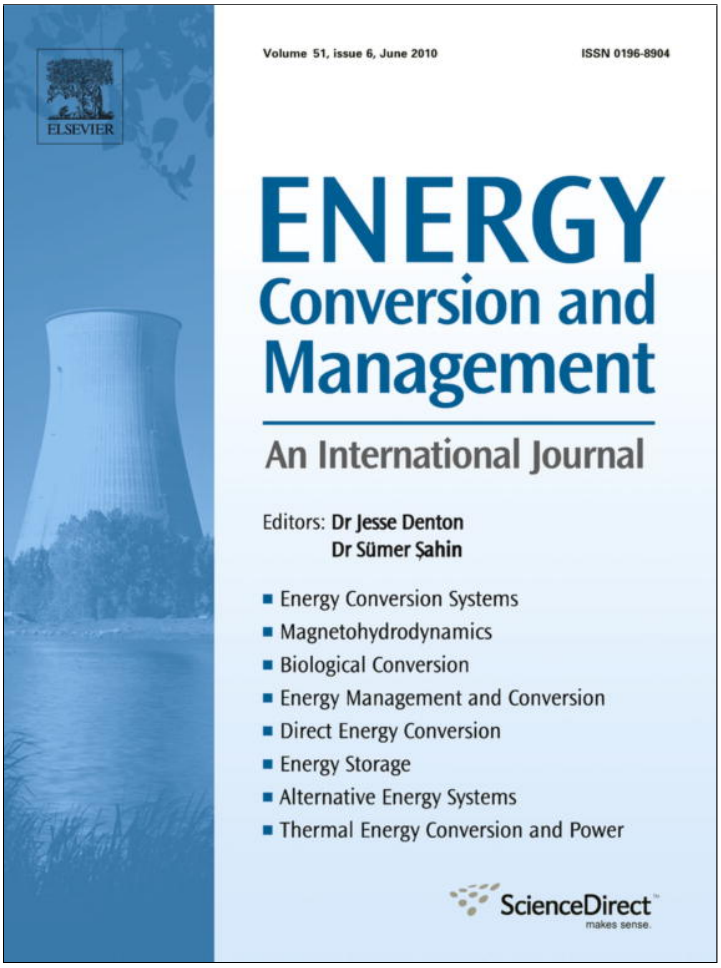
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Energy Production System Management – Renewable energy power supply integration with Building Automation System

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ABSTRACT

Intelligent buildings, historically and technologically, refers to the integration of four distinctive systems: Building Automation Systems (BAS), Telecommunication Systems, Office Automation Systems and Computer Building Management Systems. The increasing sophisticated BAS has become the "heart and soul" of modern intelligent buildings. Integrating energy supply and demand elements – often known as Demand-Side Management (DSM) – has became an important energy efficiency policy concept. Nowadays, European countries have diversified their power supplies, reducing the dependence on OPEC, and developing a broader mix of energy sources maximizing the use of renewable energy domestic sources. In this way it makes sense to include a fifth system into the intelligent building group: Energy Production System Management (EPSM). This paper presents a Building Automation System where the Demand-Side Management is fully integrated with the building's Energy Production System, which incorporates a complete set of renewable energy production and storage systems.

1. Introduction

Building Automation Systems can be considered as a tool in the hands of building operations personnel that provides a more effective and efficient control overall building systems [1]. Today, Building Automation Systems (BAS) are a widely accepted and adopted technology through homes, buildings, residential and industrial complexes. BAS are concerned with improving the interaction among integrated systems and the habitants/users of the buildings. Historically BAS were developed from automatic control of HVAC (heating, ventilation, air-conditioning) systems, simultaneously improving human comfort and reducing energy costs. In the last decades several other domains were added to BAS: telecommunications, office automation, computer building management, security, among others. Energy consumption is the domain where intelligent buildings researchers have devoted more efforts in the last years, forced by the legal power restrictions and increasing economic burden associated with energy usage [2,3]. The main control efforts in a complex actual intelligent building is the maintenance of the energy consumption below a specific maximum limit [4]. The use of renewable energies has experienced a significant growth from the crisis of the oil in the 1970s, in which renewable forms of energy started to be considered as a potentially alternative to the oil producing finite resources of the Land [5]. Recent European Community Directives point to an energy consumption reduction, leading to an annual improvement in energy efficiency of around 6% in 2012. Regular buildings try to integrate local generation, most notably photovoltaic, and more seldom wind power [6]. High performance photovoltaic systems with Maximum Power Point Tracking capabilities allow better energy efficiency [7]. Small/medium wind turbines have been improving their performance [8] and integrated into building facilities.

Demand-Side Management (DSM) coordinates the activities of energy consumption and energy supply, seeking to avoid peaks of energy consumption in order to achieve an approximately constant energy consumption that meets the characteristics of power supply [9]. However, a common and recurrent problem of renewable energies it is their strongly unpredictability [10]. Usually, one tries to establish complementary systems composed by several distinct energetic sources, having the highest preponderance in the renewable energies. Conventional systems of generation must be considered in order to meet the energetic needs, whenever other alternative sources do not produce enough energy. Alternatively one can oversize the renewable energy installations or use sophisticated systems of energy storage [11] in order to meet the energy needs in periods of insufficient production. From the economical point of view this is not the most favorable option. There are however solutions in which there is the irreplaceable necessity of securing energy storage, currently for security reasons. Nowadays there is a considerable diversity of storage technologies, at the disposal of a designer, depending on the amplitude and autonomy

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of energy that is intended to store [12,13]. On the other hand, rural and remote sites electrification is, at the present, also an important market for renewable energy based electrical production systems [14]. Autonomous electrical production systems, based on renewable energies are the most competitive economical option, when compared with solutions based only on diesel generators. Grid-connected hybrid generation systems should provide versatile power transfer in order to optimize the efficiency of the system [15].

The Building Automation System described in this paper combines the Demand-Side Management objectives with the renewable energy production system. It coordinates the several production and storage systems, keeping a balance between the demand and the production. It meets the sustainability and environmental respect criteria regarding the energetic solutions of the future – zero emitting either on production or consumption. The presented strategy will be implemented in the new Experimental Park of Renewable Energies (PETER) located in the University of Évora, Portugal. These facilities are located within Herdade da Mitra, the University agro-livestock complex, which comprises several houses, teaching facilities, animal hospital, wineries, byre, pigsty, and other agriculture facilities.

PETER Experimental Park is a result of an European research project [16] whose partners are the University of Évora (Portugal) and the University of the Frontier (Spain). Its renewable energy infrastructure is, at the present, composed by a photovoltaic solar unity (10 kW), a wind generator (1 kW) and a biomass unity (75 kW). The control and supervision of the overall system relies on an industrial network of Programmable Logic Controllers (PLC) connected to a central Supervisory Control and Data Acquisition system (SCADA).

2. Power supply system description

The power supply system is composed by several independent units of decentralized production, concerning different sources of renewable energies (photovoltaic, wind and biomass). This system also contemplates one unity for energy storage. Fig. 1 presents the electric interconnection of the several system components.

PETER facility is located in an area with a solar radiation between 1650 and 1750 kW h/m^2/year, on a horizontal surface. Fig. 2 presents 1 year estimation of the photovoltaic produced energy with the panels facing south and with a 30° angle with the horizontal base plan. The photovoltaic solar unity has 10 kWp of power, and it is composed by three different sets of PV-panel technology: (i) 3.24 kWp from Mono-crystalline silicon panels with an exposure area of 23.6 m^2; (ii) 3.50 kWp from Polycrystalline silicon panels with an exposure area of 24.4 m^2 and (iii) 3.35 kWp from amorphous silicon panels with an exposure area of 53.8 m^2.

From the distribution of the wind speed (histogram of frequency and distribution of Weibull), presented in Fig. 3, one can obtain an average wind power flow available of 26.0 W/m^2, for the PETER location.

Fig. 4 presents the vertical profile of wind speed, giving an average wind speed of 3.6 m/s (15 meters above ground).

Surrounding PETER location there are 280 ha of forest producing 110 ton of forest waste per year. Besides the forest waste usage, the projected bio-digestor will also use the liquid and solid tributaries from the pigsty, byre and wineries to produce biogas. The produced biogas will feed a motor connected to an electric generator of 75 kW.

The several renewable power supplies leads to a flow of energy and mass presented in Fig. 5.

The energy storage unit is based on the hydrogen technology. There has been a significant investment increase, both international and national, within the hydrogen technology as the future energy vector. Its use as energy storage potencies the role of renewable energies within the energetic sector. Hydrogen provides an effective way of energy storage solving the renewable energy fluctuation problem, which is a problem within autonomous systems. The energy storage unit comprises an electrolyzer (producing hydrogen from exceeding renewable electrical power),

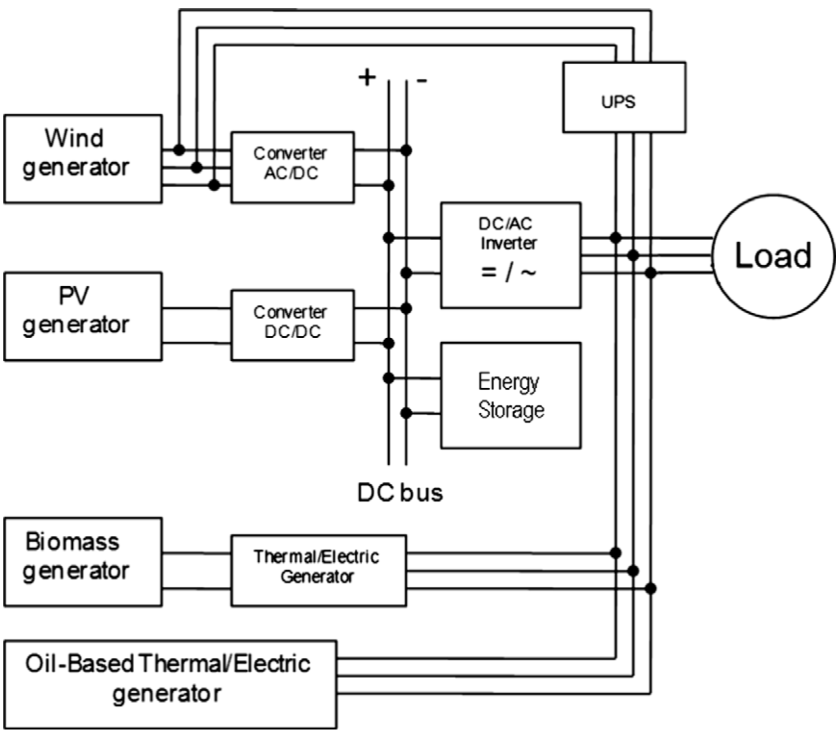

Fig. 1. Electrical structure of the PETER power supply system.

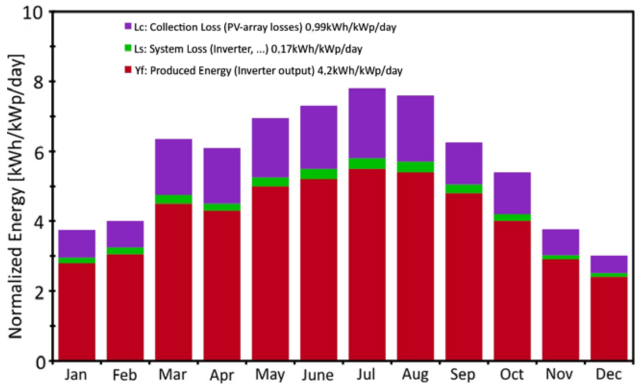

Fig. 2. PETER photovoltaic energy production.

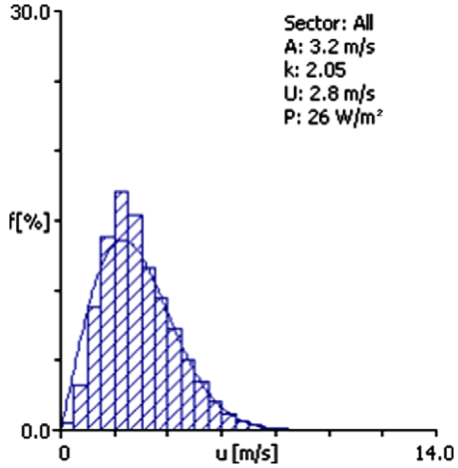

Fig. 3. Wind speed distribution.

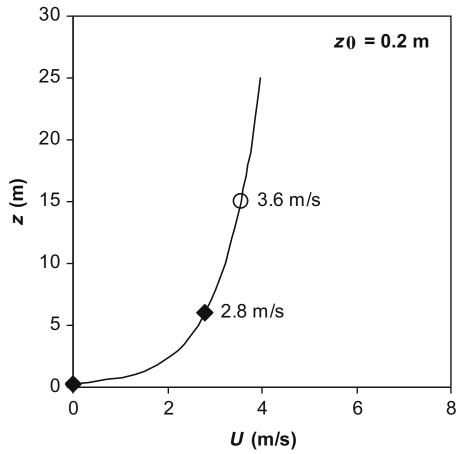

Fig. 4. Wind speed vertical profile.

hydrogen containers and a 5 kW fuel-cell (producing electrical power from stored hydrogen).

Besides the energy storage unit, conservative systems use to consider conventional energy back-up units (oil-based thermal power stations) in order to assure the stability and quality of the electric power in emergency situations. The considered oil-based thermal power back-up unit is a standard fuel generator with a power capacity of 12.5 kW (220/380 VAC, 50 Hz, 1500 rpm).

Factory automation applications involves the use of video, audio, and data communications, as well as the inherent processing involved [17]. A significant challenge for current and future manufacturing systems is to provide rapid reconfigurability in order to evolve and adapt to the users requirements [18]. The adopted control strategy is based on the integration of the Building Automation System (BAS), Demand-Side Management (DSM) and Energy Production System Management (EPSM). These algorithms are implemented in the network of Programmable Logic Controllers (PLC), where the PLCs are assigned to energy production units and building management units. Each PLC detains several control parameters of the correspondent installation, and they are connected to a Supervisory Control and Data Acquisition system (SCADA), as shown in Fig. 6. The SCADA system monitors globally the several distributed local systems [19]. Applying this strategy to the complex that is instrumented and monitored through the SCADA supervisory system, we can manage globally the entire network of distributed PLCs controlling locally each process. The SCADA application runs on a server that is a network node [20], allowing the remote access to the installation data.

3. Building Automation System (BAS) with Demand-Side Management (DSM) and Energy Production System Management (EPSM)

The BAS has several algorithms that have been developed for the intelligent building: property violation control, temperature control, gas and water leakages, garage management, etc. These algorithms were developed using the Grafcet methodology, which is a standard design tool for automated systems – Sequential Function Chart [21]. The designed algorithms were implemented in the PLC using the Ladder Diagram language [22]. For the communication between the distributed local controls, a PLC master–slave network was established through a Profibus protocol [23].

BAS is coordinated with the DSM and EPSM in order to achieve suitable comfort parameters with the available energy, provided by the renewable sources, as presented in Fig. 7. Knowing the available renewable power, DSM changes the control parameters of the BAS responsible for the control of the Herdade da Mitra complex facilities. ESPM manages the Herdade da Mitra complex facilities energy demand along with the renewable energy production system. This management involves the energy storage management and the optimal planning of the produced energy.

DSM establishes the several control parameters for the BAS, enabling the comfort standards providing the minimum energy consumption. Classical DSM tends to establish approximately constant energy consumption. Being the installation also supplied from renewable energy sources the control parameters are adjusted accordingly to the produced energy and also to the amount of stored energy. DSM also adjusts the control parameters based on the prediction of energy production. BAS manages the load demand: if the overall power is insufficient to cover the load demand non essential loads are disconnected and only reconnected whenever the generated power is in conditions of supplying the considered load.

The control of the overall system is a fully automated process that, regarding the sensor array information, establishes a set of controls that run all of the system's components. The sensor array includes information from all available data, however only some of them are essential for control purposes:

- wind and solar energy;
- H2 conditions;
- fuel-cell power;
- AC and DC busbar voltage;

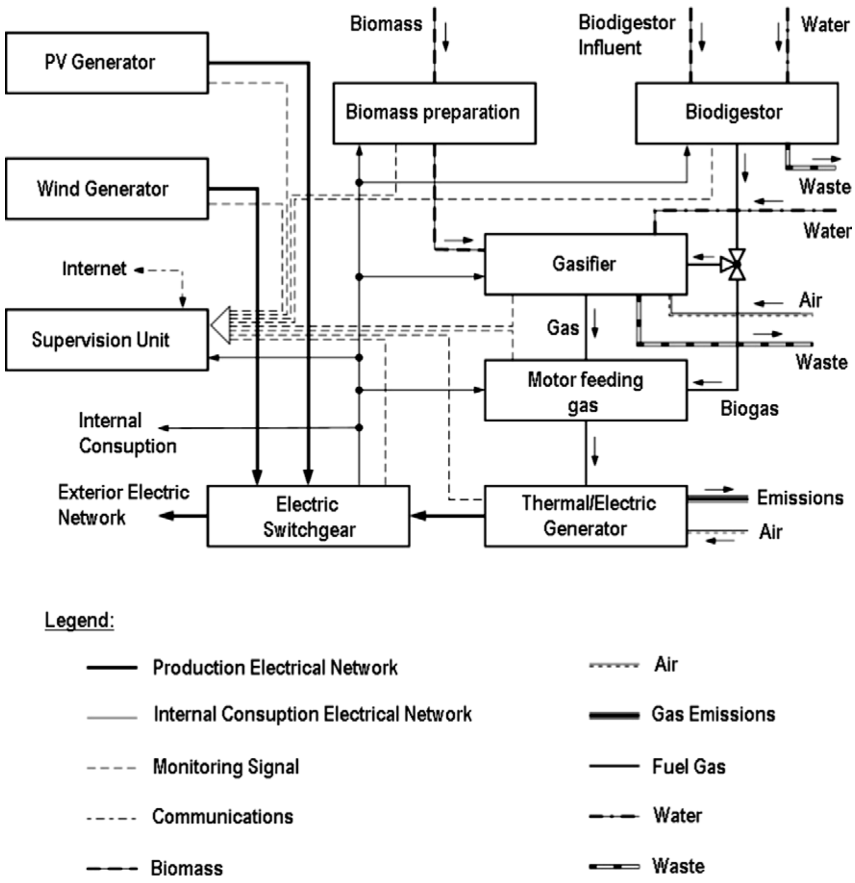

Fig. 5. Energy and mass flow of the renewable energy production.

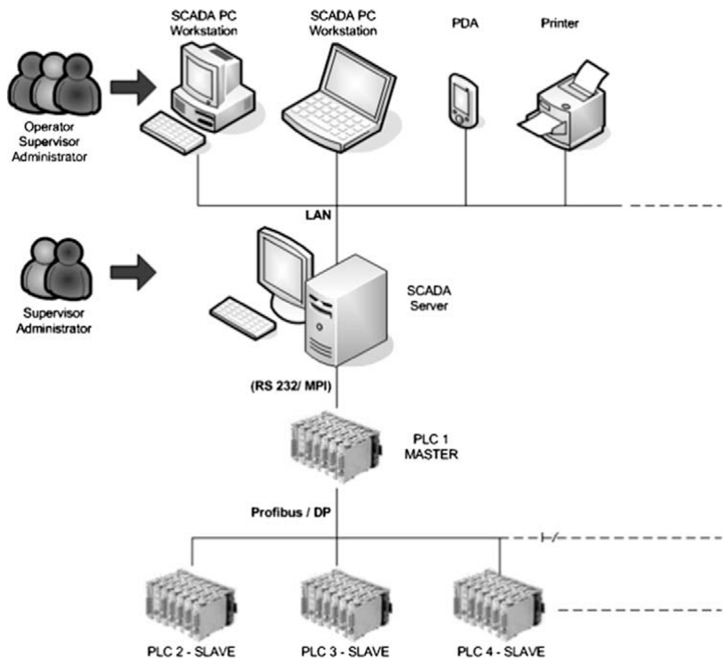

Fig. 6. PLC network and SCADA supervisory system.

- load requirements.

The control first approach considers the following set of commands:

- electrolyzer set-point and command;
- fuel-cell set-point and command (this includes its DC/DC converter);
- DC/AC converter set-point.

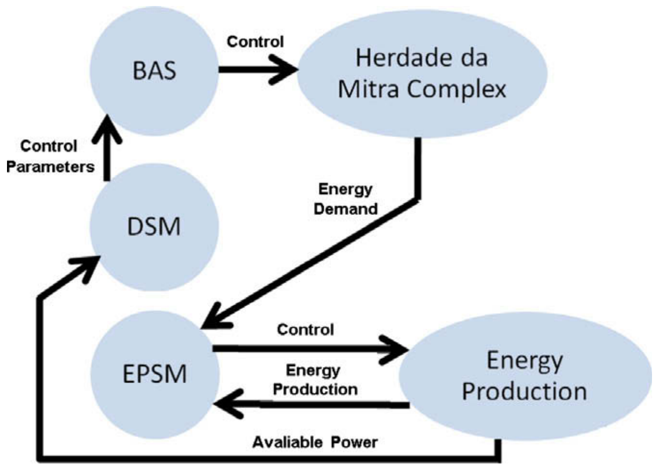

Fig. 7. System algorithms' interdependencies.

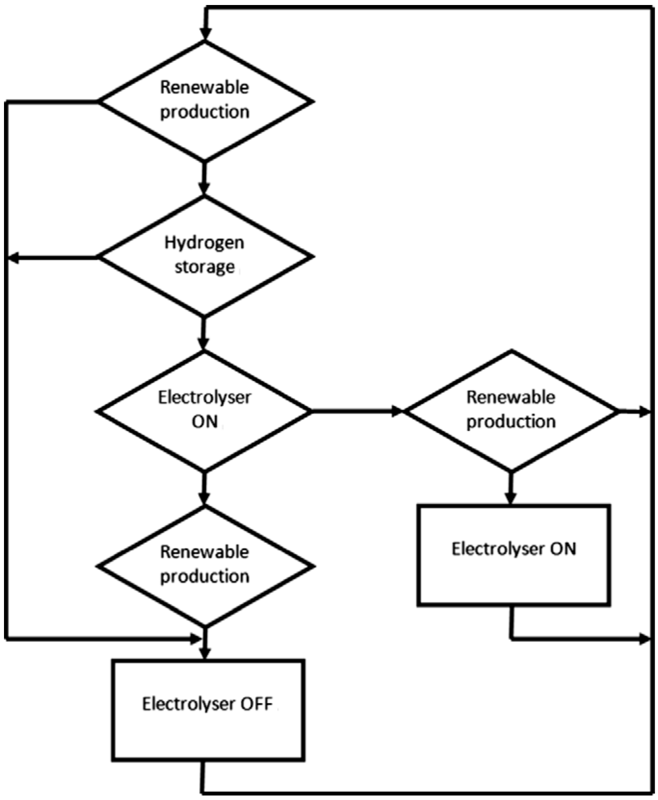

Fig. 8. Energy Production System Management and energy storage control strategy.

The basic control idea within energy storage is that the electrolyzer generates hydrogen whenever there is an excess of solar or/and wind energy. This means that if the solar and wind energy are more than enough to meet the load requirements the energy excess will be used to produce hydrogen. Whenever the wind and solar energy are insufficient to face the load demand the fuel-cell uses the stored hydrogen to produce the required lack of energy.

Several interlocks are considered to protect the system. A typical example is the one that does not allow the electrolyzer and fuel-cell to work at the same time, thus the electrolyzer should only work when in presence of excess power.

Fig. 8 presents the Energy Production System Management and energy storage control strategy. The control scheme runs as follows. First the produced and the demanded power are computed. If the produced power covers the demand one should consider the following issues. If the hydrogen tanks are full then the electrolyzer is switched off. If not and the excess produce power can run the electrolyzer, then the electrolyzer is switched on. If the produced power does not cover the demand the electrolyzer should be switched off, if it was running. Then the fuel-cell should be switched on and its set-point be adjusted to cover the power demand.

In this application, the SCADA ring is responsible for planning the optimum electrical power assigned to each generating unit, minimizing the production operating costs. Being the production a hybrid system with renewable and conventional sources, the minimization of functional costs leads to minimization of the conventional power. The power generated by each unit is monitored on-line, as well the overall energy consumption, measured in main switchboard. In order to ensure the stability and quality of supplied electrical energy, energy storage units and fuel back-up units were considered in the SCADA system. The SCADA control ring has the ability to update the optimization problem considering the actual values on-line, obtained from the multiple-source energy production system. The functional selected to minimize the costs of the energy production is given by Eq. (1) considering the restrictions given by Eqs. (2)–(8).

$$\min J = \sum_i C_{PV\,i} Y_{PV\,i} + \sum_i C_{WIND\,i} Y_{WIND\,i} + \sum_i C_{BIO\,i} Y_{BIO\,i} + \sum_i C_{OIL\,i} Y_{OIL\,i} \tag{1}$$

$$\sum_i Y_{PV\,i} + \sum_i Y_{WIND\,i} + \sum_i Y_{BIO\,i} + \sum_i Y_{OIL\,i} + \sum_i Y_{ESS\,i} \geqslant \sum_i Y_{demand} \tag{2}$$

$$Y_{ESS\,i} \leqslant Y_{MAX\,i} \tag{3}$$

$$E_{MAX\,i} \geqslant Y_{ESS\,i} \times \Delta t_i \tag{4}$$

$$0 \leqslant Y_{PV\,i} \leqslant Y_{PV\,ACT\,i} \tag{5}$$

$$0 \leqslant Y_{WIND\,i} \leqslant Y_{WIND\,ACT\,i} \tag{6}$$

$$0 \leqslant Y_{BIO\,i} \leqslant Y_{BIO\,ACT\,i} \tag{7}$$

$$0 \leqslant Y_{OIL\,i} \tag{8}$$

where $C_{PV\ i}$ = production cost of photovoltaic *i*-unit; $C_{WIND\ i}$ = production cost of wind *i*-unit; $C_{BIO\ i}$ = production cost of biomass *i*-unit; $C_{OIL\ i}$ = production cost of fuel thermo-electric *i*-unit; $Y_{PV\ i}$ = photovoltaic *i*-unit electric power; $Y_{WIND\ i}$ = wind *i*-unit electric power; $Y_{BIO\ i}$ = biomass *i*-unit electric power; $Y_{OIL\ i}$ = fuel thermo-electric *i*-unit electric power; $Y_{ESS\ i}$ = hydrogen energy storage *i*-unit electric power; Y_{demand} = demand electric power; $Y_{MAX\ i}$ = hydrogen energy storage *i*-unit maximum available electric power; $E_{MAX\ i}$ = hydrogen energy storage *i*-unit maximum available energy, assuming an average supply of $Y_{ESS\ i}$ for a Δt period of time; $Y_{PV\ ACT\ i}$ = photovoltaic *i*-unit instantly available electric power; $Y_{WIND\ ACT\ i}$ = wind *i*-unit instantly available electric power; $Y_{BIO\ ACT\ i}$ = biomass *i*-unit instantly available electric power.

Analyzing the minimizing criteria it is clear that the instantaneous change in the amount of electricity supplied by renewable energy units ($Y_{PV\ ACT}$, $Y_{WIND\ ACT}$, $Y_{BIO\ ACT}$) implies a new energy balance and the re-evaluation of the optimal operation conditions. If the renewable production supplants the demand, the excess energy is stored in the hydrogen energy storage, as explained before. If the demand supplants the renewable production, the energy deficit is filled by the hydrogen energy storage system or by the fuel thermo-electric generator.

The optimization algorithm developed in the Energy Production System Management was implemented in the outer ring SCADA

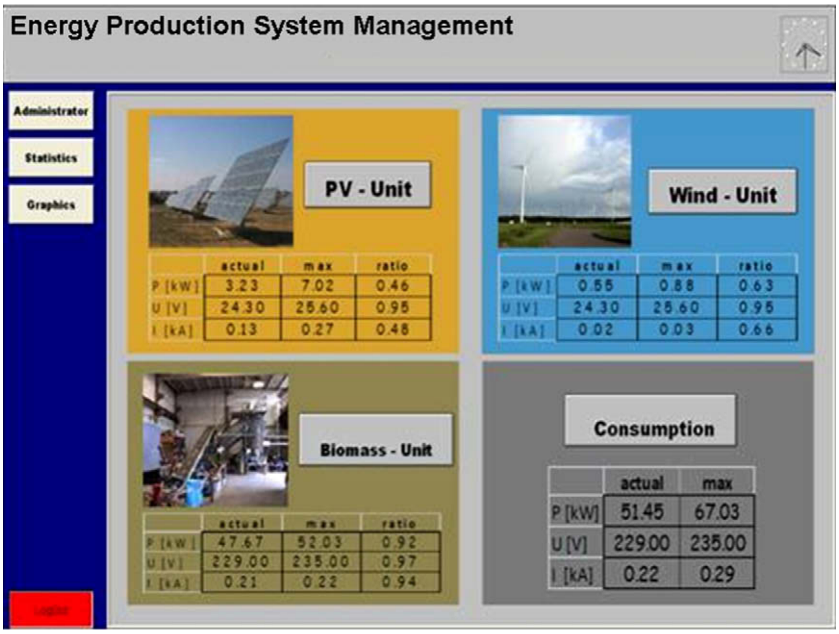

Fig. 9. Screenshot of the Energy Production System Management SCADA application.

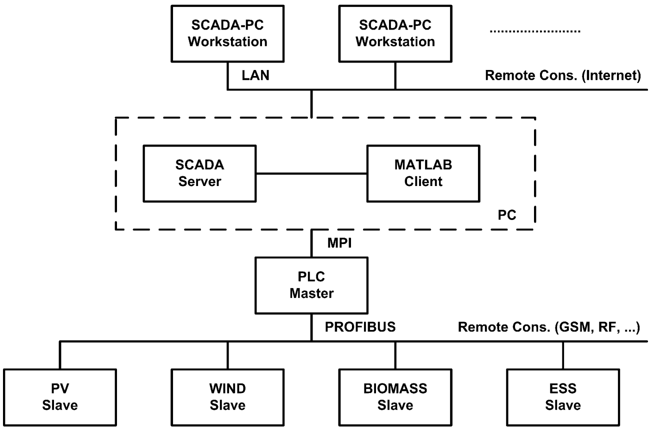

Fig. 10. Implemented communications architecture.

controller, in association with the MATLAB application [24]. Fig. 9 presents a screenshot of the Energy Production System Management displayed in the Human Machine Interface developed in the SCADA application.

The communication between SCADA and MATLAB applications are implemented with the Dynamic Data Exchange (DDE) protocol. This communication protocol was developed in the 1990s, and it is still very common allowing the exchange of data between two independent software applications running simultaneously (Client–Server).

In the developed system the MATLAB application is the client, because this application starts the communication procedure, and the SCADA application is the server, since this application responds to the client's solicitations.

Fig. 10 presents the information flow implemented in the Energy Production System Management (EPSM) developed for the Herdade da Mitra Complex. In this figure one can see the four different protocols implemented in the developed system: LAN, DDE, MPI, and PROFIBUS.

4. Conclusions and remarks

The Building Automation System described in this paper combines the Demand-Side Management objectives with the renewable energy production system. It coordinates the several production and storage systems, keeping a balance between the demand and the production. It meets the sustainability and environmental respect criteria regarding the energetic solutions of the future – zero emitting either on production or consumption. The developed strategy combines three main paradigms: Demand-Side Management (DSM), Building Automation System (BAS) and Energy Production System Management (EPSM).

BAS is coordinated with the DSM and EPSM in order to achieve suitable comfort parameters with the available energy, provided by the renewable sources. The ESPM manages the energy storage and the optimal planning of the produced energy.

The adopted control strategy is based on the integration of the BAS, DSM and EPSM. These algorithms are implemented in a PLC network, where the PLCs are assigned to energy production units and building management units. Each PLC details several control parameters of the correspondent installation, and they are connected to a SCADA system. The SCADA system monitors and controls globally the entire distributed local systems.

The presented strategy is developed for the new Experimental Park of Renewable Energies (PETER) located in the University of Évora, Portugal. These facilities are located within Herdade da Mitra, the University agro-livestock complex, which comprises several houses, teaching facilities, animal hospital, wineries, byre, pigsty, and other agriculture facilities.

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