STOP-START SYSTEM USING MICRO-HYBRID TECHNOLOGY FOR INCREASING FUEL EFFICIENCY

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Abstract— The national mandate set forth by the Environmental Protection Agency (EPA) to increase fuel efficiency and reduce greenhouse gas (GHG) emissions by 5% each year for all new model mid-size cars, medium-duty cars, and light-duty trucks is pushing automobile makers to convert their fleets to hybrid-electric and micro-hybrid vehicles. Implementing automated start/stop (SS) technology in a passenger vehicle is a cost effective way to improve fuel economy (FE) and reduce emissions without affecting consumer acceptance. In urban areas, where much of the vehicle driving time is spent idling at stop lights or in traffic, the engine can be shut down when the vehicle is stopped to save fuel. The engine is quickly and quietly restarted as the driver demands torque for acceleration. This operating strategy is often utilized in full hybrid-electric vehicles that have powerful electric systems, but is becoming more popular in micro-hybrid vehicles that use traditional starter/battery configurations. It is challenging to maintain drivability and achieve efficient start-ups using a micro-hybrid configuration. This research investigated the feasibility of using a micro-hybrid configuration to achieve efficient start transients for SS technology. The consumption of energy by the starter/battery was analyzed by creating a model of the engine SS dynamics. The model was calibrated and validated through experimental testing on a vehicle and engine that had been provided. The model was used to simulate start transients for different component packages. As the preliminary simulation results which suggest that traditional starter/battery combinations may be appropriate and a fuel savings of over 5% expected in regulatory urban driving cycles. The model and selected component package will be used for development and control of a SS system in a test vehicle.

Keywords—Environmental Protection Agency (EPA), Greenhouse gas (GHG), Fuel economy (FE), Start/Stop (SS).

I. INTRODUCTION

A. Micro-Hybrid Technology

A micro-hybrid is the simplest kind of ICE-electric technology. It usually consists of an energy storage device and a strengthened starter-motor that can also act as a generator. The main and important feature of a micro hybrid is the 'stop-start' function. According to various research studies, in urban areas vehicles are at a standstill for one-third of the time. Stop-start systems could help to reduce exhaust pipe emissions, make cities quieter and boosts fuel efficiency. A stop-start system operates by cutting the engine when the vehicle comes to a complete standstill. The engine is automatically switched back on when the driver releases the brake pedal. A first generation of alternator-based 'stop-start' system has been in serial production with Citroen, on the C4 since 2004 and on Smart cars since 2007. This system performs a function of stop-start that is transparent to the driver: the belt-driven starter-alternator system shuts down the engine during idle phases and automatically restarts the engine when the driver wants to move off. As a result, there is no fuel consumption, vibration or noise, gas emission at standstill. By using this system in the European standard driving cycle, fuel consumption is reduced by 6%; while in congested urban traffic, savings of up to 25% have been observed [6, 7]. However, disadvantages to this type of system can be the noticeable starting and stopping of the engine and the inability to run major electrical loads such as air conditioning without the engine restarting.

B. Micro-Hybrid Start/Stop Technology

With the stop/start system activated the engine is automatically turned off and goes to standby mode when the vehicle is brought to a stop at traffic lights, stop signs and in traffic jams. The engine instantly restarts when the brake pedal is released, the vehicle pulling away once the accelerator is pressed. The 508 & 308 models, which will be on sale in late October in Australia, will be the first mass-produced cars equipped with this innovative system. The system is combined with another leading-edge technology already commercially available – the electronically controlled manual gearbox (EGC). Thanks to precise metering and innovative computer control, repeatedly stop and start of the engine can reduce fuel consumption by 10 % in city driving, 6 % in a standard combined cycle and up to 15 % in heavy traffic. CO_2 emissions are thus reduced in similar proportion. And drivers see the result in the dash board display showing total time spent with the engine off.

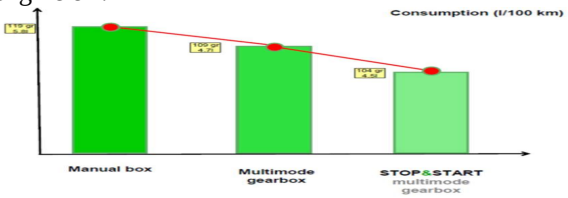


Fig. 1 Consumption of fuel lit/100 km & Emission of CO_2 gram/100km [1]

The stop/start system also helps to improve the quality of life in cities with no mechanical noise during the times the vehicle is stopped.

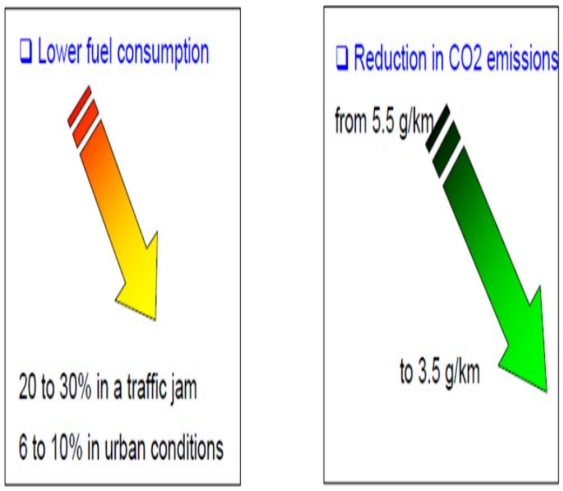


Fig. 2 Reduction in fuel consumption & CO_2 emission [1]

Companies produced the stop/start system as part of its strategy to develop new technologies to reduce fuel consumption and CO_2 emissions while enhancing drivability, and this latest development reinforces the company's strategic focus on creating useful technology for every day, with benefits for customers and society as a whole. This pragmatic approach has been systematically shown to produce quick-to-the-market, cost effective solutions [1].

II. LITERATURE REVIEW

A. Broader Impact

In response to President Obama's May 2010 directive to reduce greenhouse gas (GHG) emissions and fuel consumption (FC), the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) are mandating an increase in fuel economy (FE) and reduction of GHG emissions by 5% each year for all new model mid-size cars, medium-duty cars, and light-duty trucks [9]. National mandates like this, along with rising fuel prices, continue to push the automotive industry to improve its corporate average fuel economy (CAFE). By 2025, the fleet-wide average FE will by 54.5 miles per gallon (mpg). Mid-size and medium-duty cars will jump from 32 mpg as of 2012 to 62 mpg in 2025. The FE of light-duty trucks will go from 26 mpg in 2012 to 44 mpg by 2025. In order for new vehicles to reach these standards, the average price of a vehicle in 2025 will increase by about $1800. However, a family that purchases vehicle in 2025 will save $8200 in fuel costs compared to a similar automobile in 2010. Automakers are reaching out to find new ways to quickly and affordably stretch the fuel economy of their vehicles to meet the new standards. Improvements are being made to the engines, transmissions, and auxiliary loads of conventional vehicles. Many manufacturers are beginning to produce hybridized vehicles where much of the power train architecture and auxiliary loads of the vehicle are electrified. This increases the vehicle efficiency because of the potential to recuperate energy that is otherwise lost in a traditional vehicle structure. Precise control of electrified components also minimizes losses during driving to improve overall vehicle efficiency.

B. State of the Art

Start/stop (SS), sometimes termed idle-stop or auto start-stop, is a vehicle operating strategy that shuts down the engine during periods when the vehicle is not moving. This eliminates the fuel consumption that would normally be spent to keep the engine running. During idle periods the engine is not providing any useful energy to move the vehicle, therefore the engine is technically operating at a zero efficiency state. However, the vehicle auxiliary loads require power even when the vehicle is stopped, making it is necessary to have a secondary energy source to meet those needs. For this reason, past use of SS technology had be restricted to hybrid power trains with larger secondary power sources and electric machines that provided ample power for the auxiliary loads and on-demand engine restarting.

1) Overview of Start/Stop Systems:

Many conventional vehicles, or vehicles with non-hybrid power trains, are being equipped with SS. Because adding SS technology to a vehicle is the lowest form of hybridization these vehicles are classified as micro hybrids. Companies that have SS systems on vehicles available in the U.S. market today include Audi, BMW, Ford, GM, Honda, Kia, Mercedes-Benz, Porsche, Mahindra and others. Some of these systems will be reviewed here. Ford has introduced a SS system for their 2013 Fusion vehicle that only costs $235 to implement and has an 18 month payback [10]. This system increases the FE by 3.5%. The only added cost comes from the addition of an upgraded starter along with an electric hydraulic pump to maintain the internal pressure of the automatic transmission. The controls for the system closely regulate the vehicles auxiliary loads to determine when the SS function is appropriate to use. The controls also use voltage blending to maintain driver acceptance when SS is enabled. The electrical system is unmodified and uses a lead-acid 12V absorbent glass mat (AGM) battery, which has become the industry standard for vehicles with small SS systems. To protect the battery from advanced aging, Ford has strict controls on the battery depth of discharge (DOD) and regulation of dynamic charge acceptance (DCA). DCA directly affects the amount of energy that the battery can accept during regenerative braking. BMW implemented a SS system for its 3-series that uses the system to perform

auto start-stop function (ASSF) and regenerative braking [11]. This system uses the traditional 12V AGM battery to gain a 3.5% increase in FE. The electrical system closely manages a partial battery state of charge (partial-BSOC) in order to maintain the battery. The BSOC range is approximately 79-85%. The only additional components for the SS system are a battery sensor and a power management software module that controls the decision making process for SS and regenerative braking. This system runs on manual transmissions, Here the engine start-up and shutdown is controlled by the driver engaging and disengaging the clutch. The SS system along with vehicle road load reductions were shown to provide a 33% increase in FE over the EPA city drives cycle.

2) Start/Stop System Components description:

- Engine ECU - Manages the Start & Stop system.
- CAS - Car Access System
- Startup motor - It is responsible for starting the internal combustion engine.
- Instruments panel - Informs the driver about the status of the Start & Stop system activated/deactivated.
- MSA Centre console switching center
- Speed sensor - Informs, normally through the ABS unit, of the vehicle's speed.
- Battery sensor - Informs the engine unit about the current entering and leaving the battery in order to estimate charge level.
- Bonnet switch - Warns the engine unit of bonnet opening.
- Seat belt switch - Indicates to the engine unit whether the seat belt is fastened or not.
- Clutch pedal position sensor - Signals the pedal's position. If the lever is slightly shifted (a hand is resting on it), the motor starts after pressing the pedal by 90%.
- Clutch pedal position sensor - Signals the pedal's position. If the gear lever is in neutral position, the motor starts after pressing the pedal by 10%.
- Brake servo vacuum sensor - Located on the servo brake, sends a signal proportional to the brake's vacuum.
- Neutral position sensor - Located on the gear box, signals the gear lever position. After replacement, calibration needs to be carried out using diagnosis equipment.
- Automatic Heat and A/C integrated Climate control unit - Requests startup of the engine when it needs thermal units (A/C compressor) or calories (heating radiator) to reach the temperature selected by the driver [12].

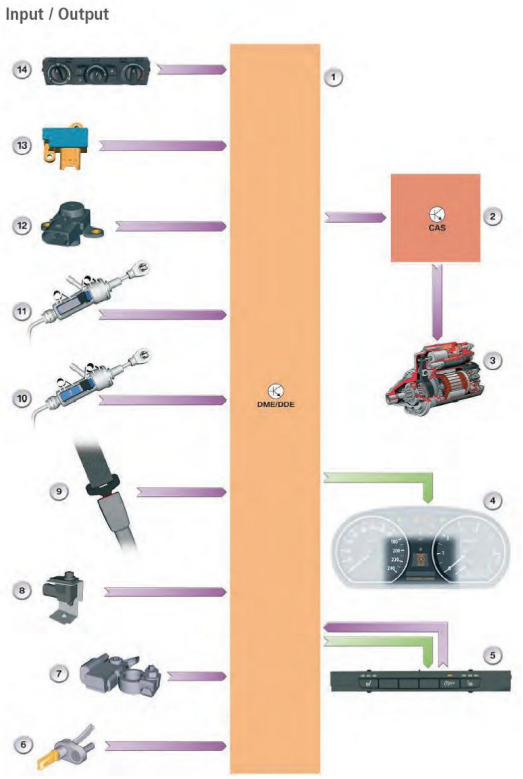


Fig. 3 Start/Stop System Components [12]

3) Start/Stop Control:

Sophisticated control is needed for a fuel-efficient SS system that maintains consumer acceptance; offers enhance vehicle drivability, meet emissions standards and avoid noise, vibration, and harshness (NVH) signatures due to engine start-up and shutdown. Control software must manage regenerative braking, torque assist during vehicle launch (if used), auxiliary load management, transmission operation, advanced start-up firing, battery management, and SS logic algorithms [10].

C. Improvement of the components compared to a conventional system

- Due to constant startups, we will incorporate a current stabilizer to avoid power spikes. When there is a startup or the battery voltage is below 10.5v, the stabilizer feeds the vehicle's electrical system through an internal battery Boost mode. Once the startup stage is completed, the system operates without the stabilizer, Bypass mode, and uses the situation to recharge the internal accumulator.
- It is common to find batteries with AGM technology (Absorbed Glass Mat) in vehicles of this type. This type of battery is able to withstand numerous deep discharges and has a low rate of self-discharge. At the same time, they need no maintenance. In some vehicles, a reset is needed with diagnosis equipment after replacement.

- Start motor is improved to achieve longer lifetime. The bearings are strengthened, planetary gear improved and a stronger pinion drive is used.
- Alternator is improved to be 60% more efficient and to enable more battery charge at lower RPM [12].

III. WORKING

A start-stop system used in automobiles automatically shuts down and restarts the internal combustion engine to reduce the amount of time the engine spends idling, thereby improving fuel economy and reducing emissions.

In a typical situation the driver releases the accelerator pedal, activates the brake paddle and the vehicle comes to a halt. The driver takes the car out of the gear i.e. in neutral position.

The Engine ECU checks the following:

- Engine is in idling condition and no gear is engaged.
- The wheel speed sensor is showing a zero speed.
- Electronic battery sensor is showing adequate battery charge for next start operation.

When all these conditions are satisfied the engine will wait for some manufacturer specific denounce time and then switches off automatically. The starter pinion is engages in the ring gear 1 preparing for the next start. This can causes the engine to be started quickly. (Ring gear is a medium carbon steel ring with teeth, it transfer torque from the starter motor pinion to the flywheel to rotate the engine to begin the cycle.) As soon as the clutch is actuated the starter receives the signal to restart the engine. The engine is started quickly and quietly and is immediately ready for operation again [2]. The conditions in which the system will go to stop mode may differ with various customers.

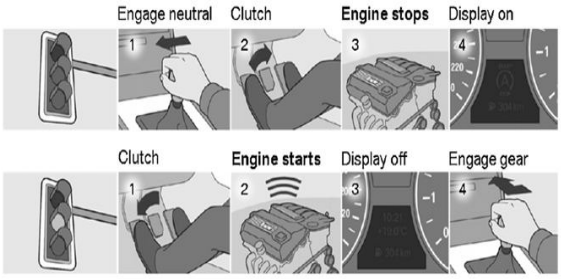


Fig. 4 Start/Stop Procedure of BMW's with Manual Transmissions [11]

A. Operating Details - Fuel Smart Start-Stop System

When a vehicle is stationary and engine is idling particularly at traffic signals / traffic jams, considerable amount of fuel is consumed and emissions (CO_2) are released to the atmosphere.

With stop start mechanism, the engine is automatically stopped to reduce the fuel consumption at traffic signals / traffic jams.

The Engine will automatically **stop**, if all the conditions mentioned below in are met:

1) Pre-Requisites:

- If the engine temperature at start of the ignition cycle is low, then Initial warm up period will be around 15 minutes. Otherwise, the warm period will be 1 minute.
- Stop-Start feature is selected through selection switch.

2) Conditions:

- Engine speed in idling range.
- Accelerator Pedal Not Pressed.
- Clutch pedal Not Pressed.
- Vehicle speed is zero.
- Battery condition is healthy.
- Gear box in neutral.
- Bonnet remains closed.

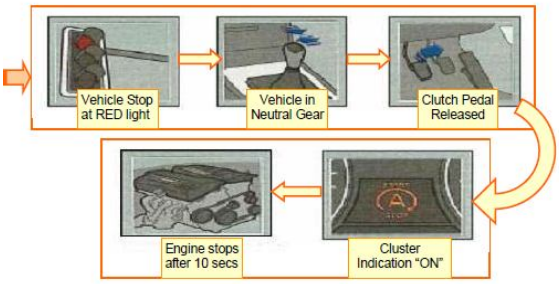


Fig. 5 Shows conditions for Auto Switch off Engine [3]

The Engine will **start** automatically, if all the below conditions are met:

- Engine Speed is zero.
- Vehicle Speed is zero.
- Gear Box is in Neutral.
- Bonnet remains Closed.
- Stop Start feature is selected through selection switch.
- Vehicle stopped automatically / stalled due to Auto Stop.
- Clutch Pedal is pressed fully.

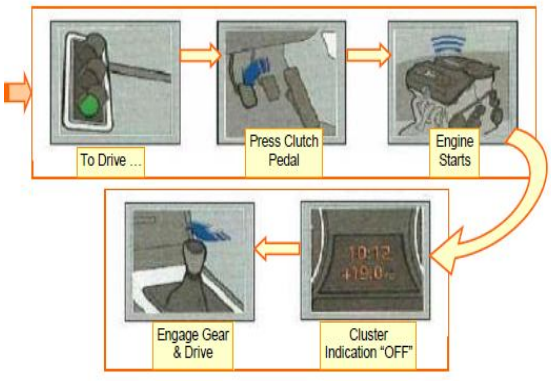


Fig. 6 Shows conditions for Auto Restart Engine [3]

3) Diagnostics Procedure:

The Stop Start (i.e., Fuel Smart) Mechanism has built in diagnostic algorithm to detect any error / fault in the system:

- The system is automatically taken to by-pass mode, if any fault is detected by the system.
- In by-pass mode, the system does not stops or starts automatically.
- If auto stop or start is not happening, the system has to be taken into diagnostic mode.
- In diagnostic mode, blink code(s) will be generated, which indicates the error in the system.

If engine does not start, check the following –

- Loose connection of the connector with controller.
- Continuity of 10 A fuse present in the line between ignition and controller [3]

4) Entry into Diagnostic Mode:

Follow the flow chart given below to enter into diagnostic mode –

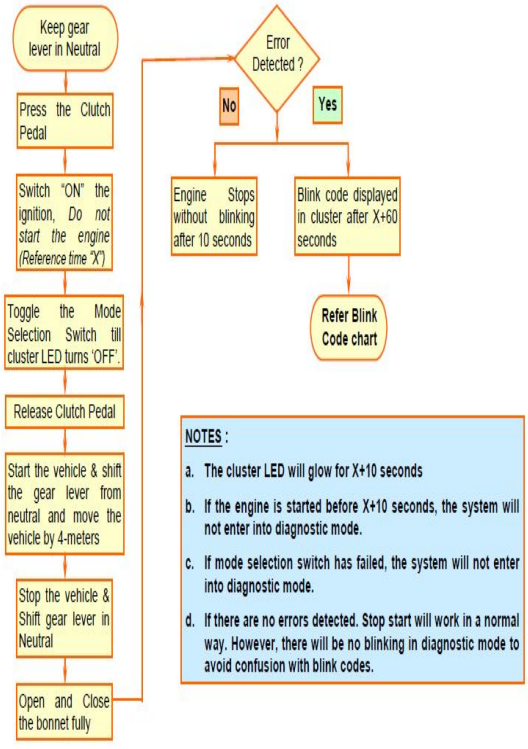
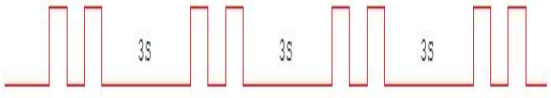


Fig. 7 Flow Chart of Entry into Diagnostic Mode [4]

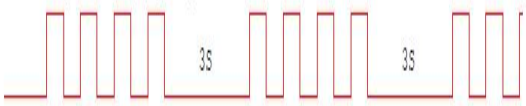
5) Blink Code Chart:

- Clutch Switch Signal Failure: The LED will blink twice and then there will be a delay of 3 seconds. The process keeps repeating.



- Mode Selection Switch Signal Failure**:** The LED will blink thrice and then there will be a delay of 3 Seconds. The process keeps repeating.

- Alternator 'W' terminal Signal failure: The LED will blink four times and then therewill be a delay of 3 Seconds. The process keeps repeating.



- Vehicle Speed Signal Failure: The LED will blink five times and then there will be a delay of 3 Seconds. The process keeps repeating.

- Neutral Sensor Signal Failure: The LED will blink six times and there will be a delay of 3 Seconds. The process keeps repeating.

- Bonnet Switch Signal Failure: The LED will blink seven times and then there will be a delay of 3 Seconds. The process keeps repeating.

- Battery Not Healthy: The LED blinks eight times and then there will be a delay of 3 seconds. It keeps repeating.

- Controller Failure: The LED remains continuously 'ON'. This condition exists even without entering into diagnostic mode.

NOTE: For more than one error conditions (if occurs simultaneously) then the LED will –

− Blink first for higher priority

− Then there will be a gap of Six seconds and

− Then it will blink for lower priority error.

For example: If there is Stop Start Feature Selection Switch Signal Failure and Neutral Sensor Signal Failure then LED will blink for three times then after 6 seconds LED will blink for six times.

- Fail Safe Mode of FUEL SMART Controller: The LED blinks for one second 'ON' and two seconds 'OFF' in normal mode to indicate malfunction (This condition exists even without entering into diagnostic mode).

NOTE: Fail safe mode is activated when there is signal failure due to error in system. In fail safe mode, system will enter in by-pass mode (i.e., auto stop start will not work). [4]

IV. ADVANTAGES, DISADVANTAGES & APPLICATIONS

A. Advantages of Start-Stop system using Micro-Hybrid Technology

- Fuel consumption is reduced by up to 5% to 10% in city driving.
- CO_2 emissions are reduced by up to 5% to 10% in city driving; almost the same as the gain from fuel Economy.
- The engine restarts within 350 milliseconds and in complete silence.
- Eliminate engines noise and vibrations when the vehicle is at a temporary Standstill, which represents 35% of city driving time.
- Implementation cost is not very High (generally in range $300-$400)
- The engine stops and restarts automatically.[2]

B. Disadvantages of Start-Stop system using Micro-Hybrid Technology

- Fuel saving is not as good as Fully Hybrid.
- Some vehicle functions may not run when engine is off (Air conditioner etc.)
- Even though the Implementation is cheap, The vehicle manufacturer will charged huge amount for vehicles with Start-Stop systems.[2]

C. Applications

- Mahindra & Mahindra has introduced the stop start based Micro Hybrid system to Indian Automotive market known as "Fuel Smart" and is implemented in its SUV's Mahindra Scorpio_2008, Mahindra Bolero_2010 and Mahindra XUV5OO_2013.
- Tata Motors has introduced this system on their LCV Tata Ace_2010.
- Fiat introduced this system in the end of 2008 in Fiat 500.
- The Honda Civic-Hybrid has been using Start-Stop system since 2006.
- Volkswagen began using Start-Stop system with Polo, Golf & Passat_2007.
- BMW uses Start-Stop technology across many of its cars & MINI line for 2008.

There are many others vehicles which will implement Start stop in near future [2, 13].

D. Comparison of Start-Stop System with Conventional I.C. Engine

CONVENTIONAL I.C. ENGINE	START-STOP SYSTEM
Conventional vehicles without Start-Stop features.	With Start-Stop vehicles, the engine is switched off during short stops – for instance at traffic lights – in order to save fuel and to reduce CO2 emissions by 5 – 10%.
Technology focus: 1) Includes bio fuels, natural gas and diesel technologies. 2) Market shift to smaller vehicles and more efficient engines. 3)Weight reduction and improved aerodynamics	**Technology focus:** 1) Responding to CO2 reduction targets set by EU 2) Allows engine to be shut off instead of idling while the vehicle is stopped 3) Nearly all vehicle manufacturers launching Start-Stop platforms in Europe
Battery requirements: Primary battery function is engine starting	**Battery requirements:** Battery is required to start engine more frequently and provide energy for device support whilst in "stop" mode Battery used is integrated within a sophisticated energy and battery management system
Battery technology: **Predominately traditional lead-acid technology**	**Battery technology:** **Absorbent Glass Mat (AGM) and Enhanced Flooded Battery (EFB)**

E. Need for Start-Stop System using Micro-Hybrid Technology

In comparison to different hybrid concepts i.e. fully hybrid pure electric vehicle which carry significant costs for returns of improvement in fuel economy, start-stop technology costs relatively much less. It is estimated that start-stop vehicles costs few hundred of Euros additional to conventional vehicles yielding significant improvement in fuel economy (approximately between 5-10%). Start-stop technology is not only promising but also costs a fraction of what its competitor technologies do.

To sum up, with ever increasing customer demand for eco-friendly cars, depleting oil reserves, stringent emission regulation, no doubt that SS technology will be a standard or even mandatory technology for vehicles in future [5].

CONCLUSION

More than 50% of the newly registered vehicles will have start-stop as standard technology after 2013. Even though the technology is widely utilized for small / mid segment cars in Europe it also has high potential for compact and luxury car segments. It can be expected, that especially Micro-Hybrid technology will gain increasing relevance in the coming years as technological challenges are solved (high voltage electrical system, for e.g. 48V). The Start-stop is a key technology to be used in conjunction with other fuel saving technologies to attain the stringent carbon norms of 2020.

FUTURE WORK

The start/stop function in automatic transmission vehicles is straight forward for the driver: press the brake pedal and once the vehicle has come to a standstill, the engine control unit will stop the engine, and then to restart the engine brake pedal have to be released. However the time available for the system to restart the engine compared to a manual transmission, in which the driver will depress the clutch (declutch), engage gear and re-engage the clutch, is a lot less. So in essence Bosch engineers had to speed up the processes responsible for re-starting the engine. The first step was to modify the software in the engine control unit that controlled the direct fuel injection system. The crankshaft sensor was programmed to monitor the running of the engine and detect which cylinder to inject and ignite as soon as the brake was released. The transmission ratio of the starter motor was adjusted by engineers and also they altered its pinion-ring gear combination. Work was carried out in collaboration with several car manufacturers and the system can now be fitted into the Audi A8, Fiat 500, Porsche Panamera and Volkswagen Passat [12].

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