Analysis and Design of a Domestic Solar-Wind Hybrid Energy System for Low Wind Speeds

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ABSTRACT
A solar-wind hybrid power generation system has been presented here. The application based system illustrated in this paper is designed on the basis of the solar and wind data for areas in Northern India. The power generated by the system is intended for domestic use. The most common source of unconventional power in homes is battery based UPS (Uninterrupted power supply) inverter. The UPS inverter charges the battery with conventional grid power. This system will charge the battery of UPS inverter by using only wind and solar power, which will make the system cost effective and more reliable. The reason for using both solar and wind is that recent studies have proven that combined system can be more productive and consistent and other thing is that neither of them can be used for continuous power generation. In the system illustrated in this paper the solar-wind system provides power periodically which is controlled by electronic methods and a microcontroller is used to monitor the power from both the inputs. The switching action is provided from the microcontroller to the battery charging based on the power received from solar photovoltaic panel and wind generators. In this paper, an efficient system has been presented comprising of solar panel, wind generator, charge controller and charge storage unit (battery). Solar panel is selected as the main input and the wind resource will be used only in the absence of the solar photovoltaic (PV) output.

Keywords
photovoltaic, hybrid, UPS, grid

1. INTRODUCTION
In the recent times the need for energy has increased globally. The electrical energy has now become the base for almost everything. This has made us to increase our energy production which in turn has put extra pressure on our non-renewable resources. The other way is to generate energy by using renewable resources of energy. The renewable resources like hydro power are being utilized to generate power but these projects take years to complete and there are lots of other factors involved which discourages these projects. The more suitable form of renewable energy in the modern era is the solar energy. The solar energy can be utilized in many ways. The two of the most basic uses of sun light to make electrical energy are:

- Solar Photovoltaic.
- Solar Thermal.

Solar photovoltaic is a system to convert light energy (photons) into electrical energy. Solar thermal means to use the heat energy of the sun to generate electrical energy thermally. The solar water heaters and steam based solar turbine are the systems where solar thermal technique is used. The paper presented here is based on the solar photovoltaic systems. The solar photovoltaic has given us the chance to become producer of easy and clean energy. The solar systems can be installed on a small house or a big industry. The solar panel uses the solar irradiance to generate electrical energy. A solar panel uses energy of the incident photons on its surface to generate electrical charge. The solar panel consists of small silicon cells. The cell output voltage for a single cell is of the order of 0.7V (under open circuited conditions) which cannot be utilized for power generation. These cells are placed in series-parallel combinations to get usable voltage.
The other renewable energy resource is the wind energy. The wind energy is utilized by converting the kinetic energy of wind in to rotational motion by using a wind turbine. This rotational motion is converted into usable electrical energy. For this purpose a wind generator has been used which contains a wind turbine and an alternator.
The systems with only solar or wind generation are productive but there are problems linked with both of them. The solar power is not available for 24 hours and wind is not continuous all the time. So a hybrid system containing solar and wind has been designed to overcome these shortcomings. A system has been designed in this paper which utilises both solar and wind power generation systems. Recent researches in the field of renewable resources shows that the solar and wind hybrid power generation system can work with increased outputs and increased practicality [6]. The block diagram of this system has been shown below

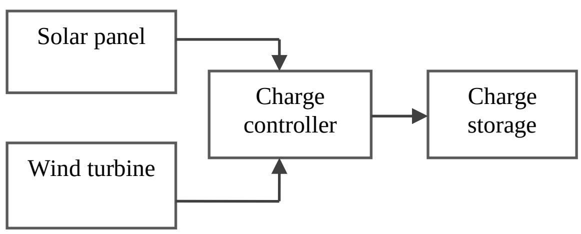

Fig 1: Block diagram of the solar wind hybrid system

The system illustrated in this paper has been designed on the basis of the solar and wind data available for the selected area that is north India and for more accurate working Chandigarh has been selected as a more specific location and all the calculation here after are based on Chandigarh and on the areas surrounding Chandigarh. The following charts show the solar irradiance and wind speed data for the selected location. The data has been acquired on the basis of following details:

- Area: - Chandigarh
- Latitude: - 30.7353 °N
- Longitude: - 76.7911 °E
- Elevation:- 695m

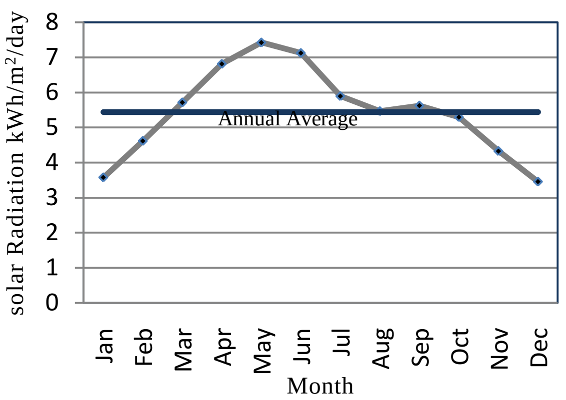

Fig 2: Yearly solar isolation data for Chandigarh area

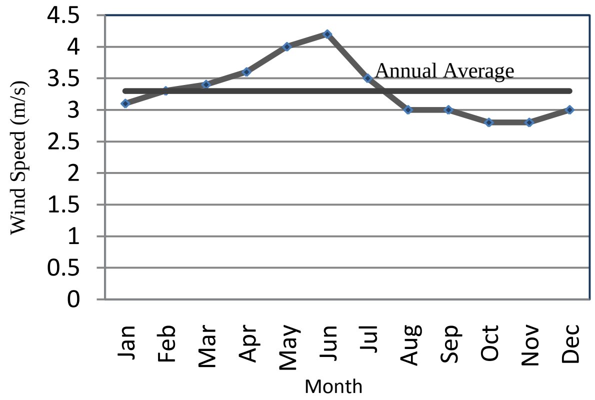

Fig 3: Wind speed chart for Chandigarh area

On a sunny day, the solar output is high and wind generation is less but during night time or cloudy and windy days the wind generator output is more. This results in a complete self dependent system.

2. APPLICATION

The proposed system in this system is designed to charge a common domestic UPS battery. The normally used battery with domestic UPS is having capacity of 150Ah. So, the main aim of this system will be to control the charge storage from solar and wind inputs to the battery. The units of this system are:

- Solar photovoltaic panel.
- Wind generator.
- Charge controller.
- Storage unit (battery).

These units have been discussed in detail in next sections.

2.1 Solar Photovoltaic Panel

The basic working principle of a solar panel is that it contains silicon cells which have small p-n junctions inside them. The incident photons create free charge carriers. These charge carriers are separated through the junction and then electric current is generated. The different arrangements of the silicon cells generate different levels of voltage and current.

The solar photovoltaic panel is selected on the basis of system requirements and before selecting the panel it should be kept in mind that it is preassembled and its specifications cannot be altered thereafter. The battery used to store charge is of 150Ah capacity. The selection of the solar panel depends on the time it takes to charge the connected battery. To calculate the charging time the following equation [9] can be used:

$$peak\ hour\ required = \frac{V(batt)*Capacity(batt)}{power(SPV)} \quad \text{………(1)}$$

This equation can also be written as

$$power(SPV) = \frac{V(batt)*Capacity(batt)}{peak\ hr\ required} \quad \text{………(2)}$$

Since there are only 4-6 hours of peak sun so, a panel will be required which can charge the battery in 4-6 hrs initially.

$$Power(SPV) = \frac{12V*150Ah}{6hrs}$$

So, the power comes to be 300W. Considering the losses a 350 Watt solar photovoltaic panel has to be used or rather a panel arrangement that will produce 350W output. The costing of a 350W system will be around 30,000 which will be quite high for a domestic use. To lower down the cost panel wattage should be decreased and for that increased charging time has to be compensated. Since, the battery is not discharged completely on daily basis and the UPS is used only when grid is not there. So, this will allow us to scale down the system. The system designed here uses 100W solar panel which has following specifications: -

- Maximum Power Pmax – 110W
- Maximum Power Voltage Vmax- 17.25V
- Maximum Power Current Impp (A)- 5.79A
- Open Circuit Voltage – 21.7V
- Short Circuit current- 5.90A
- Module Efficiency- 13.35%
- Module Dimensions- 1350 *650 *32mm (±1.5mm)
- Mounting Hole & Distance -6.9 & 200mm
- Weight - 7.9Kgs
- No. of cells-36
- Cells configuration – 13*3
- Price-9,000 (Approx.)

Now inserting the given value into the formula to get the charging time for the battery:-

$$peak\ hours\ required = \frac{12V*150Ah}{100W}$$

Peak hours required = 18hrs.

Since 18 hrs is a long time provided that a solar panel generates peak power only for 4-6 hours a day. So here this hybrid system proves useful because it can generate power at times when sunlight is not present.

2.2 Wind Generator

Analysing the wind pattern and designing the wind turbine for this system proves to be most challenging work. Since the average wind speed at this area is around 3.5m/s. But the provided data suggests the wind speed on an average basis in which there are times when wind blows with high speeds and there are times when there is no wind. During night time the speed of wind is quite high of the order of 8-12 m/sec and this system will convert that kinetic energy into electrical energy. The maximum power available through wind resource is given by this equation [1]: -

$$P=0.5*\rho*A*V^3\ (in\ watts)$$

Where P= Power

ρ=density of air (1.2kg/m^3)

A=Area perpendicular to the flow of wind

V=Wind velocity

The above equation only gives theoretical power but in reality the output is much lesser so, a power coefficient has to be added with the given equation C_p=0.4.

$P=0.4*0.5*\rho*A*V^3$ (in watts) ..... (3)

Since the system is designed for low wind speeds and domestic use so the wind turbine needs to be small and efficient. For the calculation purpose the assumed diameter of the turbine is 1 metre and that gives us the area of the wave front of the turbine to be 0.785m^2. For Chandigarh the data can be calculated as follows: -

ρ=1.23 (kg/m^3)
A=0.785m^2
V=6.5m/s

The power output of this system according to equation (2) is 53.03 watts. This result is totally theoretical and the actual results may differ.

2.2.1 Turbine Design

The construction of the wind turbine starts from the design of the turbine. There are basically two types of designs which can be implemented: -

A. Horizontal Axis Wind Turbine (HAWT)
B. Vertical Axis Wind Turbine (VAWT)

An HAWT is the most commonly used because it is more efficient because the blades are always facing against the wind. This makes them to extract maximum power out of the wind but the drawback is that a tail has to be used so that it should be always in the wind's direction. Whereas in VAWT there is no need of a tail but the full power of wind is not utilized in this design it is more suggested for high wind speed applications.

A wind turbine of 1 meter diameter is sufficient for this project. The blades have been made from normal PVC pipe. The generator is directly attached to the rotor. The generator used in this system is a simple permanent magnet DC motor. Since the wind speed at the area is less so, the RPM (Revolution per Minute) of turbine will be less and the motor chosen as a generator should have a low RPM. If motor used has high RPM rating then gears have to be attached to adjust the RPM between rotor and motor. The motor/generator used in this system has the following specifications: -

- Voltage – 90volts
- R.P.M.- 2500
- Current- 3.9Amp

Since the motor produces 2500RPM at 90 volts so, when rotated at 2500 RPM the motor will generate approximately 90 Volts of voltage theoretically. This gives us the ratio of RPM to volts to be -:

$$\text{RPM to volts ratio}=\frac{RPM}{voltage} \quad \text{....... (4)}$$

Substituting motor specifications in to equation (4)
RPM to volts ratio=2500/90= 27.78 RPM/Volt
So to generate 12volts from the generator the generator should have RPM=27.78*12=333.36. Now calculate RPM of the rotor. To calculate RPM, TSR (Tip Speed Ratio) has to be calculated but TSR also requires calculation of tip speed of the blades which is possible only when the turbine is ready. So this simple empirical formula [9] is utilized:-

$$\lambda = \frac{4\Pi}{n} \quad \text{......... (5)}$$

Where λ= Tip Speed Ratio for maximum power output
n=no. of blades

Since, the no. of blades used in this project are four so, the TSR is 3.14. So using this TSR value the theoretical RPM can be calculated for this turbine- :

$$RPM=60*V*\frac{TSR}{\Pi D} \quad \text{......... (6)}$$

Where V=Wind Velocity (m/s)
TSR=Tip Speed Ratio
D=Diameter of Turbine (m)

Now substituting values into equation (6), V=5m/s, TSR=3.14, D=1meter, then obtained RPM=300. So, at the speed of 5m/s the turbine rotates at 300 RPM and that is sufficient for the system as the electrical generation will be more with increasing wind speed. The proposed system will work on both solar and wind energy. The generated dc output will be monitored by the microcontroller continuously and on getting suitable input and suitable condition the generated power is supplied to the charge storage unit.

2.3 Charge Controller

The charge controller is an electronic circuitry which monitors the solar and wind input and generates control for the charging. It is discussed in detail in this section. Charge controller works on electronic circuits and masters the system functioning. The charge controller is connected to both solar and wind inputs. It senses the voltage level from solar panel and wind generator. Then as per the algorithm defined it selects the suitable resource that is either solar PV or wind turbine to store the charge. The batteries used in the system are 12V batteries so we need at least 13-14 volts system input to charge them continuously.

A solar panel is normally rated for 12 volt output but the peak open circuited voltage for the panel goes around 20-21 volts. The output of the same solar panel drops to 17-18 volts when connected to load. Similarly the output of the wind turbine also changes with the change in the wind speed which occurs frequently. So a charge controller has to control these changes also. The algorithm followed by the charge controller used in this system is as follows:

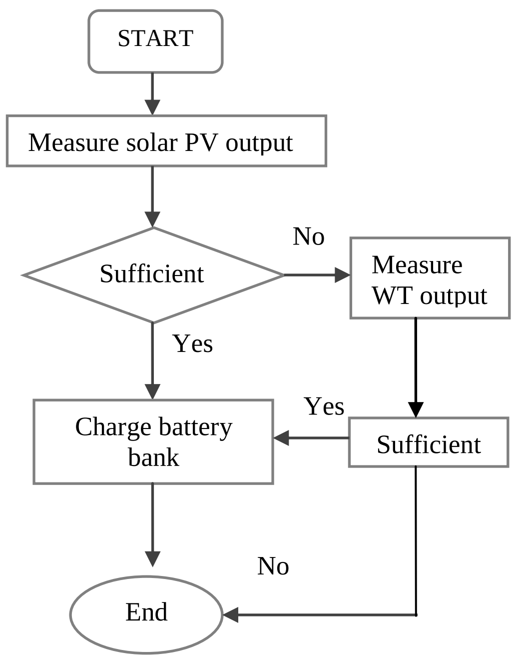

Fig4: Flow diagram of the controller algorithm

The algorithm aims at the solar panel output as the main input for the system as it is more dependable. The various switching operations are performed by the charge controller. The heart or brain of this system is the 8051 microcontroller. The microcontroller model used in this system is AT89C51 which is most commonly available microcontroller in the market. The reason for using 8051 is that it has each and everything available onboard which is required for this system and also for the future improvements in the system. Other thing is that it can be programmed easily with simple assembly language programming or C language program and is cheaper than other families of microcontrollers.

The working of the microcontroller depends upon the input output signals provided to it by other connected circuitry. To sense the solar panel input voltage, a voltage sense circuit has been used. This circuit contains a zener diode and a grounded emitter npn transistor. The circuit diagram of this sense circuit has been illustrated below.
The input from the solar panel is supplied to a resistor network comprising of two 10kohm resistors which divides the panel output and then feeds it to the zener diode. The zener diode has nominal zener voltage of 7.5volts. So, when the voltage at the zener diode exceeds 7.5 volts then the current flows through the diode to the transistor. As the gate voltage at the transistor increases the transistor goes to saturation mode. Then the voltage at the collector grounds through emitter and hence it provides a logic low to the microcontroller input pin. Pin P1.0 has been used to sense the solar panel output.

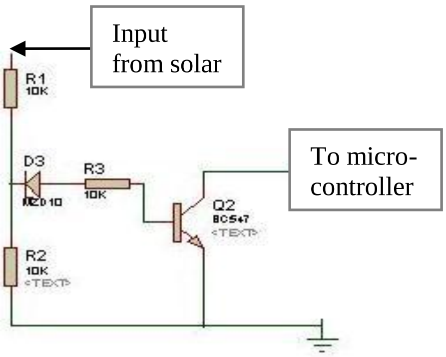

Fig5: Solar panel voltage sensor with grounded emitter transistor

The microcontroller senses for the logic low at P1.0 and sends a corresponding logic high signal to the pin which has been connected to the relay controller circuit. The relay controller circuit has been described below: -

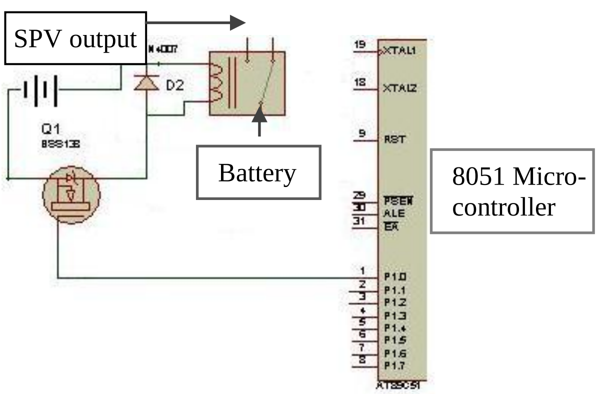

Fig6: Circuit to control the switching

The pin P1.1 has been connected to the gate terminal of the power MOSFET. The MOSFET used in this project is IRPF460. This is an n-channel MOSFET which is used for high power and high switching speed applications. When the gate voltage is applied to the MOSFET it operates in saturation region and the relay connected in series to the transistor energises and the panel output is connected to the battery. This will enable the charging of the battery.

Before connecting the solar panel to the battery it is also required to check for the battery voltage if the battery is fully charged then we need not to connect it to the solar panel. The same circuit with some modification can also be used to sense for wind turbine output. To completely monitor the battery voltage with load supply control, an ADC has to be used. For serial input and parallel output ADC 0804 can be used.

An LCD has also been used in this project to guide the user about various things happening inside the charge controller. The LCD used in this project has been used in 4-bit mode to save the pins of the microcontroller. In 4-bit mode only 6 pins of the microcontroller are required to be interfaced with the microcontroller. This LCD will have messages like “Charging on”, “Battery full”, “Battery low” etc. LED’s have also been used in the circuit to indicate common functions.

3. SYSTEM COSTING

The system costing is based on the price of various items that are available at the time of the installation. However the price may be different for different locations and working conditions.

Table1. Solar-wind hybrid System installation costing

Serial no.	Item	Cost (in Rs.)
1.	Solar panel	9,000
2.	Wind Generator/Motor	4,500
3.	Charge controller	600
4.	Wind Turbine assembly	800
5.	Panel mounting	300
Total		15,200

4. DISCUSSION

Based on this analysis this solar-wind hybrid system can be used by any domestic user at a place where wind speeds are not that good. It will charge the inverter battery even when there is no grid power. There is lots of space for improvement in this system like Maximum Power Point Tracking (MPPT) or other power enhancement methods. This improvement can be incorporated without any big increase in the system costing because there is only a little addition to the electronic components to the charge controller circuitry. This can prove a vital system in the field of renewable energy resources and can be seen in every household in the northern India.

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