Integration of solar-hydrogen technologies for sustainable housing

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Abstract

The continuous and accelerated growth of population has brought an increase in the energy demand for the production of goods and services. This has caused at the same time high cost environmental as well as economic troubles such as global warming and increase in electricity costs. These issues generated international actions to mitigate the consequences due to fossil fuels overexploitation; Mexico participates in these actions so it is promoting projects fostering environment care, such as the proposal described in this work, aimed to develop sustainable systems through the integration of technologies related to renewable energy sources.

In Mexico, greenhouse gas emissions are mainly due to the transport sector and electrical power consumption by industry. Regarding the last sector, electrical power consumption per household is around 33%. Electrical service users are classified according to power consumption as established by the Electricity Federal Commission, CFE. Lamps and fridges are the most used energy consuming households reaching around 50% of total consumption. These devices are commonly used in most houses during the day. TV and DVD's are other appliances used in most Mexican houses, representing a 25% of power consumption.

In this work a sustainable house was designed to be powered by a solar-hydrogen system. The whole project was divided in three stages; the first stage consists in setting up a photovoltaic system; in the second one, the integration of an electrolysis and hydrogen storage system to the solar system will be carried out. The third stage corresponds to the integration of a fuel cell device. We report the installation of a 1 kW PV system consisting of: two 540 W Si solar panels, controller, inverter and a set of batteries to supply power to basic services, such as lamps, fridge, TV, DVD and a laptop. We analyze the performance of the PV system regarding the power supply and consumption to the house.

Keywords: solar-hydrogen system, renewable energies sources, sustainable house.

1. Introduction

Nowadays the growing energy demand for the production of goods and services in the world and the need to produce it in a clean and sustainable way has generated in recent years a strong global interest in developing new technologies and materials. Extensive research to achieve the best approach to generate clean energy has been largely transformed from "scientific competence" to "scientific cooperation" to achieve social and environmental well-being, since the best way to generate sustainable energy is to harness the weather of each region and integrate key systems such as solar photovoltaic and other renewable energy sources such as hydrogen through fuel cells. [1] [2]

In the case of Mexico, the generation of greenhouse gas emissions is mainly due to the transport sector and the electrical power consumption by industry. However, the environment has also been badly damaged by the oil industry in different regions of the country. On the other hand, a factor of great importance in Mexico is the rapid increase in energy prices, being gasoline and electricity tariffs an important key factor to get a virtual stable economy in the country, but in the last 10 years it seems that actual economic instability in energy is jeopardizing national development. Among the principal electric power consumers in Mexico, household users represent 33% of total consumption, being the most used appliances like the refrigerator, TV, DVD player and interior lighting; based on this premise CFE has established a minimum power consumption average standard home in Mexico. [3] [4] [5]

This project is divided in three stages for its development, the first stage consists in installing a photovoltaic system whose power is according to the energy demand required to be covered. In this case a bimonthly energy demand of 150 kW·h was established so it can meet the basic energy needs of a CFE 01 rated house according to its average energy consumption. The second stage involves the integration of an electrolysis hydrogen production and storage system. The third and final stage is the integration of a fuel cell device to the photovoltaic-hydrogen system.

The implementation of renewable energy is currently growing in Mexico at a moderate pace, mainly due to lack of government support and ignorance on the benefits that can be obtained from its application for sustainable housing. On the other hand, some government programs encouraging investment in these technologies begin to appear, such as the INFONAVIT credit program called "Green mortgage" and the recent advantage of establishing a contract with CFE to interconnect these sustainable systems to the federal power grid. As these renewable energy systems supply electric power to the grid, they cause a reduction in the cost of current high electricity tariffs.

2. Experimental

3D Modeling

In order to project and visualize the scope of the sustainable housing system, a useful tool that we will use is the 3D digital modeling, so we worked on a preliminary design to define the necessary space and functionality of the structure, considering the house should support the weight of a 1 kW solar panels photovoltaic array and allow simulating the location of the other components of the photovoltaic system in this first stage.

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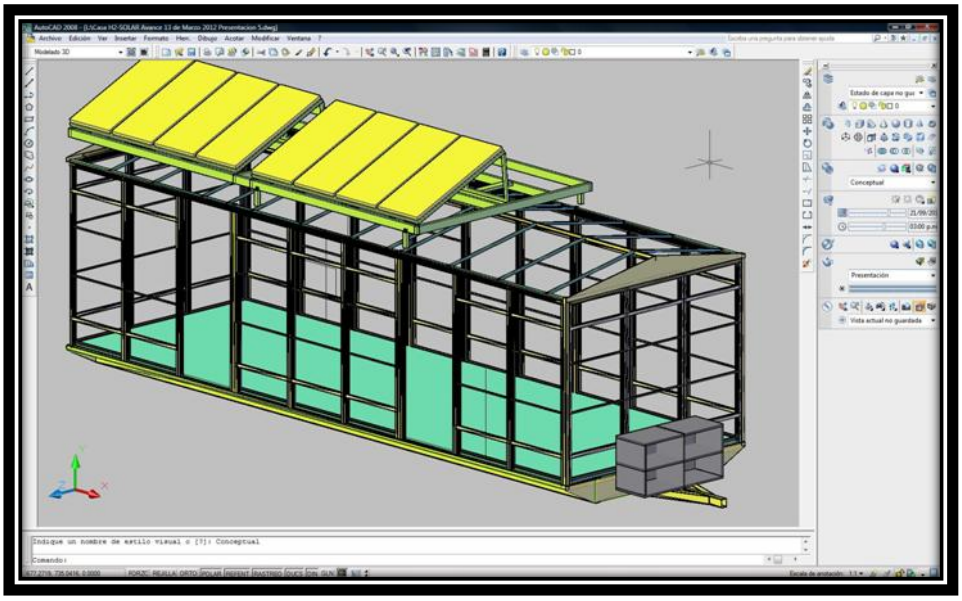

Figure 1. 3D Modeling of the Sustainable Housing

In order to create a functional design for the house, a mobile platform was considered so it could be used with the necessary flexibility, such as translating it to different locations for climate studies in different geographic locations or in didactic exhibitions for educational training. It was also thought that it should have a modular structure for performing subsequent modifications or adaptations and a simple and easy integration of friendly technologies to the environment, such as a solar water heater, rainwater collectors, electrochromatic windows, bioclimatic architecture and solar illumination among other technologies and materials.

The design was made with AutoCad software dimensioning the size of the structure to determine the areas of opportunity in the design. A prototype was developed which helped to define the real dimensions of the final model shown in this paper.

Dimensioning the Phtotovoltaic System

The capacity of the installed photovoltaic system (PVS) was calculated from the electric power demand based on the most commonly appliances used in a Mexican family typical house, establishing a baseline bimonthly consumption average of 150 kW·h. A conventional PV system was installed consisting of polycrystalline Si solar modules, a charge controller, a DC-AC electric inverter and a bank of batteries to obtain a fixed time interval of energy autonomy.

Due to the good average solar irradiance in our country and particularly in Mexico City, we considered 5 hours of effective sunlight per day. This factor shows that Mexico has an important solar potential to successfully implement the photovoltaic technology at homes. Most photovoltaic systems are mainly installed at the present time in public or private companies.

Photovoltaic modules for this stage were acquired of polycrystalline silicon, considering factors such as price, durability and efficiency, since the cost of investment is important for estimating the future savings and recovery cost. On the technical side an automatic charge controller was chosen to prevent that batteries suffer any damage due to overloading or unloading in excess due to the intermittency of solar radiation and the variable consumption of the energy stored in the bank batteries. [6] [7]

The selection of the inverter was considered for operating in isolated systems, such as the bank of batteries, and also to operate in an interconnected system to the grid, with the purpose that the investment may be lower and the return cost takes place in lower time delivering power to the federal electric grid, since in an isolated PVS the use of batteries corresponds approximately to 30% of total investment. The battery bank has the ability to provide 2 days of autonomy to the house, without exceeding the established daily consumption of 2.5 kW·h. The diagram of the PVS is shown in Figure 2.

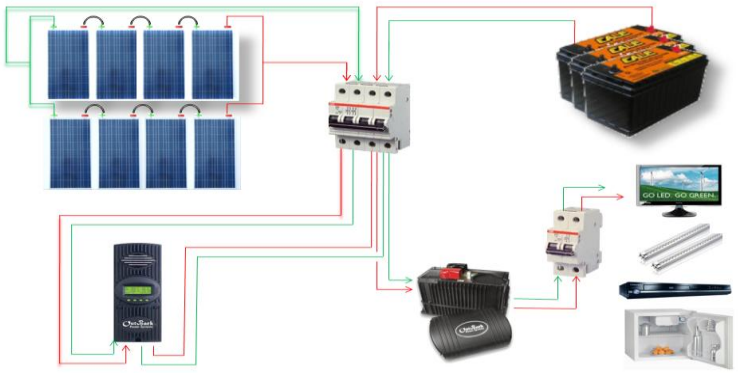

Figure 2. Photovoltaic System Diagram

3. Results and discussion

The photovoltaic system corresponding to the first stage of the sustainable housing project supplies the necessary electric energy making the house to become autonomous in energy for a certain time, covering the electricity demand established within the isolated system due to the use of the household appliances daily in its range of use as indicated above. Figure 3 shows a 3D digital modeling and photograph of the house with the solar panels installed in the roof of the house. On the other hand, the actual technical characteristics for working in the second stage are already established, which consists in the integration of the electrolyzer and hydrogen storage system.

Figure 3. Sustainable house developed at IPN with a 1 kW solar photovoltaic system powering the house. Solar panels installed in the roof are made of polycrystalline Si.

The sustainable housing project is intended to be used as a mobile testing laboratory for studying national and ecological technologies developed to produce clean energy, since it is projected to gradually replace each existing commercial component with devices developed in our labs. The commercial solar panels installed in the house with the technical data obtained to describe its performance for supplying energy to the house will be used as a reference such that we can compare with the performance of the devices we develop in our labs. The Solid State Physics Group of the Physics and Mathematics High Studies School of IPN (ESFM) is currently working on the development of thin film solar panels, with the aim to obtain energy conversion efficiencies values comparable to those of the commercial devices in order to substitute them in the sustainable housing and as a mean to foster a national industry for the production of solar panels.

In addition the School of Chemical Engineering and Extractive Industries of IPN (ESIQIE) in conjunction with the School of Electrical and Mechanical Engineering (ESIME) and the Center for Research and Advanced Studies of IPN (CINVESTAV) are developing prototypes of electrolyzer and PEM (Proton Exchange Membrane) fuel cell devices in order to be integrated and studied in fixed systems.

It is important to point out that other institutions are working on proposals for sustainable housing applications such as the construction of solar monitoring instruments, development of new materials to be used in these technologies, methods to reduce the cost or making affordable the use of PVS, economic impact studies to implement these technologies, and bioclimatic design of structures, among other topics.

4. Conclusions

This multidisciplinary project shows the feasibility of integrating renewable energy technologies based on photovoltaic and hydrogen devices for the development of sustainable housing, which could be located in urban or marginal rural areas. The project was divided in three stages and the first stage has been completed. The benefits of using solar energy has been demonstrated by supplying the necessary electric power to a CFE 01 rated house according to its bimonthly average energy consumption of 150 kW·h, allowing daily at least 5 hours of electric autonomy.

The short-and long term benefits lie in saving up to 100% of electricity consumption in the house, or at least in reducing the power consumption by harnessing a free and inexhaustible energy source as the sun. A direct impact is achieved due to the reduction of electricity consumption tariffs thus benefiting the citizens economy.

On the other hand, another important benefit can be obtained by compensating for the effect caused by the High Consumption Rate (DAC) established by CFE since the last couple of years, which generates electric rate costs greater than 200% of the standard tariff. The DAC applied to a user causes the CFE withdraw of the energy subsidy to the user, when he exceeds the electric energy consumption limit for a period of 12 consecutive months. The consumption limit is determined according to the contracted rate established by the user with CFE.

5. Akcnowledgements

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