A Biological Approach for Energy Management in Smart Grid and Hybrid Energy Storage Systems

Paul Nicolae Borza[1], Indrajeet Prasad[2], Sofia Sanchez Mateo[3], Manuella Kadar[4]
Professor, Dept. of Electrical and computer Engineering, Transilvania University of Brasov, Romania[1]
Assistant Researcher, Dept. of Electrical and computer Engineering, Transilvania University of Brasov, Romania[2]
Assistant Researcher, Dept. of Electrical and computer Engineering, Transilvania University of Brasov, Romania[3]
Associate Professor, Dept. of Mechanical Engineering 1 Decembrie 1918, Alba Iulia, Romania [4]

Abstract— This paper is a proposed inspiration from the biological system of this world for the new era of technological advancement. The paper reviews the biological control systems which assures the stability and dynamic evolutions of the living world. Homeostasis and allostasis phenomena and associated paradigms have been presented. An overview of power networks and energy systems has been presented as well. The structure of the smart grid and its characteristics is also included in order to compare it with biological structures and system control designs. Examples are presented related to the configuration, sizing, design and control of the hybrid storage systems with similarities with biological systems.

Index Terms— Allostasis, Bio-system integration, Energy management, Electrical energy storage, Hybrid energy storage system, Homeostasis, Smart grid.

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1 Introduction

BIOLOGICAL systems represent the infinite inspiration source for developing technical systems which lead the progress of human civilization.

Thus, biological systems illustrate many metaphors used for shaping our thinking style in order to reveal and valorize the patterns of the nature in techniques and technology. The main advantage of such systems consists in the default validation of solutions by Biosystems themselves. Both, the structure occurred in Biosystems (bio mimetics) - which can be imitated in technical systems -, and also the complex functionalities and their reciprocal interferences (metaphors) argue the necessity to use it in approaches to the complex problems and finding solutions for the modern systems.

The concept of smart grid has evolved during last years. Smart grid is now a collection of power devices, Distributed Energy Sources (DES), Renewable Energy Sources (RES), monitoring devices that interact using Information and Communication Technology (ICT). A reliable power network management needs to be resilient and redundant to prevent malfunctions in the power network operation. This paper presents a biological approach to manage smart grids using characteristics such as self-healing, different types of control strategies (feedback, feed forward), learning algorithms, different types of energetic storage, and hierarchical architecture. These characteristics are present in living beings and are vital for the smart grid management.

The paper reviews the biological control systems which assures the stability and dynamic evolutions, namely, homeostasis and allostasis phenomena in section 2. The paper is organized as follows: Section 3 includes the overview of power network and energy systems. The structure of smart gird and its characteristics is presented, in order to compare it with biological structure and control designs. Section 4 presents biological control strategies in smart grid structure and section 5 presents examples related to configuration, sizing, design and control of the hybrid storage systems. The similarities between biological system and energy storage systems are also presented in this section. In section 6 some conclusions and future work are discussed.

Bio systems illustrates the intimate relation established between the structure of the system and the generation of potential functionality. This paper describes the two main phenomena: Homeostasis and allostasis. Even if these two phenomena are common for biologists, however their paradigms may constitute the essential key phenomenon for the technical system design.

Organization of structural and functional redundancies of the systems is extremely important for obtaining performance. The hybrid nature of the systems elements improves the reliability and availability of the systems. Also the control loop functions specialization on variety of signals (information flow) and source of the signals are very important.

Among several works illustrating the analogies and methodologies resulted from the biologic system, it is remarkable [1] which presents the pathway for innovation of technical systems inspired by biological systems and their paradigms. A methodology based on biological system mimicry is applied to the technical systems.

2 Biological System Inspiration Sources for Electrical Storage System and Smart Grid

Every living being in this world has its own system which could be perceived as the inspiration of the next era of technology. Comparison of two alternative models of physiological regulation for the inspiration of electrical energy storage advancement is hereby provided. The first model corresponds to homeostasis ("*stability through constancy*"), which has dominated physiology and medicine since Claude Bernard declared, "*All the vital mechanisms...have only one object – to preserve constant the conditions of ... the internal environment*". His dictum has been interpreted literally to mean that the purpose of physiological regulation is to clamp each internal parameter at a "set point" by sensing errors

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and correcting them with negative feedback. Based on this model, physicians explains that when a parameter deviates from its set point value, some internal mechanism must be broken. Consequently they design therapies to restore the "inappropriate" value to "normal" [1].

In [2] The Algorithmic and analytical method for integrating, analysing and querying biological sequence data are presented with the example of selection algorithm in complex information network. Genetic regulation and cellular signalling, inference of domain interaction, inference of regulatory networks, identification of function module, network alignments, network motives are described in this paper. Network based functional inferences are presented in details with the models of functional coherence of molecular networks respectively connectivity, proximity and recurrent patterns.

2.1 Homeostasis

The thermal equilibrium of the body is obtained from balanced action between two subsystems: the nervous system and the chemical system organised as feedback loops (see Figure 1). The biological thermal control system should have a response at every kind of excitation from outside and inside of the body. The variety of internal behaviour signals is lower compared with the environmental behaviours. The thermal system responds at this specific.

While external conditions may change, the human body must maintain a reasonably constant behaviour at the level of cells, tissues and organs. That phenomena are called Thermal Homeostasis.

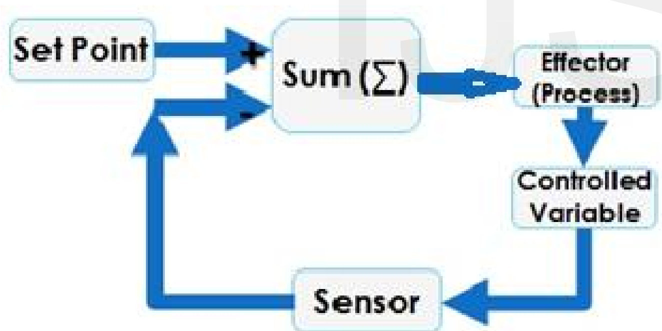

Figure 1: Homeostasis model

The homeostasis is recognised in case of biological system as well as for other kind of control parameters. The homeostasis model has contributed to the theory and practice of scientific medicine. In physiology, evidence accumulates that parameters are not constant. And their variations, rather than signifying errors, are effectively designed to reduce errors. Several example illustrating the homeostasis phenomena are enumerated below:

I. Thermal equilibrium
II. Chemical equilibrium of organism and components (Aqueous concentration and pH)
III. Dimension of cells, tissues, organs and entire body

A homeostatic control system has three functional components: a receptor, a control center, and an effector. Homeostatic control systems function by negative feedback, where build-up of the end product shuts the system off. Sometimes the elements included in feedback loop can suddenly reverse the control signal phase, which is called "Shock". The physicians describes it as hemorrhagic shock, thermal shock, or anaphylactic shock.

Feedback Mechanisms in Thermoregulation: Mammals regulate body temperature by negative feedback involving several organ systems. In humans, the hypothalamus (a part of the brain) contains nerve cells that function as a thermostat.

Thermal sensor characteristics presents opposite slopes (Positive and negative) and sensors are distributed on skin and other internal organs.

Thermal homeostasis: The complementarity and structural redundancy of the thermal regulation system brought an exceptional quality of temperature regulation (see Figure 2). The system illustrates the specialization of control based on time frame and variety of processed signal. The sensors present adapted sensitivity functions of inputs signals. Thus, into the normal working domain the gain factor is maximal emphasizing the differences. Outside this the sensitivity is reduced in favour of increasing of width for input signals. The control centre is hierarchically organised on fast and slow reaction time at perturbations. These systems are redundant and regarding the external and internal behaviour, the variety of signals are in accordance with the source of perturbations.

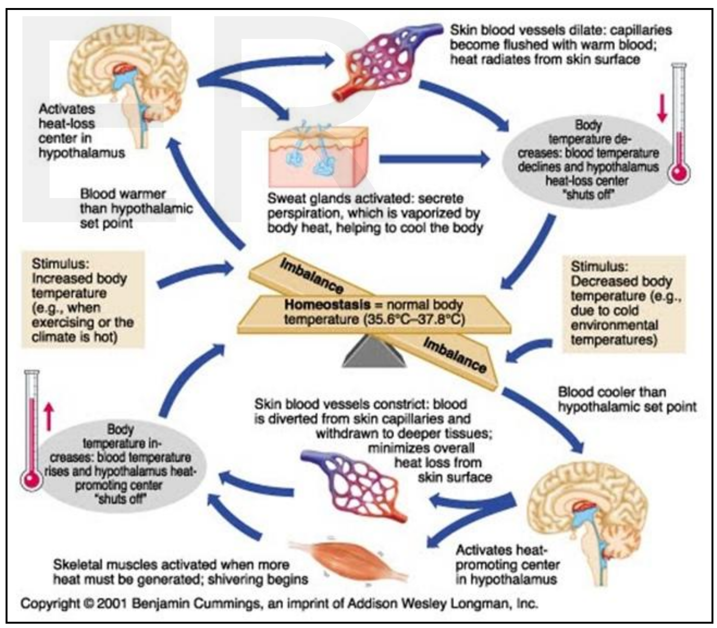

Figure 2: Thermal Homeostasis[3]

The different time constant of the sensors and actuators bought a new level of quality in temperature regulation (seeFigure 2).

Main paradigms of the thermal homeostasis:

I. Central controller: Signal processed on anterior (Exteroceptive) and posteriors (interoceptive) hypothalamus are separated.
II. Distributed sensors: The temperature sensors are placed on skin and all internal organs.
III. Variety: Function of variety of signals exists between different control loops corresponding to exteroceptors and interoceptors

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IV. Specialities of elements: Specific sensors for cold and hot, interior or exterior. Specific actuators for thermolysis and thermogenesis.
V. Time constant: Actuators have different time constants: Short and long periods.

All these features make the thermal homeostasis system not only resilient but also very reliable reflecting a high quality of static and dynamic temperature regulation.

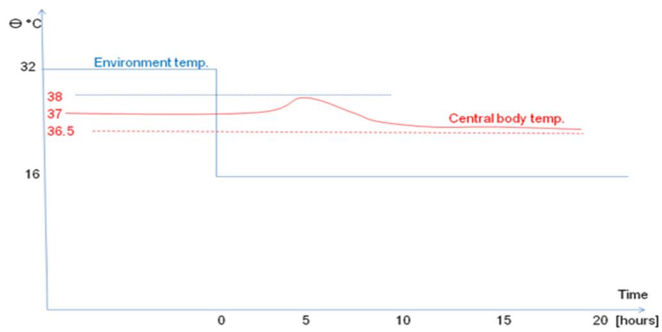

Figure 3 : Exceptional quality of temperature regulation

In[4], Examples of homeostasis translation into technical systems are described. The negative and positive feedback along with the control strategies, simple metaphore for homeostasis is also presented. Pathways that alter homeostasis are also presented in this paper.

2.2 Allostasis

Allostatis (“stability through change”), reflects virtually the opposite view. It suggests that the goal of regulation is not constancy, but rather, fitness under natural selection. Fitness constrains regulation to be efficient, which implies preventing errors and minimizing costs [6].

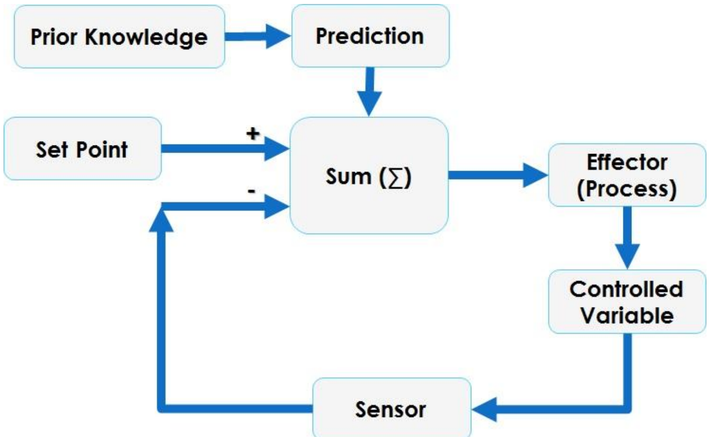

Figure 4 : Allostasis model

Homeostasis describes mechanisms that hold constant a controlled variable by sensing its deviation from a “set point” and feeding back to correct the error. Allostasis describes mechanisms that change the controlled variable by predicting what level will be needed and overriding local feedback to meet anticipated demand [[6]. The main features of allostatis are: Hierarchical control, acting on base of automatic chosen patterns, events priority management, synergic and redundancy acting.

Central processing in case of allostatis are conserved at local level by homeostatic process. The pattern collection tries to anticipate the demands. These where discovered, classified and stored as potential next stages enriching the pattern collection during life of organism. The pattern collection overrides the various feedbacks that oppose changes and a comparably high redundancy on each level of control system is present. The redundancy is reflected by the distributed, and also specific sensors and actuators.

This acting system adopts the prior knowledge prediction as forecasting on medium time range in comparison with sampling frequency used by the closed loop systems (see Figure 4), which comply with the Shannon theorem.

2.3 Cellular energetic reserves and expenditure.

In [7] the main energetic cycles are described which assure the functionalities of organism. The acid adenosine triphosphate (ATP) is the principal energetic reserve that by anaerobic process generate the energy necessary for everybody. Two chemical systems provide the energy necessary for life assuring the permanent regeneration of cellular energetic reserves. The amount of energy reserves at cellular level is relatively low. This is spent in very short time (several seconds) to provide the action potential. By an anaerobic process the regeneration energy is provided during resting period and even during activity. In this cycle, ADP (acid adenosine diphosphoric) and also phosphocreatine (PCr) allow the continuity of energy reenergized by phosphorylation back to ATP. The catalisator of reenergised chemical reaction is creatine kinase. The aerobic energy source is based on glycolysis that has as resources the glucoses and glycogen resulted from carbohydrates [21]. Looking at the power reserves distribution in muscle cells, it can be observed that ATP power reserve represents 58% of total, power reserves (ATP+ADP) activated on medium term represents 25% and only 16% are power reserves based on lactic acid cycle, respectively aerobic generation [21]. The transportation phenomena are revealed in case of aerobic processes.

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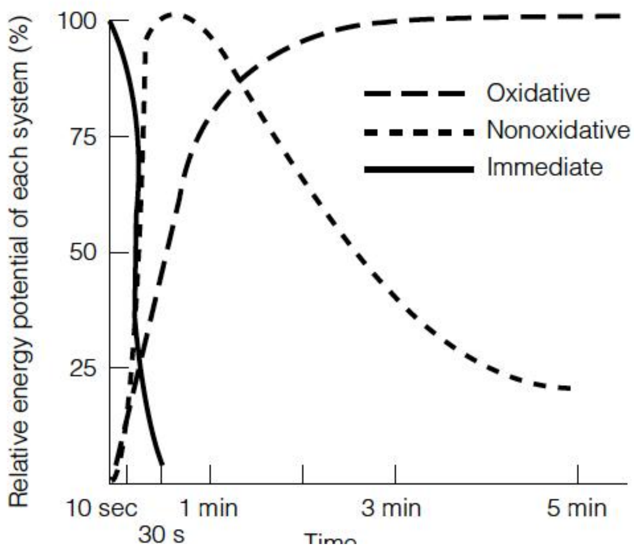

Figure 5: Energy sources for muscle as a function of activity duration [21]

The described successive energetic reactions assure the "flat response" in time of living being's muscles.

3 Smart Grid functionalities and their challenges.

A "smart grid" is simply an advanced electrical distribution system that has the capability to balance electrical loads from diverse, and often intermittent, alternative energy generation sources. The automatic metering infrastructure (AMI) play the essential role in smart grid technology by fusion between the energy and information. One key component of the "smart grid" is the capacity to store electrical energy; this allows the demand from consumers to easier meet the requirements.

The Smart Grids are:

- adaptive, with resilience on operations, particularly in responding rapidly to changing conditions;
- predictive, in terms of applying operational data to equipment maintenance practices and even identifying and predicting the potential outages;
- Integrated, in terms of real-time communications and control functions.
- interactive between customers and markets and also
- optimized in order to maximize reliability, availability, energy efficiency and economic performance.

3.1 Energy system and its characteristics

In simple words we can describe "energy" as capacity to provide an action. While in electrical energy, it must be consumed when it is produced in all other situation appear losses. The electrical energy resources and generations are limited. There are different forms of energy as such: electrical, mechanical, chemical, thermal, radiant etc. The energy sources can be based on: fossil reserves or renewable sources.

While chemical conversion is widely used for conversion of fossils energy in electricity from: coal, petrol, natural gas, and atomic. Renewable sources use the radiant way to convert the renewable energy in electricity by capturing and converting the sun or other related energy sources. Such as, direct solar radiation conversion by PV cells, thermal cells, wind mills and wind power farm, water by hydro-electric power, tidal wave energy and biomass based power plants.

Fossils fuel technology is mature and presents high energy density but it also generates the harmful greenhouse gases. While the 'green' technologies are dependent on sun radiation and local factors like latitude and climate etc.

3.2 Power network evolution

The power network has always been a critical step and it is improving according to the demand and load of consumers. It has evolved a lot from past till now. In 19th century, power network was insulated. It was generation based on local power plants majority functioning with coal-steam on island networks. Then in 20th century it's the century of integrated and aggregated networks. Nowadays, power network hanged from centralized to decentralized generation as a result of large deployment of renewable energy sources (RES) technologies. The RES are highly dependent on natural resources and its variety raises new management problems related its stability and its high reliability in power supplying. As resut of this evolution many traditional consumers became producers of energy respectively prosumers.

While in next generation, the power network would might be prosumers centred. It would have complete integration between generation and consumption by ICT (Information communication technology). The new features brought by these new technologies are: self- healing, which means that the system would be able to manage by feedback. The permanent and tide balance between generation and consumption at local level will be the basis to building up the whole system equilibrium. Such approach will generate a new higher level of energy efficiency. A key factor toward increasing of the energy efficiency will be the usage of the energy storage systems as services suppliers for power networks.

3.3 Smart grid functionalities

There are several important functionalities of smart grid evolution:

- Fault Current Limit devices able to automatically limit high current that occur during faults
- Wide Area Monitoring, Visualization & Control
- Dynamic Capability Rating
- Power Flow Control having as objective to reduce the power flow travel along power networks
- Adaptive Protections
- Automatic Feeder and Line switching
- Automatic Islanding and Reconnection
- Automatic Voltage and VAR Control
- Diagnosis and notification of Equipment Conditions
- Enhance Fault protection
- Real-time Load measurement & management
- Real time load transfers as result of feeder reconfiguration
- Customer electricity use optimization

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3.4 Smart grid challenges

Development of a secure, reliable and resilient communication system is needed which creates redundant infrastructures. Improvement of M2M connectivity down to the last elements integrated into the power grid is also a significantly challenge in smart grid. Development of standard and regulations that impose the usage of strict security solutions in order to avoid possible intrusion into SG systems is considered as a significant challenge.

There are several challenges in smart grid which is describe below as:

- Development of appropriate strategies in order to pass-off or avoid the "silent" –unresponsive nodes that should be over passed
- Developing device-oriented security platform and their integration into products
- Strict control of propagation delays on operational network in order to maintain the "real-time" capabilities for whole system
- Developing and adapting the network for integration of dynamic, mobile and variable storage elements brought by massive introduction of electrical vehicles
- Advanced metering infrastructure (AMI)
- Bi-directional communication based on standard protocols
- Incentive system necessary to build-up for optimization of energy efficiency by influencing the prosumers.
- Visualization in real – time of current status of the power network
- Distribution of commutation and control facilities between different smart grid elements.

4 Biological control strategies in smart grid structure

Electric power grid is undergoing revolutionary changes through increased integration of electric power generation. This section in lights the possible control strategies for future smart grids based on living system dealing mechanism.

Electrical grids are subject to a variety of environmental and internal stresses including human error leading to supply-demand load imbalances, frequency drift and, in worse cases, cascading blackouts. The operational security is another major factor in smart grid technology. Which means security—the investigation, mitigation and recovery from stresses, perturbations, and disruptions, both transient and longer lasting is a major requirement of the smart grid.

The operational security approach of the smart grid is the same as homeostasis phenomena from biological system approaches of a living system. Smart grid should be capable of carrying out the following operations:

• Rapidly detect and respond to loss of energy balance (energetic homeostasis)
• Limit local damage when it occurs
• Initiate inter-site communication and compensation
• Prevent or limit the propagation in cascade of failures
• Fast recover and return to normal operations.

It is important to emphasize that the structure of biological systems facilitate implementation of their functionalities.

In case of Biosystems, there are three sub-systems acting coordinated: the immune, nervous, and endocrine. In particular, the nervous system provides central homeostatic feedback controlling the whole organism by using own fast responses neural networks in parallel, by activating umoral regulation, which generate specific biochemical markers. These will activate the innate immune system like macrophages and neutrophils with long term effect on whole organism.
Acting together, the innate immune and nervous systems provide a coordinated response to stress, injury and micro-organisms aggressions [10].
The stress stages [11] are exceptional situations that appear as result of external aggression of organism that overpass the normal variation limits of the organism influence factors.

4.1 Central control by nervous system, innate immunity and macro phase pattern behavior of the system

Central control of living being is very complex. In Figure 7control ways are presented in case of stress which affects the control of inner and outer worlds and many internal organs (Figure 6 : Neural networks connecting inner (body) with outer (environment) worlds [13]).

The organism reaction at micro-organism's aggression includes not only the innate immunity response with generation of anti-body but also the organism will combat the same aggression with a metabolic adaptation by changing the settled point of central temperature (fever apparition) and / or pain sensation of the living organism. The reactivity can manifest as a tissue inflammation (local reaction) or can generate consequences at whole body reflected by fever (systemic reaction), anti-body (macrophage) generation, pain etc. All these reactions have as scope to assure the protection and integrity of whole system (body) against infections and promotes the destruction of the invader. The first features of macrophage behaviour worth noting is that both circulating and tissue.

A gradual and ranked reaction from organism side will reveal from successive similar aggressions. The organism will react on long term by permanent changes in accordance with the type or aggression. This will represent the individual or species adaptation phenomena that are frequently described in pathology and physiology too.

The first features of macrophage behaviour worth noting is that both circulating and tissue resident macrophages are utilized in innate immunity. The macrophages are highly plastic and respond to environmental cues by reversibly switching from one phenotype (behaviour) to another.

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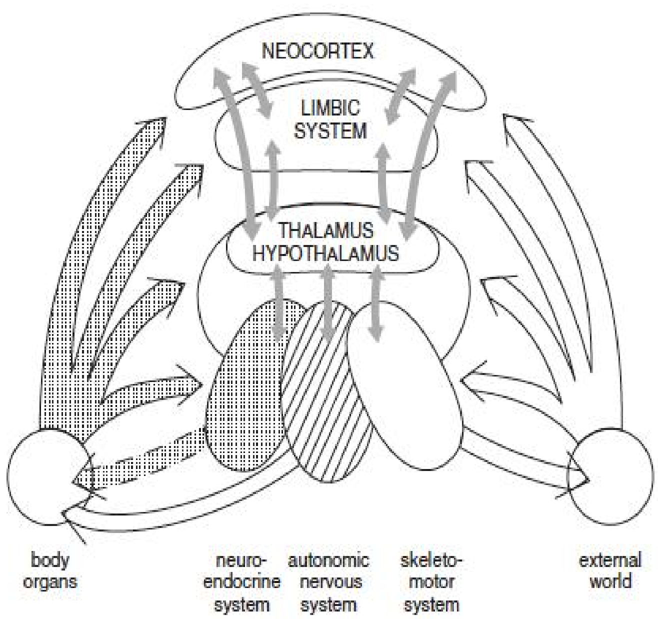

Figure 6 : Neural networks connecting inner (body) with outer (environment) worlds [13]

The reactivity of organism reflects a "programmed response" at aggression, respectively a preset sequence adopted by the organism. This can be treated similarly as Markov chains which describes a sequence of states. In which over various stretches the probability of each transition in the same way. In case of living systems, redundant loops are identified (Nervous and umoral). These also presents a heirachical character. This is illustrated starting from tissue inflammation at local till system level where the immune response is revealed and the thermal homestasis modification with consequences are illustrated at the detailed level of whole organism.

4.2 Central pattern generator (CPG)

Central pattern generators (CPGs) are volitional or involuntarily triggered sets of successive actions each during a specific time and activated with a specific delay after triggering the pattern. Some of these patterns are stored at highest level of the control systems respectively at cortex level, others are only spinal reflex arcs. In case of gait control, for example, the spinal reflex arcs are supervised by the limbic system that provide the specific patterns assuring also the motric intercorrelation between the different muscular groups acting correlated. These kind of patterns are responsible for activities such as walking, swimming, breathing, chewing and digestion. Generation of these behaviours is autonomous—the circuits are self-contained, able to generate rhythmic patterns independent of timing input and sensory feedback. This Central pattern generator system idea is being used in Robotics for the movement control. The combination between intricate control loops some of these supervised by specific schedulers are desirable to be developed in the future for complex controlling of the electric power grid. By mimetics with biologic systems and, in accordance with the power networks structure and organization, (elements, lines, topologies and switching elements), can develop in the future stable and responsiveness control systems which assure and maintain the consistency of all components and system outputs too.

4.3 Redundancy and degeneracy

Biosystems also represent examples of redundant systems optimized with an extremely high stability and reliability. The reduncy of the systems is manifested both in terms of structure and composition of elements and in terms of their functions.

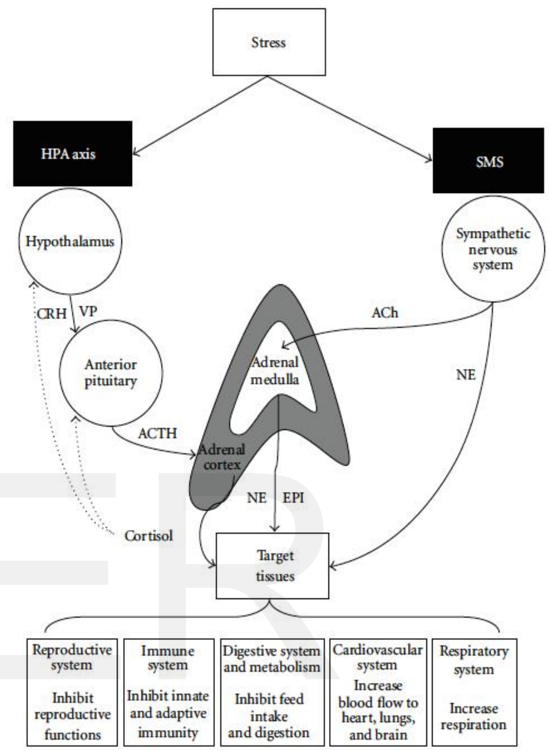

Figure 7: HPA - hypothalamic-pituitary-adrenal axis and SMS -sympathomedullary system, response to stress. Corticotrophin releasing hormone; VP: vasopressin; ACTH: adrenocorticotropic hormone; ACh: acetylcholine; NE: norepinephrine; EPI: epinephrine. [14]

It is a traditional way of dealing with circuits and other structures build from fault- and failure-prone elements. In comparison with redundancy, the degeneracy differs from this in a fundamental way. In the case of degeneracy, a particular function is carried out by structurally different elements. Which is, there exists multiple, no identical ways to produce a desired output and in each instance one of these solutions is selected. Several observations made during the past few years support the notion that biological systems extensively exploit degeneracy and not redundancy to achieve robustness and resilience to malfunctions and loss of components. The degeneracy can be reflected in some situation by "compensation" of functionalities as result of malfunctioning of primary functional system. These compensation phenomena are in general "learned lessons" and reflect the "plasticity of neuronal and subordinate humoral control systems.

4.4 Dynamic energy budget

The DEB is a generic theory about living systems development starting from embryonal phase till death of the living system.

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The Kooijman's theory provide a full energetic frame woks for living systems identifying the generic main sources of energy and how these resources are spent [16]. In the last years, a large group of researchers' have revealed significant examples about DEB applied in different biocenosis. In [17], the biocenosis of Iceland is analysed for capelin population as a result of specific nutrition chain. Dynamic energy budget model is conceived and described for this biocenosis. The article [18], the prediction of population dynamics from the properties of individuals is reveals as a cross level test of dynamic energy budget theory. The model based on Kooijman's theory is parameterized in this paper using the DEB-IBM methodology. The simulation is showing the evolution of Daphnia model (Growth phase, Decline phase, dead from starvation etc). With the little modification as shown in [18], DEB model can be used for many applied purposes for population growth rate under environmental toxicity.

In [19], DEB model was developed and applied for pacific oyster crassostrea gigas in central New Zealand. A similar estimation model based on customization of DEB model was done in [20] for Mediterranean tooth carp growth. The habitat interaction, feeding process, reserve accumulation and its spending on offspring maturity reproduction and growth (Somatic maintenance) was analysed.

The three basic fluxes are assimilation, dissipation and growth. Each fluxes are analysed from the point of view of chemistry, biology, and physiology and system integration. This illustrates the deep connection between their features and the performance, stability, variety and aging.

The different stages that appears during life time of living being are modelled. A different chemical elements based on life and different environment affects the living being. Analysis Between the substances and biological phenomena are mentioned: Nutrition with food, biomass generation and usage, creation, storage, usage of energetic reserves, faeces, and chemistry main constitutive elements of Biosystems. The carbon dioxide, ammonia, water, and dioxygen are described as variation and behaviour dependent. A way proposed to valorise the similitudes which would reveal the Biosystems and smart power grids. Which consists fitting and superposition of the maps of biological system with the elements of smart grid identifying the similar elements and their similar roles in:

- leading, usage and waste management of energetic resources;
- structural and functional organization of the principal functionalities;
- in implementation and realization of the programming facet of the systems, pattern designing (flow action tables –successively and work flows diagrams- and complex collection of these considered as actions strategies) smart grid structure and design flow making according to the biological structure map design.

Building maps of smart power grids similar with the maps of Biosystems energetic circuits have created the premises of deep biomimetic development of research in this field. A similar mapping could be done for functionality of bio systems and the smart grid. In this way, complex scheduling and strategies could be translated from Biosystems to smart grids. Bio energetical models are presented in this paper based on kooijman's DEB theory and a set of equation describing the standard DEB model is provided [20].

5 The Biological Approach in Hybrid Energy Storage System

Having as paradigm the assembly of consideration above mentioned, an illustrative example of methodology proposed is considered for the optimization of the electric storage systems. Arguments sustaining this approach could be mention as:

- Native similar organization between living cells and the energy storage cells;

The organization of the storage reserves inside the living organism and the types of "reserves" that present a spread time constants function (short term Acide adesinotriphosphoric ATP, medium term- acid adezinodiphosphoric ADT and –long term - glycogen). According to the application requirements and like the biological systems, a HESS is composed with different types of energy storage to fulfil the energy and power requirements as seen in Figure 8.

In this sense, the evaluation of paradigms providing the mechanical effort in case of sport activities can offer an appropriate view about, which, when, and how to spend the energetic reserves in our body. The activation mechanism for energy spend and regeneration of reserves, where and how these are used are relevant for potential new implementations of energetic systems, especially for insulated one.

- The "activation mechanisms of each kind of energetic reserve function of specific demand (duration, variation in time and necessary amount) for "short efforts" of the local reserves are activating and the reaction time is very short. As a continuous transition, the medium term reserves, having a bigger capacitance, are activated sustaining the "flat response in time" of the entire system. Finally, the long term energetic reserves are used, but this usage is the result of transportation and conversion phenomena (blood as carrier of glycogel, Crebs cycle as work flow for transforming in usable resources the long term stored resources, etc).
- The synchronization in action and consumption revealed when an organism provides actions (see the example of gait phenomena with successive activation of different muscular groups and coordination of many hierarchical levels between different biological control loops).

The hybridization illustrating also a heterogeneity of system components are justified by the inexistence of a single ideal type of energetic reserve. Each known energy cells satisfay only partial necessary features and performance requested by majority of applications. Thus, "combination" of different types of storage devices appear, to assure better organizations for these, to group adequately and to build up adapted functions for the control. The desired features could include:

- Find out adequate time of local energetic equilibrium in majority of stages.
- Building up specific groups of cells and at this level

International Journal of Scientific & Engineering Research, Volume 7, Issue 3, March-2016
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specific functionalities;

- Find out a "portfolio" of strategies ("acting collections"), activated as result of a permanent discovery and classification of own power networks stages,
- Assuring the Dynamicity in dealing with the aging processes, respectively adaptation of the system at its self-cells degradation phenomena.

In this section a biological approach in HESS is presented with

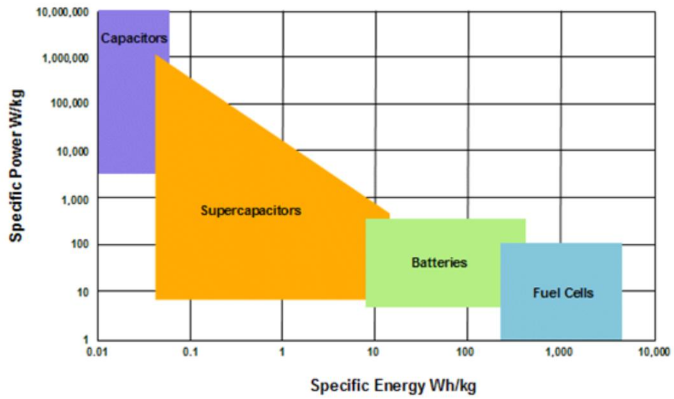

Figure 8 : Ragone diagram

the paradigms identified in section 2. Biological cell group can be considered as a distribution energy sources. A group of cells represents a redundant energetic and informational source, in which the compensation phenomena can be identified in the organism. The redundancy, represents a major feature of the energetic systems assured by structural design of the safe functioning even in condition of apparition of a first or several malfunctioning cells and / or functions. There are several similarities between the biological and the energy system.

In structural terms, a HESS needs to fulfil some requirements to be considered as ideal. An appropriate sizing of every element in order to assure the adequate ratio balance between short and long term energetic resources. An adequate dimensioning satisfies the requirements of bidirectional power flow according to the demands of the specific application and represents one of the major decisions that must be taken during design process. This is determinant not only for line out energetic resources but is also in dependence with the functions that must be conceived.

The approximate entropy (see [22] and [23]) as measure of variety of load demand can be used to size the fast release component of the storage system. Another approach that can be considered in evaluating of load demands is Bayesian series method which assure the sequencing of data [24].

A HESS should also be able to provide a flat response in time of the hybrid cell.

Redundancy assures the system's reliability in biological systems and HESS. In biological systems, the *integration* of cells and the consequent internal interaction between the cells result in new features availability. This integration and functionalities result in high reliability due to redundancy. While in technical systems the redundancy is the results of several factors. The system need to be closely interconnected to each other through pre-emptive wiring solutions. These are also the optimal solution for energy efficiency of the system. Every cell in the system needs to provide minimum set of functionalities to enable the fusion between energy and information. These functionalities allows behavioural or / and self-dynamic reconfiguration to provide the isolation of damage cells. This also provides specific energetic requirements of the system.

An optimal implementation can be achieved using an essential HESS hierarchy. The implementation of a biological approach in a HESS is a challenging task considering the investigation of this 3 aspects of the system: Sizing, Communication and Control strategy.

5.1 Sizing

Using a mimic strategy to conceive the hybrid storage systems, each system components should be dimensioned according to the application demands. The ratio between the fast, medium and eventually long term release storage elements must be considered. Thus, the validated proportions revealed at the level of biologic systems (see the muscle energetic resources) and also the variety evaluation should be appreciated using approximate entropy or Bayesian series which must be harmonized.

The size requested by the application can be achieved using different type of cells that reach the same capacitance. This is an important aspect which reflects not only by electrical implementation but also has consequences in thermal management of HESS.

The design flow for HESS must fulfil the application requirements and can also assures a reliable, a redundant and a resilient system. But one should not spend unnecessary money and resources in HESS over sizing.

The location of the energy storage device is important to avoid energy loss and to provide energy at the adequate time constrain.

5.2 Communication

A tide interdependency between size, cells and organization of hybrid storage system and implementation of communications is necessary to be considered. Thus, it is necessary to perform the fusion between energy and information in order to build-up the adapted functionality not only related application implemented but also related to the organization and specificity of HESS. Like in the biological systems the hierarchy should follow the organization to implement the superiorization of informational flow. In case of HESS, the proposal involves minimum three or four hierarchical levels. i). Cell level where the self-integrity functions like: over-charging, over-current, over temperature must be controlled by local systems. ii). Device level functionality will be implemented by Battery Management System (BMS) and by the Supercapacitors Management System (SCMS). At this level, aspects of aging, optimal sharing and short term scheduling functions will be implemented. This first integrative system (SCMS) will allow the integration of power and energy follow to reach the high energy efficiency for the applications. This Hybrid Energy Storage System Management (HESSM) will provide or sink the adequate power and energy

International Journal of Scientific & Engineering Research, Volume 7, Issue 3, March-2016
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amounts. and it will interchange data and control with the application supervisor building up evolving and also an evaluated functionality.
All described tiers of the system map, even the living organism hierarchy and the "superiorization" function meets in living entities.
Meanwhile, looking at the networks modern theory, it can be remarked that the analogy with optimal building up solution is done by colonies of bacteria (*Dictyostelium amoebae*) [25] and also neural informational system of human beings.
It is suitable to adopt such systems as solutions. The Ethernet base solution with different protocols in accordance with the function implementation. Thus, IP (Internet Protocol), User Datagram Protocol (UDP), Internet of Things (IoT) and Internet of Everything (IoE) protocols can be adopted together.
For flexibility reasons, the Near Field Communication, Passive Tags, and active solutions like Wi-Fi (802.11 a,b,n,ac), Bluetooth (802.11) Personal Area Protocol (PAN) and 802.15.4 Wide PAN (WPAN or/and ZigBee) and many other can be used adequately. To support a high degree of data transfer reliability by protocol itself would be very essential. And also the high degree data transfer reliability by developed topology and designed structural redundancy would be essential.
The biological paradigms reflect "cost of the life" can orient the innovative solution to validated one.

The communication system will be correlated to the degree of evolution at every level of constitutive elements in case of HESS. The security in communication and the energy efficiency will promote adequate solution where the range of transceiver combined with the cripting of information will assure the high reliability and resilience of communication. In order to combat the random, unattended malfunctioning situation a correlation must be realize also with the functionality build up at every hierarchical level of HESS. In the case of an information network malfunction it will not be possible to reach the energy storage device that should fit with an internal control system to overcome the unavailability. This will also make the device not to be fully dependent of his superior control in the hierarchical chain operating independently when necessary.

5.3 Control strategy

The control strategy needs to be defined according to the application's specifications, the granularity and the hierarchy of the Combined Energy Cell (CEC) or HESS implementations (Figure 10). In accordance with the sizing and organization of the HESS, the control will provide adequate functions.

At the cell levels, in general, the hardware sub-systems provide for fast response functions for limitation of the over-current, over-voltage and over-temperature. At the same level, the microcontroller based sub-system can provide raw data about State of Charge (SoC) and eventually State of Healt (SoH). Some of implementations permit detection of malfunctioning situations and even the self insulation of cell inside the storage pack informing in the same time the next hierarchical control level about. A such action will be taken by the storage cell in case of malfunctions self detection. In general, the limitation functions and also the self insulation actions comply with the real time constraints.

At the device level, the controllers of a CEC colony must be or-

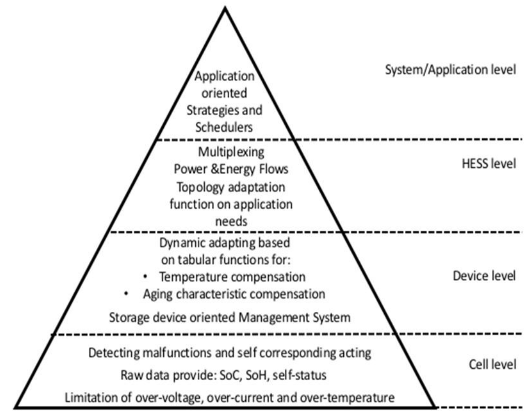

Figure 10: Distribution on system hierarchy of the functionalities in case of a HESS

ganized into a cluster for computation and control of Combined Energy Source (CES). This will form the Storage Management Systems (SMS) and this will be responsible for dynamic balancing of charging and discharging processes. The granularity of the energy sources is worth of study according to the system's application. At device level the thermal and charge management functions play an essential role in avoidance of accelerate aging process of CEC colonies or HESS.
An important group of functions are dedicated for intelligent schedule of power and energy supply (providing and sinking). The control functions implemented at HESS level should illustrate the "wisdom" of a humanized system. For example, some actions like controlled insulation and/or replacement of damaged cells and their compensation at the system level in such situations must be implemented like in case competitive phenomena occurred in living environments. Also at this level some systems can adapt function of application requirements the HESS internal topology and can adequately distribute the power flow function of SoC and SoH of HESS' components.
The real time constraints will be determinant in function design and fit with requested performances functionality of the HESS. Also, considering the granularity, the control strategy based on hierarchy and distributed systems needs to be performed according to real time constraints of the individual storage cell or the constrains of a Distributed Energy Management System (DEMS).
It depends if the controller is running to a DEMS or an active filter system. Resuming the main goal of the control algorithm and strategy is to improve the system energy efficiency.

6 Conclusion

The paper reveal the very large diversity of biologic paradigms that can be implemented for advancement of technology. Some examples from living world are emphasized and can be used in designing and development of complex technical systems by mimics and analogy. The complex phenomena are emphasized, like management of energy, storage of electrical energy and

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their stationary and mobile applications which can take the benefit of such way in development.

The feedback loop controls revealed in case of homeostatic phenomena, but especially the feedforward loops which are similar with the allostasis phenomena, constitute living and validated examples that can be applied in technology of the intelligent management of power networks and also in case of hybrid electric storage systems.

The review of significant processes appearance inside the living world is presented in this paper .like, the aging, the compensation phenomena, the structural heterogeneity, the cellular organization and hierachisation and many other examples clearly reveal phenomena from the domain of living organisms which can be taken as examples for development by mimics and functional analogies of the modern technical systems. A simple example of energy management is muscular fibers. Where the different kind of energetic reserves are stored and mobilized in case of providing effort. It reflects the intimate correlation between the stored quantity of different energetic reserves, their time constants and the reserves mobilization schedule adopted by living systems in order to satisfy the functional necessity of the system assisted. Also the transportation phenomena (we refer especially at oxygen in case of aerobic metabolism) can represents models of optimal and resilient phenomena which can be also used in case of HESS.

The heterogeneity sustains a structural treatment of the need to assures adequate responses from system in case of any type of demands.

The functional organization, which reflects on which level of organization are allocated for the functions of the systems is another important aspect reviewed in the paper.

The future development of ideas structured into the paper will be applied in case of an optimized HESS which will use to supply a personal vehicle. The particular case reveals the intimate connection between the large number of application parameters and its development.

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