

Intelligent Alternator Employment To Reduce Co₂ Emission and to Improve Engine Performance

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ABSTRACT

In modern internal combustion engines a greater reduction of CO₂ emissions is required in order to significantly reduce fuel consumption and minimize the emissions of polluting gases, allowing them to fall within the strict limits set by current regulations. In a conventional engine control system, it is not possible to optimize the efficiency of the alternator in terms of emissions and fuel consumption, due to a constant voltage which is imposed and is not modifiable. On the contrary, in a system capable of controlling the voltage of the alternator, referring to such an alternator as “smart” hereafter, it would be possible to optimize its efficiency as a function of the vehicle/engine working points. This system requires first and foremost a communication protocol between the alternator and engine control unit, and a special sensor that gets data on the charging status of the battery.

In this chapter a management strategy is proposed for regulating the alternator regulation voltage in order to maximize its efficiency on the basis of the engine and vehicle conditions. This is done by using an “Intelligent Alternator Module (IAM)”, that communicates using the LIN protocol with the Engine Control Module (ECM), and an “Intelligent Battery Sensor (IBS)”, which provides the information about the battery State-Of-Charge (SOC).

These procedures are implemented for both Gasoline and Diesel Engines and the expected improvement has been achieved: the average life of the vehicle battery has been increased, fuel consumption and emission have been reduced. In particular, measurements done have shown that consumption reduction due to the control system described above is about 2-3% on NEDC homologation cycle.

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INTRODUCTION

In Figure 1 the mono-phase equivalent circuit of the alternator is reported in order to better shows the voltage and the current under analysis.

The voltage u is the output of the three-phase bridge showed in Figure 2. The three-phase bridge has as output voltage (1) the signal with a frequency pulse six times higher than the individual voltage signal in input, and having a medium value showed in (2).

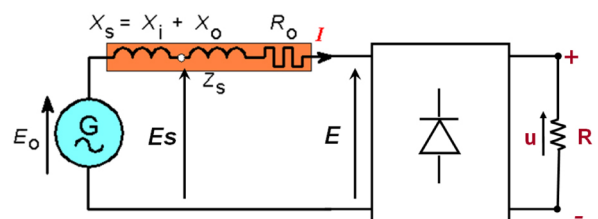


Figure 1. Alternator circuit.

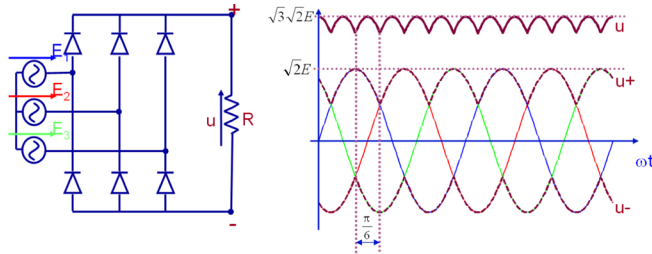


Figure 2. Three-phase bridge.

$$E_i(t)=\sqrt{2}\cdot E\cdot sen(\omega t+\varphi_i) \tag{1}$$

$$U_m=\frac{3\sqrt{6}}{\pi}E\cong 2.34\cdot E \tag{2}$$

In short, there is a constant of proportionality between the effective value E and the output voltage on the load u.

By referring to [Figure 1](#), the impedance Z_S is the parameter of the equivalent circuit that takes into account the following phenomena:

- Ohmic losses R_0 on the stator wrapping;
- Dispersion X_0 of the main flow (in air or into the wrapping not active);
- Presence of the demagnetizing armature reaction $X_{i,}$.

By analyzing the elements from which this parameters depend, it is possible to evaluate the effect on the current output.

In [\(3\)](#), the relationship of the current output I is reported:

$$I=\frac{E_S-E}{Z_0}\propto\frac{N\cdot\omega_{alt}\cdot\varphi(I_{ecc},I_{phase})-E}{N^2\cdot\sqrt{c_R+c_X\cdot\omega_{alt}^2}} \tag{3}$$

In order to maintain the current $I>0$, the alternator speed has to be:

$$\omega_{alt}>\frac{E}{\varphi(I_{ecc},I_{phase})\cdot N} \tag{4}$$

With ω_{alt} low, we have:

$$I\propto\frac{\omega_{alt}\cdot\varphi(I_{ecc},I_{phase})-E}{N\cdot\sqrt{c_R}}=-k_1+k_2\cdot\omega_{alt} \tag{5}$$

With ω_{alt} high, we have the maximum value for the current given by:

$$I\propto\frac{N\cdot\omega_{alt}\cdot\varphi(I_{ecc},I_{phase})-E}{N^2\cdot\sqrt{c_X\cdot\omega_{alt}^2}}=I_{max} \tag{6}$$

- Where:
- N is the number of conductors in the stator;
 - ω_{alt} is the alternator rotational speed;
 - φ is the magnetic flow.

By considering the battery voltage constant and assuming N conductors, in [Figure 3](#) it can be seen the plot of the current as a function of the angular velocity.

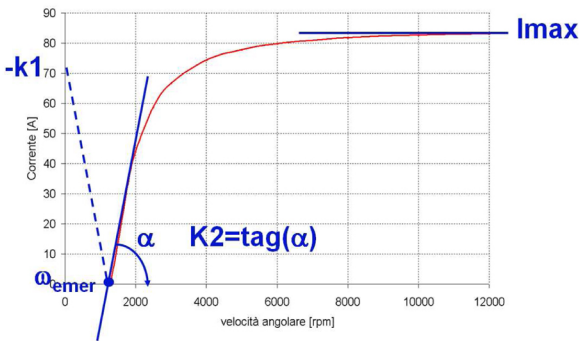


Figure 3. Alternator characteristic at E and N constant.

GENERAL DESCRIPTION OF SMART ALTERNATOR SYSTEM

The current state of the art of the alternator voltage regulation consists of the regulation of the rotational speed and current of the alternator in relation to an efficiency index related to the actual working point of the engine [\[1\]](#) [\[2\]](#). This solution has, as a disadvantage, that the current depends on the electrical loads and on the battery voltage. The loads are not controllable while the latter is only slowly controllable. This approach may not take into account in an appropriate way the battery SOC. Therefore, the control action is not aimed at preserving the battery life time for as long as possible.

The proposed solution consists in the regulation of the alternator voltage on the basis of the engine and vehicle conditions so as to maximize its efficiency. This is done by using an “Intelligent Alternator Module (IAM)”, that communicates with the Engine Control Module (ECM) using

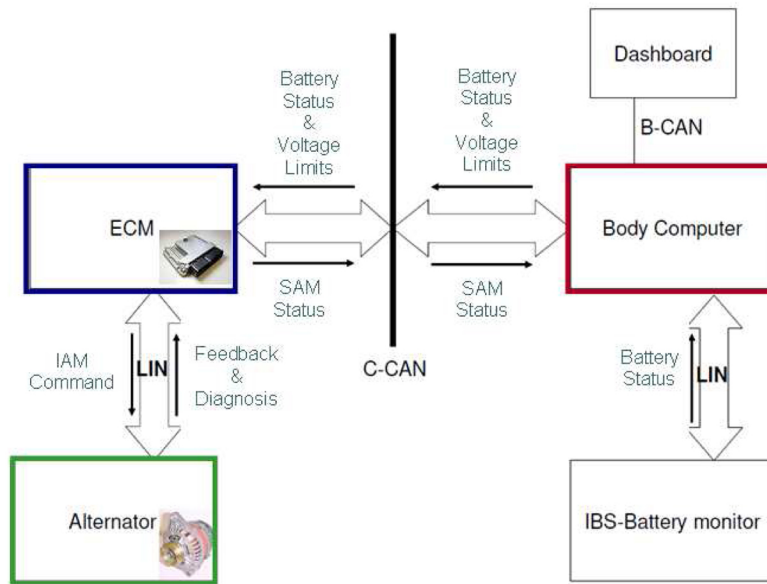


Figure 4. Logic Architecture Scheme.

the LIN protocol, and an “Intelligent Battery Sensor (IBS)” which provides the information about the battery SOC.

The main features of the management strategy are:

- switch off the alternator during tip-in manoeuvres in order to maximize the performance;
- switch off the alternator when the catalyst is cold, so as to reduce the emissions, and when it is in idle conditions if the battery SOC is high enough;
- increase the alternator load during tip-out manoeuvres, braking or cut-offs, and during shut-down in order to recover the kinetic energy otherwise dissipated as heat in the brakes;
- control the alternator voltage in steady-state as a function of battery SOC, loading it only when needed

LOGIC ARCHITECTURE

The components required to perform the above mentioned algorithm are:

- The Intelligent Alternator Module - IAM
- The Engine Control Module - ECM
- The Body Control Module - BCM
- The Intelligent Battery Sensor - IBS

The ECM manages:

- The alternator via LIN protocol by sending the command set-point control;
- The vehicle/engine condition to identify the driving conditions;
- The engine condition to establish the regulation voltage boundaries versus IAM module;

- The regulation range of voltage coming from the BCM module, comparing it to the ECM boundaries;
- The transmission of diagnostic information coming from the IAM module.

The BCM handles:

- The vehicle electrical loads (e.g. fog lights or headlights, windshield wipers, heated rear window) to establish the voltage control range and forward it to ECM module via CAN protocol;
- The transmission to ECM module of the information about the battery status (SOC, voltage, current, temperature) coming from IBS module;
- The alternator warning lamp on in case of fault occurrences.

The IAM manages:

- The voltage regulation starting from the set-point received via LIN from ECM;
- The sending of the feedback messages coming from the alternator (e.g. diagnostic information, operating duty cycle).

ALGORITHM DESCRIPTION

The main states of the Smart Alternator Management (SAM) strategy are:

- **PB** : Passive Boost, in which the alternator is switched off during tip-in manoeuvres. When a fast increase or, alternatively, a high absolute level of torque is required, the ECM controls the alternator with the voltage level as low as possible, according to the voltage limits imposed by the BCM module.
- **RB**: Regenerative Braking, in which the alternator is regenerating in braking manoeuvres. When the vehicle is

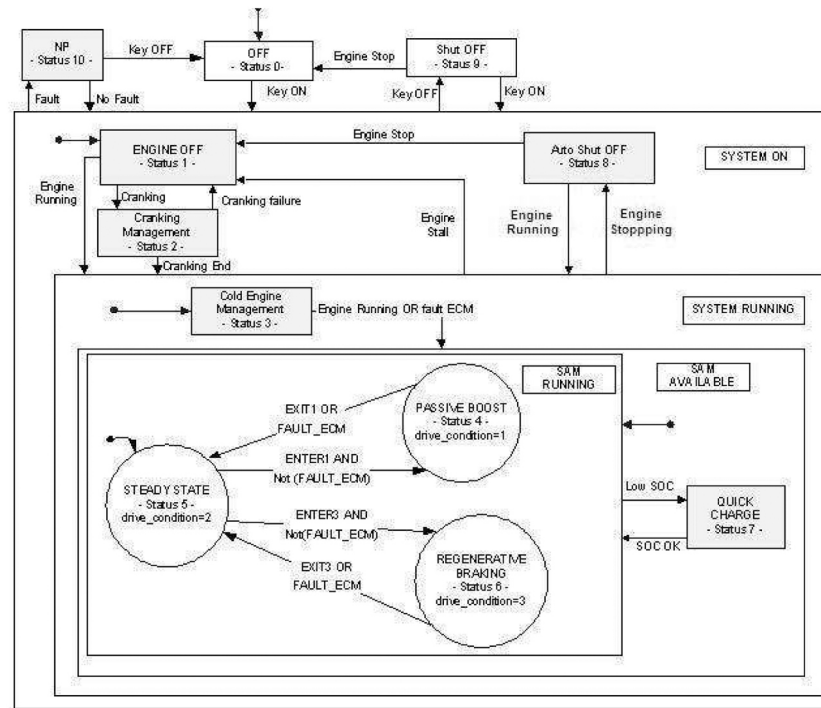


Figure 5. State flow diagram of Smart Alternator Management.

decelerating (braking or cut-off manoeuvres) the ECM controls the alternator with the voltage level as high as possible, according to the voltage limits imposed by the BCM module.

- **SS:** Steady State, in which the Battery SOC is controlled. Outside the above conditions, the ECM controls the voltage to maintain an optimal SOC, chosen as a trade-off value between fuel consumption and battery life.

- **CE:** Cold Engine Management, in which the alternator can be:

- switched on during cold conditions in order to increase the engine load for quickening the catalyst light-off phase (Diesel engines);
- switched off when the catalyst is cold, so as to reduce the CO₂ emissions (Gasoline engines).

- **CRK:** Cranking Management, in which the IAM is managed during engine crank or automatic re-start (for Stop & Start feature). During the cranking phase, depending on the engine speed, two starting sub-phases are defined in which the set-point voltage regulation is kept low at first, in order to facilitate the engine speed rising, and then is increased (with ramp law) to a high value, in order to reduce the engine speed overshoot in the post-cranking phase without compromising the FEAD (Front End Accessory Drive) system performance.

- **SHUTOFF:** Shutoff Management, in which the IAM is managed during engine shutdown (either manually from the driver or automatically from a Stop & Start strategy). During

an engine shut down the ECM module controls the alternator with the voltage level as high as possible, according to the limits imposed by BCM module, in order to increase engine load for reducing engine bouncing during shutdown and quickening the whole maneuver.

- **QC:** Quick Charge, when the SOC is too low, it's required that the alternator is set to the highest possible voltage level in order to quicken recharges the battery.

- **NP:** Normal Production, in which the IAM is set in the case of recovery. In the case of fault occurrences in the system (either components or communication lines, either LIN or CAN bus), the ECM controls the alternator with typical voltage set-points of current productions (usually with values between 15V and 14.5V).

In PB, RB, QC states, two controls are applied by ECM: one in open-loop, used to calculate the target voltage set-point and one in closed-loop based on a filtered battery voltage signal, where the instantaneous noise on the IBS measurement is reduced.

The first alternator control algorithm, used in Passive Boost state, is in charge to determine the target voltage V_{obj} through the following steps:

- compute the $VECM_{lim}$ voltage, that is related to the vehicle electronic equipment rotating with the internal combustion engine, e.g. the engine cooling fan assembly rotating to a preset speed;