MECH TECH 2016

ASSOCIAZIONE ITALIANA
DI INGEGNERIA AGRARIA

Università di Sassari
Dipartimento Agraria

Mechanization and new technologies for the control and the sustainability of agricultural and forestry systems

PROCEEDINGS

Alghero, Italy, 29th May-1st June 2016
Ex Ospedale Santa Chiara, Bastioni Marco Polo, 77 – Alghero (SS)

www.mechtech2016.uniss.it **ISBN 979-12-200-1098-6**

Energy efficiency analysis of a hydrogen and geothermal stand-alone system for greenhouses heating.

Alexandros Sotirios Anifantis, Simone Pascuzzi, Francesco Santoro

Department of Agricultural and Environmental Science (DiSAAT), University of Bari Aldo Moro, Via Amendola 165/A – 70126 Bari – Italy. Email: alexandrossotirios.anifantis@uniba.it

Abstract

This study investigates the performance characteristics of a hydrogen and geothermal stand-alone system for greenhouses heating. The systems consist of photovoltaic panels connected to an electrolyzer that, during the daylight hours, produce hydrogen and then it is stored in a pressure tank. However at night, thank to a fuel-cell, the hydrogen was converted to electric energy in order to feed a ground source geothermal heat pump for greenhouse heating. The following conversion energy efficiencies factor of each system were measured: photovoltaic panels, 13%, electrolyzer, 48%, fuel-cell, 41% and finally, the coefficient of performance of geothermal heat pump of 5, and then the overall system efficiency, starting from the amount of solar energy available during the daylight hours, was of 12.8%.

Keywords: *Renewable energies stand alone system, hydrogen production, ground source heat pump, greenhouses heating.*

1. Introduction

The Greenhouses are the most innovatory expressions of modern agriculture, widespread in many nations, and it is expected for them to expand numerically with vigor in the future, especially in those areas with unfavorable climatic conditions (Baldoin et al., 2008). Nonetheless, advanced greenhouses mainly need energy for heating systems in the vegetable and floricultural production and winter heating for greenhouses can reach 70% of production costs (Scarascia Mugnozza et al., 2009) and, unfortunately, the great majority of greenhouses depend on fossil energy sources (Vox et al., 2010). Diesel, LPG and natural gas are generally used as fuel in heating greenhouses and, although the use of renewable energy can improve the sustainability of the crops in a protected environment, these still play a niche role in the energy panorama due to the non-simultaneity of the energy production during the daylight hours compared to the night energy required. The scientific community is aimed at testing new energy storage technologies, such as new batteries with very high efficiency, re-pumping water into elevated water storage systems, boilers powered by solar thermal systems. An interesting solution consists in the solar energy conversion in hydrogen(H_2) in order to implemented a totally renewable and stand-alone system for greenhouse heating. In this respect, the geothermal heating systems are economically advantageous having a lower environmental impact in the agricultural sector especially for greenhouse heating demands (Ozgener, 2010). Different processes can generate hydrogen but actually hydrogen is produced worldwide by fossil sources employing coal gasification or natural gas reforming process (Mueller-Langer el al., 2007). Water electrolysis is the only one without carbon dioxide emissions being released into the atmosphere and generates “zero emissions” if the electricity necessary for electrolysis is produced from renewable sources (Scarascia Mugnozza et al., 2011). The incorporation of an efficient and suitable vector as a secondary power supply also means reducing consumption of imported liquid fossil fuels therefore, a reduction of environmental pollution. (Posso et al., 2016).

2. Materials and Methods

The study was carried out at the experimental farm of the University of Bari sited in Valenzano, Bari, Italy, where an air inflated, double layer polyethylene film tunnel greenhouse of 32 m^2 of cover surface (A_{gr}) was heated by a Ground source heat pump(GSHP). The electric power generated by 56 m^2 (A_{PV}) of polycrystalline photovoltaic panels(PV), during day time from 08:00 to 18:00, feeds the electrolyzer which, in turn, produces hydrogen gas by water electrolysis. The hydrogen is stored in a pressure tank (Fig. 1) and, when photovoltaic is not operative, during night time from 19:15 to 07:50, it is used by a fuel cell system producing electricity for a GSHP in order to suit the greenhouse heating energy demands when the internal air temperature falls below 20°C. The specification of the plant are reported in Tab.1. The experimental test was conduct on March,1-2, 2015.

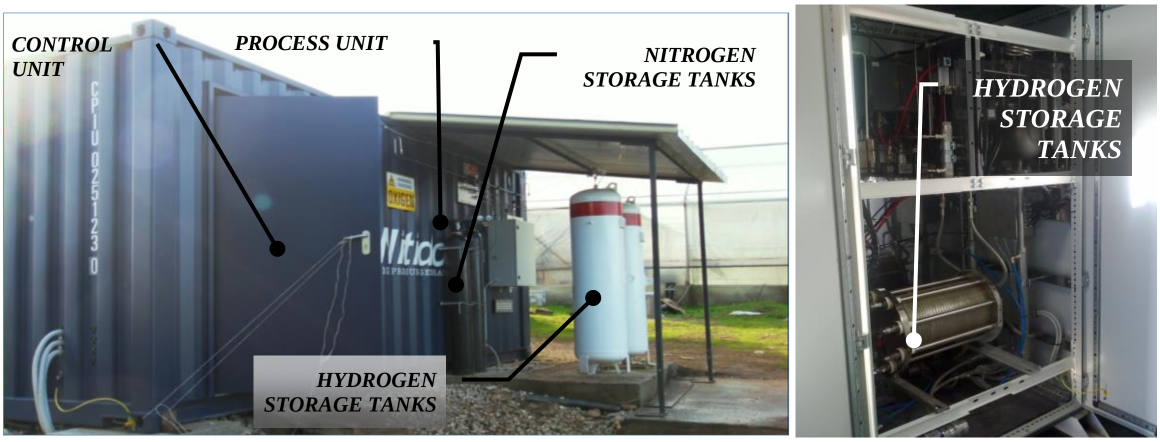

Fig. 1. Stand-alone hydrogen plant external layout and electrolyzer internal stack.

Components	Specifications
Photovoltaic array	BYD 240P6-30, 34 module, 8.16 kW peak
Electrolyzer	Monopolar alkaline electrolyser 2.5 kW, 0.5 Nm^3/h
Fuel cell	Proton exchange menbrane Fuel Cell (T-2000TM), 2 kW, 24 or 48 V
Battery	10.8 kWh
H_2 storage	30 bar, 0.6 m^3
Heat pump	Model RAA-EF, Riello, 7.0 kW thermal absorbing, with inverter controller
Geothermal borehole	120 m vertical double U-bend ground heat exchanger
Fan-coil unit	Carisma CRC53MV,Cooling/Heating capacities:2.28/3.59kW;air flow rate 495m^3/h
Greenhouse	Air inflated, double layer polyethylene film tunnel greenhouse

Tab. 1. Specification of hydrogen renewable energy plant.

Solar radiation: The first step for evaluating the performance of a tilted PV array is to determine the total hourly solar radiation on tilted PV array (I_T): $I_T=I_bR_b+I_dR_d+I_gR_r$, where R_b, R_d and R_r are respectively the tilt factors for the direct, diffuse and reflected part of the solar radiation, while I_b, I_d, and I_g are respectively the direct normal, diffuse and global solar radiation components, in W/m^2, falling on a tilted array. These components depend on several parameters that can be calculated using the (Kolhe et al., 2003) formulation.

PV panel: Neglecting the degradation factor of the PV array, and the wiring efficiency of the PV array system, the instantaneous PV array power output is given by $P_{pv}=A_{PV}\cdot I_T\cdot \eta_{pv}$ where η_{pv} is the PV array efficiency.

Electrolyzer and Fuel cell: The energy efficiencies of the electrolysis and the PEM fuel cell reaction are given in terms of the lower heating value of hydrogen (LHV_{H2}=119.96

[MJ/kg]) by the expressions, (Calderón et al, 2011): $\eta_{el}=(\delta_{H2}\cdot q_{el,H2}\cdot LHV_{H2})/P_{el}$ and $\eta_{el}=P_{fc}/(\delta_{H2}\cdot q_{fc,H2}\cdot LHV_{H2})$, where δ_{H2} is the hydrogen density at standard condition (0.08988 [kg/Nm^3]), η_{el}, η_{fc}, P_{el}[W], P_{fc}[W], $q_{el,H2}$ [Nm^3 s^{-1}], $q_{fc,H2}$ [Nm^3 s^{-1}], are respectively for electrolyzer ($_{el}$) and fuel cell ($_{fc}$), the energy efficiencies, the power input and output and the hydrogen consumption rates at standard conditions.

Ground source heat pump systems: The coefficient of performance (COP), is the ratio between the thermal power produced (Q_1) and the electric power required (L): $COP=Q_1/L=Q_1/(Q_1-Q_2)$, where Q_2 is the heat power extracted from the underground. The COP is strictly linked to the working condition of both the heat exchange systems. A simple way for calculated Q_2 is: $Q_2=q_r\cdot l_t$, where q_r is the heat exchange rate and l_t is the total active length of the borehole.

Greenhouse thermal systems and energy requirement: The thermal energy requirement of a greenhouse depends on many factors as the solar radiation, the inside and outside air temperature, the wind speed, and so on. Considering the steady state and the overnight winter conditions, the heating power requirement Q_1 of a hot water pipes heating system has been evaluated through the equation(Ozgener and Hepbasli, 2005): $Q_1=K\cdot A_{gr}\cdot(T_i-T_o)$, where K is the total conductivity coefficient of the greenhouse and (T_i-T_o) is the difference between greenhouse inside and a temperatures.

3. Results and Discussion

A partly cloudy day was analyzed for the experimental test. The PV efficiency (η_{PV}) is 13% thank to the low temperature of the solar panel. As show in Fig.2 the electrolyzer hydrogen production($q_{el,H2}$) start from 08:00 to 13:15, when the solar radiation(I_T) get over to 200 W/m^2 or rather when the PV power output (P_{PV}) is more than 1400 W.

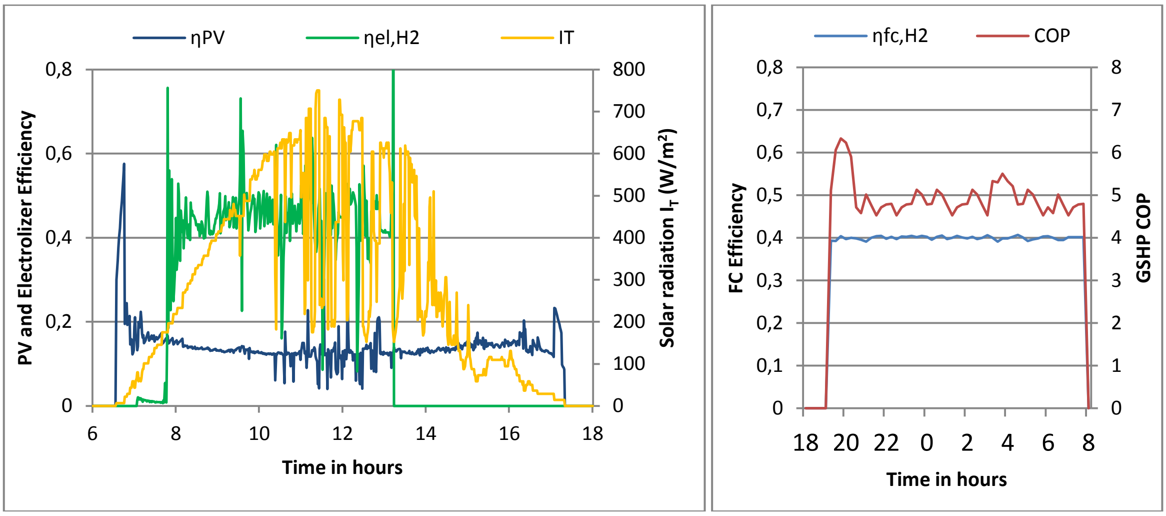

Fig. 2. Stand-alone hydrogen plant efficiencies and solar radiation input.

The electrolyzer power input(P_{el}) is similar to the P_{PV} neglecting the energy loss for device and inverter efficiency. The performances of the electrolyzer depend on the I_T trend, after 13:15 the $q_{el,H2}$ falls down due to the not stability of I_T. The electrolyzer energy efficiency on average is 48%, higher value were obtained for clear day. During the night time the fuel cell and the GSHP worked from 19:00 to 08:00 when the temperature decrease to 20°C. The fuel cell power output (P_{fc}) is 160 W and it depend on the load demand, P_{fc} is equal to the electric power demand(L) of the GSHP. Thank to the modularity of the fuel cell, the energy efficiency (η_{fc}) is 41% and did not change with the P_{fc}. Instead the coefficient of performance of the GSHP is very sensitive to the change of the temperature of hot side related to the internal air temperature of the greenhouse. The Q_2 is 640 W and q_r, for a double U-bend pipe, was 5.4 W m^{-1}, this value lower than the maximum heat extraction rate of the borehole in good agreement with the little plants analyzed by the technical standard. The thermal power output(Q_1) of the GSHP is 800 W and the COP is 5. Thank to Q_1, the difference between greenhouse inside and outdoor temperatures (T_i-T_o) is 8 °C with a total thermal conductivity of the greenhouse equal to 3.21 W/m^2 °C. Finally, taking in account the energy efficiencies of the each part of the plant the overall system efficiency was of 13%.

4. Conclusion

This study analyzed the overall performance efficiency of a GSHP systems coupled with a stand-alone hydrogen plant. If on the one hand, competitive technologies, such as the solar thermal panels joined to the water storage systems can lead to a 40% of the overall energy efficiency(Vox et al., 2008), on the other hand the air temperatures and the thermal levels reached in the greenhouse by means of solar thermal systems are lower than those achieved by the presented system, making ineffective the use of the solar thermal systems and interesting the installation of the studied system. Furthermore, a combination of the solar thermal energy plant and the stand alone hydrogen-GSHP system will be study in order to high the enthalpy of the heat water necessary for the greenhouse heating system.

References

Baldoin, C., Balsari, P., Cerruto, E., Pascuzzi, S., Raffaelli, M. 2008. Improvement in pesticide application on greenhouse crops: Results of a survey about greenhouse structures in Italy. Acta Horticulturae, 801 PART 1, 609-614.

Calderóna M., Calderóna A.J., Ramirob A., Gonzálezb J.F., Gonzáleza I. 2011. Evaluation of a hybrid photovoltaic-wind system with hydrogen storage performance using exergy analysis. International Journal of Hydrogen Energy, 36, 5751–5762.

Kolhe M., Agbossou K., Hamelin J., Bose T.K. 2003. Analytical model for predicting the performance of photovoltaic array coupled with a wind turbine in a stand-alone renewable energy system based on hydrogen. Renewablehttp://www.sciencedirect.com/science/journal/03603199 Energy, 28, 727-742.

Mueller-Langer F., Tzimas E., Kaltschmitt M., Peteves S. 2007. Techno-economic assessment of hydrogen production processes for the hydrogen economy for the short and medium term. Int. J. Hydrogen Energ. 32 (16), 3797–3810.

Ozgener O., Hepbasli A. 2005. Performance analysis of a solar ground-source heat pump system for greenhouse heating: an experimental study. Building and Environment, 40, 1040–1050.

Ozgener, O. 2010. Use of solar assisted geothermal heat pump and small wind turbine systems for heating agricultural and residential buildings. Energy, 35, 262–268.

Posso F., Sánchez J., Espinoza J.L., Siguencia J. 2016. Preliminary estimation of electrolytic hydrogen production potential from renewable energies in Ecuador. International Journal of Hydrogen Energy. 41: 2326-2344.

Scarascia Mugnozza, G., Anifantis, A. 2009. Dal fotovoltaico al termico. Colture Protette, 6, 40-43.

Scarascia Mugnozza, G., Pascuzzi, S., Anifantis, A., Verdiani, G. 2011. Photovoltaic and geothermal integration system for greenhouse heating: an experimental study. Not numbered volumes pp. 135-138 in Proc. 5th Int. Sci. Symp. Farm Machinery and Process Management in Sustainable Agricolture, Lublin, Poland, ISBN 83-922409-9-5.

Vox G., Schettini E., Lisi Cerone A., Anifantis A. 2008. Solar thermal collectors for greenhouse heating. Acta Hort. 801 (PART 1), 787-794.

Vox, G., Teitel, M., Pardossi, A., Minuto, A., Tinivella, F., Schettini, E. 2010. Chapter 1: Sustainable Greenhouse Systems, Sustainable Agriculture: Technology, Planning and Management, Nova Science Publishers, New York, NY, USA.