Electric Vehicles Control using Biological Paradigms

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Abstract: This paper it want to emphasizes on importance bio-systems paradigms the in design of new and optimized solution for technical systems. The homeostasis and allostasis are remarkable phenomena and these are revealed in case of bio-systems representing, in the same time, sources of inspiration for optimal design of the control systems. The functions discovered and also the organization and structure of bio-systems can be considered as optimized. An example is detailed, in regarding the management of energy and starting system for a diesel hydraulic locomotive.

Keywords: *bio-systems, control, homeostasis, allostasis*

1. Introduction

The energy management of insulated systems such as electrical vehicles is the key process that can foster the success of electrical vehicles technologies. The limited energetic resources on vehicle must be consumed in an efficient way in order to maximize the distance and performances of the electric vehicles (EVs).The control systems of EVs assures a high energy efficiency, a dynamic adaptation of control strategies according to vehicle stages, traffic, and route conditions in order to fulfill the transport mission. The complexity of tasks performed by EV control systems is very high and the real-time control optimization demands as mandatory necessity of available and reliable communication systems Vehicle to vehicle communication (V2V) and Vehicle to infrastructure communication (V2I) to assure bidirectional data transfer between both control systems.

This paper is dedicated to reveal on one hand, the bio-systems features, and on the other hand, how these analogies can be transferred to optimal implementations in EVs solutions.

2. Control strategies of EVs

Despite all the advantages in pure electric vehicles [7], the range limitation is still an issue and plug-in hybrid electric vehicle (PHEV) is receiving some attention due to the possibility to continue the journey with a combustion engine. Several control strategies for PHEV can be found in the literature [7] where the key challenge is to achieve a near-optimal while keeping the control methodology as simple as possible. Optimization of the control strategy can be made using several approaches, namely: local, global, deterministic, stochastic, gradient, and derivative [1]. Gao and Ehsani discuss the design methodology focused on energy and power capacity of PHEVs. Different control methodologies focused on electric range and charge depletion range are also presented in [4]. More control strategies for high-power electric vehicles using different energy and power sources are presented by Garcia et al, which were tested in a real urban street railway. Five control methods were tested, namely: operation mode, cascade control, equivalent consumption minimisation strategy (ECMS), fuzzy logic based control, and predictive control. All of them had similar performances, but ECMS is the one best suitable for high-power hybrid electric vehicles [6]. Dib et al developed an online energy management for eco-driving applications that considers an urban driving, where the vehicle trajectory is affected by traffic and road infrastructure. Eco-driving can reduce the fuel consumption and is based on the idea that for a specific journey, there are different ways of driving which are not equivalent from an energy point of view [9]. A real-time energy management based on optimal control theory was also developed on. The control strategy was developed using a variety of driving cycles, which one different in terms of total distance, maximum speed, grade profile, and average speed. A control strategy for parallel hybrid electric vehicles (HEVs) based on genetic-fuzzy algorithm was developed in [10]. It is used a fuzzy logic controller that is tuned by a genetic algorithm over three different driving cycles, to minimize the fuel consumption, while the driving characteristics are maintained or even enhanced. Kim et al use the Pontryagin's minimum principle to control hybrid EVs in optimality, from a mathematical perspective. Optimal control in real-time is shown to be a optimal solution, assuming the internal resistance and open-circuit voltage of a battery independent of the state-of-charge (SOC). Payri et al presents a stochastic approach for optimal energy management in HEVs. ECMS is upgraded with a stochastic estimation of future driving conditions based on the vehicle previous power demands [8]. A different approach can be used when the trip is known in advance. Yu et al purpose a trip-oriented energy management control strategy for PHEV, considering both the non-linearity of the battery efficiency and the complexity of PowerSplit architecture. The control strategy is based on the driving pattern and on trip information loaded in the energy management system, and it is implemented using a feedback control system [2]. Other offline approach, model-based for PHEV energy management focused on lowering the CO2 emissions directly or indirectly produced from vehicle utilization is presented in [3]. A energy management strategy in real-time considering ultracapacitor (UC) and batteries for PHEVs is described in [5]. The fuel optimization is based on the choice of three parameters: energy storage system (ESS) weight; UC weight ratio, and the power provided by the ESS due to the UC. Both ESS and UC sizing is according to the vehicle size and weight, and the driving cycle. As seen in the literature, offline and online optimization can be performed. The trip needs to be known in advance in offline optimization, raising control problems when a different route is used or when different conditions occur (e.g. traffic, road works, etc). Online optimization can be made in two ways: online assessment, when the optimization is performed after a section of the trip is performed; or online assistance, when the optimization is performed in real-time.

3. Biological paradigms for optimal control

Several interesting processes were discovered during the time in bio-systems. The home- ostasis processes (thermal, aquas, pH) [12], also known as feedback loop control systems, that assures a high quality of parameters regulation by maintaining relatively constant the internal behavior independent on perturbations. Between representative examples can be mentioned "thermoregulation" - the mechanism that assures the constancy of body temperature and "osmoregulation" functions that manage in tide limits the water content on the body [15].

The allostasis processes (name proposed by Sterling and Eyer in 1988) [13] were discovered later and these are more complex processes that suppose a permanent adaptation of reference values and functionality in correlation with the current stage of the bio-systems. In this case, the parameters vary and this variation anticipates the demand. As source of inspiration the bio-systems can be considered as optimal organized systems and their organization can be applied for technical systems such as PHEV/EV. All the sensors and actuators in case of thermoregulation are redundant. It exist cold and warm sensors (Ruffini and Krause [15]) having complementary static characteristics. Around 36 centigrade degrees, these have slopes with opposite signs [15]. The neural connection that transmit the signals from these pair of sensors, will offer the difference between the values of the signals collected from each thermal pair (cold & warm) of sensors. Thus, the resulted signal will determine, a high sensitivity of thermal sensor characteristic around normal values of temperature. As result of conversion from analog values (temperature) to neural spikes the interferences between the different neural channels for temperature sensors will be realized in the fusion point that is represented by the hypothalamus.

Related the same thermoregulator system, is important to emphasize that the signals acquired from exteroceptors that presents a larger variety compared with the signals produced by enteroceptors thermal sensors are transmitted on different processing area on anterior and respectively posterior hypothalamus. These aspects show how living organism adapt their processing system optimally in correlation with the information flow. In case of the same system is interested in observe that the cortex can provide specific "set-point" for temperature in case of a disease or an important cerebral load. Such reaction proof the existence of predefined reaction programs at different kind of excitation and these reactions have also a "predictive" character, trying to anticipate the overall demands of organism preserving in this way the stability.

The energetic system of cells is based on "burning" of fuels like ATP, ADP or glycogen that are the three fuels with different time constants: small, medium and long term, respectively. ATP and ADP are found in each of the cells of the body, and glycogen is stored in liver, being transported and processed in the cell when is necessary. Thus, the reserves of energy will be provided in correlation with the current and anticipated needs. The recovery of energy reserve is related to nutrition process, named Dynamic Energy Budget theory [14], and the existing theories related are able to describe how the energetic resources are share between different organs functionality provided, spent on different actions and lost into the organism. In fact DEB is able to describe with fidelity the metabolic processes and this can represent optimal examples for control functions design in case of energetic systems.

A hierarchy will be established between the different influence factors and a linear, heuristic, stochastic or self-learned strategy for control set of functions selection will be established. It is worth notice the necessity to have a “set of functions” that are together selected to be used to control the vehicle because, in this way, the vehicles can react better at various perturbations that appear during the transport mission. Control system will include three levels with three different time constrains, short, medium and long term.

4. Implementation

The implementation illustrates the fusion between energy and information as main way to assure the energy efficiency optimization in case of mobile, intermittent connected and full power-grid connected systems [11]. This fusion is also present in all bio-systems and represents a key topological factor. In Figure 1 image illustrate the structural similitude between bio and technical system. As design example considering the analogies between bio-systems and technical systems, a control system for energy management for a diesel hydraulic locomotive was developed. The solution was implemented using storage devices with different time constants (ultra-capacitors and lead-acid batteries) and a three levels control system.

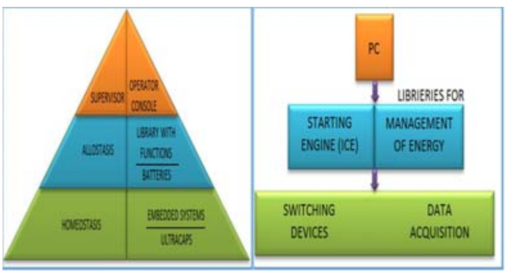

Figure 1. Comparison between biological and technical systems

The first level (supervisor) includes a display (the human machine interface) also is the Ethernet network manager that assure the link with the intermediate level. In this level are stored the different kind of functions that are adopted for operating the control system according to the status and the optimal settlements established for the starting process, the time constants for the charger, and for the energy management system applied on locomotive and train. The third level is formed by all the embedded systems that assure the regulator functionality, the switching of circuits and the acquisition of all date referring control signals on locomotive (current, voltage, time, frequencies and periods).

5. Conclusions

After the study of bio-systems physiology and organisation, their principles were implemented on a energy management system for a LDH1250 diesel hydraulic locomotive. The principles were applied on the control system design, dedicated for start-up the engine and for optimal energy regulation. The architecture was selected according the bio-systems organization, allowing a better fitting on the requirements for signal processing and acqui- sition, and to control the main elements of the locomotive. A library was implemented through automated control functions using the similarities with bio-systems, for managing the operating stages of the locomotive.

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