

An Intelligent Alternator Control Mechanism for Energy Recuperation and Fuel Efficiency Improvement

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ABSTRACT

With the current state of ever rising fuel prices and unavailability of affordable alternate technologies, significant research and development efforts have been invested in recent times towards improving fuel efficiency of vehicles powered with conventional internal combustion engines. To achieve this, a varied approach has been adopted by researchers to cover the entire energy chain including fuel quality, combustion quality, power generation efficiency, down-sizing, power consumption efficiency, etc. Apart from energy generation, distribution and consumption, another domain that has been subjected to significant scrutiny is energy recuperation or recovery.

A moving vehicle and a running engine provide a number of opportunities for useful back-recovery and storage of energy. The most significant sources for recuperation are the kinetic energy of the moving vehicle or running engine and to a lesser extent the thermal energy from medium such as exhaust gas. This paper describes and analyzes a method to recuperate electrical energy from a portion of the vehicle kinetic energy through an intelligent alternator control mechanism. The intelligent alternator control system, its implementation on a demonstrator vehicle including the control logics, and measurements of recuperated energy and fuel saving under different test conditions are presented as part of this paper.

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INTRODUCTION

Conventional Electrical System

The conventional power train electrical system consists of a battery that provides power to start the engine and to serve key-off loads, a starter motor that cranks the engine and an alternator that charges the battery and serves the electrical loads. A representative schematic of the conventional electrical system is shown in [Figure 1](#).

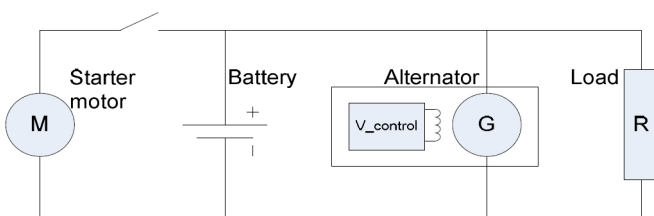


Figure 1. Conventional electrical system of a vehicle

In the conventional system, the alternator is controlled by a self mounted voltage regulator which controls the excitation current in order to maintain a constant target voltage. In cases where the ambient air temperatures around the battery and the alternator rise and fall in a proportional manner, in order to achieve optimal charging of the battery, the target voltage at the alternator terminal is varied (typically at a rate of $-10\text{mV}/^\circ\text{C}$) with respect to the internal temperature at the voltage regulator, though with acceptable levels of inaccuracies. It is also important to note that power conversion by the alternator in this case is always activated irrespective of the driving conditions.

Opportunities for Electrical Energy Recuperation

During any typical drive cycle (such as the NEDC shown in [Figure 2](#)) a vehicle goes through four different modes of operation namely the stationary phase, the acceleration phase, the coasting phase when the vehicle moves by its own inertia

rather than by the power from the engine, and finally the deceleration phase.

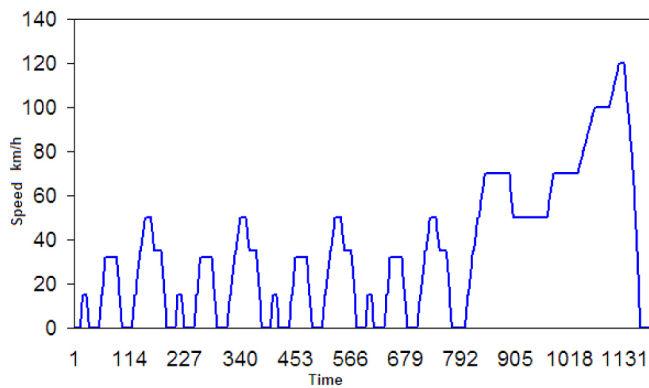


Figure 2. NEDC showing the stationary, acceleration, coasting, and deceleration phases

It is clear from the drive cycle that there are four different fuelling modes when (1) fuel is burnt to keep the engine idling (2) fuel is burnt to move the vehicle, (3) fuelling is stopped during coasting, and (4) fuelling is stopped when braking. Figure 3 illustrates the operation of the conventional electrical system under all these fuelling modes and also identifies opportunities to recover energy with the Intelligent Alternator Control System (IAC).

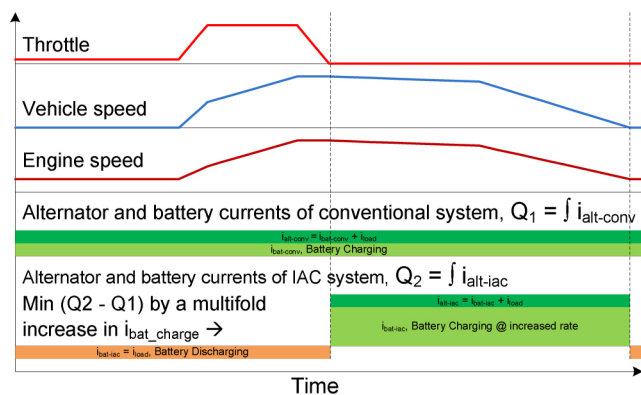


Figure 3. Opportunities for energy recuperation

As shown in Figure 3, in the case of the conventional electrical system, when the load consumption is kept a constant, the alternator behaves in the same manner during all the four fuelling modes. It generates electrical power to feed the loads and to charge the battery at the nominal voltage (typically 14.4V at an ambient temperature of 25°C). Hence the alternator loads the engine in the same manner irrespective of whether fuel is being burnt or not. Fuel efficiency can be effectively improved if the fuel energy is utilized as much as possible to drive the vehicle rather than power the accessories such as the generator. Hence there is a possibility to turn off the alternator during the fuelling modes 1(engine idling) and 2 (vehicle acceleration). The alternator can be turned on during the fuelling mode 4 (braking) when a

portion of the vehicle kinetic energy is converted back to electrical energy. During the fuelling mode 3 (coasting), even though the fuelling is stopped, the vehicle is still moving. Recuperating the kinetic energy during this mode will mean a loss of mileage, but since the electrical recovery power is very minimal (in the range of 1kW maximum over a few seconds - limited by the alternator power rating and the battery charge acceptance) in comparison to the total vehicle kinetic energy, the recuperation is activated in this mode also. Another benefit of enabling energy recuperation in fuelling mode 3 (coasting) is that the battery is provided with a good opportunity to recover back the charge that was lost in modes 1 and 2. Now due to the shorter charging periods for the battery in the IAC system, in order to maintain the charge status and also to recuperate energy quickly, it is necessary to increase the battery charging rate during the periods when the battery gets charged. This can be achieved primarily by increasing the charging voltage to higher than normal levels and secondarily by improving the charge acceptance characteristic of the battery.

System Modifications Necessary to Support Energy Recuperation

The most important modification to the conventional system in order to make it suitable for energy recuperation is to make the alternator externally controllable. Hence the normal alternator is converted to an intelligent alternator which provides an interface for an external controller to set its terminal voltage and excitation. The engine ECU software will need to be modified to also include the IAC control algorithm. With the reduction in the battery charging time, it is necessary to introduce a battery sensor which can sense the battery status and inform the master controller whether it is safe to turn off the alternator or execute a recuperation phase. Due to the increased cycling of the battery charge that is likely to occur due to the introduction of the IAC system, the battery may also need to be enhanced for cycling robustness. Apart from the above major modifications, a set of minor changes to accommodate the different sensors and actuators required by the system also need to be taken care of.

INTELLIGENT ALTERNATOR CONTROL SYSTEM

System Modifications Necessary to Support Energy Recuperation

The IAC system architecture is illustrated in Figure 4. The main components of this system are (a) the Engine Management System ECU (EMS), (b) the Intelligent Alternator (IAL) and (c) the Intelligent Battery Sensor (IBS).

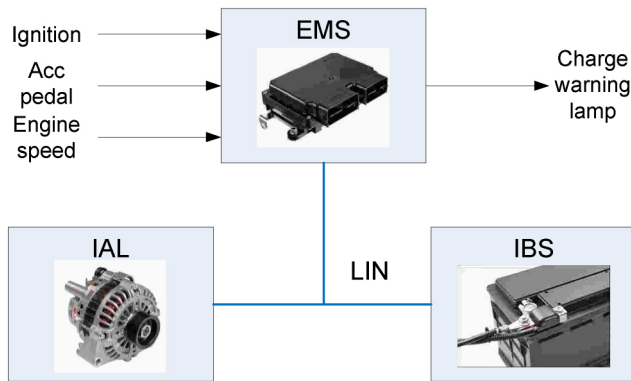


Figure 4. IAC system architecture

The EMS acts as the main controller holding the alternator control logic. It is connected over a LIN bus to the IAL and the IBS. A single common LIN bus has been used. The EMS acts as the LIN master node while the IAL and IBS are two slave nodes. The EMS reads battery status input from the IBS, and engine speed and accelerator pedal inputs from the respective sensors, processes the information according to the control algorithms and informs the target voltage and excitation current to the IAL.

The Intelligent Alternator

The intelligent alternator is similar to the conventional alternator on the electric machine aspect, but has a different type of voltage regulator. Instead of the fixed type voltage regulator, here the set point for voltage regulation and the excitation current limits are externally programmable through a LIN interface. A LIN 1.3 compliant voltage regulator has been employed. Figure 5 shows the internal schematic of the IAL and Table 1 describes the signals supported by the IAL over LIN.

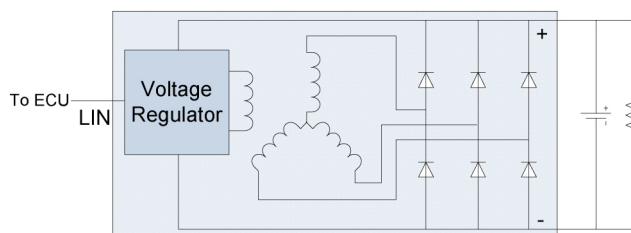


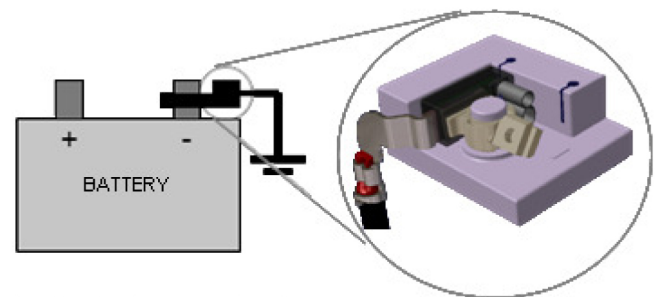
Figure 5. Internal schematic of intelligent alternator

Table 1. Intelligent Alternator Signal List

alt_vlt_op	Alternator voltage set point output
alt_exc_lim_op	Alternator excitation current limit output
alt_lrc_tim_op	Alternator load response control time output
alt_lrc_spd_op	Alternator load response control speed output
alt_tmp_flg_ip	Alternator temperature flag input
alt_mec_flg_ip	Alternator mechanical flag input
alt_elc_flg_ip	Alternator electrical flag input
alt_dfm_ip	Alternator duty field monitor input
alt_exc_cur_ip	Alternator excitation current input

The Intelligent Battery Sensor

The Intelligent Battery Sensor (IBS) is the component that enables battery management. The function of the IBS is to provide accurate estimates of the current status of battery charge and health to the control algorithm residing in the EMS. As shown in Figure 6, it consists of hardware elements to measure battery voltage, battery current and battery ambient temperature on a real time basis, and software models to estimate the battery state of charge (SOC), state of function (SOF) and the state of health (SOH).



Physical Measurements: V , I , T

Model Estimates: SOC, SOF, SOH

Figure 6. Intelligent battery sensor

The continuous real time measurements of battery, voltage and ambient temperature are fed into the convergence models for charge health estimation. In this manner, based on the V , I and T measurements, the SOC, SOF and SOH are continuously updated. Table 2 describes the data provided by the IBS to the EMS over the LIN communication bus.