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DESIGN OF GRID CONNECTED-PV SYSTEM FOR A HYDROGEN REFUELING STATION

Sachin Deshmukh, Yahia Baghzouz, Robert F. Boehm
Center for Energy Research
University of Nevada, Las Vegas
Las Vegas, NV 89154-4027

ABSTRACT

This paper describes the design of a 14 kW grid-tied photovoltaic system for powering a hydrogen generation and refueling station that is being constructed at the Las Vegas Valley Water District. The fixed array layout is determined by considering the available space, aesthetics and impact of shading on annual energy production. Computer simulations using PV-DesignPro software and area hourly solar radiation data are conducted to simulate the energy flow into and out of the electric utility grid for different profiles of hydrogen use. Stand-alone system operation is also simulated to estimate the maximum amount of hydrogen that can be produced under limited storage.

INTRODUCTION

The vision of the hydrogen economy is based on the expectation that hydrogen can be produced from domestic sources that are environmentally friendly, and that applications using hydrogen (in the transportation sector, for example) can gain market share in competition with the alternatives. The steps that should be taken in terms of technical, social, and policy challenges, to move toward the hydrogen vision and to achieve the sought-after benefits are discussed in detail in Ref. [1]. As a consequence, various ways are being sought for the production of hydrogen from renewable energy sources [2]-[6], and many of the major automobile manufacturers are currently pursuing the development of hydrogen engines and fuel cell powered vehicles [7], [8].

Since the solar resource in Southern Nevada is one of the best in North America, it is an obvious choice to drive a local hydrogen generation system. This paper describes the design of a grid-connect PV system to power a Hydrogen Generation and Dispensing System (HGDS) that is being constructed at the Las Vegas Valley Water District (LVVWD). Both analytical models

and experimental studies have been conducted on photovoltaic-hydrogen generation system in terms of performance and economics at great length [2]-[3]. However most of the studies are conducted on a stand-alone basis where power availability and energy storage is of primary concern. First, a brief description of the software tool used for computer simulations is given. This is followed by the electrical characteristics of the load to be served, and the selection of the PV array layout. Simulation plots of electric power flow into or out of the electric utility grid for various load profiles are presented. The case of a stand-alone operation with no battery storage is also simulated to estimate the yearly hydrogen production under such operation. Finally the experience of the authors with attempts to secure Renewable Energy Credits (RECs) that have been established in Nevada is described.

SIMULATION TOOL

The computer simulation tool that was used in this study is PV-DesignPro (originally developed by Sandia National Laboratory, and currently marketed by Maui Solar Energy Software Corporation [9]). This software is designed to simulate photovoltaic energy system operation on an hourly basis for one year, based on a user selected climate and system design. Three versions of the PV-DesignPro program are available: "PV-DesignPro-S" for standalone systems with battery storage, "PV-DesignPro-G" for grid-connected systems with no battery storage, and "PV-DesignPro-P" for water pumping systems.

Since the PV system being simulated is grid-connected (with the option of operating off-grid), the G version of the above software is used. Further, the Perez et al. solar radiation model is selected in lieu of the Hay-Davies-Klucher-Reindl (HDKR) model since the former is more detailed as compared to the latter [10].

ELECTRICAL LOAD

The electrical load of the hydrogen station consists of the following:

- An electrolyzer (developed by Proton Energy Systems) that is rated at 6.5 kW (at which it produces nearly 0.92 kg of hydrogen per hour). The amount of hydrogen produced at lower power is nearly proportional to the current draw.
- A 3 hp motor that drives a compressor of the hydrogen storage subsystem (that is provided by Air Products Inc.). The compressor power draw depends on the storage tank pressure and temperature, and its maximum power demand is expected to be nearly 2.5 kW.
- Auxiliary load such as facility lighting and controls. The power demand of these small loads is estimated not to exceed 0.25 kW.

The total electric load above adds up to nearly 10 kW, when taking the power converter and transformer losses into account.

Two small hydrogen-powered vehicles (one is powered by an internal combustion engine and another by a combination of a fuel cell and deep-cycle batteries) will utilize the hydrogen produced while being driven regularly at the host's main facility. The hydrogen dispensing rate and periodicity highly depends on the frequency and duration of use of these vehicles. A rough estimate for hydrogen requirement of a small car powered by hydrogen-fuel cell could be made based on published information on prototype vehicles. For example, the fuel cell powered Honda FCX's published characteristics show that the hydrogen consumption/range is 4.6 kg hydrogen/395 km range. If we assume 15,000 km driving per year, the annual hydrogen consumption of this particular vehicle will be nearly 175 kg.

PV ARRAY AND LAYOUT

The following are constraints that are imposed on the PV array design:

1. The Las Vegas Valley Water District allocated a rectangular space (measuring 40 x 50 feet) that is adjacent to the HGDS for the installation of the PV array.
2. Due to its simplicity and minimal maintenance, the fixed-array type is selected over 1-axis and 2-axis tracking systems.
3. Due to the high initial cost of photovoltaic systems, the system size should be in the range of 14 kW (peak).
4. Aesthetics should be taken into consideration by keeping a low array profile (not to exceed 6 feet in height).
5. A specific type of PV panel (namely, Sharp ND205U1) is to be used due to the fact that the Las Vegas Valley Water District is placing nearly 3 MW of these panels at other facilities within the Las Vegas Valley. Some of the electrical characteristics of Sharp

ND205U1 are listed below, while more details may be found in [3].

- **Power Rating:** 205 W
- **Cell Type:** Poly-crystalline silicon
- **No. of Cells and Connections:** 60 in series
- **Open Circuit Voltage (Voc):** 36.3V
- **Maximum Power Voltage (Vpm):** 28.9V
- **Short Circuit Current (Isc):** 7.91A
- **Maximum Power Current (Ipm):** 7.1A
- **Maximum Power (Pmax):** 205W
- **Module Efficiency:** 12.6%

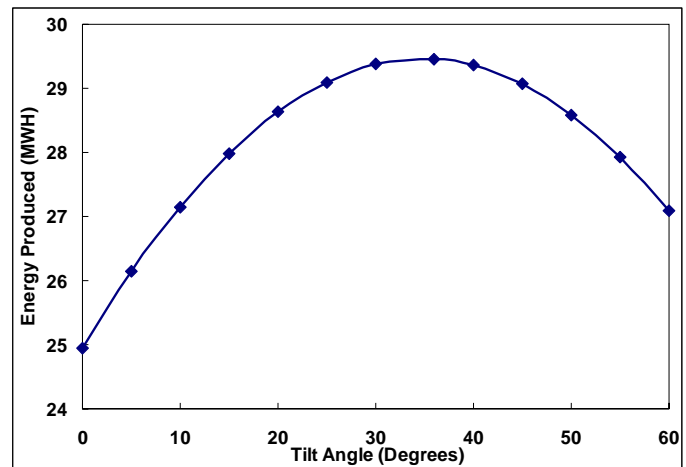


Fig. 1: Annual Energy Production of 14 kW PV Array as Function of Tilt Angle.

Another element to consider is the tilt angle of the array. The optimal angle that results in maximum annual energy production is equal to the latitude angle (i.e., 36 degrees) as depicted in Fig. 1 below. The wind loading imposed on the PV array also strongly depends upon the array size and tilt angle: A higher tilt angle results in higher wind load, thus a stronger and more expensive structure is required to hold the array in place.

After considering the above constraints and taking the impact of shading into account, it was determined that one of the best configurations is to have five rows, each consisting of two strings of 7 panels as shown in Fig. 2. The array is tilted at 36 degrees from the horizontal facing south, and it is less than 6 ft in height. The PV mounting structure is 2 ft above ground, and the spacing between two adjacent rows is six feet.

Electrically, the 10 PV panel strings are connected in parallel, thus resulting in an overall PV system with the following electrical specifications: Open circuit voltage = 254 VDC, short circuit current = 79 A, and maximum power = 14.35 kW. Shading for this specific layout was found to reduce the annual energy production by just over 5%.

GRID INTERCONNECTION

The 14.35 kW PV system will be grid-connected so that excess power can be fed into the local power grid, which in

turn provides power at night and during cloudy days. The local electric utility company has a net metering allowance; hence, the LVWD can redeem decreases in the power bill at the same energy cost.

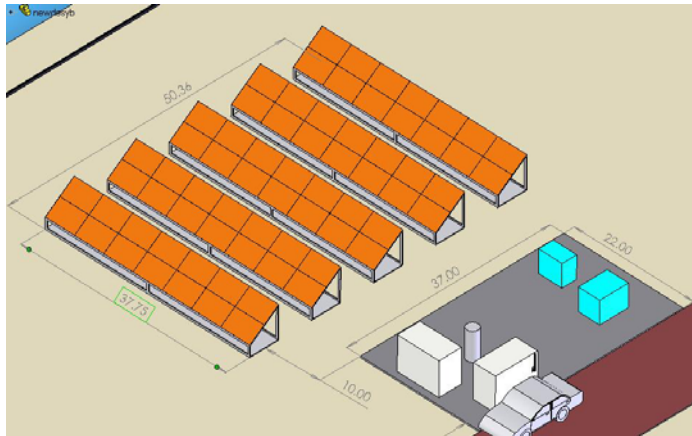


Fig. 2: Final Array Layout.

Fig. 3 shows a block diagram of the PV grid-interconnection. The PV terminals are fed through a DC disconnect switch to a three-phase grid-tie inverter that is connected to a 3-phase 208/480 V step-up transformer through an AC disconnect switch, then to the utility distribution transformer through a net meter. The hydrogen generation and dispensing station is normally supplied from the 480 VAC terminals. As an alternative, the station can also be supplied by the PV system through a DC/DC converter. This latter case is applicable when operating in stand-alone mode, or during utility power outages.

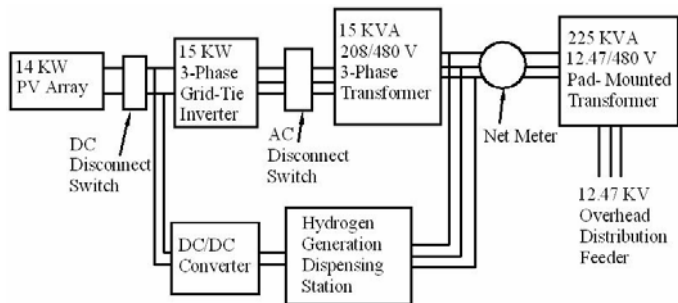


Fig. 3: Block Diagram of PV Grid-Interconnection.

One of the main concerns of the electric utility company when it comes to grid-connected PV systems is the issue of possible islanding. To mitigate this concern, non-islanding inverters - designed to safely interface with the utility grid - are required for such installations. If a utility has to shut down a distribution line for repair or maintenance, or the line is damaged, the non-islanding inverter will automatically disconnect from the grid. It does so by sensing the deviations in line voltage and/or line frequency that occur under abnormal grid operating conditions.

COMPUTER SIMULATION

Simulations are conducted by specifying a certain hourly electrical load profile of the Hydrogen Generation and Dispensing System. The actual electrical demand will depend on the profile of the hydrogen use, which in turn reflects the frequency and duration of use of the two hydrogen vehicles described earlier. The limited hydrogen storage tank capacity of 7 kg is also plays a critical role on the electric power utilization.

Fig. 4 shows the linear relation of the net yearly energy supplied by the utility grid as a function of hydrogen produced. Obviously negative values, which occur at lower hydrogen production, mean that the PV array produced more energy than required by the load. Zero net energy flow occurs at a hydrogen production rate of around 285 kg/year. This corresponds to PV generation of nearly 31 MWhr. If the station operates at full power 24/7 every day of the year, it will produce just over 800 kg of hydrogen, and consume a total of 87.5 MWhr of energy (of which 56.5 MWh comes from the power grid).

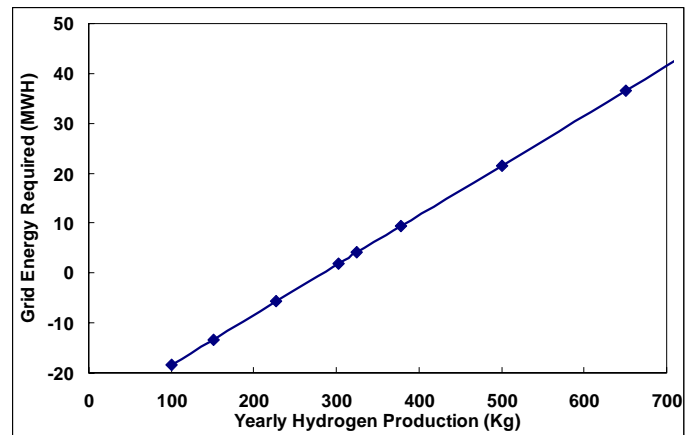


Fig. 4: Yearly Utility Energy Supply as Function of Hydrogen Production.

The expected power flow in or out of the utility grid can also be examined on an hourly basis for a given load profile. For example, Fig. 5 shows both utility and PV array power supply for at constant full load, i.e., 10 kW, over a 24 hr period of a typical summer day. Note that power flows back into the grid during the 10:00 AM – 2:00 PM time period where the PV generation exceeds the load demand.

Another illustration is depicted in Figs 6 and 7 where the daily energy produced by the PV array matches the load demand (i.e., net energy supplied by the grid = 0). In here, the station can either run at 40% capacity over 24 hours (Fig. 6), or at 100% capacity over 9 hours (Fig.7). As far as the utility company is concerned, it is best to run the Hydrogen Generation and Dispensing System at night during the months of peak demand, namely, May through September. Such operation will assist in utility load leveling by reducing the

apparent demand during the day and increasing it during the night hours.

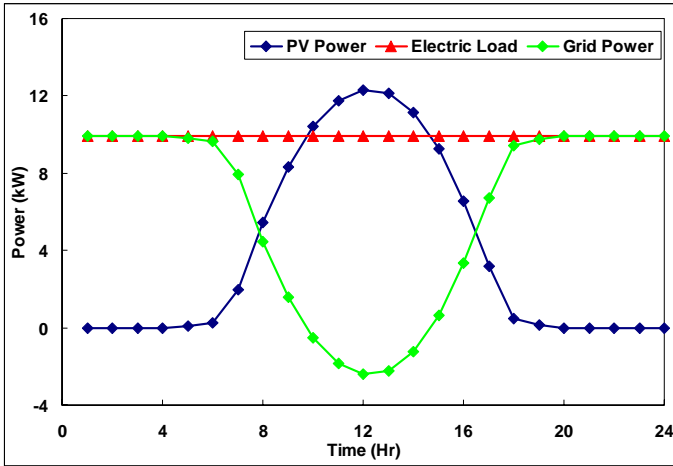


Fig. 5: PV and Grid Power during Typical Summer Day (Load Demand = 100% Over 24 hr.).

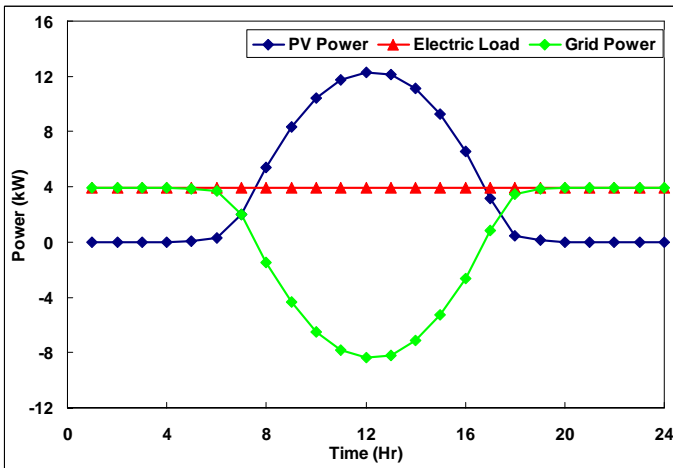


Fig. 6: PV and Grid Power during Typical Summer Day (Load Demand = 40% Over 24 hrs.).

The simulated PV system should qualify for Nevada Renewable Energy Credits (RECs). These are a result of Nevada Revised Statutes 704.7821 that requires each provider of electrical service in the State generate or acquire electricity from renewable sources, or save electricity in the amount of not less than 6% of the electricity in 2005 and 2006 (it increases in later years). Of that amount, at least 5% has to be generated or acquired from solar. Hence RECs are worth money to the utilities in trying to meet the requirements of the RPS, and this is set at 1 REC/kWh. The Nevada Public Service Commission has stipulated that photovoltaic generation where at least 50% of the power generated is consumed on site qualifies for 2.4 REC/kWh. This should apply to the system described above, thus decreasing the cost of the system to the supplier.

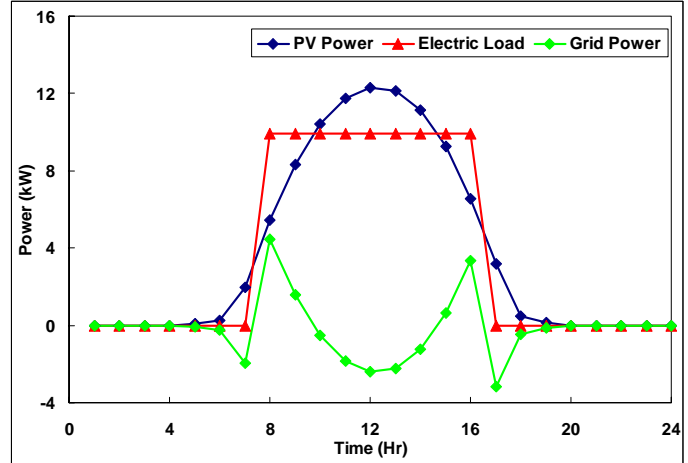


Fig. 7: PV and Grid Power during Typical Summer Day (Load Demand = 100% Over 9 hrs.).

STAND ALONE OPERATION

This section describes the performance of the hydrogen refueling station when operating in stand-alone mode. Operation in this configuration is limited to periods of sunshine due to lack of energy storage. In addition, the extra energy that is available during time periods where the PV system the peak demand cannot be utilized, thus reducing the

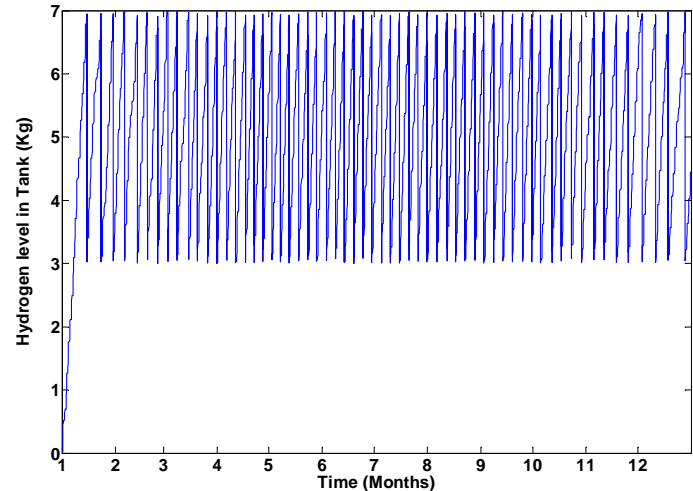


Fig. 8: Hydrogen Level (kg) in Storage Tank. effectiveness of the PV array.

Simulations are performed over a one-year to estimate the total amount of hydrogen to be expected from solar energy only. Since the storage tank is limited to 7 kg, it is assumed that every time the tank reaches 100% state-of-charge, it is discharged down to a state-of-charge of 42% (i.e., 4 kg are removed) to maintain adequate dispensing pressure. Fig. 8 shows the hydrogen tank level (in kg), while Fig. 9 shows the corresponding total amount of hydrogen that is discharged as a function of time. After 60 discharges, with an average of 6 days between discharge periods, the total amount of hydrogen that is discharged is nearly 240 kg.

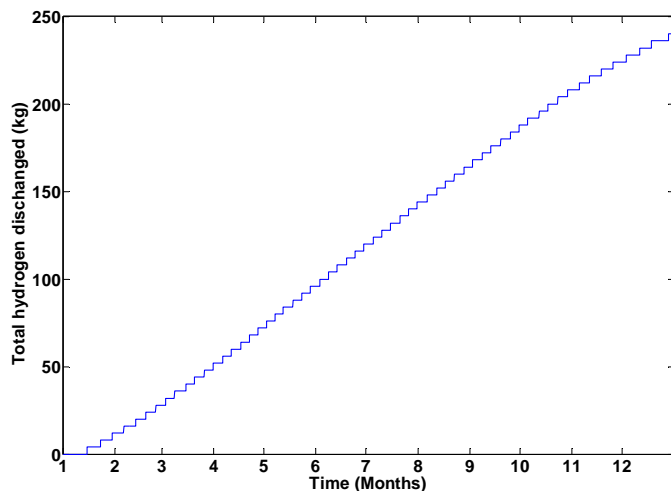


Fig. 9: Total Hydrogen Discharged (kg).

CONCLUSION

This paper described the design of a 14.35 kW grid-connected PV array to assist with the electrical power demand of a local hydrogen generation and dispensing station. The array layout was determined after considering some specific constraints in terms of land availability, aesthetics and array size. Computer simulations were conducted to determine the net energy supplied to or by the power grid for different amounts of hydrogen produced. Stand-alone operation is also simulated in case the owner wants to operate the station on solar energy only. Future work will report actual data on the plant performance once the pv array and hydrogen station are installed.

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