

An Approach to Developing Power Grid Control Systems with IEC 61850, IEC 61499 and Holonic Control

VALENTIN VLAD, CORNELIU BUZDUGA, CALIN CIUFUDEAN

Electrical Engineering and Computer Science Department

Ștefan cel Mare University of Suceava

Str. Universității, 13

ROMANIA

{vladv | cbuzduga | calin }@eed.usv.ro

Abstract: - This paper presents some models and concepts for developing smart power grid control systems based on holonic concepts and the open standards IEC 61850, IEC 61499. Along with the proposed holonic models for different levels of control, we present a simple fault protection application illustrating how the IEC 61499 artifacts can be used for modeling and implementation of IEC 61850 compliant applications.

Key-Words: power grid, holonic control, IEC 61499, IEC 61850

1 Introduction

In the last years an increase in the degree of automation and intelligence of power grids can be observed, the future trends being on developing the so called “smart grid”, which should allow a more efficient management of energy consumption, a more robust behavior in case of perturbations (e.g. equipment failures or fluctuations in energy production or consumption) and the facile integration of renewable energy sources [1].

The complexity of the decision process in the smart grid imposes its distribution to the low levels of measuring and automation devices rather than being realized in a centralized form as in the majority of the actual distribution networks. Consequently, on the information and communication technology (ICT) side the focus of current research is on developing distributed control architectures based on open standards like FIPA (Foundation for Intelligent Physical Agents), IEC 61850 and IEC 61499, with a view to support the decision-making process and to allow the effective integration and interaction between different automation devices [2]-[16].

2 IEC 61850

IEC 61850 is an important new international standard for substation automation, considered to have a significant impact on how electric power systems are designed and built for many years to come [17]. Focused on communications between automation devices, the standard deals not only with the specification of protocol elements (like legacy communication protocols) but also with the internal

organization of data in devices, which allows for a better interoperability and easier configuration of devices [18].

The standard adopts a model-driven approach by standardizing device, object and service models. The control logic resides in microprocessor-based devices named *intelligent electronic devices (IED)*, equipped with one or more microprocessors, memory, and communication interfaces (e.g. serial ports, Ethernet interfaces), like the everyday used computers. IEDs can be classified by their functions, common types including relay devices, circuit breaker controllers, recloser controllers, voltage regulators, etc. One IED can perform more than one function, given its general-purpose microprocessors [19].

An IED is defined by its network address and may contain one or more *logical devices*. Each logical device contains one or more *logical nodes (LN)*, which are named grouping of data and associated services, logically related to some power system function. There are logical nodes for automatic control, for metering and measurement, for supervisory control, protection, switchgears, etc. Each logical node contains one or more elements of Data each with a unique standard name. Each element of data within the logical node conforms to the specification of a common data class (CDC), describing the type and structure of the data.

The abstract model of the device is mapped to a specific communication protocol stack based on MMS (Manufacturing Messaging Specification – ISO 9506), TCP/IP, and Ethernet [20]. In this mapping, the standard specifies a method of transforming the model information into a named

MMS variable object that allows the unique identification of each element of data in the model. The communication services defined by the Abstract Communication Service Interface (ACSI) are also mapped to MMS Services.

In addition to the MMS mapping, the standard defines profiles also for other type of communication, as depicted in Fig. 1: the Sampled Values and GOOSE (Generic Object Oriented Substation Events) applications map directly into the Ethernet data frame thereby eliminating processing of any middle layers; the Generic Substation Status Event (GSSE) is the identical implementation as the UCA (Utility Communication Architecture) GOOSE and operates over connectionless ISO services; TimeSync messages use the UDP/IP protocol.

Fig. 2 illustrates the substation architecture defined by the standard IEC 61850. The monitor and control equipment is placed on three levels, namely process, bay and substation level.

The process level is related to gathering information, such as voltage, current, and status information from the transformers and transducers connected to the primary power system equipment. This information is digitized by Merging Units and transmitted to the upper level through a “process bus”, realized as a high bandwidth Ethernet network.

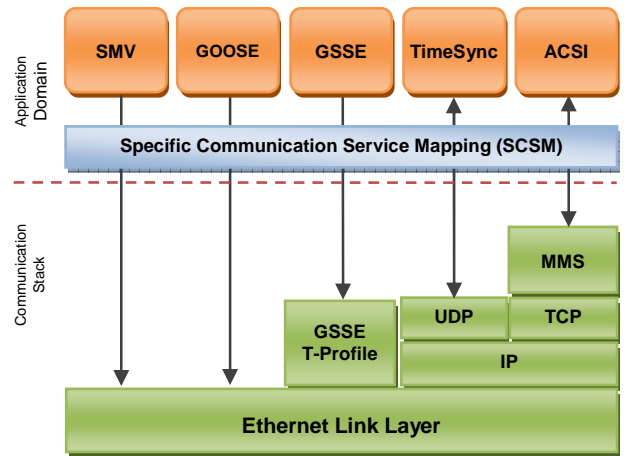


Fig. 1. IEC 61850 communication profiles [17]

The bay level includes Intelligent Electronic Devices (IEDs) running applications for protection and control, and communicating with each other through a “station bus”. The substation bus is realized as a medium bandwidth Ethernet network, which carries all ACSI requests/responses and generic substation events messages (including GOOSE and GSSE). A substation usually has only one global substation bus but multiple process buses, one for each bay. On the station level there are applications for monitoring and control of the whole station. Remote network access is supported through a secure gateway.

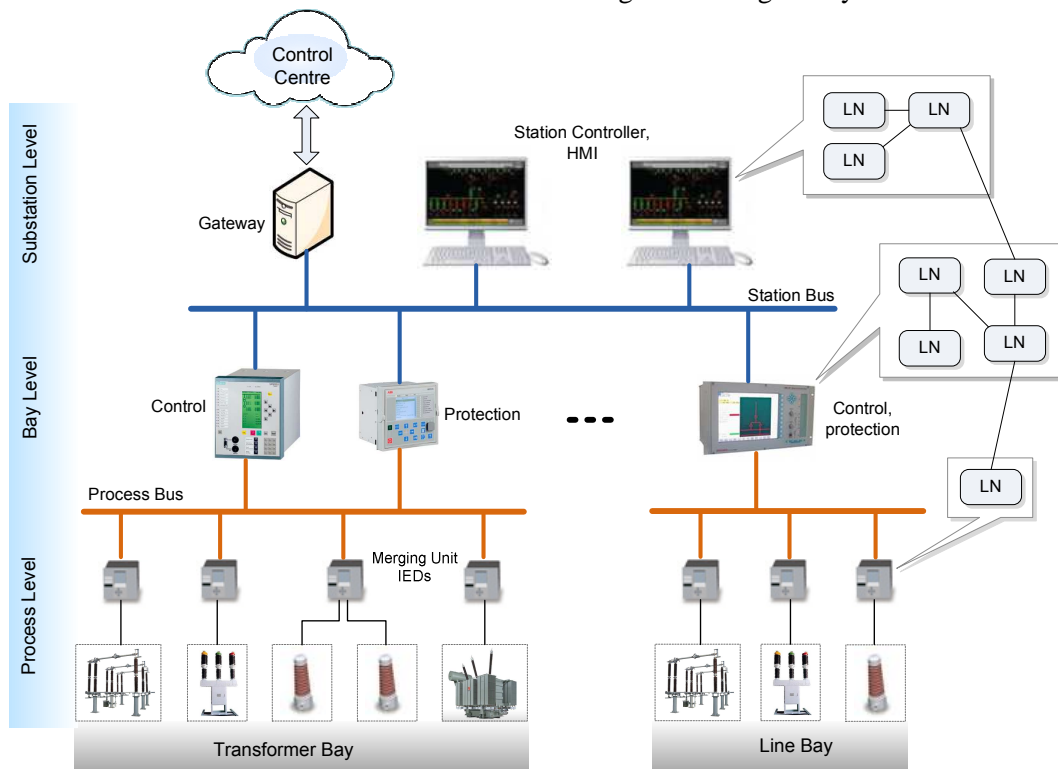


Fig. 2. Substation architecture according to IEC 61850

3 IEC 61499 standard and holonic concepts

3.1 IEC 61499

The IEC 61499 standard defines an open architecture for distributed control and automation. The programming unit of the IEC 61499 is the function block. There are three types of function blocks: basic function blocks, composite function blocks and service interface function blocks. A basic function block executes an elemental control function, such as reading a sensor or setting the state of an actuator, and contains algorithms and an execution control chart (ECC). Basic function blocks may be combined together in a composite function block, to encapsulate a higher-level control function. The service interface function blocks have the role to abstract the specific functions of a hardware platform, allowing the application developer to focus on the application logic. A common example of service interface function blocks is represented by those for communication services [21].

Other key elements of distributed control architecture under IEC 61499 are application, device and resource. An application is a related set of functions that must talk to each other to fulfill a control task. A device is a control unit having one or more processors. It interfaces to the physical I/O and also communicates with other devices on the network. A resource is essentially a processor on which part of a distributed application will run.

3.2 Holonic concepts

Holonic concepts originate in the observations of writer Arthur Koestler about the way biological systems and social organizations are constructed. Koestler introduces in 1969 the term „holon”, as a combination of two words from the Greek “holos”, meaning “whole” and “on”, meaning “particle”, to describe the idea that components within a complex system behave both as a whole which can be divided into subcomponents and as a component which belongs to a greater whole [22].

The holons are characterized by autonomy and cooperation, and collaborate in order to accomplish the global objectives of the system. Holons are organized in dynamical hierarchies, called holarchies. Holarchies are recursive in the sense that a holon in a holarchy can in itself be an entire

holarchy of other holons. Holons on the lowest level, which do not include other holons, are called simple holons (or elementary holons), while the holons representing holarchies of holons are called complex holons.

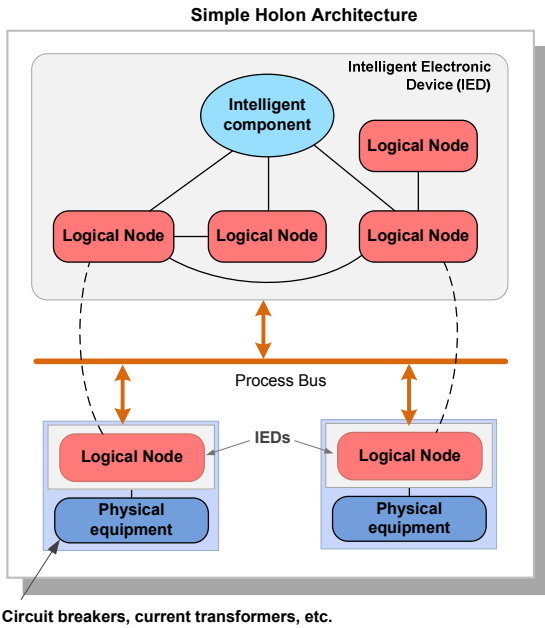
Different research works for applying holonic concepts in modeling the power distribution grid are reported by the scientific literature, e.g.[23], [24].

4 Holonic models for power grid control systems

The power distribution systems include a large and diversified range of equipment, from equipment within power substations to the domestic renewable energy sources and smart appliances. In defining the architecture of holons we focused on the area of power substations, but the proposed models can easily be extended to other areas.

A holon is an intelligent entity with decision-making capabilities, which can interact with other holons to collect information for his decisions or provide information to them.

In structuring the control of the power stations according to the holonic principles, we tried to keep the architecture and models defined by the IEC 61850 specifications. As showed in Figure 1, the standard groups control functions and data in logical nodes (LN) placed on different control levels (process, bay, and station) and distributed among several Intelligent Electronic Devices (IEDs). The process level is dedicated mainly to the acquisition of data from the primary equipment, transmission of this data to the devices on the upper levels, and execution of the received control commands. The devices on the bay level include logical nodes for protection and control of the primary equipment, which in some cases collect information from other bays for their decisions. Due to these control responsibilities, we decided to define the simple holons at the bay level. A simple holon will include in this case the primary equipment of a bay, the modules for acquisition and transmission of data, the IEC 61850 logical nodes for protection and control of the bay, and an intelligent component for local decision and interaction with other holons. Fig. 3 depicts the proposed general architecture of a simple holon.



Circuit breakers, current transformers, etc.

Fig. 3. Architecture of a simple holon

Figure 4 contains the example of a simple holon modelling a transformer bay. The meanings of the acronyms for the IEC 61850 logical nodes are given below.

- XSWI Circuit switch
- XCBR Circuit breaker
- TCTR Current transformer
- YLTC Tap changer
- CSWI Switch controller
- CILO Interlocking
- MMXU Measurement
- PTOC Protection Time Overcurrent
- ATCC Automatic tap changer controller

For the implementation of the control logic we chose the specifications of the IEC 61499 standard, both for the IEC 61850 logical nodes and the intelligent component of the holon, as illustrated in Figure 5.

The simple bay holons can be grouped along with station-level control components in a complex holon, representing the whole substation. The communication between the bay holons is done through the station bus, as illustrated in Figure 6.

Different substation holons in a region can be further grouped in a complex holon with high-level goals such as optimizing the distribution of energy in that region and reducing the effects of perturbations.

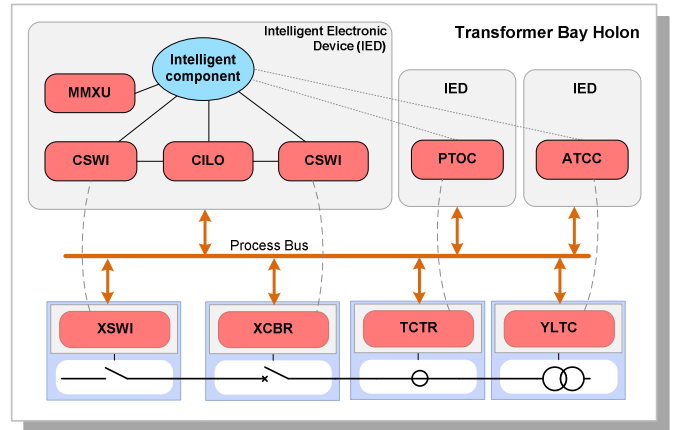


Fig. 4. Example of a simple holon for a transformer bay

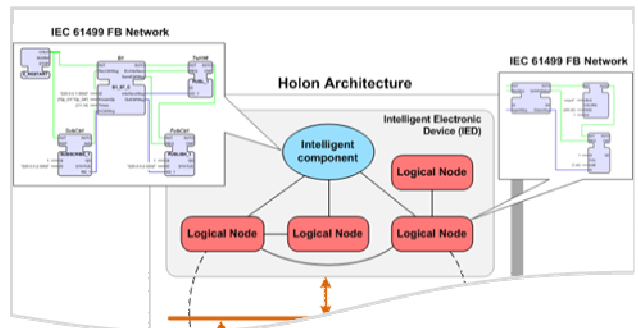


Fig. 5. Implementation of the control logic through IEC 61499 models

The holonic concepts and models developed can be used beyond the area of power substations, wherever there is an opportunity for operation efficiency improvement through smart control. Examples on the customer side include smart appliances, electric vehicles and micro-CHP units.

5 Example of protection application with IEC 61499 function blocks and GOOSE messages

This section presents a minimal protection application, modeled and implemented with IEC 61499 artifacts. The fault protection scenario, which is illustrated in Fig. 7, involves the transmission of GOOSE messages between several IEC 61850 logical nodes for tripping the circuit breaker and for publishing its new position.

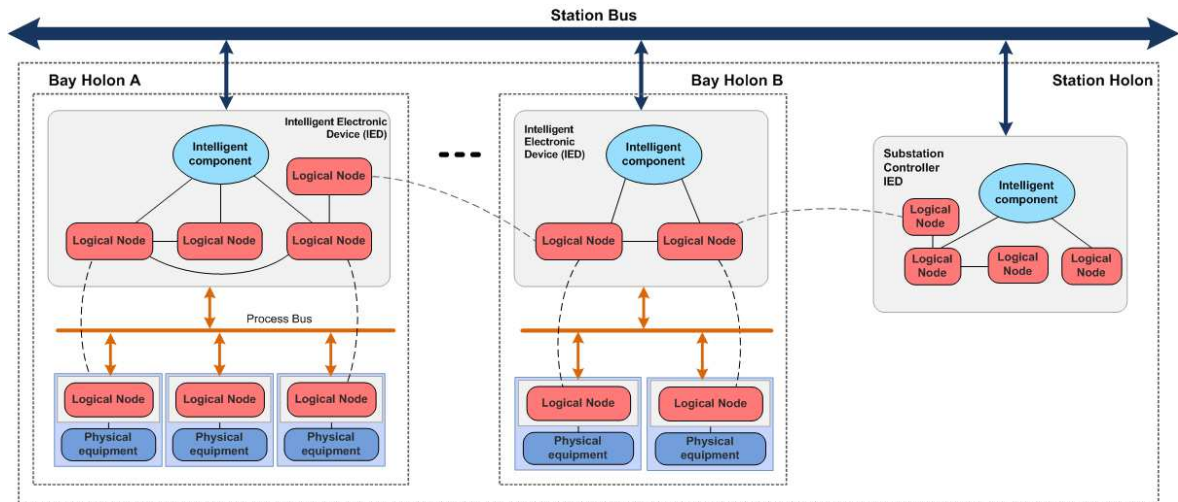


Fig. 6. Simple bay holons grouped in a complex station holon

The values measured by the current transformer (CT) are transmitted to a PTOC logical node. When an overcurrent is detected, PTOC communicates the anomalous condition to the PTRC (Protection trip conditioning) LN, which issues a *trip* command (in form of a GOOSE message) to the XCBR LN. As a result the circuit breaker (CB) is open and the new status is transmitted (also through GOOSE messages) to the PTRC and RREC (Auto-reclosing) logical nodes. After a short time, RREC issues a *reclose* command to the XCBR LN, which closes the circuit breaker and publishes its new status.

As shown in Fig. 8, the IEC 61499 system modeling the fault protection application includes three IEC 61499 devices: *BreakerIED*, *ProtectionIED* and *DISPLAY*. The *BreakerIED* device contains the XCBR logical node (modeled as a service interface function block), while the

ProtectionIED encapsulate the protection and autoreclosing logical nodes. The *DISPLAY* device includes two function blocks for modeling and visualization of the physical equipment, i.e. the circuit breaker and the current transformer.

Fig. 9 presents the visualization display and the function blocks behind it. The user is able to set the value of the feeder current between two limits with a slider. The set values are transmitted continuously to the PTOC logical node through IEC 61499 publish/subscribe communication services. When the values exceed a certain threshold (e.g. 20 units), the logical nodes undertake the protection scenario presented in Fig. 7. The opening of the circuit breaker will set the slider at the zero value, while the reclosing will set it at a non-zero low value (e.g. 10 units).

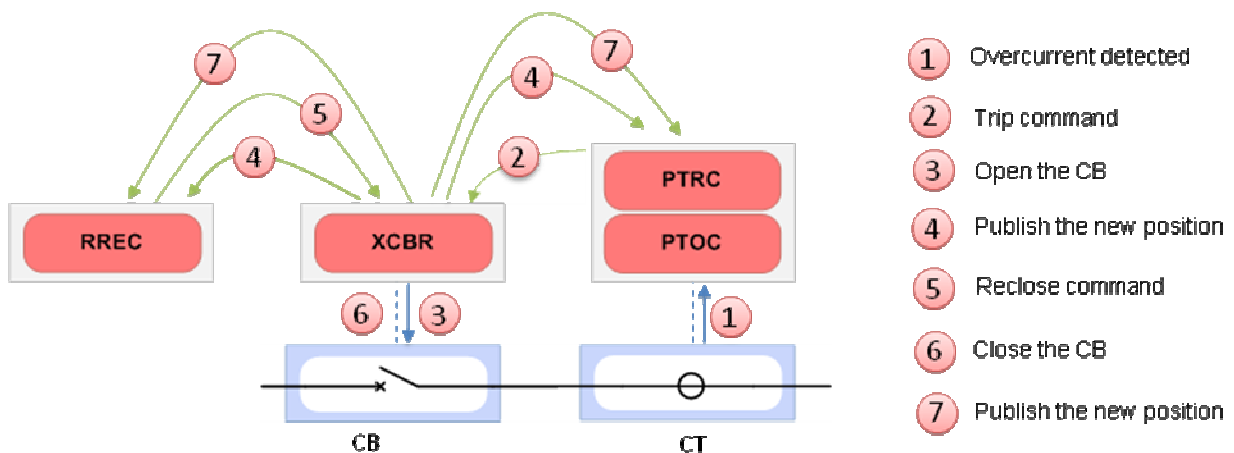


Fig. 7. Fault protection scenario

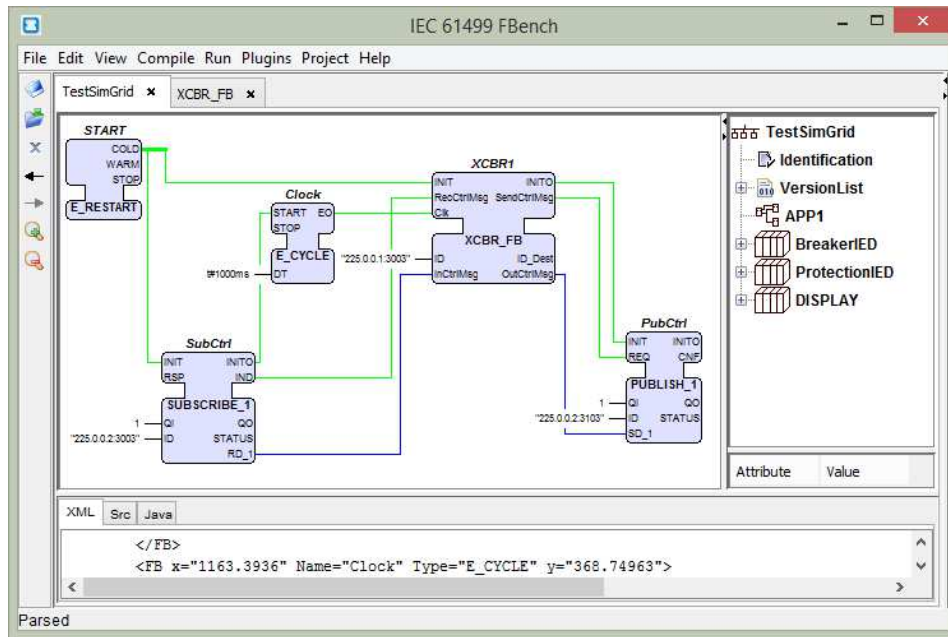


Fig. 8. The IEC 61499 system modeling the fault protection application

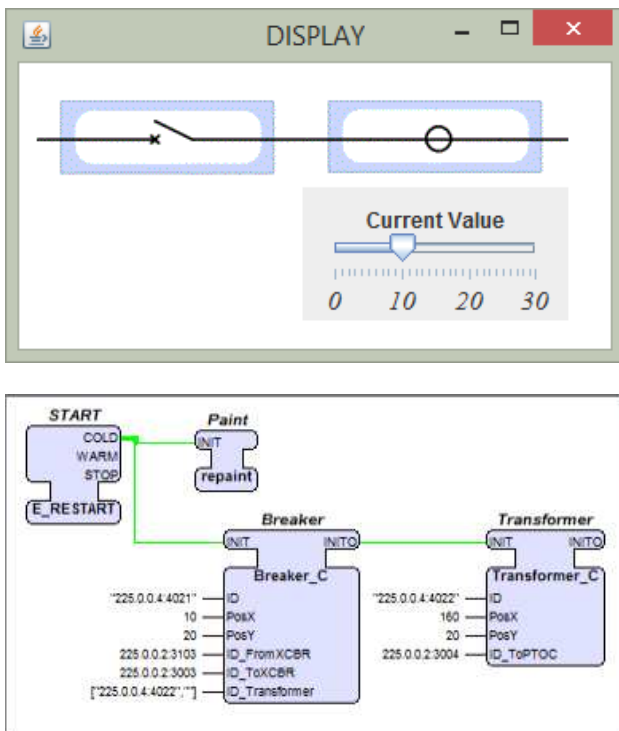


Fig. 9. The visualization display and the corresponding function blocks

References:

[1] J. Moonjong, B.N. Ha, S.W. Lee, D.Y. Seo, The Study on the Construction of the Smart Grid Test Plant and the Integration of the

Heterogeneous Systems, *WSEAS Transactions on Power Systems*, Vol. 8(2), 2013, pp. 95-101.
 [2] M. Azzouzi, F. Neri, An introduction to the special issue on advanced control of energy systems, *WSEAS Transactions on Power Systems*, 8 (3), 2013, p. 103.
 [3] P. Karthikeyan, F. Neri, Open research issues on Deregulated Electricity Market: Investigation and Solution Methodologies. *WSEAS Transactions on Systems*, 13, in press.
 [4] M. Panoiu, F. Neri, Open research issues on Modeling, Simulation and Optimization in Electrical Systems. *WSEAS Transactions on Systems*, 13, in press.
 [5] C. Guarnaccia, F. Neri, An introduction to the special issue on recent methods on physical polluting agents and environment modeling and simulation. *WSEAS Transactions on Systems*, 12 (2), pp. 53-54.
 [6] A.V. Doroshin, F. Neri, Open research issues on Nonlinear Dynamics, Dynamical Systems and Processes. *WSEAS Transactions on Systems*, 13, 2014, in press.
 [7] C. Ciufudean, F. Neri, Open research issues on Multi-Models for Complex Technological Systems. *WSEAS Transactions on Systems*, 13, 2014, in press.
 [8] F. Neri. Open research issues on Computational Techniques for Financial Applications. *WSEAS Transactions on Systems*, 13, 2014, in press.
 [9] F. Neri, Open research issues on Advanced Control Methods: Theory and Application.

- WSEAS Transactions on Systems*, 13, 2014, in press.
- [10] P. Hájek, F. Neri, F. An introduction to the special issue on computational techniques for trading systems, time series forecasting, stock market modeling, financial assets modeling, *WSEAS Transactions on Business and Economics*, 10 (4), 2013, pp. 201-292.
- [11] Z. Bojkovic, F. Neri, An introduction to the special issue on advances on interactive multimedia systems, *WSEAS Transactions on Systems*, 12 (7), 2013, pp. 337-338.
- [12] L. Pekař, F. Neri, An introduction to the special issue on advanced control methods: Theory and application, *WSEAS Transactions on Systems*, 12 (6), 2013, pp. 301-303.
- [13] F. Neri, An introduction to the special issue on computational techniques for trading systems, time series forecasting, stock market modeling, and financial assets modeling, *WSEAS Transactions on Systems*, 11 (12), 2012, pp. 659-660.
- [14] M. Muntean, F. Neri, Foreword to the special issue on collaborative systems, *WSEAS Transactions on Systems*, 11 (11), 2012, p. 617.
- [15] L. Pekař, F. Neri, An introduction to the special issue on time delay systems: Modelling, identification, stability, control and applications, *WSEAS Transactions on Systems*, 11 (10), 2012, pp. 539-540.
- [16] C. Volos, F. Neri, An introduction to the special issue: Recent advances in defense systems: Applications, methodology, technology, *WSEAS Transactions on Systems*, 11 (9), 2012, pp. 477-478.
- [17] R. E. Mackiewicz, "Overview of IEC 61850 and Benefits", *Power Engineering Society General Meeting*, 2006, pp. 8.
- [18] H. Ito, K. Kaneda, K. Hamamatsu, T. Tanaka, K. Nara, Improvements in Dependability and Usability for a Substation Automation System with Redundancy, *WSEAS Transactions on Systems*, Vol. 7 (10), 2008, pp. 1104 – 1116.
- [19] S. Aggarwal, Security Hub Architecture Support for IEC61850 Information Exchange Protocols, *2012 IEEE PES Innovative Smart Grid Technologies Conference*, 16-20 January, Washington, SUA.
- [20] *IEC 61850 Communication Networks and Systems in Substations*, IEC 61850, 2004.
- [21] V. Vyatkin, IEC 61499 Function Blocks for Embedded and Distributed Control Systems Design, *Instrumentation Society of America*, 2007, USA.
- [22] A. Koestler, *The Ghost in the Machine*, *Arkana Books*, London, 1969.
- [23] E. Negeri, N. Baken, M. Popov, Holonic Architecture of the Smart Grid, *Smart Grid and Renewable Energy*, Vol.4, 2013, pp. 202-212.
- [24] A. Pahwa et al. Holonic Multi-agent Control of Power Distribution Systems of the Future, *Cigre Grid of the Future Symposium*, 2012, Kansas City, Missouri - United States of America.