INTERFACES FOR RENEWABLE ENERGY SOURCES WITH ELECTRIC POWER SYSTEMS

Paulo Ferreira, Manuel Trindade, Júlio S. Martins and João L. Afonso

University of Minho, Braga, Portugal
paulo.alves.ferreira@sapo.pt, manuel.ramos.trindade@sapo.pt, jmartins@dei.uminho.pt, jla@dei.uminho.pt

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ABSTRACT

This paper presents technological solutions that intend to contribute both for the efficient production of electric energy from renewable non-pollutant sources (namely Wind and Sun) and to the improvement of power quality in the electrical systems. It proposes the development of low-cost and high-efficiency power controllers that optimize energy extraction from hybrid systems, constituted by photovoltaic solar panels and wind power turbines, in small renewable energy power plants. Main innovations are the use of a single microcontroller for both sources' power control and the development of an interface between the DC link and the AC electrical system. This interface uses a control system based in the p-q theory that takes into account power quality issues. The paper also presents a cost study regarding products for renewable systems available in the market.

INTRODUCTION

The environmental issue and energy dependence represents a great concern of the European Community. The quantity of CO_2 emissions must be decreased to satisfactory levels, in order to reduce the negative impact in the climate change. To achieve this reduction within a growing energy dependent Europe, alternative non-pollutant energy sources must be considered [1]. The European Union (EU) dependence on energy imports is high and is expected to reach 70% by the year 2020 [2]. The challenge is the generation of "clean" and efficient energy within European borders, in order to decrease both environmental pollution and the energy dependence. Renewable energy sources haven't been sufficiently exploited yet, and must be promoted and developed.

The European Union has been developing efforts to promote the use of renewable energy, to increase the diversification of energy sources, to improve the quality of the environment, and to consolidate the economic sector linked to renewable energy. Summarising, the EU is concerned with the environment and energy dependence, and has created several programmes such as the 6th EU Framework Programme (FP6) to promote research and technological development in the energy field [3, 4].

Europe is already world leader in energy production from wind. The growth prevision in this sector is even superior to the objectives set by the White Paper to 2010, as shown in Figure 1(a) [5]. The evolution of the produced electric energy from photovoltaic solar panels has also experienced a fast growth, although much inferior to expectations, as illustrated in Figure 1(b) [6].

Portugal is committed with the utilization of clean energy sources. In 2001 the values of installed wind and photovoltaic power in Portugal were respectively only 80 MW and 1 MW. However, the estimation for 2010 is 3080 MW for wind power and 41 MW for photovoltaic solar panels.

Wind and Sun are two renewable sources that can and must be used more strongly and this can only be accomplished by making the involved technology accessible to all. The research and development of new efficient and cheaper technology is essential to make the production of clean energy affordable. The energy production in the EU from these renewable energy sources has been consummated by using large-scale power plants. Smaller production systems, such as domestic systems must be a future target.

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Nevertheless, the energy produced by these small systems, which can be hybrid systems of solar and wind power, must have a high level of power quality to be connected to the electrical grid.
This paper presents a possible solution to improve the electrical energy production using small wind turbines and photovoltaic solar panels for small consumers. These technological improvements enable a better extraction of electrical energy from the renewable energy sources and good quality in the energy delivered to the electrical system (loads and power grid). The use of components such as microcontrollers and semiconductors, which are already widely used in several commercial applications, contributes to implement the required hardware at lower costs.

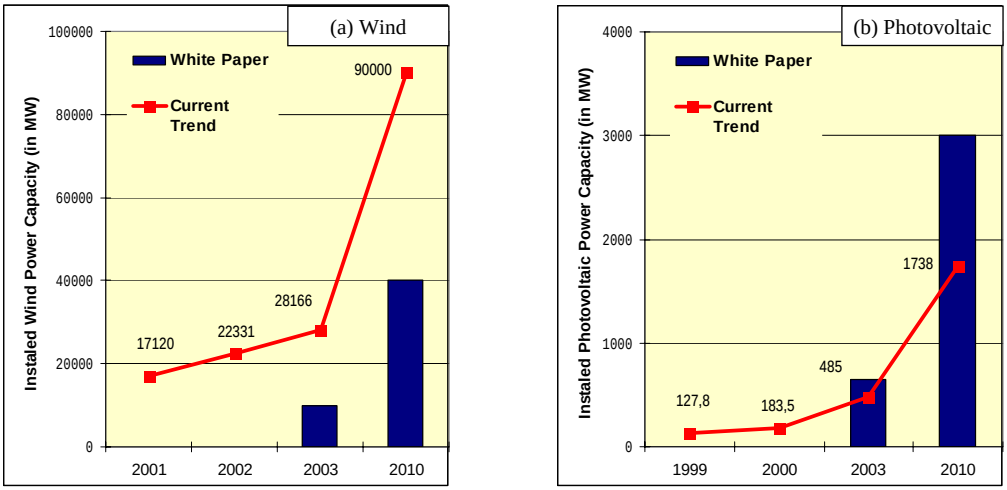

Figure 1 – Comparison of current trends with White Paper objectives (installed power in MW).

HYBRID SYSTEMS

Solar photovoltaic panels or small wind turbines depend on climatic conditions to operate and produce electrical energy. Thus, when operating alone they are poor power sources. Systems that merge both sources, wind and sun, are more effective in electric energy production. These solutions are called "hybrid systems" (examples are shown in Figure 2). They can supply stand-alone systems (isolated electric systems that are not connected to the power grid) or grid-connected systems (systems connected to the power grid). Even with hybrid systems there are periods of time when neither of the sources produces energy. In stand-alone systems energy storage is required to overcome this situation and provide energy during such periods. A hybrid system combines a small wind turbine and photovoltaic solar panels. Their outputs are optimized by power controllers. The extracted energy is used to charge a batteries bank or to supply energy to an inverter. The inverter is connected to the consumer loads and, when it is present, to the electrical power grid (Figure 3).

Figure 2 – Examples of small hybrid systems.

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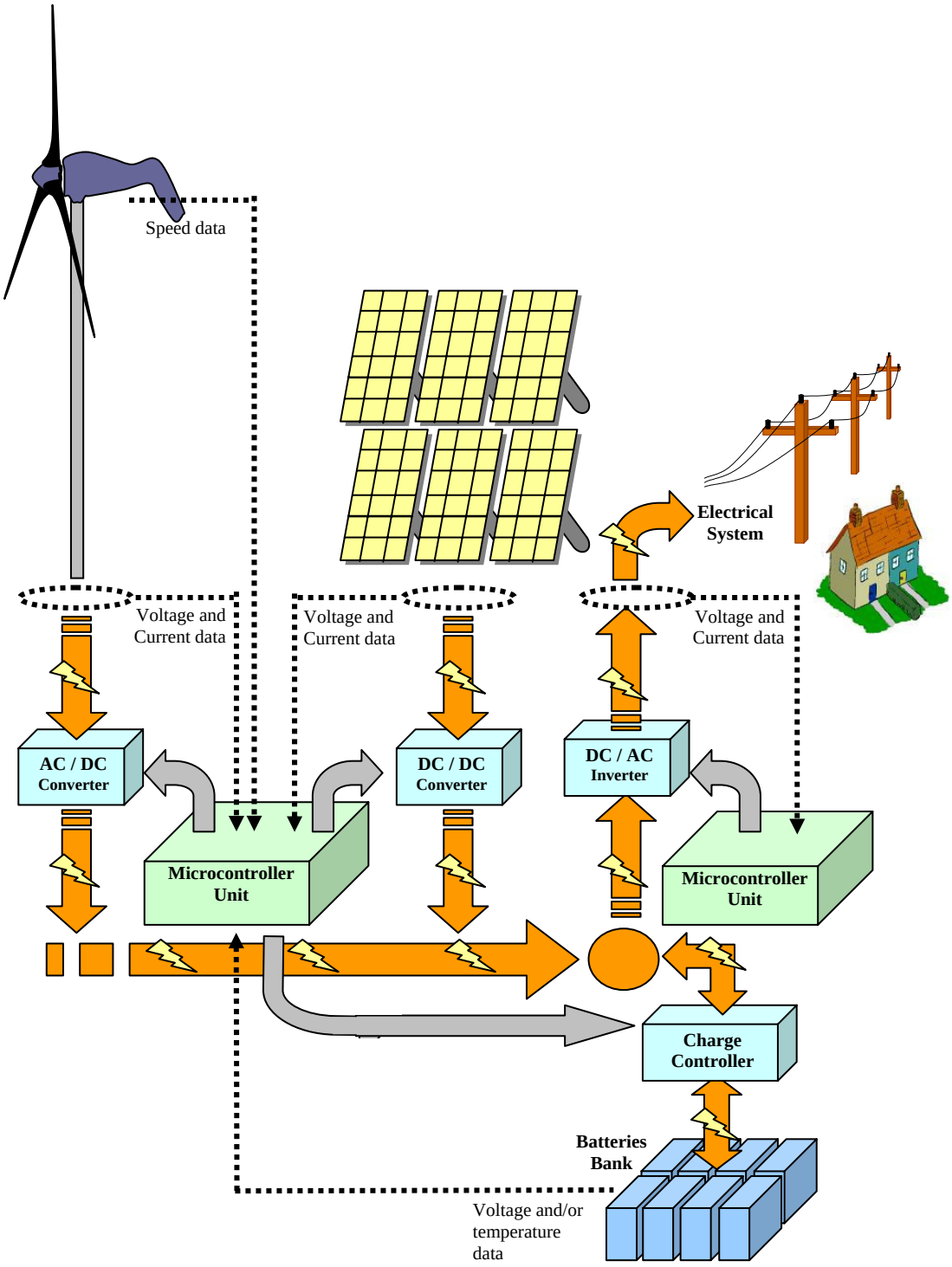

Figure 3 – Hybrid system block diagram.

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PRODUCTS AVAILABLE IN THE MARKET

Nowadays the installation of hybrid systems generally requires electronic power controllers, batteries and an inverter.

The optimization of the energy extraction is accomplished by using power controllers: a control system to the output of the photovoltaic solar panels, known as "Maximum Power Point Tracker", and an Electronic Regulator for the wind turbines.

Batteries, along with a charge-controller to prevent over-charging, are used for the electric energy storage.

An inverter is required to convert energy from DC (Direct Current) to AC (Alternating Current) and supply it to the loads or to the electrical power grid.

Table 1 presents the market costs for the implementation of a small hybrid system with a wind generator, an array of eight solar panels, a set of sixteen batteries, the power controllers and the inverter [7]. According to this table, the total cost of a hybrid system for about 1 kW of power may vary between approximately 11000 € and 19000 €.

Table 1 – Costs to implement a small hybrid system for renewable energy production

	Stand-Alone System	**Grid-Connected System**
Wind Generator (400 W / 24 V) including Controller and accessories	1000 € to 1500 €	1000 € to 1500 €
Array of Photovoltaic Panels (640 W / 24 V) including Controller	4750 € to 6250 €	4750 € to 6250 €
Batteries (6 V / 395 Ah) including Charge-Controller	2750 € to 3200 €	2750 € to 3200 €
Inverter and Control System (3 kVA / 24 V → 230 V)	2900 € to 3500 €	4400 € to 7500 €

CONTROLLERS

The variation of the available power produced by the renewable energy sources (Sun and Wind) is undesirable and is compensated with power controllers. Generally, each power source has its own power controller, one for the photovoltaic panels and another for the wind turbine. Electric power is mathematically expressed by the product of the voltage and current, and this product must be controlled and optimized.

A Maximum Power Point Tracker (MPPT) is a controller designed mainly for photovoltaic panels. Photovoltaic cells are nonlinear power sources. The MPPT acts as a monitor for the two output variables (voltage and current) of the cells array and calculates the better output combination. With this information it controls a DC/DC converter to obtain a maximum possible power at all times.

The wind power controller uses the MPPT theory with additional features. Apart from the power output control, and by braking the generator, it controls its speed to prevent over-speed caused by strong winds.

The battery charge controller observes the charging status of the batteries. This can be accomplished by monitorizing the temperature or the voltage level from the batteries, preventing the damage of the batteries bank due to over-charging.

An inverter transforms the DC power in to standard household electricity (AC power). There is a wide range of inverters and the main difference between them is the output power quality. The inverters also need a control system.

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PROPOSED WORK

The idea of the proposed work is try to reduce the costs of the small hybrid systems for renewable energy production and, at the same time, to improve the performance of these systems.

Instead of a separated controller for each component (wind turbine, photovoltaic solar panels and the batteries' charge controller), the use of a single microcontroller to control the entire system is suggested. This is a factor that may contribute to an important reduction in the final cost of the hybrid system.

A large number of small power plants can produce as much energy as a big one. Furthermore, with small power plants there is no need to build new electrical transmission power lines, since the energy production is not concentrated, but distributed. However, the small renewable energy power plants would have to comply with present legislation, especially regarding "reactive energy" production during the period of peak power consumption. According to the legislation, all energy must be delivered along with 40% of "reactive energy" during this period. Besides, they would also have to assure power quality levels.

Using a power electronics converter (a current-controlled voltage-source inverter) it is possible to inject the energy produced by the hybrid system in the electrical power grid, along with the necessary "reactive energy", at affordable costs (Figure 4). This power electronics converter injects sinusoidal currents in the power grid and therefore, the power quality of the produced electrical energy is guaranteed. Moreover, the converter can compensate for loads harmonics, power factor and unbalanced currents. As a result of the converter action, the power delivered by the renewable energy sources becomes constant in time, with a value that depends on the energy available to be delivered to the loads and to the electrical power grid, optimizing the energy production.

The controller of the proposed power electronics converter is based on the p-q theory [8-10]. This theory allows the implementation of the controller using a standard microcontroller, since it simplifies the necessary calculations of the converter control system

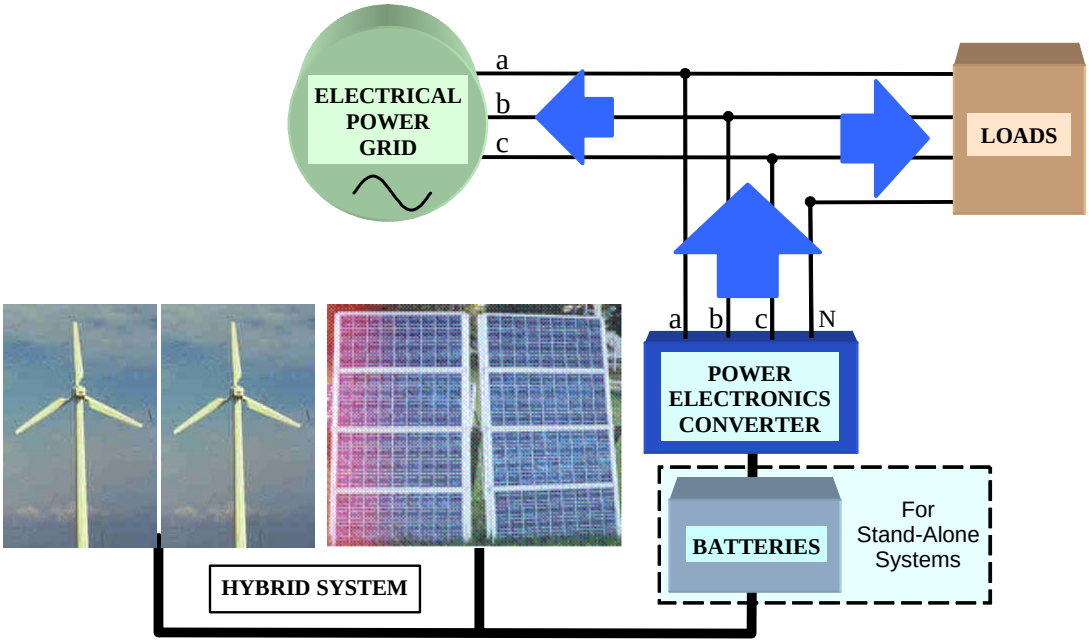

Figure 4 – Connection of the hybrid system to the loads and electrical power grid.

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CONCLUSIONS

The world environment is degrading, and all efforts must be made to invert the current situation. The reduction of CO_2 emitions is a difficult task considering the dependence on the energy as a result of our present way of life.

In Europe, power generation based on fossil fuels is responsible for most emissions nocive to the atmosphere. Increasing nuclear energy generation is not a desirable solution either. Wind and solar power are safe, and do not send emissions or residues to the environment. The production of clean energy, which is harmless and does not aggravate the greenhouse effect, must be promoted. The use of electricity generated from renewable non-pollutant energy sources (green electricity), and all technologies involved must increase.

Green electricity is a big contribution to fulfil the EU obligations included in the Kyoto Protocol. The European Community is poor in conventional energy resources, but has a great potential in what concerns renewable energy sources. It is essential to take advantage of these natural resources and create an energy independent Europe.

In the European Community several initiatives are being adopted to face environmental problems. The scientific community is also contributing with technological innovations. Nowadays, the development of Power Electronics enables economical solutions for the production of renewable energy based on small power plants. Portugal presents good conditions for the implementation of a large number of these systems, based on wind power and photovoltaic energy.

This paper proposes the development of a low-cost high-efficiency hybrid system (wind and solar) with an interface to the electrical grid that ensures the power quality of the produced energy. The proposed solution may be a contribution to a better, cleaner and safer environment and to a decrease in energy dependence.

All possible solutions to protect the environment must be implemented all around the world, because this issue is not a problem of some restricted communities. We all must have the same goal, to help promoting a sustainable development for the World Community.

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REFERENCES

[1] European Commission. “Towards an European Strategy for the Security of Energy Supply”, Green Paper.

[2] European Commission. (November 1997 Edition). “Energy for the Future: Renewable Sources of Energy”.

[3] European Commission. (December 2002 Edition). “The 6th Framework Programme in Brief”.

[4] http://www.cordis.lu/fp6.

[5] EuroObserv’ER. (February 2003). “Wind Energy Barometer”. *Systèmes Solaires*, issue 153.

[6] EuroObserv’ER. (May 2002). “The 2001 Overview of Renewable Energies”. *Systèmes Solaires*, issue 148.

[7] Richter, J. (February/March 2003 Edition). “Sustainability and the Restoration of Eden”, *Home Power Magazine*, issue 93, pp 92-96.

[8] Akagi, H., Kanazawa, Y. and Nabae, A. (1983). "Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", *IPEC'83 - Int. Power Electronics Conf., Tokio*, pp. 1375-1386.

[9] Watanabe, E. H., Stephan, R. M., Aredes, M. (April 1993). “New Concepts of Instantaneous Active and Reactive Power in Electrical Systems With Generic Loads”, *IEEE Transactions on Power Delivery*, vol. 8, nº. 2.

[10] Afonso, J. L., Couto, C., Martins, J. S. (September 2000). “Active Filters with Control Based on the p-q Theory”, *IEEE Industrial Electronics Society Newsletter*, vol. 47, n. 3, pp. 5-10.