Design Considerations for Basic Stop-Start System

Deepesh Dongre, Sr. Engineer – Product Development, HEDCI

Abstract – Considering Indian automotive market and increasing fuel prices, leading car manufacturers are trying to integrate Stop-Start systems which can increase the fuel economy along with reducing the CO_2 emissions while keeping the optimum vehicle cost. This technology will help in reducing the wastage of fuel when engine is idling for a long time. Various tests have shown an increase in fuel efficiency from 5-15% with implementation of Start-Stop system.
This paper will give an overview of the design considerations for a Stop-Start system.

The Stop-Start System

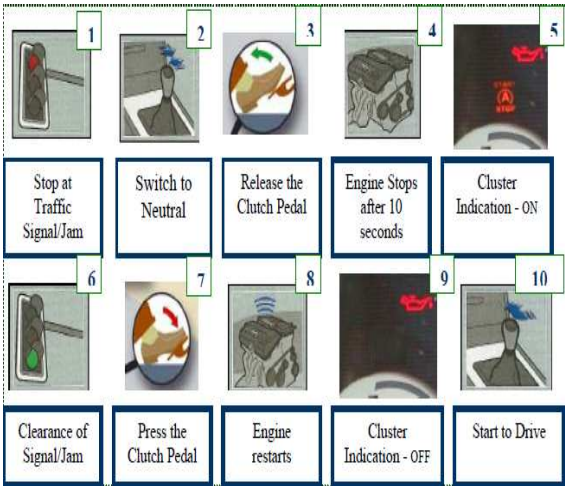

Fig. 1

Basic Stop-Start System

Stop-start systems have been developed for both gasoline and diesel applications with either manual or automatic transmissions. When vehicle comes to a halt due to a traffic signal or jam, gear is in neutral position and the clutch pedal is released then engine stops after 10secs and the information about automatic engine stop is displayed on instrument cluster. But the transition from engine on state to off state is so smooth that driver does not recognize it. When the driver again puts his foot on the clutch pedal then engine restarts automatically without driver intervention with the ignition switch and the vehicle can de driven immediately.

When the driver initially starts the engine with the help of Ignition switch, Powertrain ECU sends a control signal to connect the battery to Starter motor. And at the same time it also activates the injection of fuel-air mixture in the cylinders and the ignition timing. Once the combustion cycle starts, the engine reaches to its idling speed in some time, and the Starter motor gets disengaged from the engine. Once the engine comes to its idle stable condition, the battery is continuously charged through an Alternator. For an automatic stop it is important that the battery must be in an ideal charged status so that it can re-crank the engine.

Design Considerations

To design a Stop-Start system a proper selection of these fundamental components must be taken care – Engine, Alternator, Starter Motor, Battery, Electronic Control Unit (ECU), Intelligent Battery Sensor (IBS) and Ultra capacitor.

Engine

Once the engine is stopped, the Powertrain ECU signals the stop of fuel injection to stop the engine. At this point Powertrain ECU waits for the driver to press the clutch pedal to recognize an auto start condition to signal Starter motor to re-crank the engine. The amount of fuel required to crank a warm engine is considerably less, and with the improvements in the engine designs it is possible to stop the engine in ideal piston position so that it can be cranked in a very short time.

The piston positioning and amount of air are essential for efficient engine start. With advanced engine designs it is possible to crank an engine within 300ms.

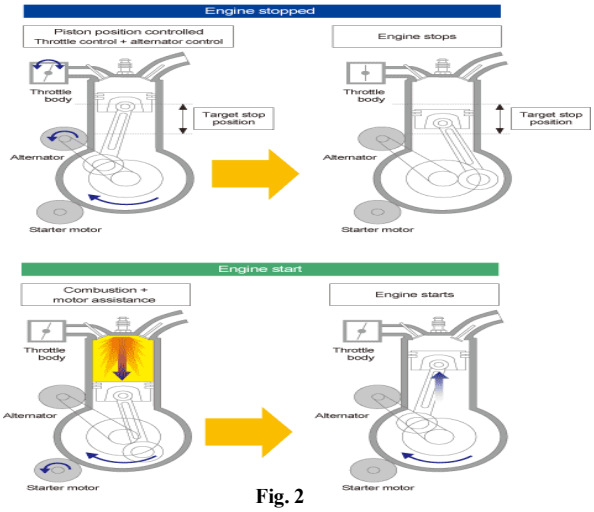

Fig. 2

Mazda's i-Stop system for fast cranking

Starter Motor

The electric starter motor selection is also a vital criterion for quick engine start in heavy traffic condition, Starter pinion and ring gears, have to be capable of many times more engagement and cranking events. Focusing at Stop-Start system some new designs are evolved for starter motors, like Advanced Engagement (AE) Starter, Tandem

Solenoid (TS) Starter and Permanently Engaged (PE) Starter.
The AE works like a typical starter, when it's energized, the pinion shifts forward, engages with the flywheel, and immediately spins. The starter has much longer life due to improvement of the electrical brushes, which have 6 to 10 times the durability compared to the conventional starter, as well as a unique structure and pinion spring mechanism that reduces the friction between the pinion gear and ring gear by 90percent [6].
The TS adopts a co-axial dual solenoid to allow for independent control of the starter's pinion gear shifting mechanism and motor rotation. Special software is required to control the timing and synchronization aspects of moving the pinion gear into the spinning flywheel.
The PE starter eliminates the starter's pinion gear shifting mechanism and mounts to the engine such that the starter is permanently engaged with the flywheel. When a restart is needed, the motor is simply energized, which immediately re-cranks the engine. There is no waiting or delay since the starter gear is already mated to the flywheel. Without having to consider gear engagement dynamics, the gear teeth profile can be optimized for low noise operation. The flywheel does require a special clutching mechanism to disconnect it from engine rpm after engine start.

Alternator
Another important component which is to be suitably selected for a vehicle with SSM functionality is Alternator. The alternator should be able to supply the current required by the loads and at the same time it should charge the battery to a level so that the vehicle can be re-cranked in case of an automatic stop or if the vehicle is stopped with Ignition off. With the application of reversible alternator it is possible to utilize the alternator as a starter motor and after engine starts it can again work as alternator. The starter alternator is driven by a belt that can also be used to drive other accessories, such as the air conditioning compressor, the water pump or the power steering. A reversible tensioner allows power to be transmitted in both directions, depending on whether it has to be operated as a starter or a generator.

Intelligent Battery Sensor (IBS)
To ensure that the battery is in good State of Charge (SOC) for an automatic Stop-Start operation an IBS is required. The IBS monitors battery internal resistance, battery temperature, battery voltage and current drawn to calculate exact SOC with the help of Body ECU. The IBS communicates over Local

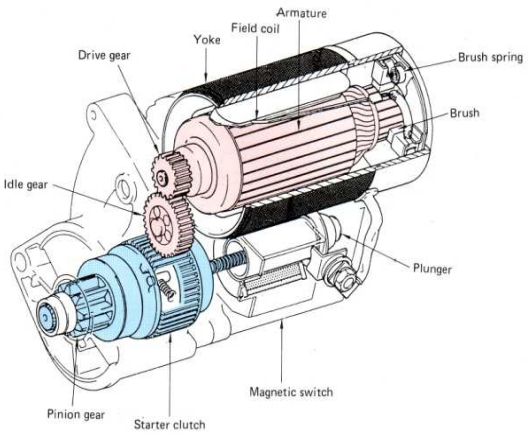

Fig. 3
Normally used Starter Motor

Interconnect Network (LIN) with Body ECU to send battery related data, and according to existing load and battery condition, the Body ECU signals the Powertrain ECU, whether automatic stop is possible or not [4].

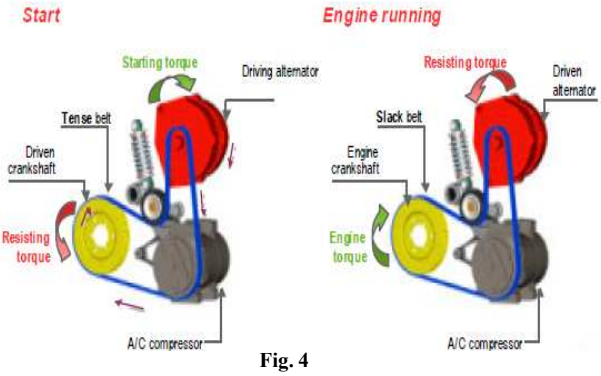

Fig. 4
The reversible alternator

Battery
An automotive battery is a second important component of a vehicle after Engine. When engine is off, battery is used to operate the lighting and accessory systems. It is used to provide cranking current while engine is starting. And battery energy may be needed when the vehicle's electrical load requirements exceed the supply from charging system.
Over time, battery capacity degrades due to sulfation (Deposition of Lead Sulfate on plates) and shedding of active material [1]. The degradation of battery capacity depends most strongly on the interrelationship between the following parameters:

- The charging/discharging regime which the battery has experienced;

- The Depth of Discharge (DOD) of the battery over its life;
- Its exposure to prolonged periods of low discharge; and
- The average temperature of the battery over its lifetime.

Considering the Stop-Start application, the batteries will be subjected to shallow cycling. This means, that during a stop, the battery must deliver the electric energy for the vehicle. ("Shallow cycling" means cycling to a depth of discharge of about 5 to 20 %, at a discharge rate of about 1C.)
Starting an internal combustion engine means very high currents for a very short time. Therefore, a low internal resistance is a must. Unfortunately, the service life of the conventional flooded Lead Acid - SLI (Starting, Lighting and Ignition) batteries, under shallow cycling conditions, is very less. The reason is acid stratification (acid will begin to settle and concentrate at the bottom of the battery) [8]. When batteries are subjected to a large number of cycles, one observes active mass degradation and loss of adherence to the grid.
On the other hand Valve Regulated Lead Acid Battery (VRLA) comprising of Absorbed Glass Mat (AGM) has the advantages of, Low internal resistance allowing them to be charged and discharged quite rapidly, Depth of discharge for optimal performance is up to 80% while flooded batteries can only be rated up to 50% depth of discharge, and VRLA batteries can operate well below 0°F or -18 °C.

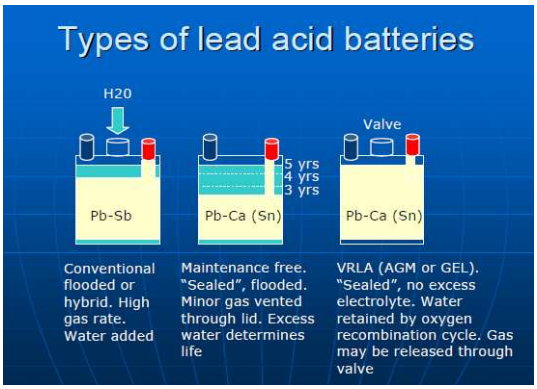

Fig. 5

According to several tests carried for DOD, the VRLA battery has very good life for 50% DOD in comparison to conventional flooded SLI battery.

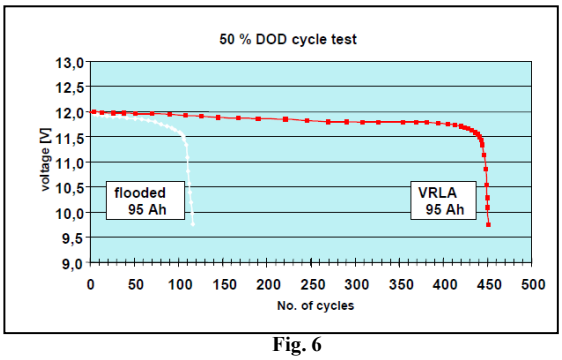

Fig. 6

Ultracapcitor

The Ultracapacitors can provide a large burst of power. For the vehicles with implementation of Regenerative braking concept, when the driver presses the brake pedal, the rotation of the wheels causes an electrical motor to turn backwards, causing it to act like a generator. The electricity that it produces is then routed to the car battery. But research has shown that battery life is negatively affected by a process called "micro-cycling," which is the frequent switch of direction of current running through the battery (i.e. when the battery is being charged, current flows into the battery, whereas current flows out of the battery when it supplies electrical energy for different systems like the starter motor, and other car electronics) and also the braking duration is very short to convincingly charge the battery. Thus to avoid this problem Ultracapacitors are used to hold this regenerated energy while vehicle stops and can be utilized to energize the starter motor, for a fast engine start.

Electronic Control Unit (ECU)

An ECU is required to monitor load conditions, vehicle speed, inside and outside temperature of the vehicle, to signal the engine whether an automatic Stop-Start is possible or not. This functionality can be integrated in a Body ECU or a standalone SSM ECU can be developed, specifically for this. Fig 7 shows the high level system diagram for implementation of SSM function.

Effectiveness

- Toyota claims that its new Powertrain with stop-start technology results in 17% lower CO2 emissions (135g/km) and a 19% improvement in fuel consumption [10].
- Kia's gasoline-powered Ceed ISG (idle stop and go) models claimed to deliver up to a 15% fuel economy improvement in city driving.
- With its 2.2 litre diesel TD4 Freelander models, Land Rover claims an improvement of Fuel consumption by 12%, which is a saving

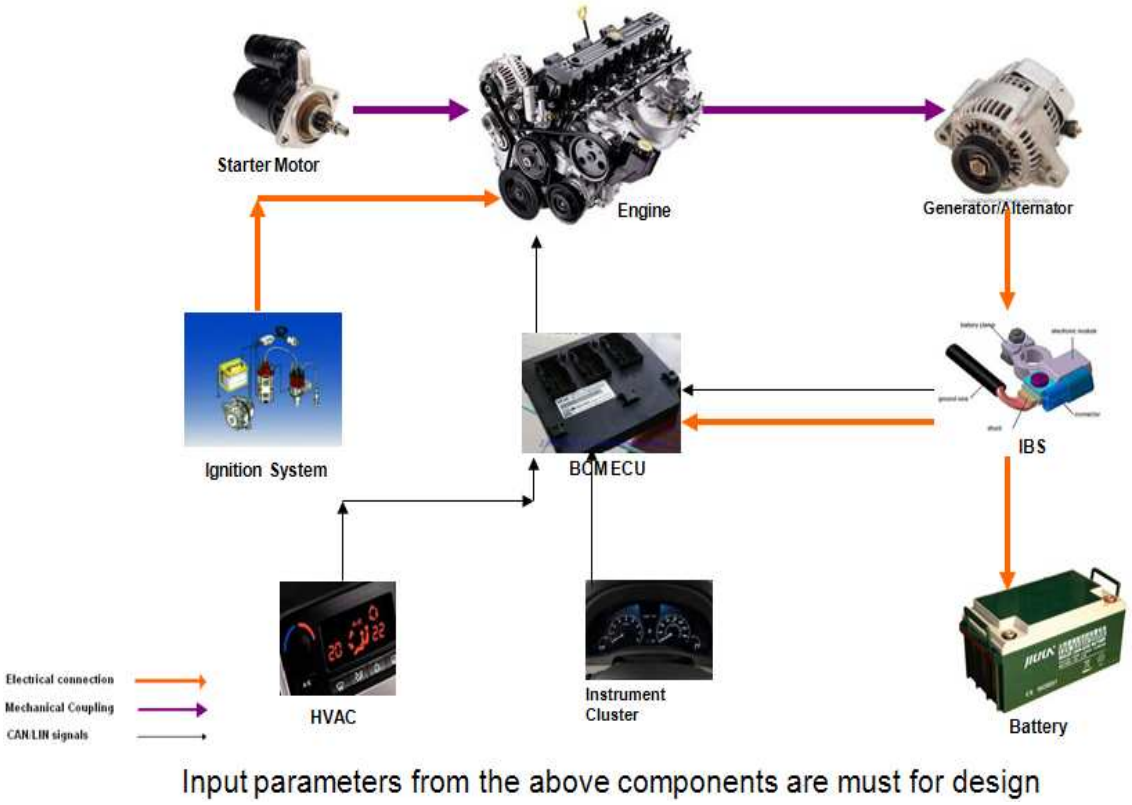

Fig. 7

of £13 on a tank of diesel at today's prices on a typical London test route.

- Volvo claims to cut down CO2 by CO2 emission by approximately ten grams per kilometer and reduces fuel consumption by 0.4 liter per 100 km.
- Nissan Qashqai 1.6 117 N-Tec Idle Stop 2WD, with the addition of Stop-Start, the first Nissan to benefit from the technology, drops CO2 emissions from 144g/km to 139g/km.

Impact on Environment

Although the stop-start system is becoming popular, the method in which it is put into effect varies from company to company. The technology is still young and is subject to great amounts of experimentation and modification. Each update to the technology improves both its effectiveness and its durability. Every company has a version of the system that they find most sustainable in their vehicles.

The European Union has released Euro 5 standards. Its most recent policy aims to limit CO_2 emissions to 120 grams per kilometer by 2015 [11], gradually tightening the restrictions each year. The standards also cover other pollutants, including carbon monoxide, nitrous oxides, and particulates. The EU policies have slowly tightened emissions regulations over the years through a series of laws, starting from the Euro 1 standards in 1992, up to the proposed 2014 Euro 6 standards. European automakers need to keep their cars up to date with new fuel-efficient technologies to keep up with these gradually increasing regulations. With Indian emission norm Bharat–IV released in April 2010, Indian Government is closely following EU emission standard for stricting emissions to 180grams per kilometer. With Indian market very much open for this technology and considering hike in fuel prices in last few years there is a huge possibility for an optimized and efficient low cost Stop-Start System.

Along with increasing fuel efficiency this technology also move us one step ahead towards a green environment.

Abbreviations

1. ECU - Electronic Control Unit
2. IBS - Intelligent Battery Sensor
3. AE - Advanced Engagement
4. TS - Tandem Solenoid
5. PE - Permanently Engaged
6. DOD - Depth of Discharge
7. SLI - Starting, Lighting and Ignition
8. VRLA - Valve Regulated Lead Acid Battery
9. AGM - Absorbed Glass Mat
10. ISG - Idle stop and go

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