Smart Stop-Start Strategy for SAMAND Micro-Hybrid Based on Traffic Qualification

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***Abstract*— This paper describes an intelligent engine stop-start strategy for vehicles equipped with this system. This controller, at first stage, monitors the history of vehicle movement and quantifies the traffic condition. At the second stage, based on this traffic degree it adjusts one controller parameter named waiting time that is the time that has to pass for engine to shut down. This way, this strategy prevents engine from shutting down in very heavy traffic condition where too frequent stop start occur, when instead of improving fuel economy it results in increasing fuel consumption. In fact, this control strategy is addressing one problem of the conventional stop-start systems where regardless of traffic condition based on a simple if-then algorithm stops and starts the engine.**

Keywords— Stop-start, Micro hybrid, Intelligent stop start strategy, Fuzzy logic

I. Introduction

Fuel crises in recent years, forces many car manufacturers and researchers to develop and use new technologies in the fuel systems. One of the key components in fuel section is injector. In conventional injectors, motion control is done by electromagnetic solenoid or linear direct-drive motors [1-2]. These actuators suffer from large space and low response speed. Recently commercialized injectors are made of piezoelectric and magnetostrictive materials. However, commercialized piezoelectric injector (e.g. J43Px) needs high voltage of 1000 V for a displacement of 130 μm while they suffer from low life of 200 hours [3-5]. Magnetostricitve materials [6-11] are good candidates for this purpose [12]. Talebian also investigated the eddy current loss [13] and Hysteresis behavior [14] of magnetostrictive materials. Although, close magnetic circuits [15-16] using low carbon iron [17] increases the performance of this injectors, magnetostrictive injectors are still expensive. Controllability of smart material injectors combined with control techniques culminates reduction of fuel consumption. For the first time, students in Shell Eco-Marathon competition proposed Start-Stop technique. Pure stop-start system, that are sometimes called micro hybrid or reinforced starter hybrid system is a system that stops engine when the vehicle comes to a halt such as stationary condition at stop light [18-19]. This system can typically provide 5-7 percent improvement in fuel economy in standard driving cycles such as NEDC [20]. However, in reality, this system is inefficient in specific conditions like heavy traffic and very stop-and-go conditions [21], because of the energy required for every engine restart is equivalent to fuel used for 5-8 seconds idle engine. This time depends on the specification of the engine we are using, start conditions and efficiency of starting and charging system [21]. For the vehicle that we are using in this paper this time is 7 seconds based on our calculations. It means that when the vehicle is stationary for a time less than this, shutting down the engine not only improves the fuel consumption but also deteriorate it [22]. Such condition is depicted in Figure 1 and Figure 2. Therefore a strategy is required to detect this condition and deactivate the stop-start system. Although the driver is able to deactivate the system an additional strategy is useful to ensure the fuel efficiency of STST system.

II. SAMAND Micro-Hybrid

Development and production of stop-start system on Iranian national car, Samand, was a project aiming to reduce fuel consumption in heavy traffic condition of the capital city, Tehran. The key components of this system are shown in Figure 3. For safety and comfort reasons some components have been added to the base vehicle. A vacuum sensor has been added to the brake booster so when the vacuum inside the booster gets below a minimum threshold, the ECU restarts the engine immediately. Gear neutral sensor is also required so only when the gear is in neutral the engine restarts or shuts down. An STST inhibition key is installed on the front panel so the driver can deactivate the stop-start system when not favorable. A starter relay provides the possibility of automatic engine restart. When starting the engine, the ECU connects the relay until the engine RPM is less than 350 rpm. An STST indicator lamp has been added to instrument cluster. This lamp can be in three states. When the STST system is inhibited by the inhibition key or a critical error occurred it is off. Otherwise when the engine is on the indicator is on and when the engine is off by the Sop/Start system the indicator is in blinking state. The condition based on which the engine shuts down or restarted are mentioned in Table I.

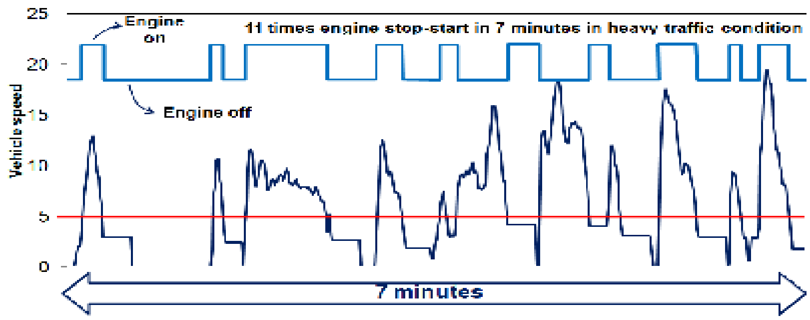


Figure 1: Driving cycle in the heavy traffic of Tehran city

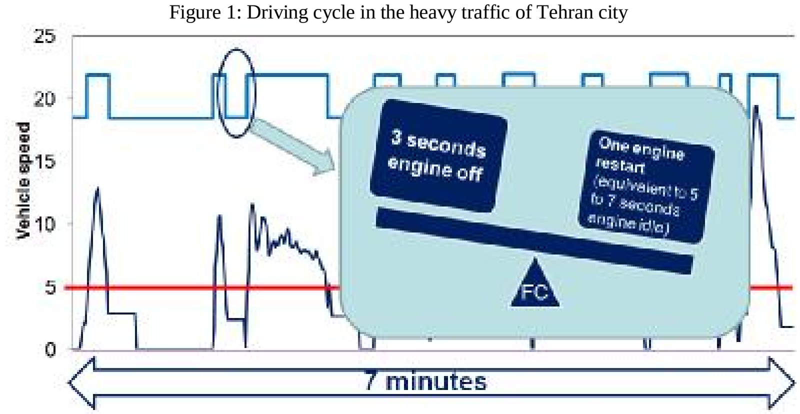


Figure 2: Engine restart fuel consumption

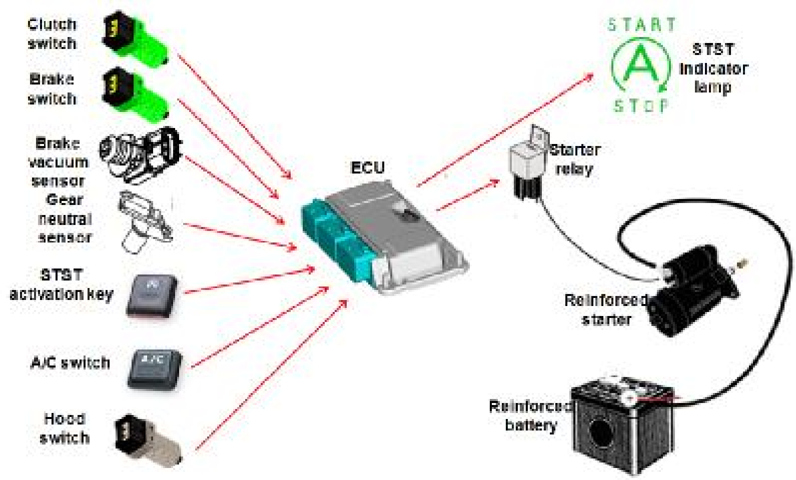


Figure 3: The key components of Stop-Start system

III. THE CONTROL ARCHITECTURE

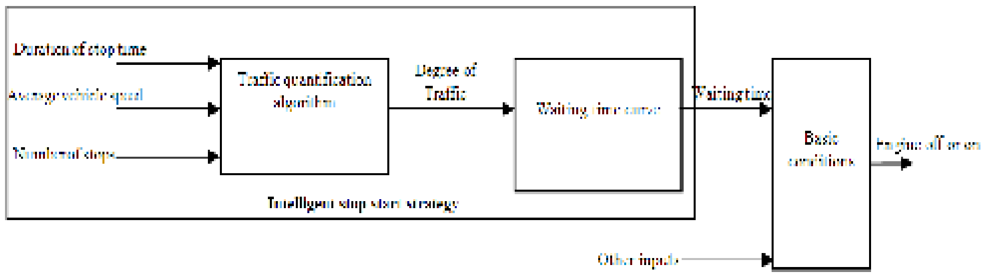
As mentioned earlier in this paper in some specific traffic conditions the STST system has adverse effect on emission and fuel consumption. This condition is very heavy traffic congestion where STST system results in too many stop starts [23]. This is where our intelligent stop-start strategy detects the situation and deactivates the STST system. This strategy at first stage quantifies the traffic conditions according to information obtained from vehicle speed over time [24]. Then based on this traffic degree it adjusts the waiting time that is one parameter mentioned in basic conditions in Table II. These two sections in more details are explained in the following sections.

TABLE I. THE STAGES OF INTELLIGENT STOP START STRATEGY

Engine on conditions (only one need to be met)	**Engine off conditions (All need to be met)**
• Clutch pedal depressed	• STST inhibition key deactivated

• Brake booster vacuum pressure less than 150 mbar • A/C system on • STST inhibition key on • Vehicle speed exceeds 7 km/h • Engine coolant temperature exceeds 110 C **Only when** • Engine hood closed and gear in neutral	• Vehicle speed less than 5 km/h • Gear in neutral • Clutch pedal released • Engine coolant temperature between 63 and 105 • Brake booster vacuum more than 300 mbar • At least 20 sec has passed from ignition key on • Waiting time: at least 15 sec has passed from the last engine restart • A/C is off • Engine RPM less than 2000 • Battery minimum voltage during last engine restart more than 6.5 V • Battery voltage during engine running more than 11.88

TABLE II. THE STAGES OF INTELLIGENT STOP START STRATEGY



A. *Traffic Quantification*

The intelligent stop-start strategy quantifies the traffic condition based on history of vehicle movement with the use of Fuzzy logic algorithm. Generally in a specific traffic condition average vehicle speed, number of stops and duration of vehicle in stationary can be attributed to the traffic degree. The membership of functions of inputs and output signals are designed by trial and experience, as shown in Fig 4.a, Fig 4.b , Fig 4.c , Fig 4.d. The amounts of these three parameters in the last 120 sec of vehicle movement are the inputs of the traffic quantification algorithm. The fuzzy rules are as follows:

B. *Waiting Time Control*

As mentioned earlier, the time interval is named “waiting time” that has to pass after engine restart for engine to shut down. In the proposed stop-start strategy the waiting time is adapted according to traffic quantity so it makes engine not to shut down in very heavy traffic condition. This waiting time is controlled again based on a Fuzzy control. Membership functions and fuzzy rules can been seen in Figures 5.a , 5.b and table 5. At low, medium and even heavy traffic condition the waiting time does not significantly change and remains around 8 seconds. However, in very heavy traffic conditions it substantially increases to high levels and prevents engine to shut down.

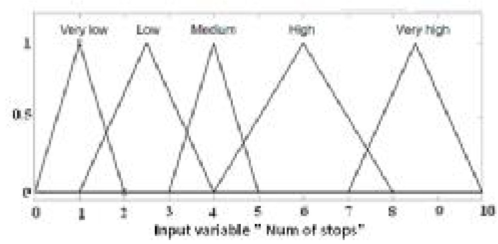


Fig 4.a Very low,very low number of stops;Low,low number of stops;Medium,medium number of stops;High,high number of stops;Very high,very high number of stops

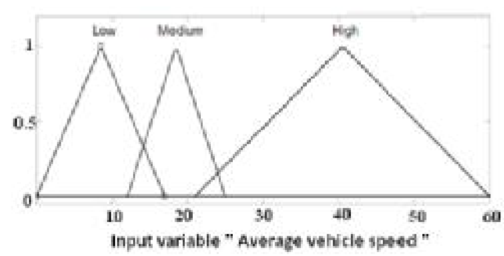


Fig 4.b Low,low average vehicle speed;Medium,medium average vehicle speed;High,high average vehicle speed

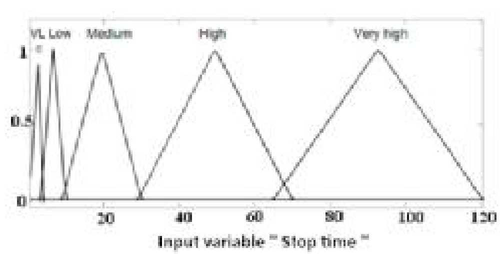


Fig 4.c VL,very low stop time;Low,low stop time;High,high stop time;Very high,very high stop time

intelligent strategy has no influence on occurrence of stop starts and accordingly the fuel consumption. However, for the very congested driving cycle of Tehran in which so many short stops happens, as shown in the table 6 ,not only the basic STST system does not improve the fuel economy but also deteriorate it. This is the condition at which intelligent stop start strategy is beneficial. In such condition this strategy inhibits the stop starts so no change of fuel consumption happens.

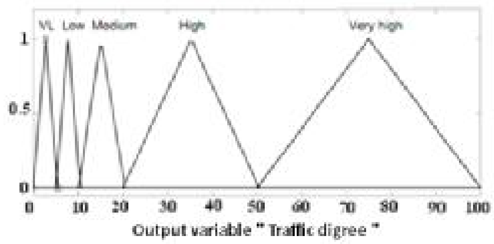


Fig 4.d VL,very low traffic digree;Low,low traffic digree;Medium,medium traffic digree;High,high traffic digree;Veryhigh,very high traffic digree

TABLE III. MEMBERSHIP FUNCTIONS OF INPUTS DURING PREVIOUS 120SEC

Average vehicle speed		**Stop time**		**Number of stops**	
0-17	Low	0-4	Very low	0-2	Very low
12-25	Medium	3-10	Low	1-4	Low
>= 21	High	9-30	Medium	3-5	Medium
		29-70	High	4-8	High
		65-120	Very high	>=7	Very high

TABLE IV. MEMBERSHIP FUNCTION OF OUTPUT

Degree of traffic	
0-5.5	Very low
5-10.5	Low
10-20.5	Medium
20-50.5	High
50-100	Very high

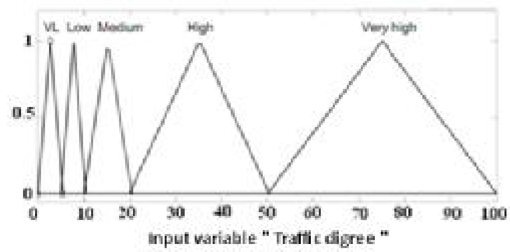


Fig 5.a VL,very low traffic digree;Low,low traffic digree;Medium,medium traffic digree;High,high traffic digree;Veryhigh,very high traffic digree

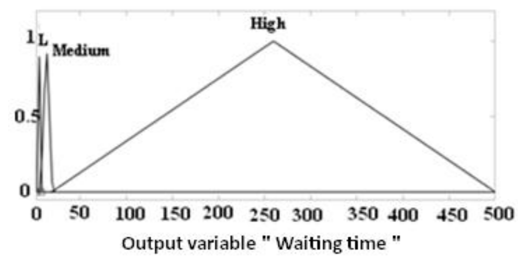


Fig 5.b L,low waiting time;Medium,medium waiting time;High,high waiting time

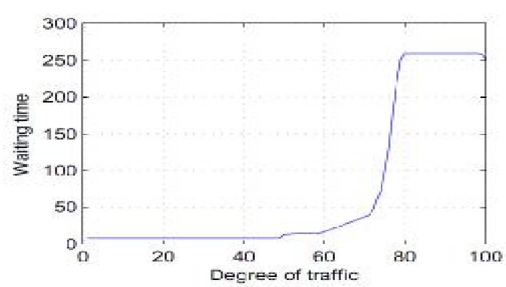


Fig 6. The result of waiting time algorithm

TABLE V. FUZZY RULES FOR WAITING TIME ALGORITHM

Fuzzy rules for waiting time calculation	
Degree of traffic	Waiting time
Low	Low
Medium	Medium
High	High

IV. SIMULATION AND RESULTS

Simulations were performed for 3 Samand vehicles :the base Samand without STST system, the one with STST system but without intelligent strategy and the one with intelligent strategy. These simulations are performed once for standard NEDC cycle and once for heavy traffic condition of Tehran. The information about heavy traffic condition of the capital city has been obtained from a data acquisition system installed on a sample vehicle when driving at the time and places where this condition occurs. This cycle can be seen in the Fig 7. As stated before in this paper this is such condition in which too frequent stop starts occur with basic STST system that results in deterioration of fuel economy.

The simulation results are shown in Table 6. As shown in this table, for NEDC cycle at which there is approximately 10 percent stop time with long individual stops, the STST system provides 6 percent improvement in fuel economy, and the

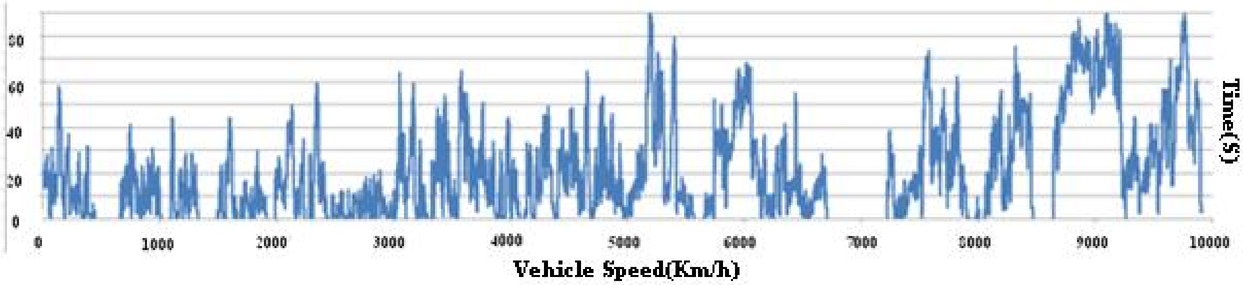


Fig 7. Driving cycle of Tehran city

TABLE VI. SIMULATION RESULT FOR FUEL CONSUMPTION (L/100KM)

	Samand w/o STST	Samand w STST	Samand w intelligent STST strategy
NEDC	**8.7**	**8.1**	**8.1**
Creeping driving cycle	**12.5**	**12.9**	**12.6**

V. CONCLUSION

The fuzzy logic controller that has been designed in this paper effectively quantifies the degree of traffic based on solely history of vehicle movement that can be used for a variety of purposes. Based on this traffic degree another part of the controller intelligently adjusts stop start of engine in a stop-start vehicle. This way this controller avoids engine stop-start in very heavy traffic condition where too many stop-starts occur that results in higher fuel consumption instead of improving it [25]. this strategy was evaluated for a specific driving cycle that was result of data from a very heavy traffic condition of the capital city, Tehran.The intelligent STST strategy could prevent 3 percent increase in fuel consumption that is imposed by employment of only basic stop-start strategy Based on Simulation results. .

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