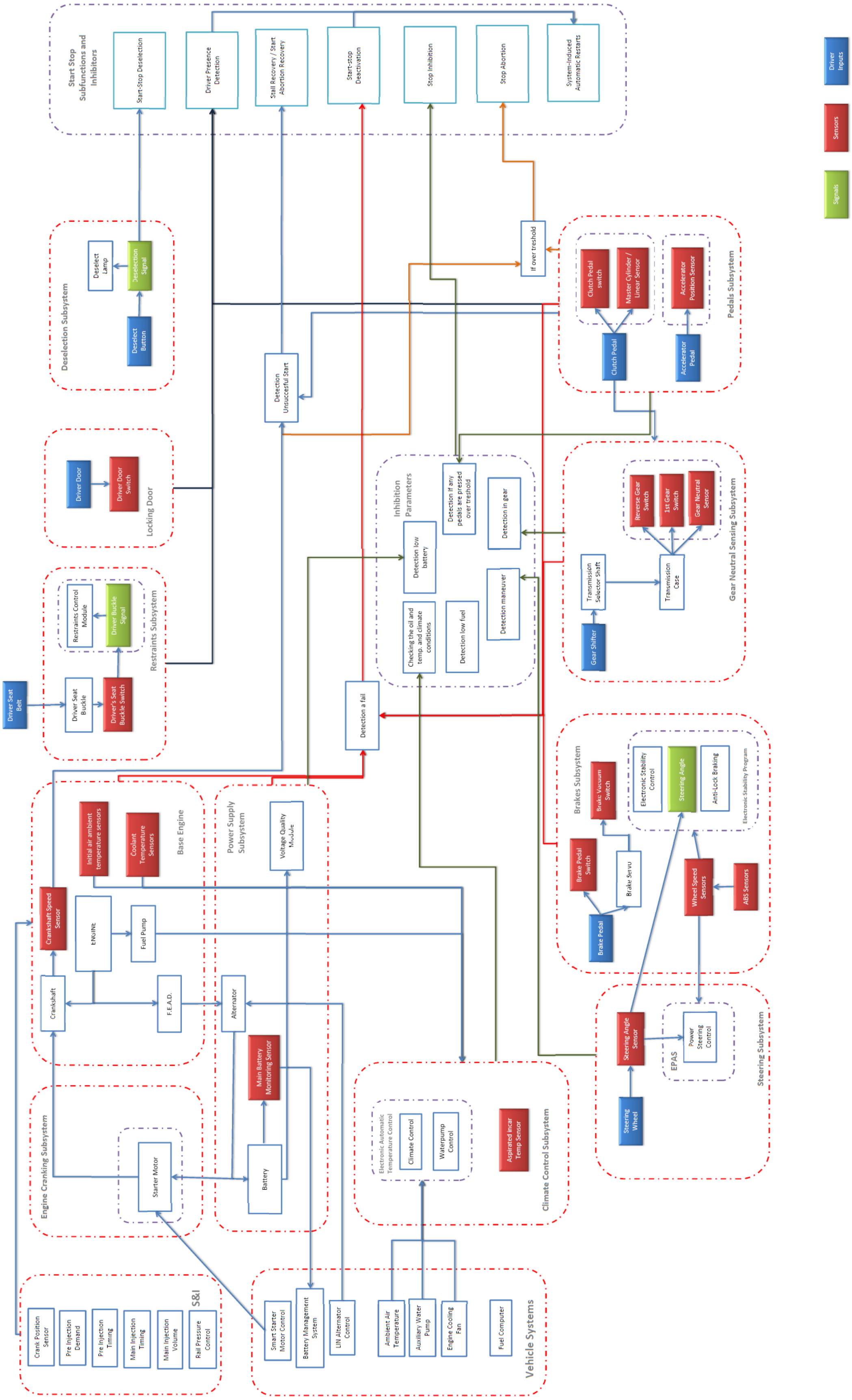

Figure 3.1 : System boundary diagram

3.1.1 System outputs and subfunctions

The outputs and subfunctions of the system are as follows:

- Stop Inhibitors
- Engine Run Requests
- System-Induced Automatic Restarts
- Stop Abortion
- Start Inhibitor
- Stall Recovery
- Stop/Start Deselection
- Stop/Start Deactivation

Stop Inhibitors

Stop Inhibitors prevent the engine from shutting down for hardware protection, safety or comfort. An example of a stop inhibitor is high ambient air temperature.

Engine Running Requests

An engine run request prevents the engine from shutting down as a stop inhibitor; but if the engine were already stopped, it would trigger an immediate restart. An example of an ERR is the low battery state of the charge. If the engine were stopped and the driver presence were detected, system induced automatic restart would be asserted.If the driver presence were not detected and system induced restart were required, with the HMI driver is requested to press any pedal.

Start Inhibitors

Start inhibitors are used to prevent unsuccesfull start/launch events. An example of a start inhibitor is critically low battery state of charge. A start inhibitor also behaves as a stop inhibitor.

Stall Recovery / Start Abortion Recovery

Stall recovery is an additional feature available with the S/S system. After an unsuccessfull launch attempt, if the driver presses the clutch pedal (for MT) within the available time period, the engine performs a fast start. With this function after an unsuccessful launch, drivers can quickly run the engine again without key cycle.

Stop/Start Deselection

The S/S system can be deselected by the driver. Stop/Start deselection behaves as a stop inhibitor or engine run request regarding to the calibration.

Stop/Start Deactivation

Stop/Start feature goes out of operation due to diagnostics or engine protection subsystem. Generally, the key cycle is required to activate the system again.

Change of Mind

With stop abortion or Change of mind (CoM) feature, if a restart trigger is received immediately after the engine starts to shut-down, then it may be possible to recover the engine by resuming fuelling [2]. Change of mind strategy depends on the engine speed while shutting down. Stop abortion can be performed with different ways such as asisted and unassisted. The figure below shows the difference between stop abortion strategies and behavior of the strategy.

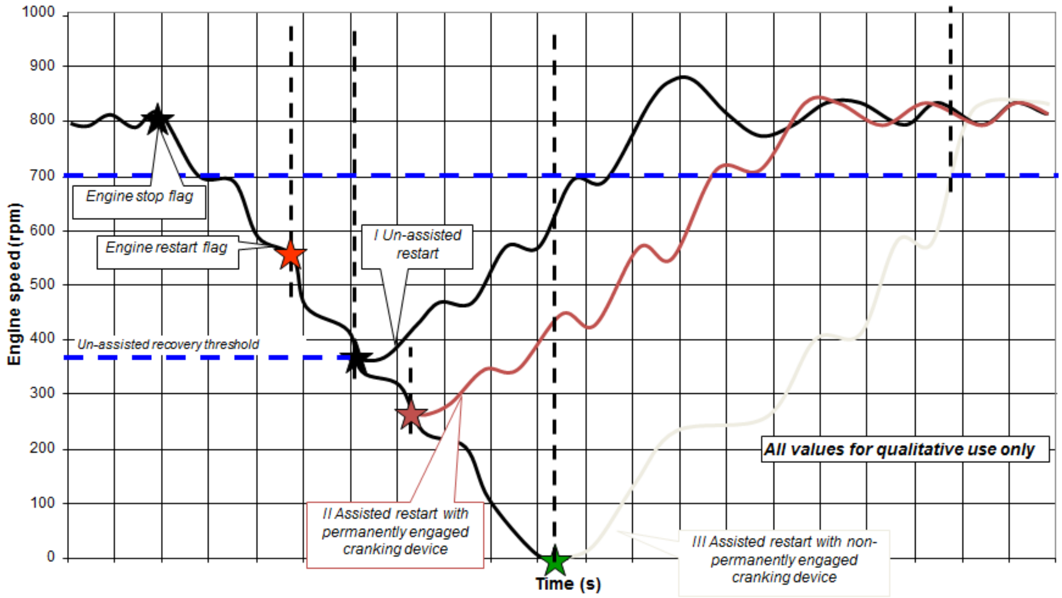

Figure 3.2 : Stop abortion strategies [3].

3.2 Control Algorithm and Subsystem Interaction

System scheduler inputs and outputs are indicated in the block diagram given below.

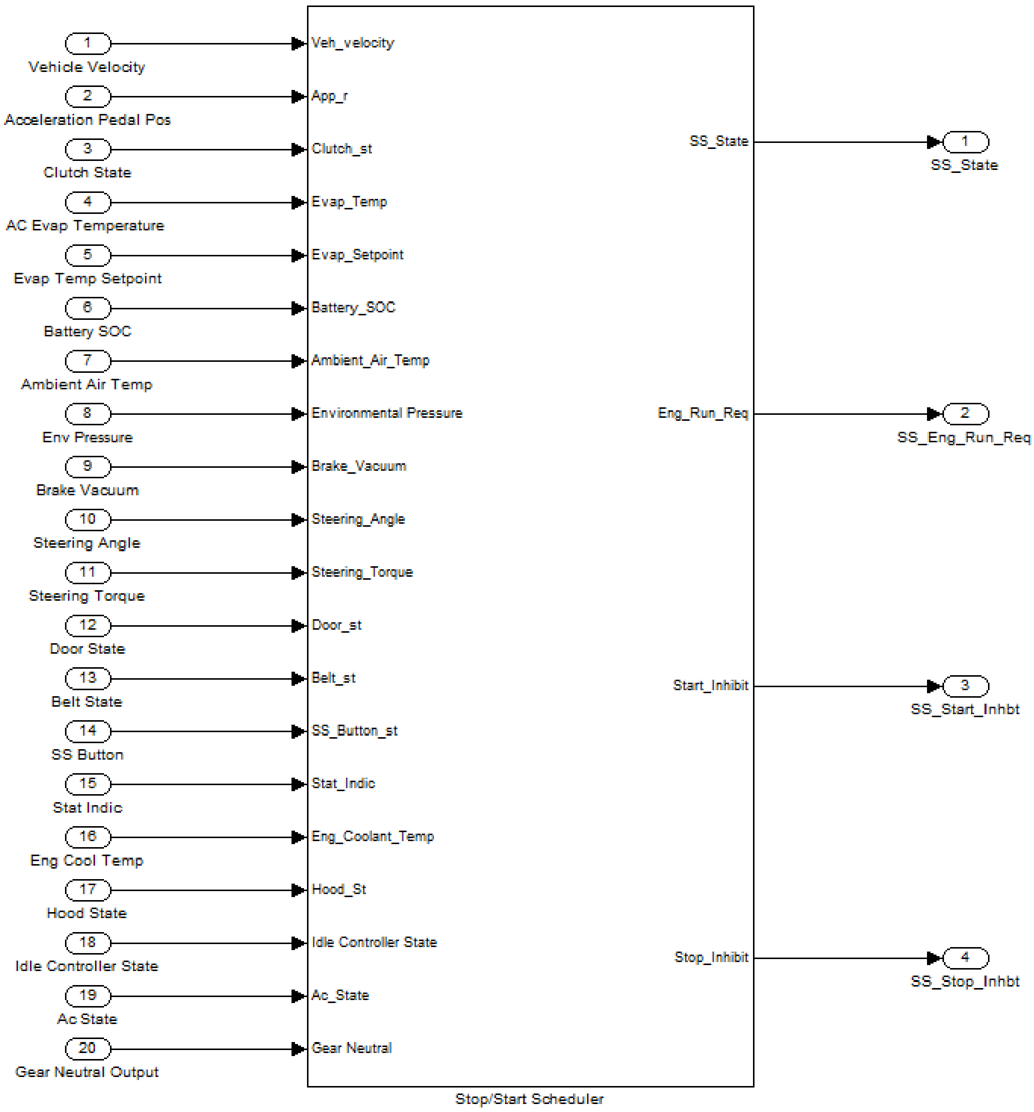

Figure 3.3 : Control algorithm inputs and outputs.

3.2.1 The Analyze of Submodels

The submodels were analyzed part by part. The outputs of every submodels are stop inhibitors, start inhibitors and engine run requests. For steering system, control algoritm is shown below.

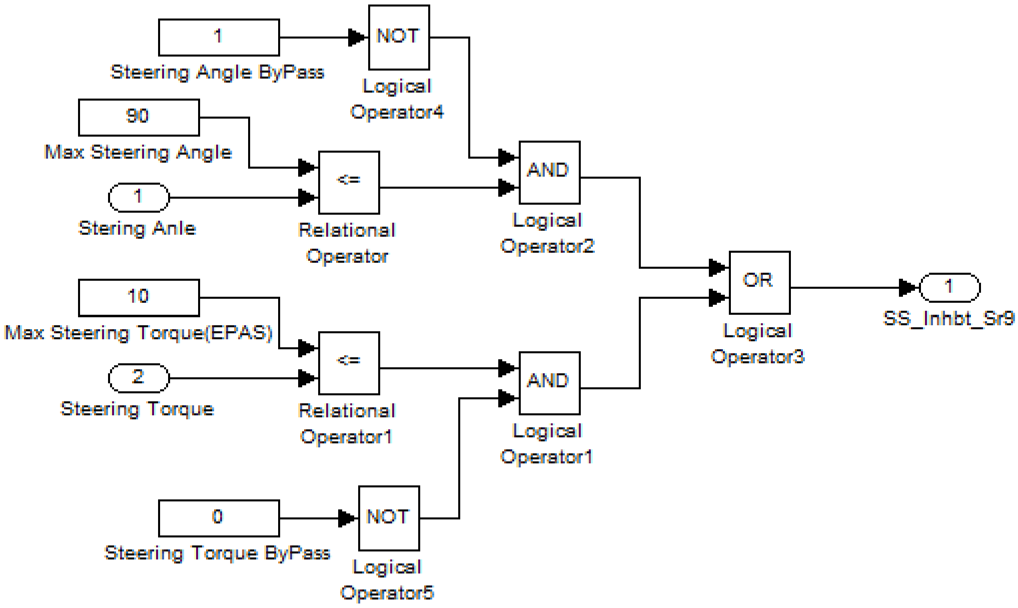

Figure 3.4 : Steering subsystem.

With calibratibles, it is possible to use the stop inhibitor regarding to the steering angle or steering torque. In addition, it is possible to use both of them. The stop inhibitor regarding to the steering angle is generally used for heavy-duty vehicles. Stop inhibition by steering torque is possible with EPAS (Electric Power Asisted Steering) which is used in this project. Stop inhibition by the steering angle was by passed and only steering torque is considered as seen in the diagram.

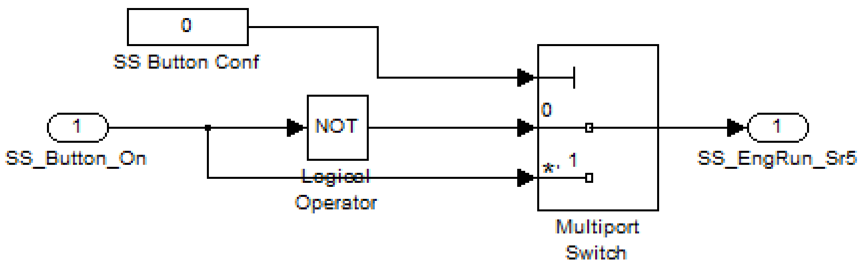

Figure 3.5 : Deselection button subsystem.

The behavior of deselection button is calibratible because different electrical architechtures can be used in different programs. Without changing the software calibrating, the deselection button is possible.

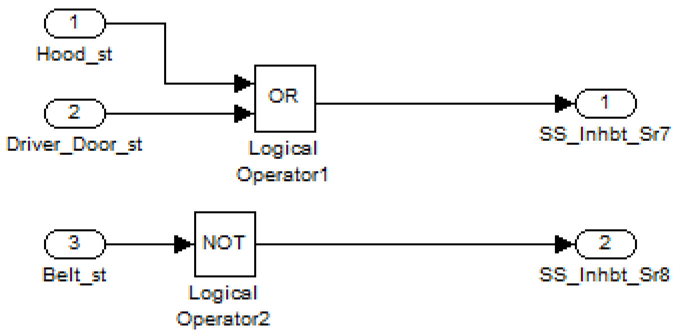

Figure 3.6 : Driver Presence Detection

For safety reasons, it is always important to check the driver presence during auto-stop and auto-start events. As seen in the block diagram regarding to the inputs from BCM (Body Control Module) for the driver door, seat belt and hood driver presence can be detected and the system behavior can be calibrated. As the driver presence, diagnostic check is important for safety. If there is, a fault code in leacky bucket, S/S system can be deactivated.

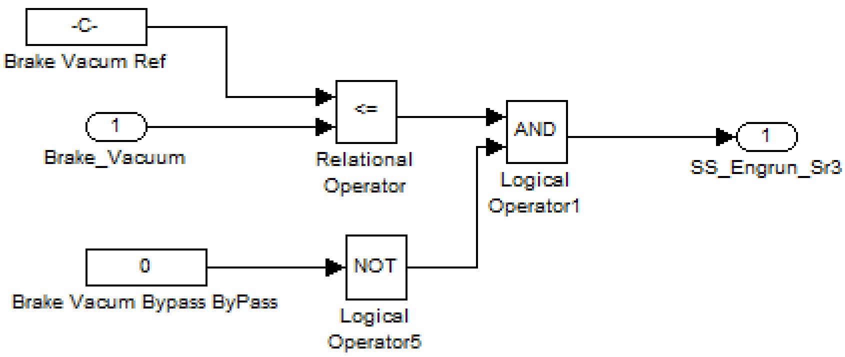

Figure 3.7 : Brake system.

According to the output of the brake vacuum sensor, an engine run request can be raised; because, when engine stopped brake vacuum cannot be decreased. For safety reasons, free rolling is available under certain vehicle speed and during free rolling; brake vacuum must be over threshold if the engine was stopped.

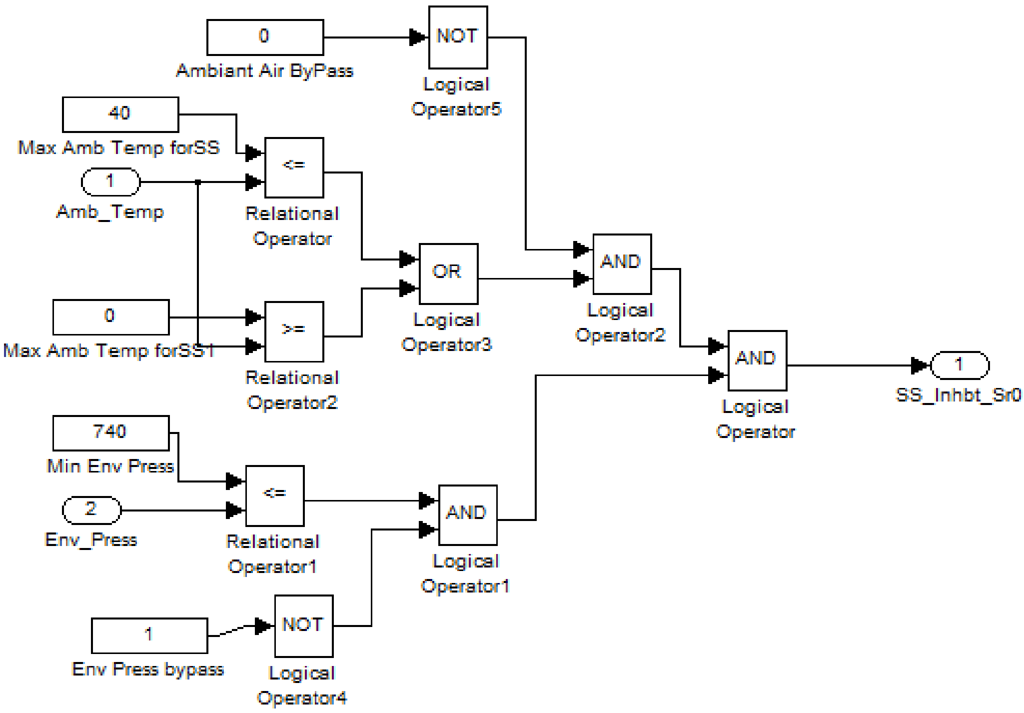

Figure 3.8 : Inhibition by ambient conditions.

For comfort and durability reasons, auto stops were not allowed for extreme ambient conditions. The behavior of the system and thresholds can be calibrated as seen in above block diagram.

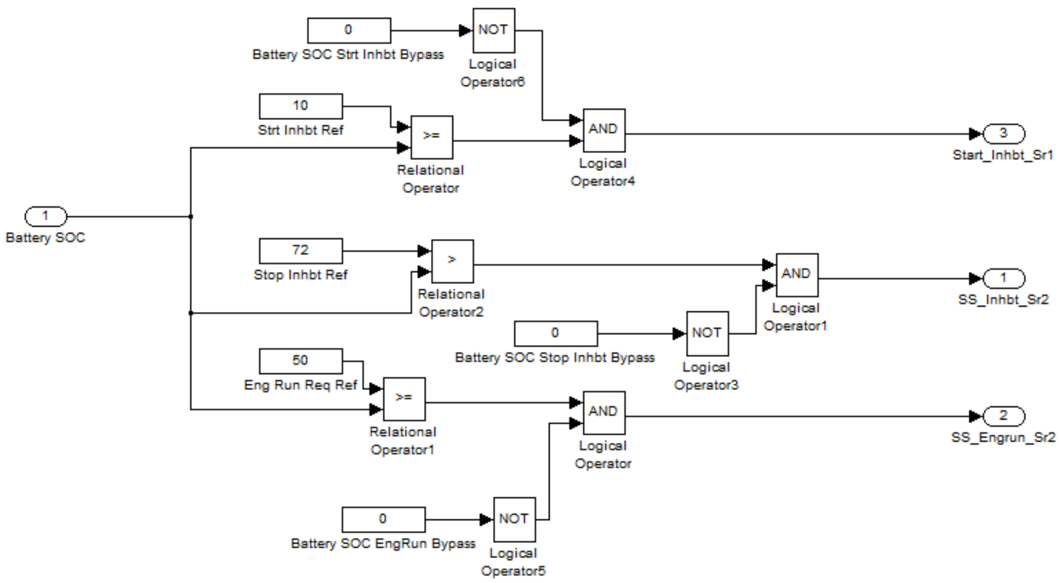

Figure 3.9 : Battery state of charge.

According to the battery state of charge, the stop inhibit, start inhibit or engine run request flag can be raised. As seen in the block diagram, these thresholds and behavior of the system regarding to these thresholds can be calibrated.

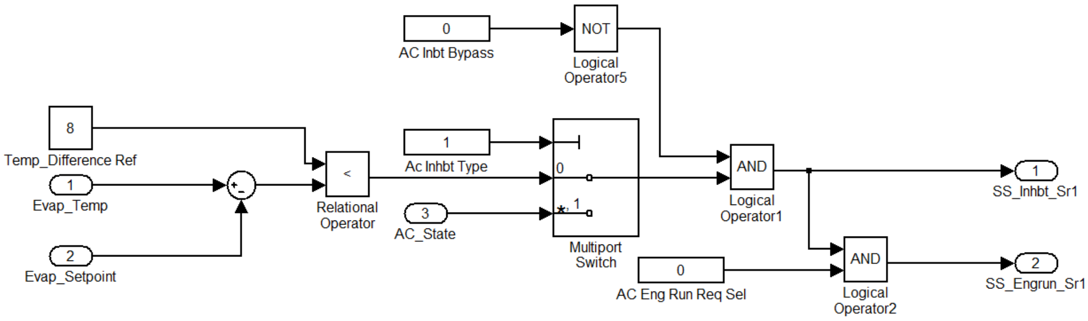

Figure 3.10 : Air conditioning system thresholds and control algorithm.

According to the air conditioning system state, the S/S system can be disabled due to thermal comfort requirements. It is possible to raise engine run request when the AC is on with calibratibles. The evaporature can keep the temperature for a while when the engine is stopped, so considering the setpoint and evaporature setpoint difference is possible. Generally, the AC compressor is connected to fead so stopping the engine means stopping the systems, which are driven by the fead.

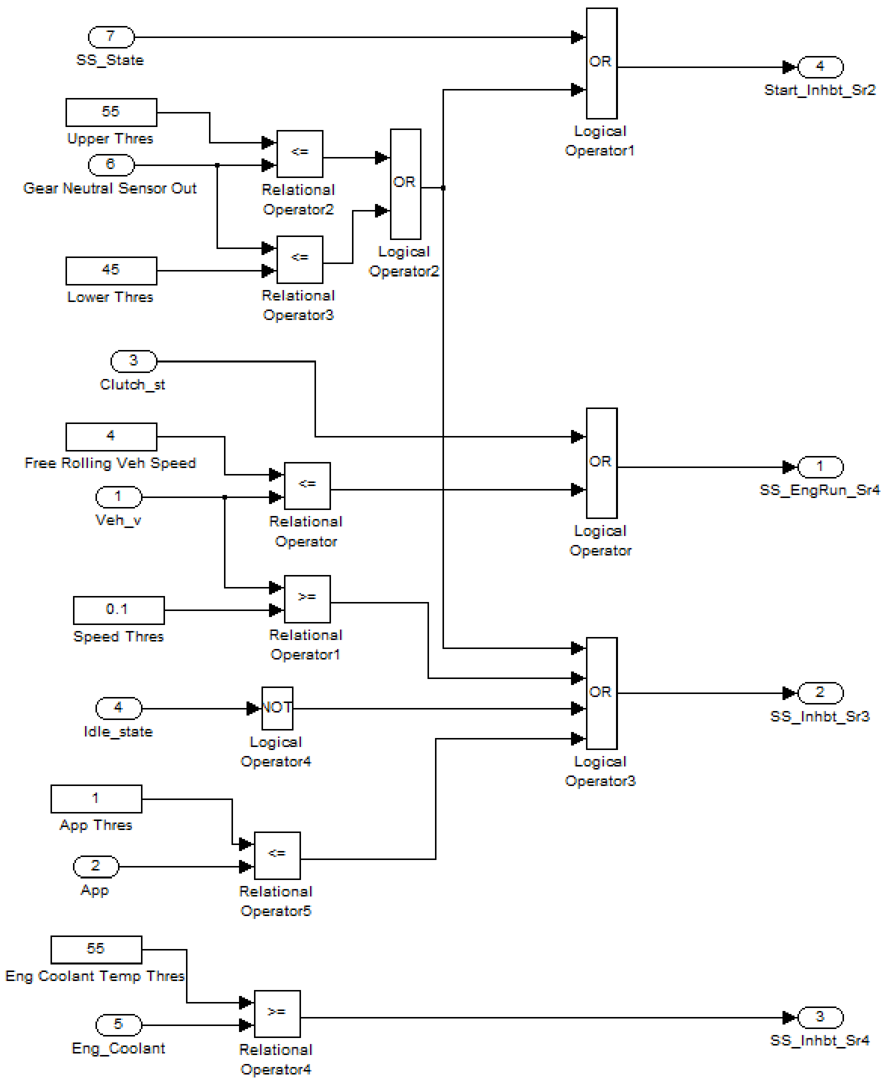

Figure 3.11 : Manoeuvering detection and engine protection.

The vehicle speed, idle control state and clutch state are used for manoeuvering detection. The clutch state and gear state are important for the S/S system. As stated before, the gear neutral sensor is used for the S/S system. Upper and lower thresholds were calibrated as seen in the diagram. For the S/S system, also an analog clutch master cylinder sensor is used to detect the clutch position. Clutch position is fed to the scheduler control system as the clutch state. Engine coolant temperature must be over the threshold for S/S system. It means that the driver has to drive for a while to activate the S/S system.

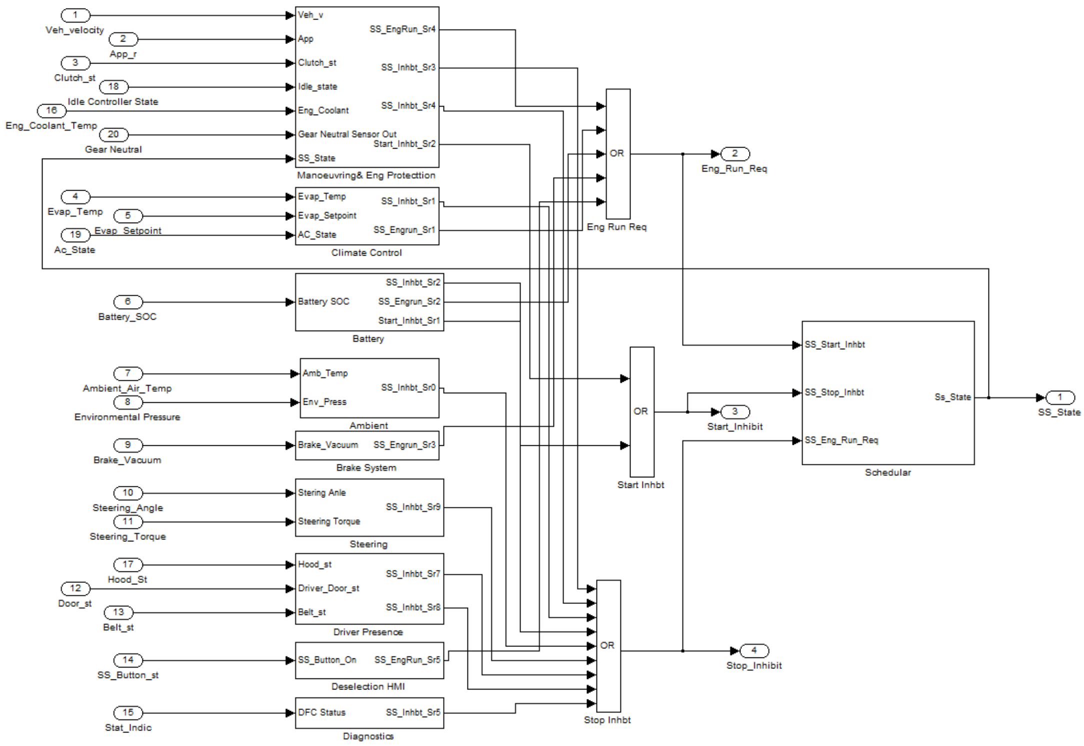

Figure 3.12 : Control algorithm overview.

4. FUEL CONSUMPTION, CO_2 MODEL AND VALIDATION

4.1 P&E Calibration and Engine Mapping

For Performance & Emission test, AVL Sprint dynomometer was used. For emission and fuel consumption model, engine mapping data is used. The internal combustion engine dynamometer system shall consist of the dynamometer, measuring systems, mechanical equipment and automation system. The dynamometer consists of dynamometer drive, torque measuring unit, power cabinet, engine dynamometer controller / control panel / control desk and cabling.

Figure 4.1 : The test cell used for the P&E calibration.

Engine mapping is a process whereby empirical models are developed that characterize various engine parameters such as torque, rail pressure, EGR system, mass air flow, manifold pressure, injections, emissions etc. During the test, the engine speed should be fixed to a value and the throttle position changed and recorded at each point. Therefore, engine mapping is a steady-state test. Between 800 and 4500 rpm at different steady state points, the engine map was obtained. These measurements are used for the FE vehicle model.

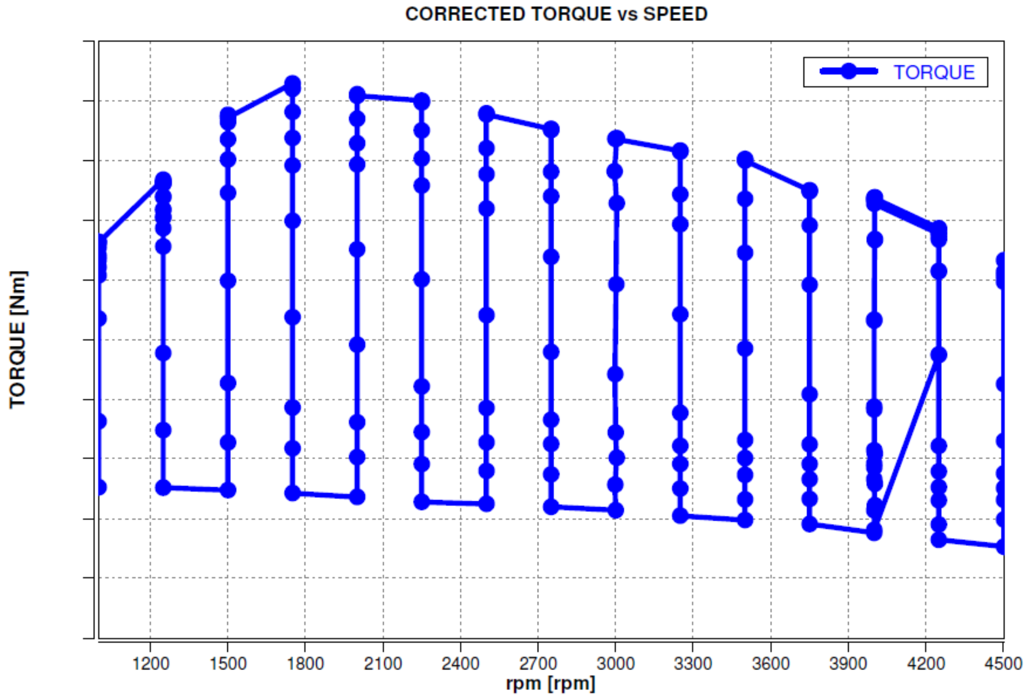

Figure 4.2 : Torque-Speed points.

The P&E calibration can be inspected in two main parts. One of them is the fuel path and the other is the air path. The Fuel path is important for fuel consumption calculations but also airpath values will be used for the air mass, air fuel ratio calculations and plausability check. Engine torque and engine speed are calculated a a given cycle. Then, the map below is used as a look up table to calculate the total fuel consumption.

According to the engine coolant temperature, the engine works in different injection configurations. There are five base maps regarding to the engine coolant temperature such as these are very cold, cold, warm, hot fast and hot slow. The engine coolant temperature model included to the model, so this base map selection is considered in the fuel consumption model.

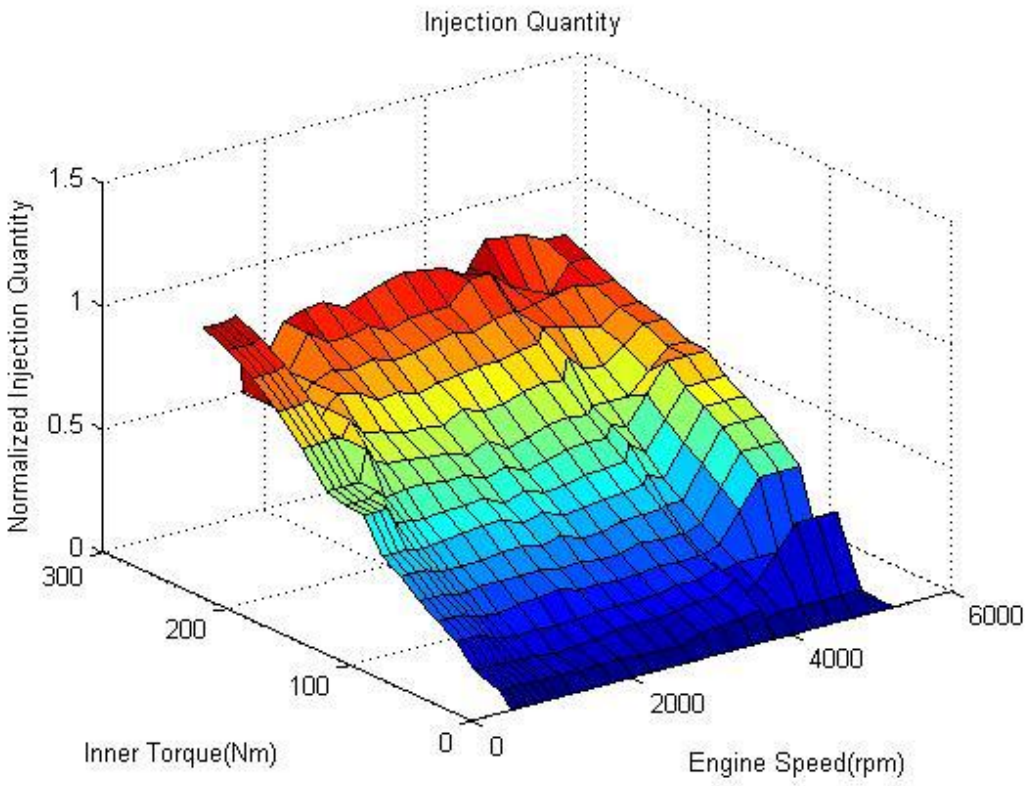

Figure 4.3 : Total injection quantities for base maps.

The NEDC is used for certification tests. The NEDC is a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars. It is also referred to as MVEG cycle (Motor Vehicle Emissions Group). The NEDC is supposed to represent the typical usage of a car in Europe. It consists of four repeated ECE-15 Urban Driving Cycles (UDC) and an Extra-Urban driving cycle (EUDC). The test procedure is maintained by UNECE World Forum for Harmonization of Vehicle Regulations [18]. The cycle must be performed on a cold vehicle at 25 °C. The cycles may be performed on a flat road, in the absence of wind. However, to improve repeatability, they are generally performed on a roller test bench. This type of bench is equipped with an electrical machine to emulate the resistance due to the aerodynamic drag and vehicle mass. For each vehicle configuration, a look-up table is applied: each speed corresponds to a certain value of resistance. This arrangement enables the use of a single physical vehicle to test all vehicle body styles by simply changing the look-up table. A fan is coupled to the roller bench to provide the vehicle air intakes with an airflow matching the current speed. Many more tests can be performed during the vehicle development with this arrangement than those with conventional road tests [18].

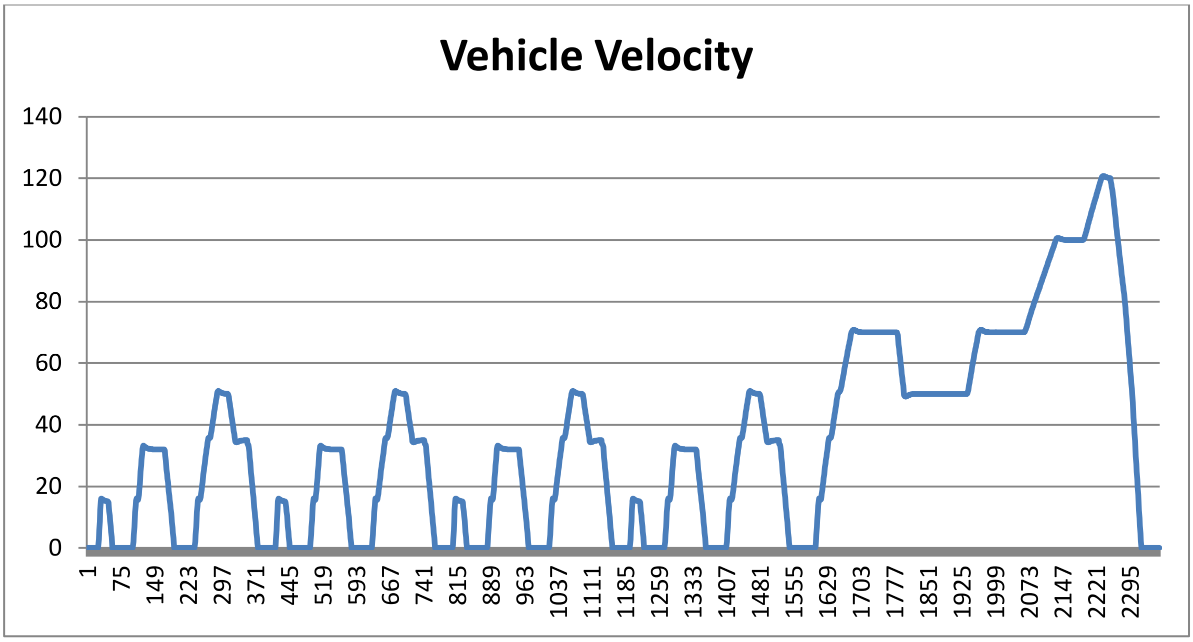

Figure 4.4 : Vehicle velocity for the NEDC.

4.2 The Equations of Motion

4.2.1 The Equation of Wheel Motion

Figure 4.5 shows the forces on a rooling wheel under a tractive force.

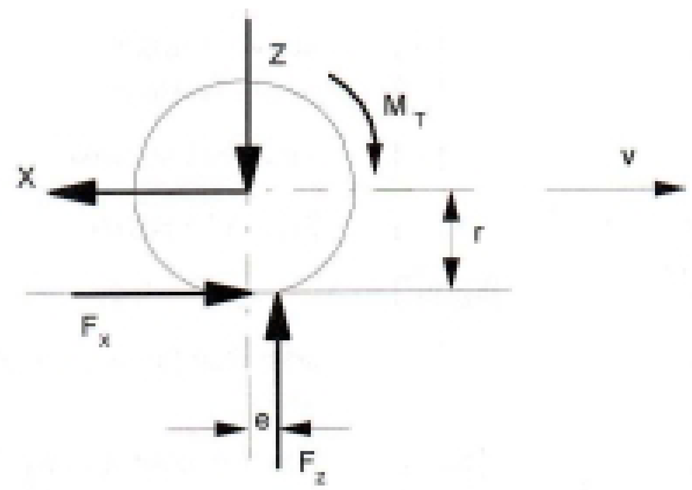

Figure 4.5 : Forces on a rolling wheel under a tractive force.

X : reaction force of the vehicle

Z : vehicle weight

W_T : wheel torque

Fx : wheel force

Fz : road reaction force

m_w : the mass of the wheel

J_T : wheel inertia

v : vehicle speed

r : static radius of the wheel

e : axis misalignment

'x' indicates the linear displacement of the wheel due to movement and z indicates displacement for vertical axis. Equation of motion can be written as below by using the acceleration, wheel mass and inertia forces;

$$m_w\ddot{x} = F_x - X \quad \textbf{(5.1)}$$

$$m_w\ddot{z} = F_z - Z - m_w g \quad \textbf{(5.2)}$$

$\ddot{\varphi}$ indicates the angular acceleration so the rotational inertia of the rotating wheel can be described as [19]

$$J_T\ddot{\varphi} = W_T - F_x r - F_z e \quad \textbf{(5.3)}$$

4.2.2 Vehicle Equations of Motion

Figure 4.6 shows the acting forces on a road vehicle which is going up on a hill. Then, the relations between these forces and resistances will be briefly discussed [13].

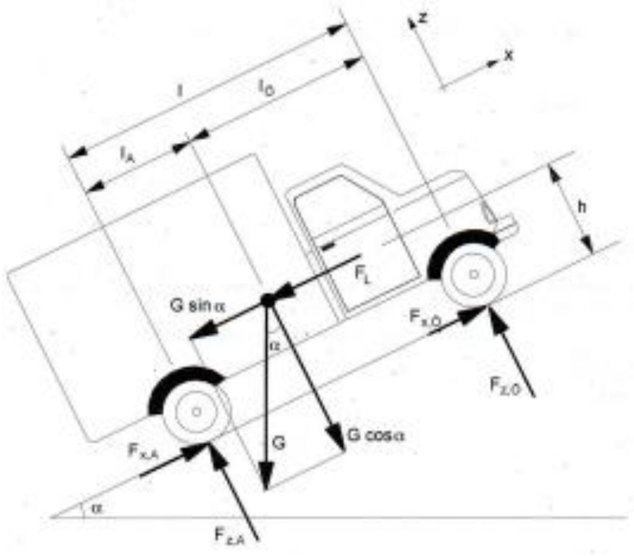

Figure 4.6 : Free body of the vehicle.

Force equilibrium equation on x-axis;

$m\ddot{x} = \ F_{x,O} - F_{x,A} - mgsina - F_L$ **(5.5)**

Briefly F_T is given by:

$F_T = F_B + F_{St} + F_L + F_R$ **(5.6)**

Where**;**

F_T : Tractive Force

$F_T \ = \frac{M_{TA}}{r} + \frac{M_{TO}}{r}$ **(5.7)**

F_B : Vehicle Acceleration Force

$r = R_O = R_A$

$\lambda = 1 + \frac{J_O + J_A}{mr^2}$ so; **(5.8)**

$F_B \ = \lambda m\ddot{x}$ **(5.9)**

F_{St}: Inclination Force

F_{St}=mgsinα **(5.10)**

For low inclination angles, the assumption tanα = sinα = p can be used. Here "p" indicates the inclination. Then, one can write,

$F_{St}=m\ g\ p$ **(5.11)**

Resistive Forces

In this section, aerodynamic forces and rolling resistance calculations and assumptions are discussed.

F_L: Aerodynamic force

$F_L = \frac{1}{2}\rho c_w A v^2$ **(5.12)**

C_w : aero coefficient

ρ : density (Ns^2/m^4)

A : frontal area

v : vehicle velocity

F_R : Rolling resistance

$F_R=f_R\ F_z$ **(5.13)**

As understood from the equation above, the rolling resistance is the multiplication of rolling resistance coefficient and wheel load. The rolling resistance coefficient can be assumed as 0.015 for our model.

$F_R = f_R(F_{Z,O} + F_{Z,A})$ **(5.14)**

By using all of the above given equations, tractive force can be written as follows.

$F_T = m\ddot{x} + (f_R + p)mg + \frac{1}{2}\rho c_W A v^2$ **(5.15)**

The total ratio between the motions of wheel and crankshatf depends on selected gear and final drive ratio. As stated earlier, the final drive ratio is 3.37 for above mentioned vehicle.

For the engine speed calculation, final drive ratio (FDR) gear ratio, vehicle speed and rolling radius measurements will be used.

Table 4.1 : FDR, rolling radius and gear ratio values.

FDR		3,37
Rolling radius		0,31 m
Gear Ratio		
	1	3,583
	2	1,926
	3	1,206
	4	0,878
	5	0,689

The engine speed is a function of the vehicle speed and gear ratio. Angular velocity of the wheel can be calculated as;

w_{t1} [rad/sec]=v[m/s]/r **(5.16)**

Total gear ratio (TGR) depens on selected gear and FDR . So angular velocity of the engine is given by;

w_{m1} [rad/sec]= w_{t1} . tgr **(5.17)**

Engine speed [rev/min] can be calculated as

w_{m2} [rev/min]= w_{m1} . 30 / π **(5.18)**

These equations are used for modelling fuel consumption.

4.3 Fuel Consumption and CO_2 Emission Model

The fuel consumption and CO_2 emission model contains the base map selection submodel, engine torque calculation, engine speed calculation, S/S system submodel, CO_2 and emission calculation.

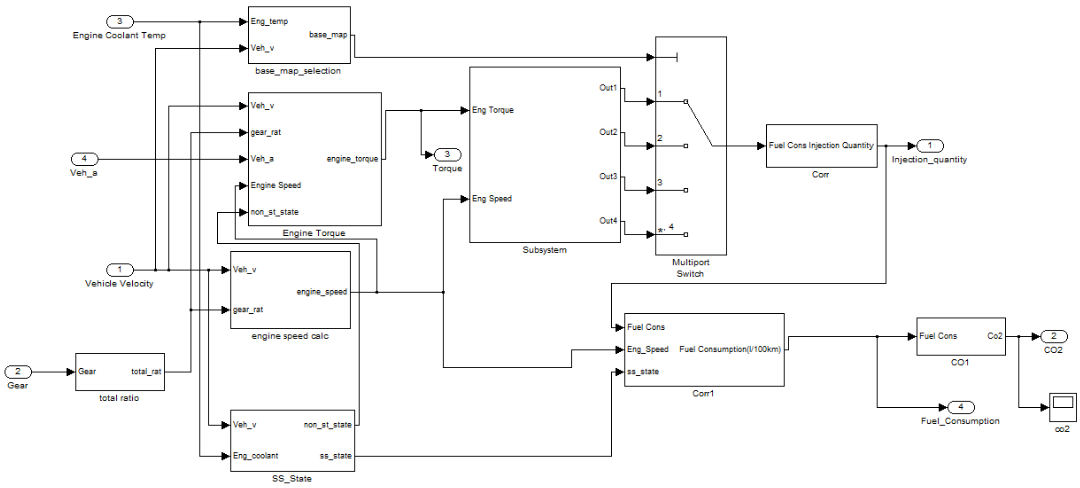

Figure 4.7 : Fuel Consumption model overview.

As stated before, different base maps are used according to the engine coolant temperature and vehicle velocity. For the base map selection, a look up table was used in the base map selection subsystem.

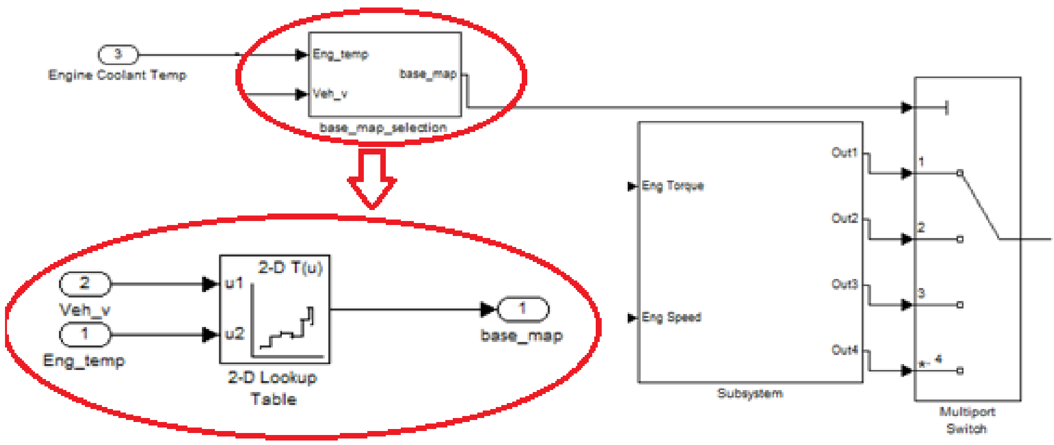

Figure 4.8 : Base map selection subsystem.

Four look up tables are used for injection quantity calculation.

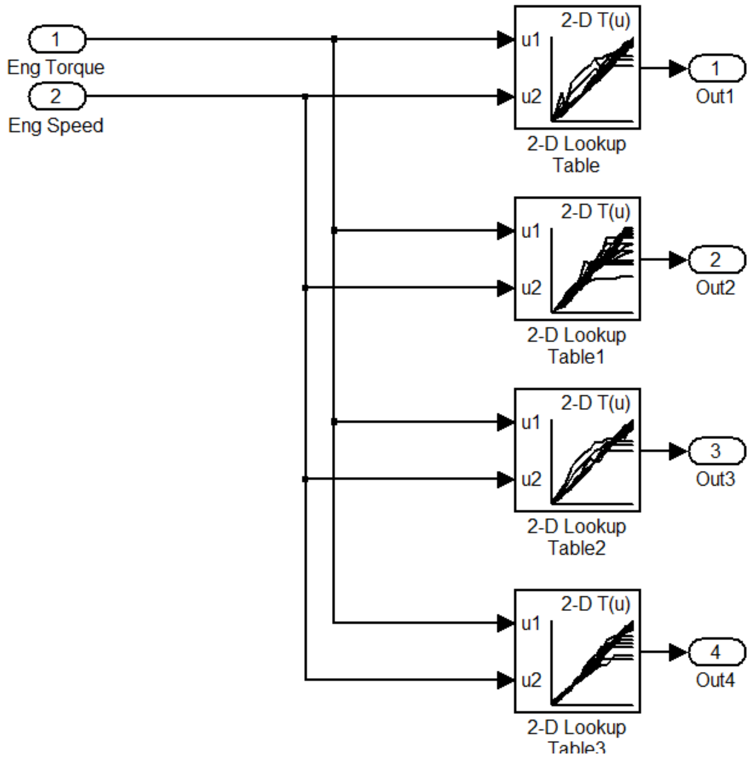

Figure 4.9 : Lookup tables for base maps.

The engine speed and engine torque are calculated with given equations. Total gear ratio, rolling radius and vehicle velocity are used for the engine speed calculation.

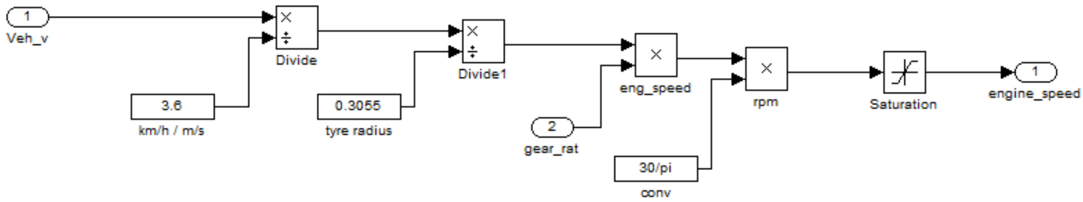

Figure 4.10 : Engine speed calculation.

Total gear ratio is calculated with a lookup table and by using the final drive ratio.

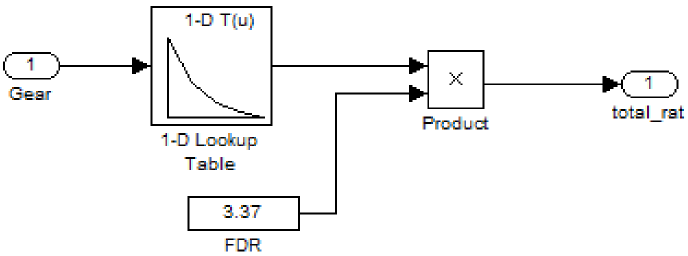

Figure 4.11 : Total gear ratio calculation.

The engine torque is calculated in the torque calculation subsystem. The engine torque can be calculated by calculation of the friction force, inertia force, total gear ratio, aerodynamic force and engine torque loss.

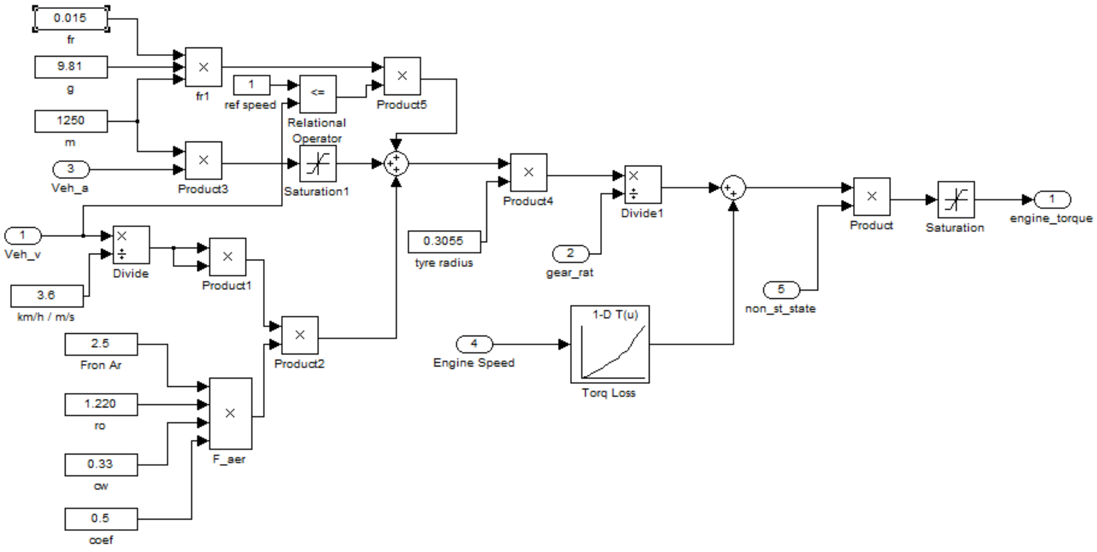

Figure 4.12 : Engine torque calculation subsystem

With using injection quantity lookup tables, injection quantities are calculated then converted to fuel consumption in liter per 100 km. A discrete integrator is used to calculate total fuel consumption.

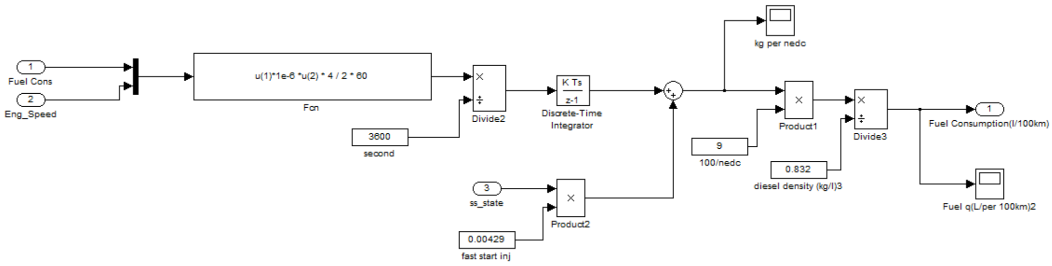

Figure 4.13 : Injection quantity for calculation of fuel consumption

As seen in the model injection from the injection quantity [mg/hub] converted to the fuel consumption [l/100km]. The injection quantity is multiplied by the engine speed and number of cylinders, then divided to seconds and 2 because the engine is a four stroke engine. For the engine, every injector is enerjized per two revolutions.

$$iq[kg] = iq[mg/hub].\ engspd[rev/min].\ (4 / 2)\ .\ 60 \qquad \textbf{(5.19)}$$

The output of this equation is integrated by the discrete time integrator. Fast start injection quantity is added to total fuel consumption if the S/S is available. The integration gives total fuel consumption for the NEDC. Total distance for the NEDC is 11 kilometers. The fuel consumption per 100km is calculated in the fuel consumption subsystem.

The simulation output is compared with the measured data. As seen in the diagram given below, the simulation data closely matches with the measured data.

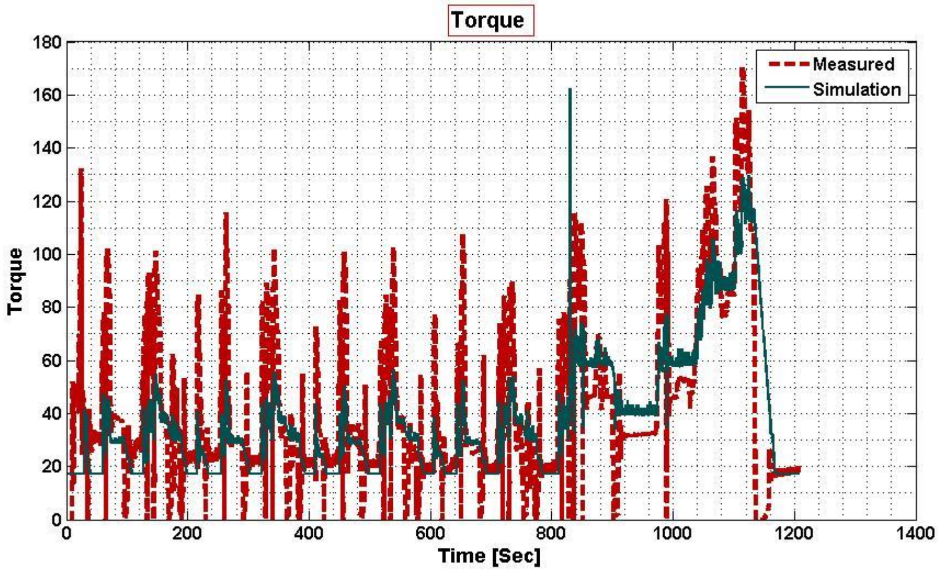

Figure 4.14 : Comparison between simulation output and measurement

Comparison of injection quantities of the simulation and measured data are also similar as given in the below diagram.

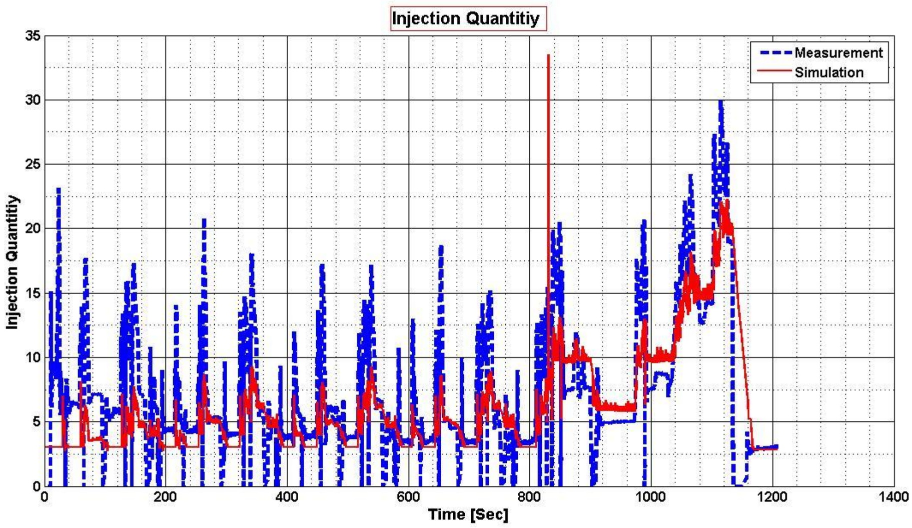

Figure 4.15 : Comparison of injection quantity of simulation and measurement.

The injection quantities are compared for the NEDC by using the calculated fuel consumption and cumulative CO_2 emissions. The diesel fuel is not a single compound, but rather a mixture of hydrocarbons. The "average" compound is $C_{12}H_{23}$. The diesel compound goes from $C_{10}H_{20}$ to $C_{15}H_{28}$ [20].

The chemical reaction equation for the complete combustion of the Diesel fuel would then be

$$4C_{12}H_{23} + 71O_2 \text{ --> } 48CO_2 + 46H_2O \qquad \textbf{(5.20)}$$

Of course, in the real world, we do not get the complete combustion of the Diesel fuel, so that what comes out the exhaust is a widely varying mixture of substances from elemental carbon to potentially unburned fuel [20].

By using the complete reaction chemical equation it can be calculated that for every 668gr diesel fuel, the output of the chemical reaction is 2112gr CO_2. The diesel density can be calculated as 0,832kg/l. CO_2 emissions can be calculated by using these values and total fuel consumption. Cumulative CO_2 emissions [gr/km] can be calculated by multiplication of the fuel consumtion [l/100km] and 26.5 [gr.100].

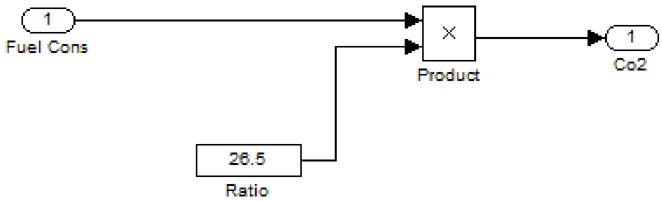

Figure 4.16 : Cumulative CO_2 calculation.

4.4 Comparison of the Simulation Output and Measurement

The system simulated with the S/S and without the S/S system. Cumulative CO_2 emission values are shown below.

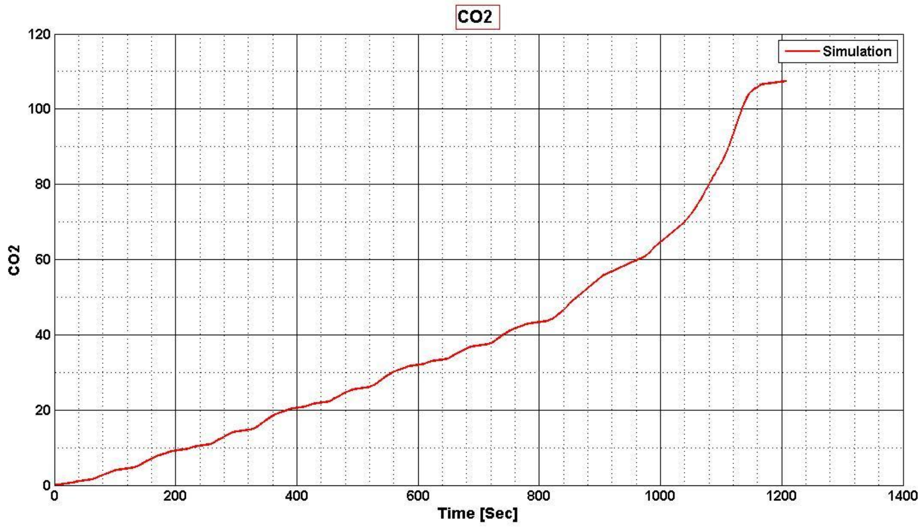

Figure 4.17 : CO_2 Emissions without the S/S systems

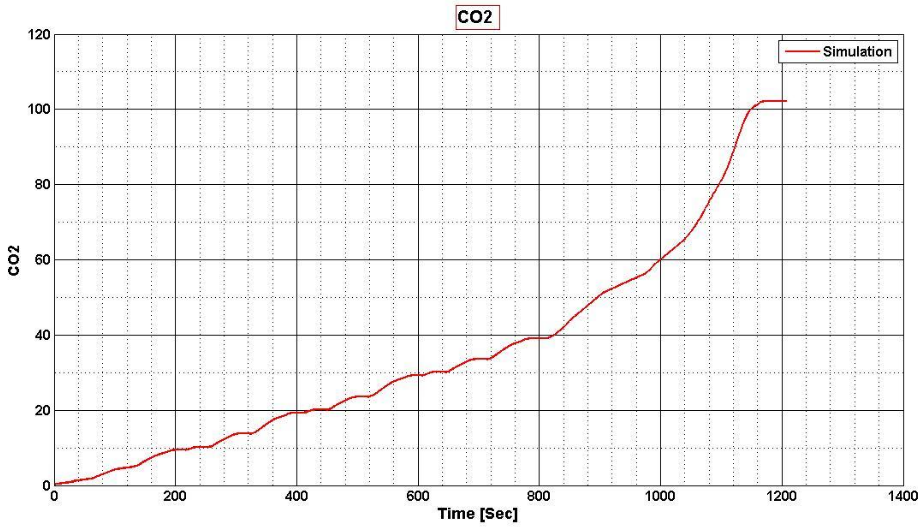

Figure 4.18 : CO_2 Emissions with the S/S systems

As seen in the figures, by stopping engine at idle phases, CO_2 emissions can be reduced. The CO_2 emission is simulated as 107.44 gr/km without the S/S system and 103.2 gr/km with the S/S system.

Tubitak MAM and OTAM chassis dynometers are used for the NEDC tests.

Figure 4.19 : Emission test at the chassis dynometer.

Table 4.2 : The S/S System benefit comparison.

	Simulation		Measurement	
	With S/S	Non S/S	With S/S	Non S/S
CO_2 (gr/km)	103,02	107,44	105	109
Fuel Consumption (l/100km)	3,89	4,05	3,96	4,11

The fuel consumption is calculated with %1.43 relative error. The CO_2 benefit of the S/S system is calculated as 4.42 gr/100km which is 4 gr exactly. The fuel consumption benefit is calculated as 0.165 liter per 100 km. With emission tests, it is measured as 0.16 liter per 100 km.

5. CONCLUSIONS AND RECOMMENDATIONS

Nowadays, hybrid and micro-hybrid systems became widespread due to fuel economy benefit and environmental concerns. Micro-hybrid systems such as Regenerative Braking and Stop/Start systems are commonly used systems in automotive industry. About the S/S system there are several academic studies. These studies are mainly based on fuel economy benefit of the S/S system, fast start optimisation and components which are being used by the S/S system. In literature review section, details about studies on this issue is given.

General information is given for the components and systems, which are used by the S/S system or in relationship with the S/S system. Most important components for the S/S system are enhanced battery, enhanced starter motor, voltage quality module, gear neutral sensor and bi-directional crankshaft position sensor.

Following, system inputs and outputs are defined. The scheduler for the S/S system is developed and validated. The calibrators have constraints because of safety and passenger comfort. The scheduler calibration provides safety and comfort for the S/S events. The subsystems such as the gear neutral sensing subsystem, restraints subsystem, pedals subsystem, brakes subsystem, steering subsystem, power supply subsystem, engine cranking subsystem, base engine subsystem, locking subsystem, HMI subsystem, climate control subsystem, engine control module, central electrical module, HS, MS CAN and LIN are inspected for the control algorithm. The outputs of the S/S system was defined such as the stop inhibition, engine run request, system-induced automatic restarts, stop abortion, start inhibitor, stall recovery, S/S deselection and S/S deactivation.

With this project, a model is developed which allows to have an idea about the fuel consumption and S/S system benefit. For early phases of a project, generally it is not possible to have test vehicles. This simulation is used to calculate approximate fuel consumption data.

Finally, simulation results indicate the fuel consumption benefit of the S/S system is 0.165 l/100 km which is measured as 0.16l /100km. For further improvements on the model, the torque model will be improved.

Table 5.1 : The S/S System fuel economy and CO_2 emissions benefit.

	Simulation		Measurement	
	With S/S	Non S/S	With S/S	Non S/S
CO_2 (gr/km)	103,02	107,44	105	109
Fuel Consumption (l/100km)	3,89	4,05	3,96	4,11

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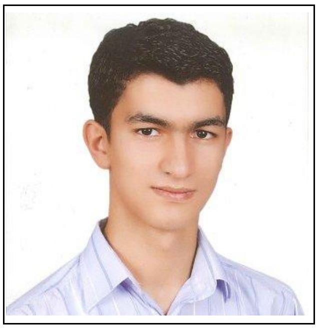

Name Surname: Abdulehad Özdemir

Place and Date of Birth: Bakırköy – 15.11.1989

Address: Huzur Hoca Caddesi, Çetiner Apt. No:12 D:4 İçerenköy/Ataşehir

E-Mail: abdulehadozdemir@gmail.com

B.Sc.: Istanbul Technical University

M.Sc.: Istanbul Technical University

Professional Experience and Rewards:

ITU Faculty of Mechanical Engineering – Student Assistant

Ford Otosan San. A.Ş. – Product Development Engineer