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Solar energy system in a small town constituted of a network of photovoltaic collectors to produce Electricity for homes and hydrogen for transport services of municipality

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Abstract

The supply of Energy resources to the villages located in inland and hilly regions, is disadvantageous both for the domestic and transport purposes. Because these conditions may produce the depopulation of the inland zone, a smart way to ease this inconvenience is to produce in situ electrical Energy for houses and fuel for cars, getting them from an available Energy source in the village, as the solar Energy. The only technology to produce hydrogen ecologically and to minimize CO_2 emission, is through RES (Renewable Energy Sources). The solar energy plants must use the surfaces of buildings instead of occupying other green areas useful for agricultural activities. On this basis, we propose in this paper a demonstrative project for a village in Sardinia, consisting of photovoltaic collectors connected in a network, to provide electricity to homes and hydrogen for transport purposes.

Keywords: demonstrative project; fotovoltaic; hydrogen

1. Introduction

The purpose of this paper is not to refer about the results of a research on the technologies of solar PV (Photo Voltaic) and of the Hydrogen, but is to show how the complex plants, like this *demonstrative project,* based on these proved technologies, still economically uncompetitive, may contribute to improve life conditions, mobility and Energy availability for the villages of the inland and hilly territories, owing to the territorial distribution of the RES; this villages otherwise are destined to be abandoned causing serious anthropological and social consequences. This *demonstrative project* has even the purpose to stimulate the public administration to realize a pilot plant to verify experimentally the performances in view of the application to several villages in the hilly Sardinia zones. For example, in the province of Cagliari, the conditions of Villasalto village, considered in this paper, occur in several villages as Ballao, Armungia, Silius, Burcei, etc.

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Similar conditions exist even in many villages in the southern regions of Italy, of France and of Spain. For these reasons some EU programs for the diffusion of the use of RES proposes the development of activities like the demonstrative project presented in this paper. The
calculations of the performance and electrical energy production by PV collectors are based on physical data of solar radiation and climatic parameters for Sardinia and Italy furnished by the Italian public administration of ENEA and by means of a software as RETScreen. This project is based on the state of the art of the solar PV technologies and of the H_2 technologies. The project is also based on the methods of electrical special plants and of the mechanical and thermodynamic plants handling gaseous flammable fluids as the Hydrogen. For the economic analysis the main necessary data used are the actual prices of PV solar collectors and inverters [1], and the prices of the main components of H_2 plant; these prices are actually high because a serial production of H_2 systems is not still well developed. In this technologic and economic context, the purpose of the project presented in this paper is not to demonstrate the economic competitiveness of these systems, but rather to clarify that these complex systems supplied by RES are useful in the solution of cultural and social problems, like the depopulation of the inland and hilly zones. The economic and social costs of the depopulation perhaps may be more dangerous than the costs of the installations similar to the demonstrative project described in this paper.

2. Geographic position of the demonstrative project - Urban location of the production system

The village of Villasalto, located in hilly inland zone, is the geographic position identified for the demonstrative project. As concerns transport infrastructures, it is in a condition of difficulty, heightened by the local orographic complexity. Therefore producing Hydrogen in situ, from the Solar Energy source, that could be used to fuel transport application, contributes substantially to reduce the isolation from the regional context, in particular from the area of Cagliari town. The village of Villasalto is located in the mountains of S-E zone of the Sardinia Island. In agreement with the municipal administration, several hypothesis concerning localization of PV systems on the roofs of the houses were examined; for the Hydrogen production and distribution has been chosen the area of the social wine cellar, which is out of service. This area is well suited both for the extension, it is large enough for the PV solar field, and for the safety requirements related of Hydrogen, being a site at the periphery of the urban area. Coherent with the principle of minimizing the environmental alterations, for the collection of solar radiation will be used the building roofs well oriented toward the sun, thus avoiding using extra territory, in particular the agricultural land. The fig.1 illustrates the village planimetry with the new electrical grid conducting to the social wine cellar.

Fig. 1 Urban location of the demonstrative project for RES in the Villasalto village in the S-E of Sardinia

3. The size of the PV solar field and the Hydrogen facility of the demonstrative project

The system for producing electricity for housing and hydrogen for transport consists of the following components: 1) Arrays of PV collectors widespread on the surface of the buildings in the village; 2) Electrolytic H_2 Generator; 3) Compressor and storage of Hydrogen; 4) Electrical grid between PV solar system and H_2 production system. The size of the electrical power of the PV solar field depends on the capacity of the electrolyzer unit. Moreover the size of the system has to be enough significant in order to achieve at least the following outcomes: a) achieving an useful research for industrial progress; b) attracting fundings for the PV system by programs of the EU; c) guaranteeing enough hydrogen to satisfies the needs of the community of

Villasalto; d) producing Hydrogen with a cost compatible with the general economic context. On the basis of a technical-economic feasibility analysis it has been adopted an H_2 generator of 6 Nm^3/ h and a PV solar collectors field of total power of 525 kW_p. The Production of electric Energy by PV solar collectors will be achieved by the following sub systems that are connected to the national grid: each one of the PV plant will be divided into two sections, one is connected to the existent electrical grid owned by ENEL, and the other is connected to a new electrical grid, managed by the municipality consortium, in turn connected to the existing electrical grid in a single point, near the H_2 production plant (in the social wine cellar). The photovoltaic system will consist mainly of three sections: a) a section of the small PV plants, on the roofs of civil dwellings well exposed to the sun of a total power of 300 $[kW_p]$; b) a section of a number of medium power plants, located on the main public buildings, characterized by a total peak power of 150 $[kW_p]$; c) a section located directly on the roof of the building that houses the H_2 production plant, having a power of 75 $[kW_p]$. All PV modules will be made of polycrystalline or monocrystalline silicon. The hydrogen facility will be electrically powered by the solar PV system described above. The hydrogen demonstrative project consists of the following main parts: 1) New electrical grid to connect the small PV plants on the buildings with the H_2 generator system - 2) Electrolytic H_2 Generator – 3) Compression and storage units at a high pressure - 4) Hydrogen distribution station for vehicles; 5) The group of hydrogen engine service vehicles three in number.

3.1 Economic factors limiting the PV system - Incentives and regulations

The costs of the H_2 facility and the PV system should be payed with the energy savings on the electrical bill and the sale of Electricity exceeding the consumption or through the mechanism of the NME (Net Metering Exchange), introduced by the Italian Government with the DM 19/02/2007. This mechanism of the NME is the remuneration of the electricity exchanged with National electrical grid. For municipalities with less than 20,000 inhabitants, like just the site under analysis, this mechanism can also be applied when the points of injection and withdrawal are not the same.

4. The choice of the Hydrogen technologies: electrolysis, storage, combustion, fuel cell

Electrolysis - Although generating hydrogen through a chemical process, like reforming, is more efficient than electrolysis, however it should be noted that the chemical technology produces pollution or toxic byproducts. When the available energy source is mechanical (hydraulic or wind energy), or solar, then H_2 can be produced by means of electrolysis of water without pollutants production. Since the price of electrical Energy produced by conventional power plants is high the electrolysis process has not been widely used in the past. But if the source of energy is completely renewable, with the NME mechanism, electrolysis will become more economically competitive compared to non-renewable resources, even more if the Italian government will establish the “green certificate” for H_2 as required by the Italian law n.239/2004. Despite the efficiency - still uncompetitive - the production of H_2 through electrolysis process, is a clean and renewable technology for storing electrical energy as chemical Energy.

Gas storage - The easiest and cheapest way to accumulate Hydrogen is to compress it up to a pressure of 200-250 - 350 bar in special tanks. This solution is suitable for residential users applications, while in the transport sector, as can be seen, is hindered by the limit of a low energy density compared with the volume and weight of conventional fuels. Recently, considerable progress has been made to reduce the problems of weight by means of metallic or thermoplastic liner, reinforced with carbon fibers, glass and aramid materials. This type of tanks have a weight 3-4 times lower than that of common steel tanks, and they are able to operate up to a pressure of 350 bar. With these new generation tanks, it is possible to obtain H_2 with a density adequate for fueling a vehicle: with polymeric materials and carbon fibers the density obtained is 15 kg/m^3 and 5% of the specific mass of Hydrogen [2]. It is worth noting that the compression requires an amount of energy between 4 and 7% of the energy owned by the stored H_2.

H_2 as fuel in combustion engine - This is the simplest and the more feasible solution for promoting a large-scale use of hydrogen. There are reliable technologies existing for high-pressure and/or cryogenic tanks. The Hydrogen engine does not involve any substantial change with respect to conventional engine, it is similar to a methane gas engine of the latest generation. The combustion of hydrogen in an ignition engine, produces as exhaust only water vapor and a small fraction of NO_x due to the high temperatures of the air during combustion.

It is worth mentioning that switching to hydrogen reduces the performance of the vehicle with respect to the conventional fuel: the power, the torque and autonomy are reduced; however, acceptable performances are guaranteed. More recently a fuel cell car has been presented at CES in Las Vegas [3,4]. The sizing of the main components is a compromise between different requirements: 1) developing an experimental system with commercial components; 2) satisfying the needs of 3 municipal cars; 3) balancing the whole energy chain of the proposed system; 4) Minimizing the cost of hydrogen production; 5) tangible repercussions on territory and society; 6) utilization of the benefits of NME for RES. The electricity for H_2 production from PV solar converters is achieved through the following sections: 300 kW_p mounted on the roofs of the dwellings of the civil citizens, of which 25% for the hydrogen production - 150 kW_p on the roofs of the municipal buildings, of which 50%,for the hydrogen production - 75 kW_p on the social wine cellar, of which 50% for the H_2 production.

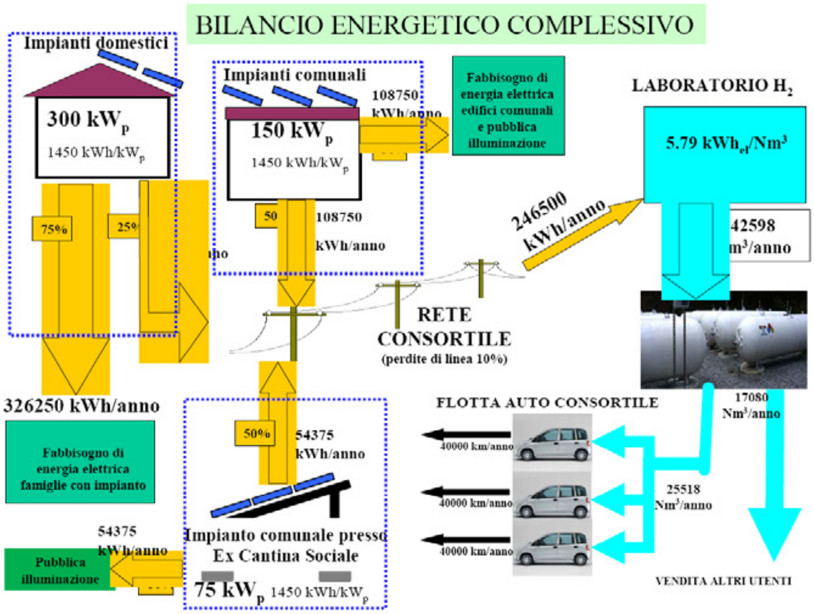

Fig. 2 Layout of the hydrogen demonstration project

Table 1. Characteristics of the hydrogen facility

Quantity	unit	value
Hourly H_2 production	Nm^3/h	6
Capacity of the electrolyzer	kW	31
specific needs of the electrolyzer	kWh/Nm^3	5.17
Capacity of the power plant for H_2 production and compression	kW	34.72
specific needs of the power plant	kWh/Nm^3	5.79
Gas station Pressure	bar	200
Daily Hours of operating	h/gg	20
Weekly days of operating	gg/sett	7
yearly week of operating	sett/anno	52.14
Nominal Hourly production	Nm^3/h	6.0
specific needs of demineralized water	l/Nm^3	0.809
specific needs of electrical energy	kWh/Nm^3	5.79
Yearly production of H_2	Nm^3/a	42598
Yearly needs of demineralized water	m^3/a	34.5
Yearly needs of electrical energy	kWh/a	246500

Each single PV solar system will be equipped by two different physical electric connections: one connection will be fastened to the existing grid of the ENEL and the other connection will be fastened to a new electrical grid, managed by the municipality consortium. For instance, a PV solar plant of 6 kW_p mounted on the roof of a civil dwelling, will be subdivided into 2 units; one unit of 4.5 kW_p will be connected to the existing ENEL grid, and will be for satisfying internal needs of civil dwelling, while the other unit of 1.5 kW_p will be connected to the municipal consortium grid. The PV system for H_2 production will benefit of the NME mechanism, its peak power is of 187 kW_p and the electricity generated by solar energy is estimated to be close to 271150 kWh per year. This amount of energy is available for the hydrogen production. The H_2 facility will have a nominal capacity of 6 Nm^3/h an electric power equal to 34.72 kW. The annual production of hydrogen will be equal to 42598 Nm^3/year. The benefit for the community will be ensured by the three cars fueled with the hydrogen and under the service of the municipality. The price of the Hydrogen will be the same of a petrol station. The vehicles will be powered with two-different fuels that are commonly purchasable on the European market, but modified ad hoc for operating with hydrogen fuel. The amount of expected yearly mileage of the 3 cars is about 120000 km/year. The main functional parameters of the H_2 Plant provided by this study are given in Table 1.

5. The project budget

The proposed demonstrative project is constituted by photovoltaic sections, the grid for the transmission of the electricity in the consortium network and finally the production, storage and distribution of hydrogen. Since the following sections: a) the photovoltaic section; b) the new electrical grid managed by the municipal consortium; c) hydrogen generator; have different time of amortization, the economic analysis will consider these sections separately (see Tab.2). If, on one hand the photovoltaic section will cover the needs for Hydrogen production, in the extent of 187 kW_p, on the other hand the photovoltaic section is supported by NME. The costs of PV systems will be charged entirely on municipality and people, or private capital, by means an appropriate financing mechanism. The costs of PV systems are not included in the economic analysis, because the incomes from savings on the electrical bill and the NME mechanism cover the initial cost of the system. Instead the income related the NME, resulting from that section of PV section connected to the new electric grid of the consortium, will be taken into account in the cash flow of the hydrogen production. The size of the those PV systems, mounted on the dwellings, covers the 100% of the electrical needs and also cooperate for the hydrogen production. Moreover, the costs supported by private citizens will be deductible in extent of 50% from the income tax, until 10 years, as established by the Italian law. Those PV systems installed in municipal buildings, will provide electricity for hydrogen production and also to satisfy the needs of different users. The same NME mechanism is valid for the PV plant of 75 kW_p, mounted on the social wine cellar. For all PV systems the 50% of the electric energy will be self-consumed while the rest will be exchanged with the existing electrical grid, managed by the national distributor (ENEL). If from one hand the aim of this study is to design and develop a hydrogen facility that is able to sustain itself as concerns the economic aspect, hence without charging on the budget of public administrator, on the other hand does not have the pretension to generate profits, being a demonstrative experimental project that produces a goods for which currently there is still no real market demand. The aim is also to promote a research and an experimentation for technicians in the automotive hydrogen sector.

Table 2. Costs of the main components of the Hydrogen facility [2]

Component	Unit	price
Demineralizer		€ 1100.00
Power plant for H_2 production and	6 Nm^3/h	€ 150000.00
New Electrical grid for consortium	(2.5 km - 120 users)	€ 235050.00
Vehicle	3 Vehicle bi-fuel	€ 84000.00
Renovation of the spaces of the old wine		€ 35000.00
Technical charges		€ 42115.00
Total		€ 547265.00

5.1 Macro-economic frame work

The costs for hydrogen production together with the new electrical grid will have to be financed by the

European Community and by some identified stakeholders. Instead the PV solar field will have to be entirely paid by the individual owners of the plant units, private citizens and public administration. As it concerns the PV system, it is considered a cost per unit power equal to 1700 €/kW$_p$. The money of private citizens will be amortized in about six years, although 25% of their plant will not produce any benefit to them. The public administration, since will not benefit of the tax relief, it will have to use a loan from the Deposits and Loans Fund, with fixed interest rate of 3% for 20 years. Therefore the public administration will be able to refund the PV system thanks to the NME mechanism and savings on the electrical bill. As it concerns the price of hydrogen at the gas station, it was considered, a middle value per unit energy, between gasoline and diesel fuel in order to encourage its use (taking into account a lower heating value of 9.51 kWh/liter for diesel and 8.63 kWh/liter for gasoline). It is therefore proposed a selling price of about 0.15 €/kWh (average between the cost of gasoline of 1.42 €/liter and that of diesel oil which is worth about € 1.34 /liter). The cost per Nm^3 of hydrogen, under standard conditions (0°C and 101325 Pa) will be equal to € 0.46, while the cost per kg will be equal to € 5.10.

5.2 The Maintenance and operating Costs

The maintenance costs, are given in Table 3, and are estimated to be varying as a function of the costs of installation, as shown in Table 2. Among the operating costs, the most significant are the salaries, which are of the order of 83%. Concerning the cost of the PV system, although these are not included on the loan, however are taken into account for the evaluation of the sale price of hydrogen.

Table 3. The maintenance costs of the power plant for Hydrogen production

Vehicle maintenance	€ 1120.00
Gas station maintenance	€ 3000.00
Electrical grid maintenance	€ 7051.50
salaries (1,5 peoples)	€ 54000.00
Costs for electrical Energy needs	€ 14211.64
TOTAL	€ 79383.15

6. Conclusions

The aim of this study is to propose a demonstrative project to improve life conditions of the villages in a inland and hilly territory, by means of RES; to obtain these benefits it is necessary to produce the Hydrogen that could fuel automotive application under break even condition between costs (annual installment of the financed capital and costs for the hydrogen production) and incomes (NME and sales of the hydrogen at gas station). Since one of the goal of this study is to stimulate the market of hydrogen for automotive application, therefore one of the result of this study is an end-user price of 0.46 €/m^3, instead of 1.43 €/m^3 as it should be to balance the operating costs. Therefore to give the right feasibility to the production of hydrogen, by means an attractive cost, it is indispensable to reduce the production costs of € 0.97 per Nm^3. The reduction of production costs, in the absence of government incentives such as the green certificate specific for Hydrogen, becomes unrealistic. One of the key results that can be drawn from this study is that it raises the question whether the high cost of the Hydrogen facility, together with the current European legislation (which does not support the production of hydrogen) not make it possible to produce hydrogen in a profitable way. Moreover the cessation of the incentive for electricity from PV solar system may represent a further impediment to the diffusion of Hydrogen system. To cover the costs, a public incentive for hydrogen of about 0.3 €/kWh will be necessary.

This study confirms the necessity of a public incentive, because the economic costs of the depopulation of many villages located in the inland and hilly zones of Mediterranean countries can be more dangerous than those presented by the installations supplied by RES similar to the demonstrative project described in this paper.

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