European Association for the Development of Renewable Energies, Environment and Power Quality

International Conference on Renewable Energies and Power Quality (ICREPQ'09)

Valencia (Spain), 15th to 17th April, 2009

Automatic management of energy flows of a stand-alone renewable energy with support of hydrogen

M. Calderón[1], A.J. Calderón[1], A. Ramiro[2] and J.F. González[2]
[1] Department of Electrical Engineering. [2] Department of Applied Physics.
E.I.I., Extremadura University
Avenida de Elvas s/n, 06078 Badajoz (Spain)
Phone/Fax number: +0034 924 289600/01, e-mail: calgodoy@unex.es, ajcalde@unex.es

Abstract

This work deals with the design and built of an automation system for controlling the electric energy flows that take place at the continuous current bus (DC Bus) of a wind-solar system with support of hydrogen. The automation system is based on a Siemens PLC s7_313C_2DP. This PLC has been equipped with a Micro Memory Card (MMC) of 2 MB in order to allow the massive storage of data related to the control and monitoring of the benchmark. This system has to perform the required switching between the components of the hybrid electric energy generator. These elements are: photovoltaic generator, wind turbine generator, fuel cell system and electrolyzer.

Key words

Wind-solar hydrogen system, fuel cell, electrolyzer, control strategies, stand-alone RE system

1. Introduction

Hydrogen as an energy carrier can play an important role as an alternative to conventional fuels, provided that its technical problems of production, storage and transportation, can be resolved satisfactorily and the system cost can be brought down to acceptable limits. One of the most attractive features of hydrogen as an energy carrier is that it can be produced from water, which is abundantly available in nature. One of the simplest practical ways to obtain hydrogen is from water by electrolysis [1].

Hydrogen can be used as a storage medium for intermittent and seasonal renewable technologies. Hydrogen will join electricity in the 21st century as a primary energy carrier in the sustainable energy future. When we speak about hydrogen, we are talking about its production, storage and utilization. Both electricity and hydrogen in the future will be mostly derived from either renewable or nuclear energy sources [2].

Energy storage capacity is a principal issue to increase the conversion efficiency of renewable energies (RE). Storage in batteries is mostly used but their limited capacity and lifetime decrease the utility of renewable systems, for instance, in the case of remote applications with high energy demand. The storage capacity, and with it the efficiency of renewable energies, may be increased with the production of hydrogen from water electrolysis, by adding an electrolyser, a hydrogen storage means and a fuel cell. The scheme of the system is shown in Figure 1. It is composed of a photovoltaic generator, a wind turbine generator, a battery set, an electrolyser, a metal-hydride system for hydrogen storage, a fuel cell and a system in charge of supervisory control and data acquisition. In the summer, solar energy is enough to power the application, maintain a high state of charge of the batteries and run the electrolyser to produce hydrogen, which is stored in the metal hydrides. In the winter, when the state of charge of the batteries is low, the fuel cell recharges the batteries avoiding the cut in electric power [3].

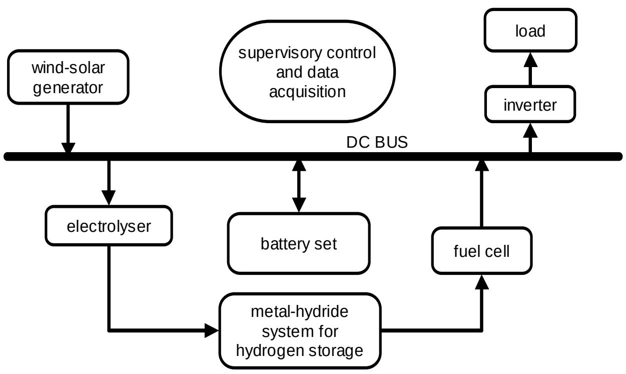

Figure 1. Scheme of the wind-solar hydrogen system

One of the advantages of this type of systems is non-interruption of the electrical energy supply, but, in order to get a competitive system, a reduction of the equipment cost is necessary.

Currently, there are many research and technical projects oriented to the development of renewable-powered mainly wind and solar-hydrogen production plants. The literature in the field is mainly concerned with the sizing, economics and power flow management of the system devices, while paying little attention to dynamic control aspects.

However, the development of suitable dynamic analysis tools are necessary to assess stability and reliability of an integrated system. Moreover, advanced control designs are also needed to improve production efficiency [4].

Thus, to achieve an adequate performance from such a complex system, one requires appropriate components and a well-designed control system in order to achieve autonomous operation and energy management in the system [5].

A stand-alone RE system based on energy storage as hydrogen has been developed and installed at the Technical Thermodynamic Lab of the Industrial Engineering School of the University of Extremadura, in Badajoz (Spain), and successfully tested for autonomous operation with developed control system and power conditioning devices.

The excess of energy produced, with respect to the load requirement, has been sent to the electrolyzer for hydrogen production. When energy produced from the RE sources became insufficient, with respect to the load requirement, the stored hydrogen was fed to a fuel cell to produce electricity. The RE system components have substantially different voltage-current characteristics and they are integrated through power conditioning devices on a DC Bus for autonomous operation by using a developed control system.

The developed control system has been successfully tested for autonomous operation and energy management of the system. The experimental results clearly indicate that a stand-alone RE system based on hydrogen production is safe and reliable [6].

2. System Description

The experimental installation, placed at the Technical Thermodynamic Lab of the Industrial Engineering School of the University of Extremadura, in Badajoz (Spain), has the geographic data shown in Table 1.

Table 1. Geographic data of the installation siting

Latitude	Longitude	Altitude
38º 53' 1,80'' N	0º 0' 12,94'' W	169 m

The working principle of the joint system is based on the block diagram that appears in the Figure 2.

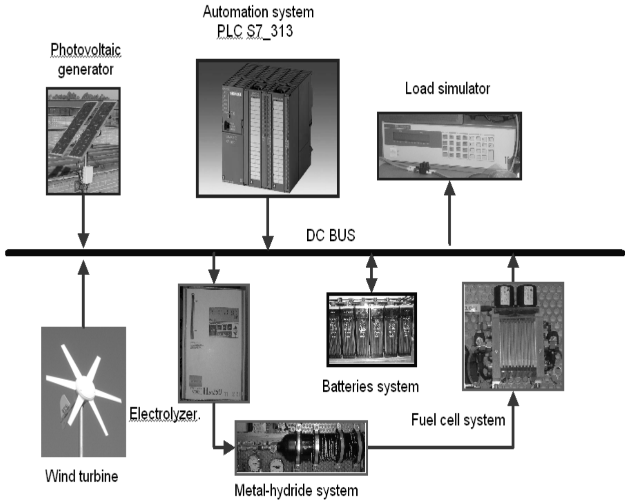

Figure 2. Flow chart of the wind-solar installation supported with hydrogen

The elements composing the wind-solar installation supported with hydrogen are collected in Table 2.

Table 2. Elements composing the wind-solar installation supported with hydrogen

Component	Characteristics
Photovoltaic generator	Helios H-45
Aerogenerator	Rutland-913
Electrolyzer	Hydrogen Works. Hart-250
Fuel cell	Heliocentrics, 40 W rated power.
Metal hydride bottle	Ovonic. Hydrogen Capacity: 600 LN (10 bar).
Battery	Trojan. 85 Ah
Electronic Load	Hp 6063B. 240 W max.
Programmable Logic Controlled	Siemens S7 313 C-2 DP
Panel Touch	Siemens. Simatic Panel Touch TP277 6".

The wind-solar generator is installed on the deck of the Industrial Engineering School and is composed of two photovoltaic modules Helios H-45 of 45 Wp, and an aerogenerator Rutland-913 of 90 W, for a wing speed of 10 m/s. Figure 3 shows this wind-solar generator.

This aerogenerator is placed on a demountable galvanized lattice tower of 7 m height, held to a concrete base of 1,5 x 1,5 x 0,20 m. Next to this tower there is an anemometer which allows to determine the wind speed.

The photovoltaic modules have been installed on a metallic structure aerial to face south, of variable slope. On this structure there is also a pyranometer which measures the incident radiation on the plane of the photovoltaic modules.

Figure 3. Wind – solar generator

The rest of the elements of the wind-solar system supported with hydrogen are placed on a experimental bench which is built on a perforated metal sheet. Figure 4 shows this experimental system.

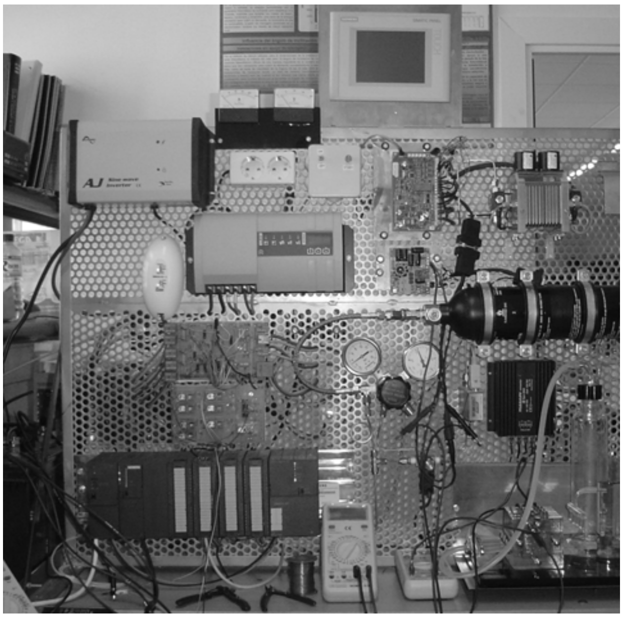

Figure 4. Wind-solar experimental system.

3. Description of the Control System

The goal of the control system of the wind-solar installation with support of hydrogen is the optimization of the performance of the combined electric energy generator/hydrogen generator system.

The main purpose of the automation system is to use the energy surplus produced when the energy demand is less than the capacity of generation energy of the wind solar generators. In these conditions, due to a high solar irradiance and/or enough wind speed, the excess of energy is used to produce hydrogen by an electrolyzer. The produced hydrogen will be stored for its subsequent use, when the renewable energies can not support the user energy demand.

When the energy produced from the renewable energy sources became insufficient, the stored hydrogen will be fed to a fuel cell to produce the required electric energy.

A totally automatic working of the installation is intended. Taking into account the measures obtained from the sensors installed and the signal conditioners, the developed control system will determine the conditions for:

- Charge battery bank by wind solar energy
- Produce hydrogen
- Generate electric energy by the fuel cell

All the electric energy exchanges and flows between the electric generator systems, charge/discharge of batteries system and hydrogen generation take place around the DC Bus. The energy balance between the electric energy supplied by the wind solar system, the required energy by the user and the state of charge of batteries is done by the comparison of the currents at the DC Bus. Moreover, the irradiance conditions and wind speed are taken into account for determining the conditions of switching of the electrolyzer. On the other hand, the fuel cell will supply the electric energy required if the load conditions impose it.

In order to obtain the measurements of the process variables, a set of sensors has been included in the benchmark. These sensors or transducers have to make the following measurements (for designing the automation system):

- Current in both fields of the photovoltaic generator.
- Voltage of the photovoltaic generator
- Irradiance.
- Temperature of the photovoltaic modules.
- Current and voltage of the wind turbine generator.
- Wind speed.
- Currents of the DC and AC loads.
- Voltage of the DC Bus (battery system).
- Current of charge/discharge of the battery system.
- Current and temperature of the fuel cell.
- Demanded current and voltage of the electrolyzer.

- Pressure of the hydrogen circuit (metal hydride system).

Moreover, the irradiance conditions, photovoltaic modules and fuel-cell temperature, wind speed and hydrogen pressure are measurements that will be taken into account for designing the automation system.

Figure 5 shows the electric scheme of the installation. In this system the current and voltage can be observed.

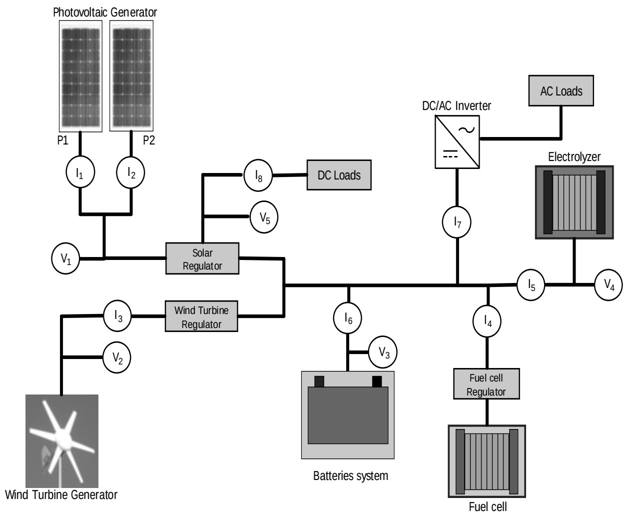

Figure 5. Electric scheme of the installation.

The working principle of the desired system is shown in Figure 6. As can be observed, before the system goes to the stationary regime, a delay must be introduced in order to initialize all the subsystems of the test bed and the involved variables. After that, the system goes to the "*Main step of working*", where the demanded energy is supported by the wind-solar generator. In this step the working regime of the global system is checked.

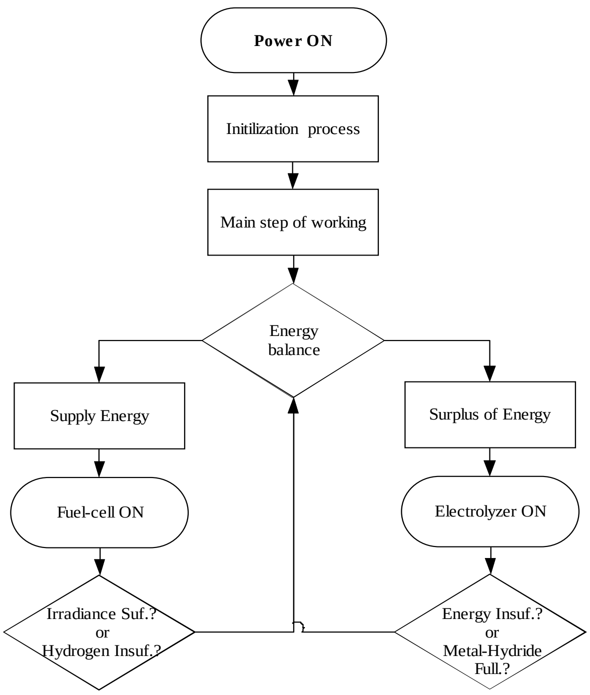

Figure 6. Flux diagram

To achieve this goal, the energy balance between the supplied energy by the wind-solar generator, the demanded energy by the user and the battery charge state is done. By means of this analysis, the working conditions for the fuel-cell and the electrolyzer are obtained.

The energy balance between the electric energy supplied by the wind solar system, the required energy by the user and the state of charge of batteries is done by the comparison of the currents at the DC Bus. Moreover, irradiance conditions and wind speed are taken into account too. In this way, the switching conditions of the fuel cell and the electrolyzer are obtained. Next, the determination of both sets of conditions is carried out.

The electrolyzer will switch "ON" when the following conditions are simultaneously fulfilled:

- The fuel-cell must be *switched off.*

- Minimum conditions of *irradiance* are necessary: The irradiance *(G) (measured by the piranometers)* should be sufficient for providing an electric current capable of generating hydrogen $G>G_{min}$. This value was previously obtained experimentally.

- The wind-solar generator must be able to generate an electric current (i_P) such that:

$$i_P > i_E + i_B + i_{DC} + i_{AC}$$

where:

i_P : is the supplied current by the generator.

i_E : is the demanded current by the electrolyzer.

i_B : is the demanded current by the battery.

i_{DC} : is the demanded current by the DC loads.

i_{AC} : is the demanded current by the AC loads.

Moreover, the pressure of the metal-hydride system for storing the generated hydrogen is between its limits. These limits depend on the selected hydrogen storage system. In these conditions, the hybrid system is generating hydrogen from the surplus energy of the wind-solar generator.

The fuel-cell will *switches "ON"*, in order to supply the necessary energy, if it is required for the energetic demand conditions, when the following conditions are simultaneously fulfilled :

- The DC Bus can provide the necessary energy level for switching on the input electro-valve of hydrogen.

- The pressure of the metal-hydride system for storing the generated hydrogen is higher than 1 bar.

- The temperature of the fuel-cell is higher than 5º C and lower than 50º C.

The fuel-cell will *switches "OFF"* when:

- The irradiance *(G)* is enough for providing the energy demand.

- The pressure of the hydrogen circuit falls down at values lower than 1 bar.

4. Practical implementation

A real prototype of the hybrid system has been built to verify the feasibility of the method proposed. The goals of this prototype are:

- Show the performance of the proposed automation system for the electrolyzer and the fuel cell working.
- Obtain experimental results with the aim of improving the operation conditions of these elements.
- Optimize the energy management.

In order to implement the automation system a Siemens PLC s7_313C_2DP has been used. This PLC has to perform the required switching between the components of the hybrid electric energy generator.

5. Conclusions and Future Works

Automatic management of energy flows of a stand-alone renewable energy with support of hydrogen has been carried out by a PLC. The developed control system has been successfully tested for autonomous operation and energy management of the installation. The designed system behaves as an effective test bed for testing control strategies and optimization algorithms based on acquired data by the monitoring and supervisory system.

Future developments focus on the optimization of switching threshold between the energy sources in order to improve the efficiency of the energy storage systems.

Acknowledgements

The authors thank the Ministerio de Educación y Ciencia of Spain and the Junta de Extremadura for its economic support through the Projects ENE2007/66668/ALT, PRI07A088 and PDT07A047.

References

[1] Richa Kothari, D. Buddhi, R.L. Sawhney. "Studies on the effect of temperature of the electrolytes on the rate of production of hydrogen". Int J Hydrogen Energy 30 (2005) 261-263

[2] Dragica Lj.Stopjic, Milica P. Marceta, Sofija P Sovilj, Scepan S. Miljanic. "Hydrogen generation from water electrolysis-possibilities of energy saving". Journal of Power Sources 118 (2003) 315-319

[3] A.M.Chaparro, J.Soler, M.J.Escudero, E.M.L. de Ceballos, U.Wittstadt, L.Daza. "Data results and operational experience with a solar hydrogen system". Journal of Power Sources 144 (2005) 165-169

[4] R. Posadillo, R. López Luque. A sizing method for stand-alone PV installations with variable demand. Renewable Energy 33 (2008) 1049–1055

[5] Kodjo Agbossou, *Senior Member, IEEE*, Mohanlal Kolhe, Jean Hamelin, and Tapan K. Bose, *Member, IEEE*. Performance of a Stand-Alone Renewable Energy System Based on Energy Storage as Hydrogen. IEEE Transactions on energy conversion, Vol. 19, nº 3, September 2004.

[6] M. Calderón, A. Ramiro, J.F. González, "Estudio de viabilidad de una instalación solar fotovoltaica aislada de la red con apoyo de hidrógeno" in Proc. V JNIT, Vigo (2007), 41 pdf.