AC 2007-2346: DESIGN OF A RENEWABLE ENERGY BASED POWER SYSTEM FOR A ZERO-ENERGY VISITORS' CENTER

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I. Introduction

The work presents the design and building of a hybrid, solar and wind powered system, which will provide electricity to a "zero energy visitors' center" (ZEVC). The hybrid energy system and the "Leed"[1] certified visitors' building will be located on the Van Ness campus of the University of the District of Columbia. The system is intended to increase the viability and deployment of renewable energy technologies by way of disseminating in the community at large, valuable information on the benefits brought to society by renewable energy sources. The proposed system will serve as a practical demonstration of the operation of a combination of solar and wind energy sources. Through the visitors' center, a variety of audiovisual systems will be operated for demonstration and educational purposes. The proposed project is expected to deliver up to 2,000W (Watts) of electric power from an array of photovoltaic (PV) solar modules, and up to 900 W of electric power from a wind turbine generator, to give a total of 2.90 KW of electricity. This hybrid system will power a 600 square-foot mobile visitors' center with a self-maintained cooling system, and equipped with a big screen television, and other small appliances. The electricity generated from the hybrid system will also be used to light up selected areas of the university's campus at night, to improve students and public safety. In addition, the system will power a DC/AC submersible pump placed in a large (800 gal.) transparent water tank, where the pumped water will be recycled back for demonstration purpose. This project will include a two-axis solar tracking photovoltaic power system for maximum conversion efficiency. Under the utility power company permit, the wind/solar system can also be net metered, so that any surplus energy will be tied to the grid. The entire design of the zero energy visitors' center and the hybrid solar/wind system is handled by University students from the various engineering and applied sciences disciplines.

II. Proposed structure of the Zero Energy Visitor's Center (ZEVC)

The proposed Zero Energy Visitor's Center, supported with a grant from the District of Columbia Energy Office (DCEO) and sponsored by the university's Center of Excellence for Renewable Energy (CERE, http://cere.udc.edu), is expected to be built on the campus of the University of District of Columbia. The initial proposed structure of the center is a 600 square feet single room with a small partition for housing the system control equipment as depicted by Fig. 1. The main room will comprise a variety of appliances and electronic components.

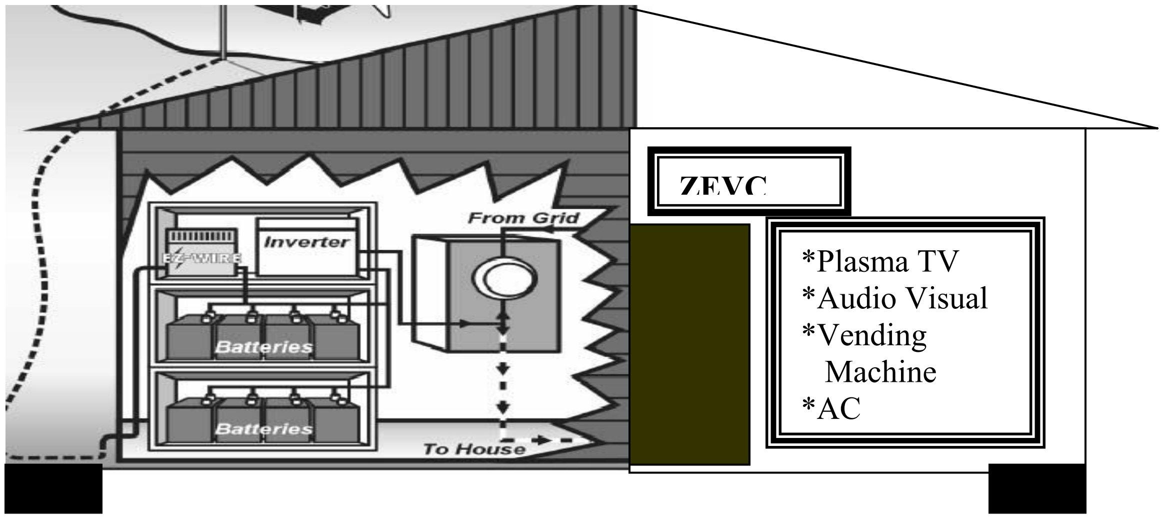

Fig. 1. Partial Depiction of the zero energy visitors' center (ZEVC)

The proposed visitor's center will initially house the following items:

1. A 42-in liquid crystal display (LCD) flat screen TV;
2. A radio/VCR/DVD combination;
3. A personal computer (laptop) with wireless internet access;
4. A vending machine;
5. A small sized window mounted air conditioning unit; and
6. A display panel which displays the instantaneous power delivered to the center.

The construction of the center is expected to secure certification as per the standards of "leadership in energy and environmental design[1]" (LEED). It is also expected to be a "mobile" structure.

The center's primary objectives are to:

1. Demonstrate to visitors the use of solar energy and wind energy to deliver enough electric power to activate the appliances and electronic components in the visitor's center;
2. Access several online renewable energy educational and public information sites in order to stream their respective video on a large LCD screen for viewing by visitors;
3. Provide 24/7 information to visitors on the total power being delivered to the center; and
4. Highlight the powering of a simple DC powered grid-independent water pumping system and its importance to remote rural communities in developing countries.

III. Power needs

Electric power is delivered to the center from renewable energy sources which are primarily solar energy and wind energy.

The basic format of power generation is depicted in Fig. 2. The solar energy is captured through an array of photovoltaic solar modules. The wind energy is transformed into electric power through a wind generator.

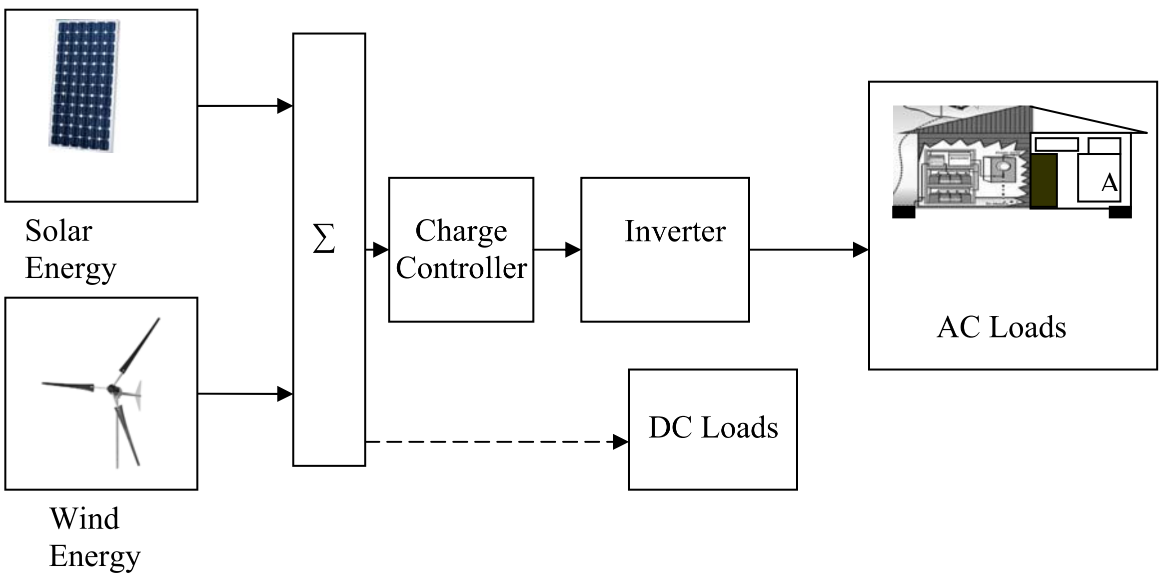

Fig. 2 Basic power generation structure

A. Solar energy

The solar energy collected by an array of photovoltaic (PV) modules required for operating, on a scheduled time basis, the appliances and electrical components of the center is evaluated as per the following standard steps:

1. Load calculation;
2. Inverter selection and evaluation of total ampere hours (Amph);
3. Solar array sizing; and
4. Battery sizing

Load calculation

The AC and DC loads have to first be listed and the total watt-hour (Wh) required per week for the prescribed operation of all the appliances must be evaluated.

Table 1 and Table 2 summarize the estimated amount of AC and DC power respectively.

Description of AC Loads	Power (Watts)	x	Hrs/wk	Wh/Wk
Plasma TV	150	x	10	1,500
Laptop computer	90	x	10	900
Lighting (4 compact fluorescent)	20	x	40	400
Small vending machine	300	x	25	7,500
Audio system (VCR/DVD)	40	x	10	400
Air conditioner (Window unit)	1,000	x	10	10,000
TOTAL				21,000
Inverter loss & battery efficiency (1.25 x Total)				26,370

Table 1: Estimation of AC power in watt hour/week

Description of DC Loads	Power (Watts)	x	Hrs/wk	Watth/Wk
Submersible Water Pump	900	x	2.5	2,250
TOTAL				2,250

Table 2: Estimation of DC power in watt hour/week

The total load will draw a power of **28,620 Watt hours/week.**

Selection of inverter and evaluation of the ampere hours per day (Amph/d)

The total ampere hour per week is derived from the general formula Power= Voltage x Current.

For the selected 24V, 2.4KW, 60Hz, 120V inverter from Xantrex[2], the ampere hours per week equivalent to the total AC and DC loads are therefore:

Ampere Hours per week $= \frac{28,620}{24} = 1,192.5$ Amph/week, yielding $\frac{1,192.5}{7} = 170.35$ Amph/day.

Solar array sizing

This step will determine the number of solar modules required to sustain the power required by the loads and estimate the wind power generated from the wind turbine. Table 3 summarizes the solar array sizing.

Total average Amph/d required by the system loads	**171**
Compensation for loss from battery charge/discharge (1.2 times total)	**206**
Average sun hours per day	**4.23**
Total solar array amps required	**48.69**
Optimum or peak amps for solar module (BP 480)	**4.7**
Total number of solar modules in parallel required	**11**

Table 3: Solar array sizing

Battery sizing

The battery sizing is summarized in Table

Total average Amph/d required by the system loads	**206**
Maximum number of continuous cloudy days	**3**
Adjusted average Amph/d	**618**
Adjusted average Amph/d to maintain 20% reserve after deep discharge	**772.5**
Battery temperature multiplier	**1**
Amph for battery chosen (12V)	**220**
Total number of batteries in parallel required	**4**

Table 4: Battery sizing

B. Wind energy

Wind energy is very limited in the Washington DC metropolitan area where the visitors' center will be located. The electric power generated by the wind turbine is therefore considered as a nonessential supplement to the electric power which will be delivered by the solar panels as evaluated in the last section.

However, the selected wind generator, the Whisper H80 wind turbine, which can withstand a wind speed as high as 45 mph, is capable of generating appreciable electric power as shown in Fig. 3, starting at a wind speed of 7mph. It generates about 45,000 Watt hours/week, at 12.5mph wind speed.

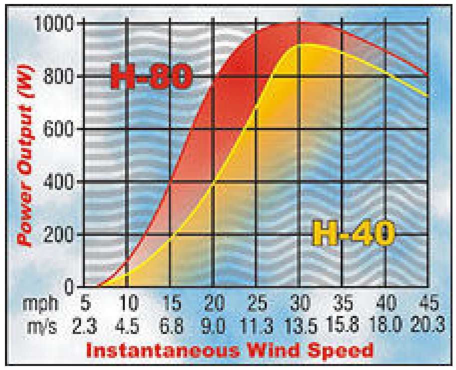

Fig. 3 Instantaneous power output performance curve of a Whisper H80 & H40 wind turbines (from Southwestwindpower Inc.[3])

As shown in Table 5, the recorded wind speed data for the last 53 years at the Reagan Washington National Airport shows the annual average wind speed is around 10 mph yielding an instantaneous power output of about 150W.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec.
Wind speed mph	10.0	10.4	10.9	10.5	9.3	8.9	8.3	8.1	8.4	8.7	9.3	9.6

Table 5 . Wind speed data recorded at the Reagan Washington National Airport (From NOAA average wind speed data through 2001[4])

It is to be noted that wind energy, unlike solar energy, is delivered at variable levels during 24 hours and could be an uninterrupted source of power albeit at a relatively lower level of power. It is therefore very conservative to assume that an average of 150Wh is generated by the wind turbine thus offsetting the total power and yielding a total of **150x24x7=25,200 Watt hours/week** as a result of its 24/7 operation.

IV. Proposed power system

The renewable energy-based systems proposed for adequately supplying the power need assessed in section III. is depicted in Fig. 4.

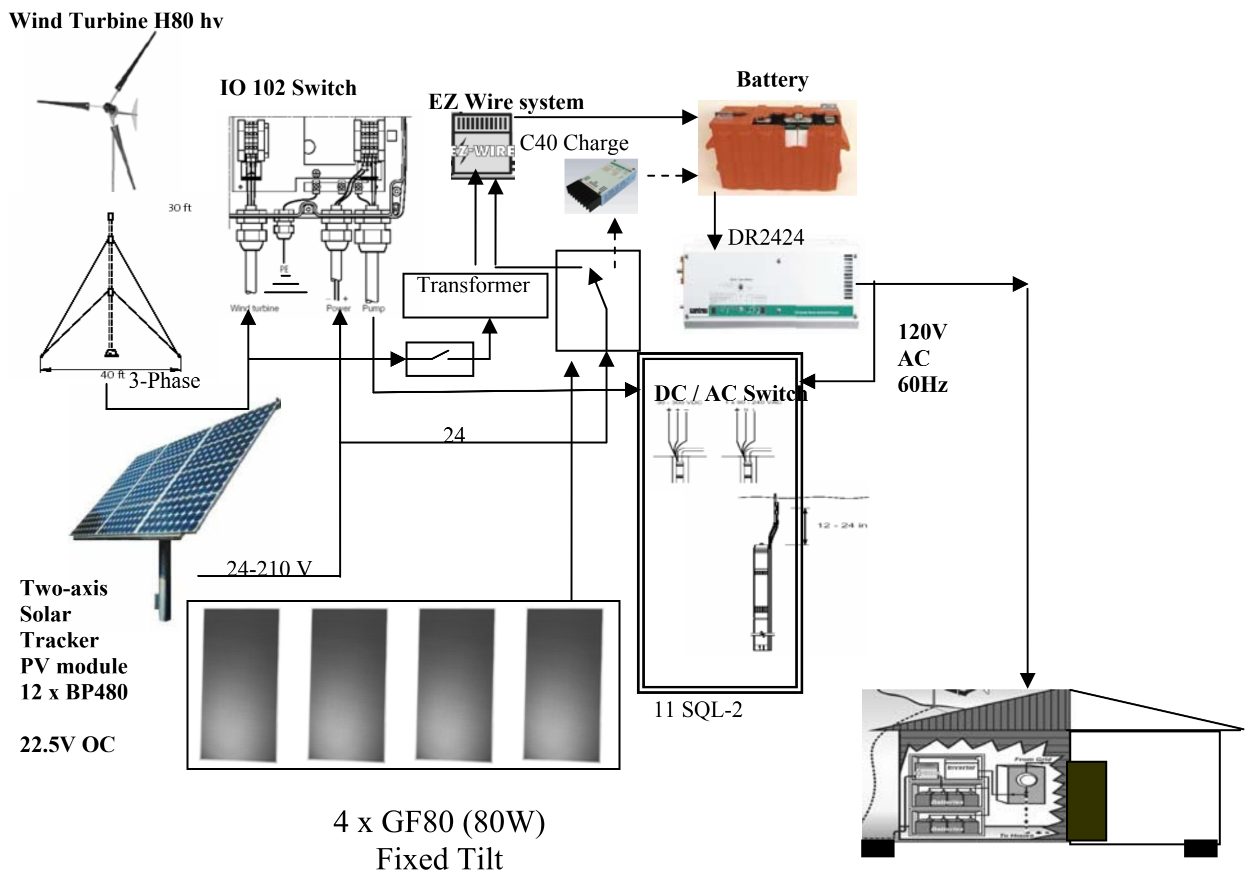

Fig. 4 Proposed renewable-energy based power

The proposed renewable energy based power system comprises the following components:

1. A solar tracking PV array of 10 BP 480 (80W) modules;
2. A Whisper 200 (H80) high-voltage wind turbine mounted on a 30-ft tower;
3. A step down transformer to step the high AC (~ 100V) voltage from the wind generator to 24V AC and its corresponding 24V AC to 24V DC converter (EZ Wire system);
4. A single pole mounted, fixed tilt set of GF80 (80W) PV modules;
5. An IO 102 switch box for combining the wind turbine output voltage and the solar tracker's output voltage to produce a single DC voltage for activating the submersible pump 11 SQL-2;
6. A C40 charge controller[2] to control the DC voltages from the PV arrays;
7. A DR2424 inverter[2];
8. A DC disconnect switch; and
9. A battery bank of 12V, 220 Amph deep cycle batteries (sulfuric acide thixotropic gel).

The items 3, 6, 7 and 8 are mounted on a mobile structure as shown in Fig. 5.

Fig. 5 Mobile module comprising a step-down transformer, C40 Charge controller, DR2424 inverter, a DC disconnect switch and a battery bank

The wind turbine and solar tracker are shown in Fig. 6. The single pole mounted set of 4 GF80 PV panels will be placed in the same vicinity.

Fig. 6 Wind turbine and solar tracking PV array

Brief description of the operation of the Solar/Wind combo power system

The Whisper 200 wind turbine (a.k.a. Whisper H80) is wired to provide a three-phase system of voltages up to 100VAC/Phase.
The solar tracking PV array is an AZ-125, Wattsun[5] tracker, equipped with 12, BP480, 80W solar modules. In addition, an array of 4 GF80 solar panels from Grundfos[6] are mounted on a

pole and set on a fixed tilt. The voltages generated by the solar tracker and the wind turbine are fed to an IO102 switch box from Grundfos. The AC voltage from the wind turbine is converted to DC and is combined to the DC voltage from the solar tracker. The DC output from the fixed-tilt solar array is fed directly to the C40 charge controller.

DC only operation

In the DC only mode of operation, the DC output of the switch box is connected directly to a Grundfos 11-SQL-2 pump, which can operate both in DC (from 90 to 300V) and in AC (from 120 to 240V). In the DC only mode of operation, only DC loads such as the pump can be operated. The system will operate only if there is enough electricity produced by the solar tracker or the wind turbine. The DC only operation is therefore limited to occasional pump operation demonstrations under an ideal weather condition.

AC only operation

Under the AC only operation, a portion (24V) of the DC output from the solar tracker is fed to a charge controller, the C40 (from Xantrex) or alternatively, the EZ-wire charge controller, which in turn charges a bank of deep cycle batteries. The batteries will then feed a DR2424 or DR1524 inverter which will produce a 120V AC voltage @ 60hz with a power which can reach 2.4KW. Also, under the AC only operation, the 150V AC from the wind turbine is stepped down thru a transformer to provide a 24V AC and fed to the EZ-Wire charge controller, which in turn charges the batteries.

V. Student participation

Student participation was essential for the success of the project. Students from the school of engineering and applied sciences have participated in the initial setup of the power station. As shown in the setup pictures, the mounting and assembly of the solar panels as well as the erection of the wind turbine were handled by students as partial fulfillment of their junior or senior project assignments.

Pictures showing the students assembling and mounting the PV modules and erecting the wind turbine

VI. Conclusion

The proposed power station appears to be well suited for the zero energy visitors' center which will be constructed by summer 07. With the exception of the single pole mounted, fixed tilt solar array which will be erected soon, all the other components are fully operational. To date, tests were conducted by supplying power to the submersible pump which was shown to visitors at various instances.

VII. Acknowledgements

The support of the following companies was instrumental in the building of the power system: BP Solar, Grundfos, Xantrex. The construction of the zero energy visitors' center is supported by a grant from the DC Energy Office.

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6. Grundfos submersible pumps and GF series panels (http://www.grundfos.com)