Local PV-Wind Hybrid Systems Development for Supplying Electricity to Industry

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Abstract *- Due to intermittent natural energy resources and energy resources seasonal un-balance, a PV-wind hybrid electrical power supply system was developed for many remote locations where a conventional grid connection is inconvenient or expensive. While the hybrid system is also applicable with grid connection, owners are allowed to sell excess electricity back to the electric utility by using net meter.*

The proposed set-up consists of a photo-voltaic solar-cell array, a mast mounted wind generator, lead-acid storage batteries, an inverter unit to convert DC power to AC power, electrical lighting loads and electrical heating loads, several fuse and junction boxes and associated wiring, and test instruments for measuring voltages, currents, power factors, and harmonic contamination data throughout the system. The proposed hybrid solar-wind power generating system can be extensively used to illustrate electrical concepts in hands-on laboratories and demonstrations in the Industrial Technology curriculum.

This paper describes an analysis of local PV-wind hybrid systems for supplying electricity to a private house, farmhouse or a small company with electrical power depending on the need at the site. The major system components, work principle and specific working condition are presented in this paper.

Keywords: solar power, wind power, hybrid generation, renewable energy, grid

1. INTRODUCTION

Energy has been playing an important role in human and economic development and world peace. Since the world economic resuscitation and boom, world total energy annual consumption in 2002 has increased, while fossil fuel (i.e. coal, oil, natural gas) provided three quarters of the total.

At current energy consumption rate, proven coal reserves should last for about 200 years, oil for approximately 40 years and natural gas for around 60 years. With the contradiction between rapid development and diminishing fossil fuel resource, as well as to avoid pollutant emissions or other environmental problems, and not to involve the resulting healthy hazard, we should consider the manner in which we produce and consume energy for sustainable development.

Renewable energy(1), i.e., energy generated from solar, wind, biomass, geo-thermal, hydropower and ocean resources, could increases diversity of energy supplies and offer us clean energy beyond all doubt. The energy generated from wind and solar is much less than the production by fossil fuels, however, electricity generation by utilizing PV cells and wind turbine(2) increased rapidly in recent years, particularly in Germany, Japan, the U.S., and Denmark.

Photovoltaic (PV) cells are electronic devices that are based on semiconductor technology and can produce an electric current directly from sunlight. The best silicon PV modules now available commercially have an efficiency of over 18%, and it is expected that in about 10 years' time module efficiencies may rise over 25%.

Wind power is electricity produced by a generator, which is driven by a turbine according to aerodynamics in flowing air. Wind power is one of the fastest growing renewable energy technologies around the world.

PV modules and wind turbines(3)are now widely used in developed countries to produce electrical power in locations where it might be inconvenient or expensive to use conventional grid supplies, while other homeowners who choose the renewable energy sources prefer to connect their energy system to the grid as a huge 'battery' for some convenient grid-tied situation. In contrast, in many developing countries, especially in rural areas electricity grids are often non- existent or rudimentary, and all forms of energy are usually very expensive. Here the PV modules and wind turbine can be highly competitive with other forms of energy supply. However, the fact that natural energy resources are intermittent and storage batteries are expensive, has led to the utilization of so-called hybrid renewable energy systems. Any power system that incorporates two or more of the following is referred to as a hybrid power system: PV panels, wind turbines, or diesel, propane, gasoline generators. For small loads, the most common combinations (4) are PV-wind hybrid system. PV and wind is good match, because inland wind

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speeds tend to be lower in summer, when solar energy can compensate, and higher in winter, when sunshine falls to very low levels.

In this paper, a PV-wind hybrid system is presented that can supply electricity to a private house, farm house or a small company or an apartment house with electrical power depending on the need at the site where used. The aim of this study is to introduce the local PV-wind hybrid system’s working principle by reviewing one case where the system is connected to the grid.

2. SPECIAL ISSUES OF WIND TURBINES AND PV CELLS

As the wind does not blow all the time nor does the sun shine all the time, solar and wind power alone are poor power sources. Hybridizing solar and wind power sources together with storage batteries to cover the periods of time without sun or wind provides a realistic form of power generation. This variable feature of wind turbine power generation is different from conventional fossil fuel, nuclear or hydro-based power generation. Wind energy has become the least expensive renewable energy technology in existence and has peaked the interest of scientists and educators the world over.

Photovoltaic or PV cells, known commonly as solar cells, convert the energy from sunlight into DC electricity. PVs offer added advantages over other renewable energy sources in that they give off no noise and require practically no maintenance. PV cells are a familiar element of the scientific calculators owned by many students. Their operating principles and governing relationships are unfortunately not as pedagogically simple as that of wind-turbines. However, they operate using the same semiconductor principles that govern diodes and transistors and the explanation of their functioning is straightforward and helps to make more intuitive many of the principles covered in semiconductor electronic classes.

Most industrial uses of electricity require AC power. Wind-turbines and PV cells provide DC power. A semiconductor-based device known as a power inverter is used to convert the DC power to AC power. This device has a relatively simple operation that is a vivid illustration of many topics traditionally covered in power electronics classes.

3. SYSTEM ANALYSIS

3.1. Specific site conditions for PV-wind hybrid system

Intermittent natural energy resources and energy resources seasonal unbalance are the most important reason to install a hybrid energy supply system. The PV-wind hybrid system suits to conditions where sun light and wind has seasonal shifts i.e., in summer the daytime is long and sun light is strong enough, while in winter the days are shorter and there are more clouds, but there is usually an increased wind resource that can complement the solar resource.

The PV-wind hybrid systems especially suit the remote location, which is inconvenient or expensive to use conventional grid supplies. The common type is connecting with battery storage. For PV array, a direction without any obstacles facing the sun is needed. For the wind turbine, appropriate wind speed and wind direction are key element to whole system. The turbine should be mounded into non-turbulent wind higher than trees and without other obstacles. Enough space is needed to site the PV modules, wind turbine tower, and also to properly anchor the guy wires.

3.2. System Components

In general, a local cost-efficient, safe, and durable PV-wind hybrid system is composed of the core part (PV modules and wind turbine); PV modules mounting and wind turbine tower; DC-AC inverter; safe equipment such as fuses, disconnects, and lighting arrestor; meters and instrumentation; batteries, charge controller regulator and backup power resource for battery storage systems; and also connection wires, switching, and wall socket.

Photovoltaic (PV) modules convert sunlight into direct current (DC) electricity. Modules can be wired together to form a PV array that is wiring modules in series the available voltage is increased and by wiring in parallel, the available current is increased. However either way, the power produced is the same since watts (power) equals voltage time amperes. A typical PV module measures about 0.5 square meters (about 1.5 by 3.5 feet) and produces about 75 watts of DC electricity in full sun.

Wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. Most turbines have either two or three blades. These three-bladed wind turbines are operated "upwind," with the blades facing into the wind. The other common wind turbine type is the two-bladed, downwind turbine. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. Utility-scale turbines range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping.

DC-AC inverter changes low voltage direct current (DC) power, which is produced by the PV or wind turbine or stored in the battery into standard alternating current (AC) house power that is 120 or 240 VAC, 50 or 60 hertz. The “modern sine wave” Inverters supply uninterruptible power, i.e. there are no blackouts or brownouts. The inverters come in sizes from 250 watts to over 8,000 watts. While there are also "modified sine wave" inverters that are cheaper but can still handle most household tasks.

However, this type of inverter may create a buzz in some electronic equipment and telephones, which can be an annoyance. The better sine wave inverters have made great strides in performance and price in recent years. Inverters can also provide a utility inter-tie between your system and the utility grid, allowing you to sell your excess energy to the utility for distribution by their grid. Many inverters also have built-in battery chargers to keep your batteries topped off from either the grid or your generator.

PV modules mounting and wind turbine tower are engineered to withstand the PV modules and wind turbine. The PV modules mounting can be a ground mount that works either on rooftops or the ground, or pole mount for getting them up in the air. Both are angle-adjustable so that PV array will face the sun as near to perpendicular as possible. Many owners will adjust their mounting racks two to four times a year to get maximum exposure as the sun changes its angle during seasons. Or if the rooftop has a good angle to the sun, the modules could be mounted solidly to the roof without an adjustable rack. Trackers are another PV mounting option, which are pole mounts that automatically adjust themselves so that the PV could face the sun throughout the day. Because the wind turbine should be mounded into non-turbulent wind, a tall enough wind turbine tower is needed (9 m above anything within 120 m). And there should also be enough space to properly anchor the guy wires.

Safe equipment includes over-current and lightning protection components. Over-current protection components such as fuses and fused disconnects protect the system's wiring and components in the event of short circuits. Fusing protects from over-current situations, and disconnects allow safe shutdown of system components for maintenance and repair. Fuses and fused disconnects are rated by the amount of current they can handle. They may be as small as a few amperes for supplying metering to as large as 400 amperes for supplying the inverter. Many renewable energy systems are in areas where thunderstorms and lightning are common, especially; the wind turbine is always the highest building in the remote area. Commercial lightning arrestors are available to help protect RE system electronics against the lightning.

Meters and instrumentation can help owners keep track of important things like the battery voltage, the amount of power they are currently consuming, the state of charge in their batteries and also how much electricity traffics between their own supply systems to the utility grid for grid connection situations. Some meters have more than one channel to monitor two battery banks or a battery bank and a generating source for the hybrid systems.

Batteries store electrical energy produced by RE resource in a reversible chemical reaction. Most batteries employed in RE systems use the lead-acid batteries typically encased in plastic and wired together in series and parallel strings by the installer. However, batteries do not belong inside the living space due to the dangerous chemicals in them and hydrogen and oxygen gas put out while being charged. Battery capacity is rated in amp-hours, which 1 amp-hour is the equivalent of drawing 1 amp steadily for one hour. A typical 12-volt system may have 800 amp-hours of battery capacity. This is the equivalent of 1,200 watts for eight hours if fully discharged and starting from a fully charged state. There are many brands and types of batteries available for RE systems and the two most common batteries are the L-16 and golf cart sizes

Charge controller regulator prevents the PV array and wind turbine from over- charging the battery. Most modern controllers maintain system voltage regulation electronically by varying the width of DC pulses they send to the batteries (this is called pulse width modulation or PWM). This means the wider the pulse; the more power goes to the batteries. Another category called "shunt type" controllers divert excess energy into a "shunt load." This type of controller is more commonly used in wind or hydro systems, since these systems generally should not be run open circuit. Unlike a PV module, most wind and hydro turbines cannot be switched on and off by the controller. A new generation of PV controllers has "maximum power point tracking." They take advantage of the maximum power available in the module by adjusting current and voltage.

Backup power resource can come either from a generator or from the utility grid when too much energy is consumed or when there has not been enough renewable energy coming into the system. However, for the hybrid system, the latter situation seems could be avoid, and a considerable energy consuming style might assist to solve the former problem.

3.3. System Establish Process and Discussion

The process of establishing the energy supply system (Fig.1) is extremely important step. Whichever system will be installed, analyzing owner’s load and renewable energy resource of the site ought to the first

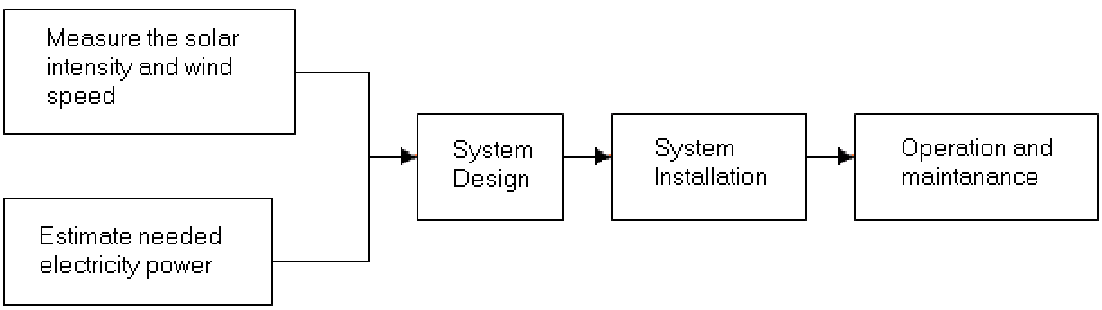

Fig. 1. Steps for establishing a Hybrid Solar & Wind Plant.

step. Load analysis lists and adds up all energy consumed by the owner's appliances. RE resource measurement affects the system structure, efficiency, and cost. If the owner's site matches the specific site conditions for PV-wind hybrid system, then the design and installation of the system requires know-how and experience. One can often benefit by having a good installing team of RE systems assisting one to site, design, and install your renewable energy system.

4. METHODOLOGY

In order to address the shortcomings of existing instructional techniques for electrical power systems, the system is designed and implemented with the following goals:

- To be completely different from traditional electricity labs and to be fresh and interesting.
- To be intimately related to real world industrial power issues such as power quality.
- To show a complex, interrelated system that is closer to the "real world" than the usual simple systems covered in educational labs.
- To motivate learning by introducing such elements as environmental and economic concerns of practical interest to the students.

5. ESTABLISHMENT OF A WIND/PV HYBRID UNIT

The hybrid unit contains two complete generating plants, a PV solar cell plant and a wind-turbine system. These sources are connected in parallel to a 120V AC line.

- The PV panel output is connected to a DC to AC inverter and is then supplied from the inverter's output to a single-phase, 120 VAC load. The overall project structure is presented in Fig.2.
- The wind turbine is installed at the top of a steel tower that has a height of 18.3 meters and a diameter of 8.9 cm.
- The instrumentation panel depicted monitors the outputs of the generator using digital panel meters. One of the low maintenance features is the turbine's brush-less alternator and an internal governor. The actual system's pictures are shown in Fig. 2.
- The turbine's blades are made of a carbon fiber reinforced composite that will intentionally deform as the turbine reaches its rated output. This deformation effect changes the shape of the blade, causing it to go into a stall mode, thus limiting the rotation speed of the alternator and preventing damage in high kinds.
- Another feature of the wind turbine is a sophisticated internal regulator that periodically checks the line voltage and corrects for low voltage conditions.
- The solar panels are 12 VDC/unit were chosen for their ultra clear tempered glass that is manufactured for long-term durability. Fig. 3 shows the DC voltage measured across the 12 volt DC bus where the wind turbine and PV arrays outputs are connected. A slight ripple in power regulation can clearly be seen. This ripple is a function of the unpredictable nature of sunshine along with the dynamic effects of the electrical load.
- One of the largest problems in systems containing power inverters is power quality. This problem becomes serious if the inverter used in the system does not have a good sinusoidal waveform output and causes problems such as harmonic contamination and poor voltage regulation. According to the IEEE (a professional society which codifies such issues) standards, a maximum of 3 to 4% total harmonic distortion may be

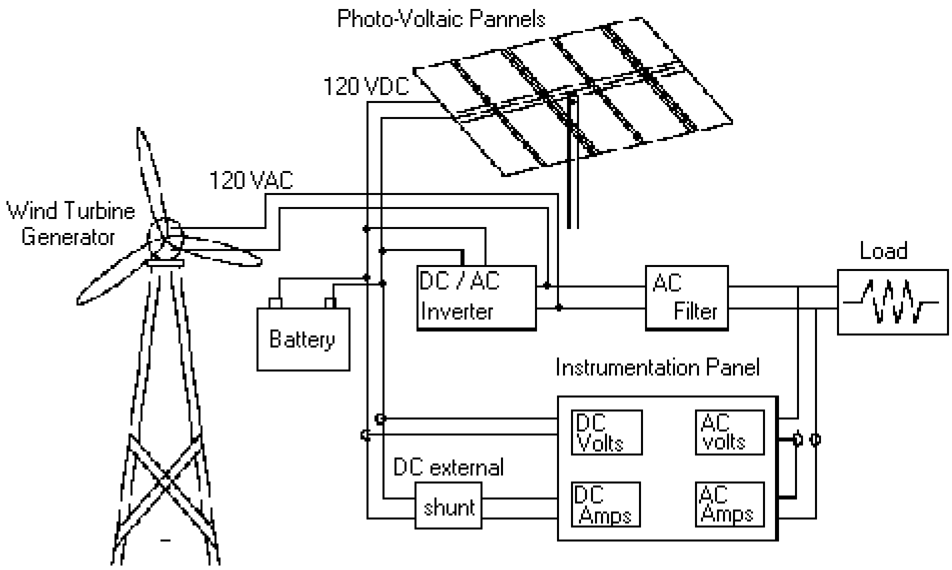

Fig. 2. A simple Hybrid Solar & Wind System.

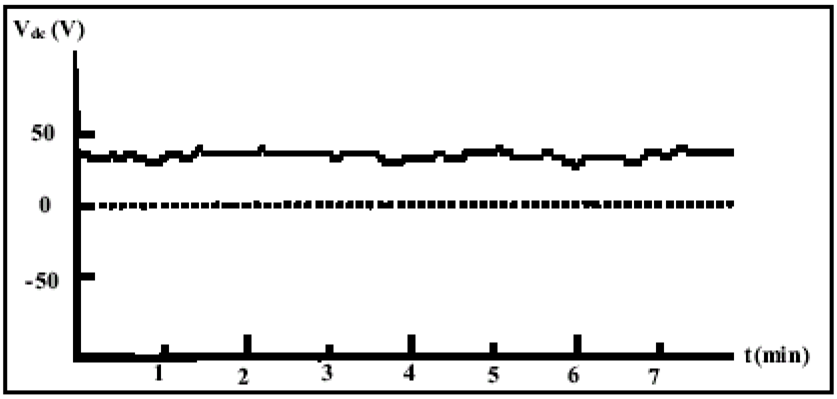

Fig. 3. The DC voltage measured across each PV unit (12 V DC)

allowed from inverter outputs. However, many inverter outputs have much more harmonic distortion than is allowed.

- To monitor and store the voltage, current, power, and harmonic contamination data, two power quality analyzers (types 39 and 41) are used in the system. In addition, permanently mounted AC/DC digital panel meters form part of the system's instrumentation. A laptop computer is interfaced to the system via the power quality analyzers to store data in real-time.
- Voltage sags may cause a crucial damage to high precision measurement and protection devices, especially computer equipment present in many highly automated industrial plants.
- The AC filter is a circuit made up of a resistor (R), inductor (L), and a capacitor (C). Such filters are commonly installed in industrial situations to remedy power quality problems.
- The inverter is of a six-pulse type and the inverter and the control circuit models are both standard models in the PSCAD/EMTDC software package.

6. FUTURE STUDY

Fig.4. illustrate the future direction of this project. A computer measurement and control bus will be added to the system. Computer controlled relays will be added to allow all the major elements of the system to be switched in and out of the system through computer programs. The measurement bus will be connected to all the major signals in the system and will allow for computerizes data acquisition simultaneously of all the major signals in the system. These improvements will allow for the study of more complex issues like power faults caused by sudden over voltages like lightning. These improvements will also allow the same benefits to instruction realized in electricity and electronics

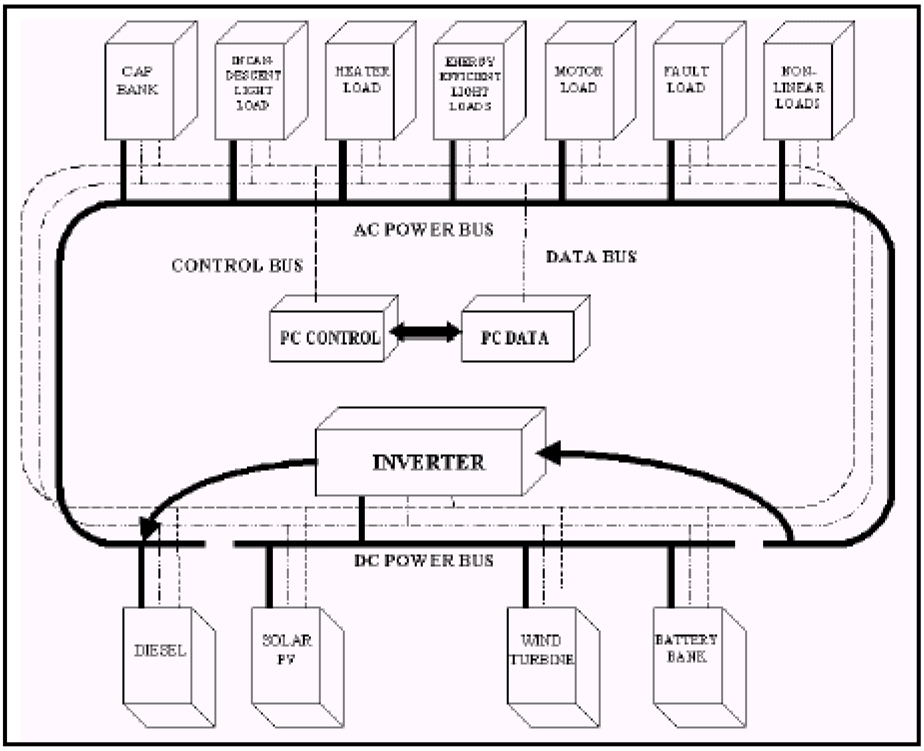

Fig. 4. Block Diagram of Scope for Future Research.

classes to be extended to control and instrumentation classes.

7. CONCLUSIONS

Obviously, a complete hybrid power system of this nature may be too expensive and too labor intensive for many Industrial Technology Departments. However, many of the same benefits could be gleaned from having some subset of the system, for example a PV panel, batteries, and an inverter, or even just a PV panel and a DC motor. The enhancements to instruction, especially in making electrical power measurements more physical, intuitive, and real world are substantial and the costs and labor involved in some adaptation of the ideas in this paper to a smaller scale setup are reasonable.

The use of solar and wind hybrid power generation is an especially vivid and relevant choice for students of electrical Technology as these are power sources of technological, political, and economic importance in a country. Hybrid combinations of wind power, solar power, geothermal power, hydroelectric power, tidal power, biomass generated power, power from incineration of solid wastes, and many other technologies could also be considered depending on local interests and resources. The key elements of this test bed concept presented in this paper are two or more renewable power sources can be connected to a power grid with complex electrical interactions.

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