A hybrid approach based on a solar PV-hydrogen system for household electric energy supply in Mexico

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ABSTRACT

Mexico as the world has a 90% energy production based on fossil fuels. Therefore billions of CO_2 tons are emitted to the atmosphere; greenhouse gas emissions are generated causing side effects as global warming. On the other hand, Mexico's oil peak production was already reached in 2005 and oil production is decreasing every day. Fossil fuels are non-renewable resources and reserves are being depleted much faster than new ones are being made. Thus the use of renewable energy sources would help to meet increasing energy needs. Besides, every day conventional energy sources increase their cost, while renewable ones become cheaper. In this work we present a hybrid approach based on a solar PV-hydrogen system for household electric energy supply. A mobile house was acquired, designed and dimensioned to be powered by this hybrid system to be used as a demonstration household. A 1 kW PV system was installed in the roof of the mobile house and a hydrogen system made out of an electrolyzer, a hydrides storage tank and a two-500 W fuel cell system will be installed to be used as a back up system. The capacity of the PV-hydrogen system was calculated from the average electric power consumption of a typical Mexican family living in a CFE 01 rated house by the Electricity Federal Agency in Mexico (CFE: Comisión Federal de Electricidad). A direct impact is achieved when renewable energy sources are interconnected to the grid so they cause a reduction in the cost of electricity tariffs, thus benefiting the citizens economy.

Keywords: hybrid approach; PV-hydrogen system; household.

1. Introduction

Mexico has a 90% energy production based on fossil fuels. Its oil peak production was already reached in 2005 and oil production is decreasing every day. As fossil fuels are non-renewable resources, the use of renewable energy sources could help to meet increasing energy needs, making good use of the fact that conventional energy sources increase their cost every day, while renewable ones become cheaper; this goes hand in hand together with technology progress.

In this work we present a hybrid approach based on a solar PV-hydrogen (PV-H_2) system for household electric energy supply. A mobile house was designed and dimensioned [1] to be powered by this hybrid system to be used as a demonstration household. For this purpose a 1 kW PV system was installed in the roof of the mobile house and a hydrogen system made out of an electrolyzer, a hydrides storage tank and a two-500 W fuel cell system will be installed to be used as a back up system.

An estimation of the reduction of CO_2 emission into the atmosphere due to the use of renewable energy sources instead fossil fuels for household electric energy supply is made considering the daily average production of electric power by the PV-H_2 system.

2. Experimental

The mobile house shown in Figure 1 was acquired and designed to be powered by a hybrid system consisting of a PV system and a hydrogen system made out of an electrolyzer, a hydrides storage tank and a fuel cell system, thus it could be used as a demonstration household. This would make possible to show this prototype house to more people as we can move it to different locations for making them aware of the feasibility and benefits of using renewable sources of energy.

Fig 1. Prototype house for household electric energy supply.

The capacity of the PV-H_2 system was calculated from the average electric power consumption of a typical Mexican family living in a CFE 01 rated house by the Electricity Federal Agency in Mexico (CFE: Comisión Federal de Electricidad) [2]. House rating is made according to its bimonthly average energy consumption; CFE 01 rated house has an established baseline day average consumption of 2.2 kW·h/day.

In order to calculate the average daily electric energy consumption of the mobile house we estimated the number of hours that each one of the appliances would be used every day. Considering energy saving appliances should be used in the house, such as lighting LED's for illumination, a 2 ft^2 refrigerator, a LCD 22 in flat screen TV, a DVD and a Laptop, the estimated average daily energy consumption was 2,253 Wh as shown in Table 1.

Table 1. Average daily energy consumption of house appliances.

Imagen	Appliance	Power [W average]	# of hours Used/day (hours)	Energy Used/day (Wh/day)
	Lighting LED	168	5	840
	LCD TV 22"	70	5	350
	DVD	25	3 4 times/week	43
	Laptop	90	5	540
	Refrigerator 2 ft^3	60	8	480
	TOTAL		⟶	**2,253**

Due to the good solar irradiance average in Mexico City, we considered 5 hours of effective sunlight per day. Thus a 1 kW PV system was installed in the roof of the mobile house and a hydrogen system made out of an electrolyzer, a hydrides storage tank and a two-500 W fuel cell system is being installed to be used as a back up system.

A direct impact may also be achieved when renewable energy sources are interconnected to the grid so they cause a reduction in the cost of electricity tariffs, thus benefiting the citizens' economy. The main purpose of this investigation is to develop a sustainable housing project 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 of the existing commercial components with devices developed in our labs.

3. Results and discussion

The PV-H_2 power system of the hybrid approach presented in this work for household electric energy supply is shown in Figure 2. The 1 kW PV system installed in the roof of the house consisted of 8 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.

PV polycrystalline silicon modules were acquired 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 other hand, the automatic charge controller was chosen to prevent batteries might 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 batteries bank.

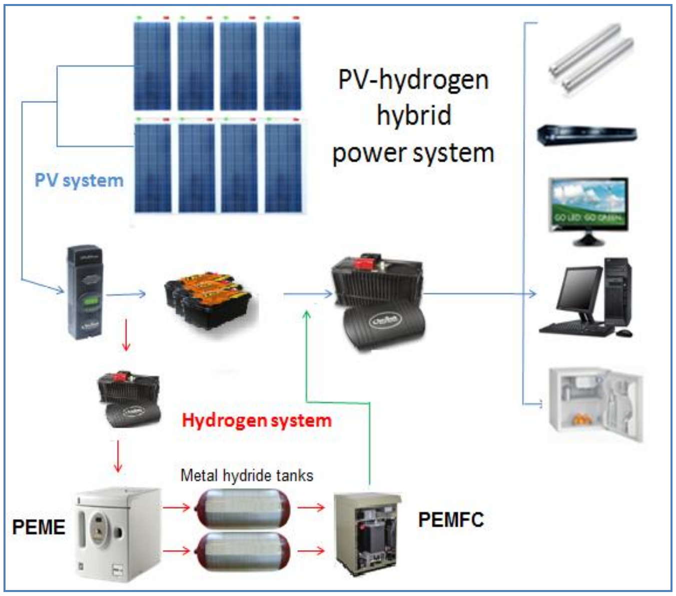


Fig. 2 PV-hydrogen hybrid power system.

The inverter was acquired to operate both in isolated systems, when the electric energy generated by the PV modules is stored in the batteries bank, and in an interconnected system to the grid, with the purpose that the investment may be lower and the cost return takes place in a shorter time delivering power to the federal electric grid. The battery bank provides two days autonomy to the house, when electric energy consumption does not exceeds 2.5 kW·h/day. This is true considering 5 hours of effective sunlight per day, which is an accepted criteria due to the good average solar irradiance in Mexico City.

Electric energy supplied by the PV modules was measured for different weather conditions; that is, measurements were made during sunny, cloudy and rainy days, so the energy output from PV modules could be fully characterized. Thus a more exact estimation of the amount of energy produced during one year by PV modules could be made, as well as an estimation of the reduction of CO_2 emission into the atmosphere due to the use of renewable energy sources instead fossil fuels for household electric energy supply. For this estimation, we considered a daily average production of electric power by the PV-H_2 hybrid system.

PV modules produce electric energy continuously with sunlight so the energy output from them was automatedly monitored using a WinVerter^{TM} Monitor OutBack (OB) Standard software and a Mac Solar V3 sensor which consists in a calibrated solar cell that measures solar irradiance and PV modules temperatures. Measurements were carried out maintaining the PV system operating continuously during 24 hours.

Figure 3 shows the display for the charge controller stage which indicates on the left side the average solar power impinging on the PV modules and the electric power produced by them being sent to the charge controller. On the right side of the display shows the output voltage from the charge controller being sent to the batteries bank. The current-voltage readings at the bottom of the display indicate the input and output power of the charge controller; readings were taken every 10 minutes.

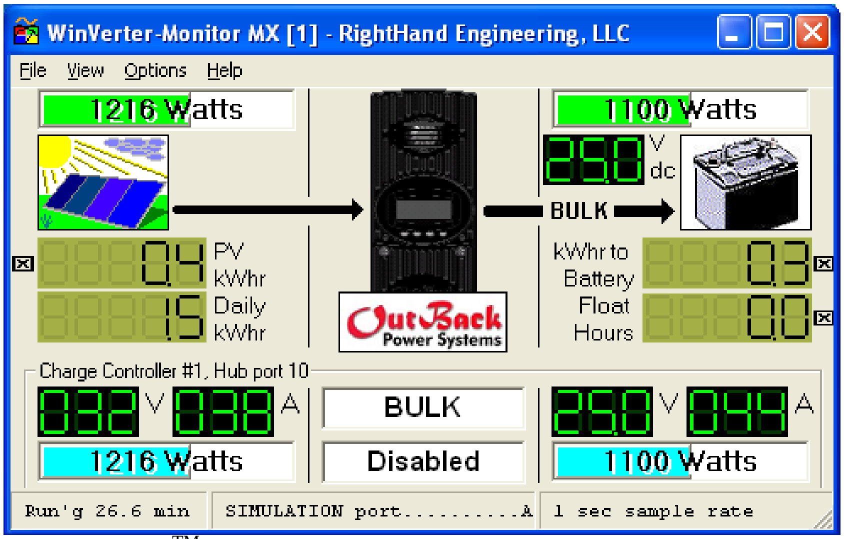


Fig. 3 WinVerter^{TM} Monitor OutBack display for the charge controller stage.

Figure 4 shows the display for the electric inverter stage which indicates in the center below the inverter drawing the direct output voltage from the batteries bank feeding to the electric inverter; the left side is useless. On the right side of the display shows the output voltage from the electric inverter which is used to supply electricity to the house. During daylight electric energy is produced in excess by the PV modules so most energy is stored in the batteries; this energy can be used at night to supply energy to the house, because the house is not connected to the federal electric grid.

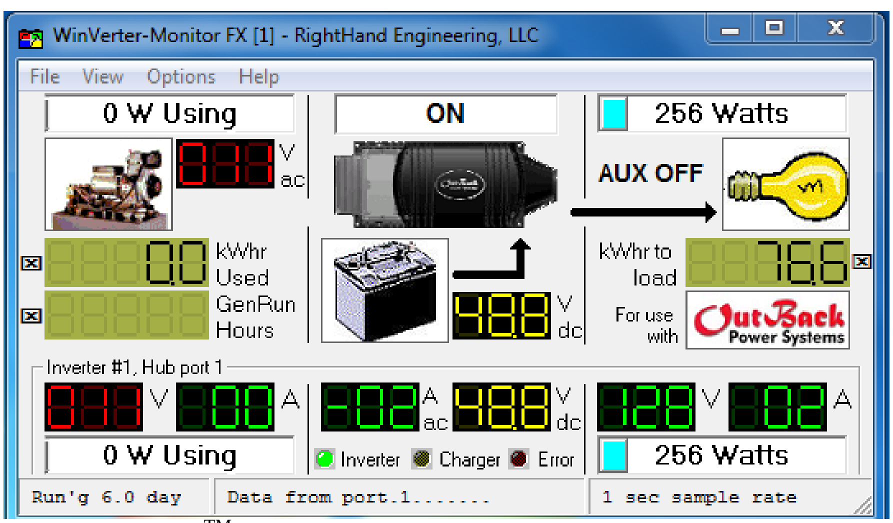
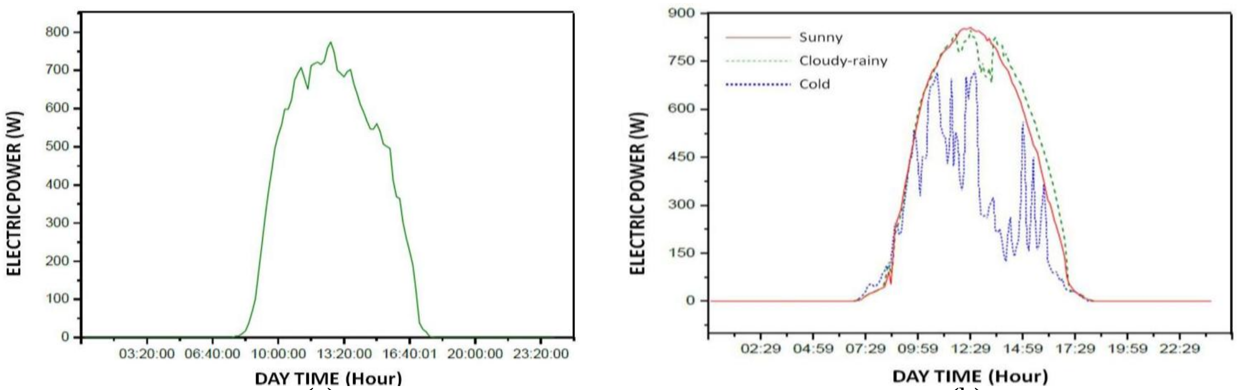


Fig. 4 WinVerter^{TM} Monitor OutBack display for the electric inverter stage.

The average electric power generated by the PV modules is shown in Figure 6 for: a) a typical day, and b) for days under different weather conditions: sunny, cloudy-rainy and cold.



(a) (b)

Fig. 5 Average electric power generated by the PV modules for: a) a typical day, and b) for sunny, cloudy-rainy and cold days.

As expected, electric power produced by the PV modules occur only during daylight, reaching its maximum production at around 13h00. Figure 5b shows that power production during cloudy-rainy days is still high close to power generation for sunny days; this occurs when days are not cold. For cold days power generation decreases dramatically; this is due to the fact that PV modules efficiency decreases with temperature affecting the power generation. In order to obtain the maximum power production by the PV modules, the house was oriented along the east-west direction and the modules placed in the roof of the house inclined an angle of 23°, with the highest side on the north direction.

In order to obtain the total amount of electric energy produced by the PV modules during one day we may calculate the area under the curve of Figure 5. This was done by numerical integration using the OriginPro 8.5 program. The value obtained for a typical sunny day was 4.5066 kW·h, corresponding to the plot of Figure 5a.

On the other hand, the average electric power consumed by all electrical appliances which are used in the house during one whole day is shown in Figure 6.

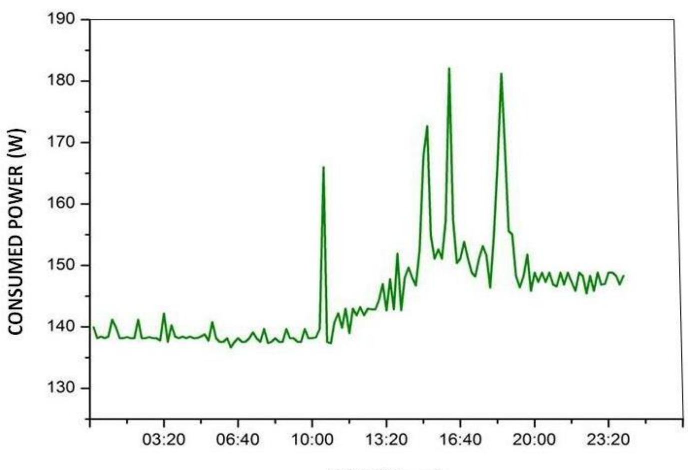


Fig. 6 Average electric power consumed by electrical appliances in the house.

The graph in Figure 6 shows that power consumption is the lowest during overnight until noon, when it starts rising to the maximum power consumption which occurs during night until the moment people goes to sleep. Sharp peaks are due to transient behavior which appear when some appliances are turned on, such as the illumination panels, TV set, DVD device, and others. Small peaks appearing during overnight and superimposing the main curve may be due to the refrigerator working cycle.

In order to obtain the total amount of electric energy consumed by the house electrical appliances during one day we proceed the same way as above by calculating the area under the curve of Figure 6. The value obtained was 3.4782 kW·h. Thus we obtained an excess electric energy produced by the PV modules of 1.0284 kW·h, which means that for sunny and cloudy-rainy days (which are not cold) this energy can be stored in the batteries bank, allowing us to have some autonomy without having to be connected to the federal electric grid. But if this were the case, the electric energy produced in excess would be supplied to the grid causing a reduction in the cost of the electricity tariffs. Due to the good solar irradiance average in most of Mexico´s territory, we can take advantage of this fact to produce electric energy for household by using PV modules. This means also that the use of renewable energies for household electric energy supply would cause an economic impact in benefit of citizens.

Production of electric energy by using renewable energy sources causes a positive impact to the environment as the processes involved do not cause CO_2 or any other contaminant emissions. In order to estimate the reduction of CO_2 emission, in our case due to the use of PV modules for household electric energy supply, we have to know the CO_2 factor (units: kg/KW·h) which indicates the kg amount of CO_2 produced in a country per kW·h of produced electric energy. This factor varies from one country to another and in the case of Mexico it has a value of 0.456 kg/kW·h [3].

The reduction CO_2 emission is obtained by the product of the electric energy produced times the CO_2 factor. In our case we have an average electric energy produced by the PV modules of about 4.5 kW·h and multiplying this by the CO_2 factor we obtain a value of 2.055 kg, which is the daily reduction of CO_2 emission. Thus we obtained a yearly amount of 750.07 kg of CO_2 which are not emitted to the atmosphere thanks to the use of PV modules.

In order to complete the development of this sustainable house prototype powered by a hybrid PV-H_2 system and continue its use as a demonstration household to show the benefits obtained from the use of renewable sources of energy, we are in the process of installing a hydrogen system consisting of: an H_2Planet PEM electrolyzer, model HyPEM XP-300 with an H_2 production of 300 cm^3/min; an H_2Planet hydrides storage tank, model MyH2-900 with an storage capacity of 900 l and two Horizon PEM 500 W fuel cell system, model H-500 (FSC-B500). This H2 system has already been acquired of which and will be used as a back up system, supplying electric power to the house during night or when the batteries power is exhausted.

4. Conclusions

We presented a hybrid approach based on a PV-H_2 system for household electric energy supply, using a mobile house powered by this hybrid system to be used as a demonstration household. We obtained an daily average production of electric energy by the PV modules of 4.5 kW·h, which surpasses the daily average electric energy consumption by the mobile house, thus causing a reduction in the cost of the electricity tariffs to be paid and having an economic impact in benefit of citizens. On the other hand, it has also a positive impact to the environment as there may be an important reduction on the amount of CO_2 or any other gas contaminant emissions.

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References

[1] Armando Yunez Cano, (Acta de examen 17740) "Modelado 3D e integración de una casa sustentable solar-hidrógeno", Tesis de licenciatura ESIQIE-IPN, 07/02/2013.
[2] Comisión Federal de Electricidad CFE: http://www.cfe.gob.mx.
[3] Power and productivity for a better world: [http://new.abb.com/energy-efficiency/globaltrends-in-energy-efficiency].