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Engineering Sustainable Energy Systems: How Reactive and Predictive Homeostatic Control Can Prepare Electric Power Systems for Environmental Challenges

Fernando Yanine [a] *,Antonio Sanchez-Squella [b],Aldo Barrueto [b],Felisa Cordova [a], Sarat Kumar Sahoo [c]

[a] College of Engineering, Universidad Finis Terrae; Av. Pedro de Valdivia 1509, Providencia,7500000, Santiago, Chile.
[b] Dept. of Electrical Engineering, Universidad Técnica Federico Santa María, Av. Vicuña Mackenna 3939, San Joaquín,8940000 Santiago, Chile., [c] School of Electrical Engineering, VIT University, Vellore Campus, Vellore Tamilnadu PIN CODE-632014 India.

Abstract

Nowadays electric power generation and distribution systems are being faced with a number of challenges and concerns which emanate not so much from a shortage of energy supply but from environmental and operational issues. They are required to respond to such challenges very rapidly and effectively so as to preserve stability and continuity of operations at any time, regardless of what may occur in the surroundings. This in fact is the true measure of what sustainable energy systems (SES) are all about, and homeostatic control (HC) of energy systems seeks just that: to enable energy systems to become highly efficient and effective very rapidly, by attaining a state of equilibrium between energy supply and energy expenditure in electric power systems (EPS) operation. To accomplish so they ought to imitate homeostasis mechanisms present in all living organisms. Ever since Cannon (1929, 1935) first introduced the concept, attention on homeostasis and its applications have been the sole patrimony of medicine and biology to find cures for diseases like diabetes and obesity. Nevertheless, homeostasis is rather an engineering concept in its very essence—even more so than in the natural sciences—and its application in the design and engineering of sustainable hybrid energy systems (SHES) is a reality. In this paper we present the groundwork that supports the theoretical model underlining the engineering of homeostasis in SHES. Homeostasis mechanisms are present in all living organisms, and thus are also applicable to EPS in order to enable and maintain a sustainable performance when EPS are linked to energy efficiency (EE) and thriftiness. In doing so, both reactive and predictive homeostasis play a substantive role in the engineering of such mechanisms. Reactive homeostasis (RH) is an immediate response of the SES to a homeostatic challenge such as energy deprivation, energy shortage or imbalance. RH entails feedback mechanisms that allow for reactive compensation, reestablishing homeostasis or efficient equilibrium in the system. Predictive homeostasis (PH), on the other hand, is a proactive mechanism which anticipates the events that are likely to occur, sending the right signals to the central controller, enabling SES to respond early and proactively to environmental challenges and concerns. The paper explores both concepts based on previous work in order to advance the research in the field of HC applied to electric power systems.

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* Corresponding author. Tel.: +56-2-24207560.
E-mail address: fyanine@uft.cl

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1. Introduction

Ever since Cannon first formulated the concept of homeostasis, over 80 years ago [1,2] attention on homeostasis has been largely focused on its role in medicine and biology to find cures for diseases like diabetes and obesity for example, where research focused chiefly on the corrective responses and metabolic changes initiated after the steady state of the organism is perturbed. However, the concept of homeostasis, as important as it is in medicine and biology, has also been applied to Electric Power Systems (EPS) research [3-20], and in fact it should be extended, not only to include reactive homeostasis (RH) but also predictive homeostasis (PH) so as to understand the precise HC mechanisms that can be designed to enable a sustainable energy system to predict when environmental challenges are approaching or are most likely to occur and anticipate their impact early on in a recursive manner [3-10]. Sustainable energy systems (SES) encompass both reactive and predictive homeostasis operating recursively and proactively, in coordination with one another, in the face of an environmental challenge or some other system's issue which may raise concern. Reactive homeostasis (RH) in SES, as the name suggests, is a feedback-enabled mechanism driven by energy generation and supply versus energy consumption or expenditure. This can be engineered in EPS by employing sensors, control limit actuators (for example set-point fired responses) as well as AI algorithms that allow the system to make decisions when and how they are needed, in order to respond to changes in a predetermined array of the system's control variables. Thus whenever necessary, HC engineered in SES enable the energy system to take the actions required to counteract or fend off adverse conditions and noise which may affect the system's normal operation [3-20].

On the other hand, predictive homeostasis (PH) mechanisms generate responses well in advance of potential or possible challenges, once the system has reached a threshold, signaling a predetermined degree of likelihood that an event will occur. Hence there is a set of precise SES responses that come about early on, anticipating predictable or very likely environmental challenges or some other glitch in the system. Such PH responses enable the energy system to immediately prepare itself, taking the necessary precautions and actions to adapt and even reconfigure itself if necessary, in order to respond to the challenge effectively with sufficient anticipation. Such actions may come in several forms and will depend on the resources and intelligence built into the energy system, but they are all geared towards making the EPS more secured and able to withstand the upcoming challenge or threat by activating its readiness control mechanisms. Actions may come differently in magnitude and timeliness; some may be big and swift, aiming to adjust parts of the SES operation, while others may come more slowly and gradually, in the form of smaller changes in the system, largely as a result of stage-by-stage preparedness protocol building over time. The decision of which changes will occur first, how they will occur and under which conditions and circumstances, as well as where and how big will they be, will all be determined by both RH and PH control mechanisms designed and engineered in the EPS. Some may come very soon, while others may come at a longer time in anticipation of a probable environmental challenge [5-10].

Natural disasters, like earthquakes, volcano eruptions, and violent weather phenomena that we have seen happening more often in recent years, such as prolonged periods of intense rain and snow are nothing new indeed. On the contrary, with climate change on the rise, weather patterns are becoming more menacing, bringing strong winds and torrential rain out of the blue. Although such phenomena are not uncommon to humanity, they have become more recurrent and harsher in some parts of the world, like North and South America. The difference is that in today's 21st century world, much of the fragile living systems and economic sustainability depend on