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Hybrid Power Generation Using Solar and Wind Energy

Varahala Dora Petla[1*], Asari Nagendra[1], Y. Devi Prasad[2], E. Ravi Teja[2], K. Bala Murali[2]
[1]Assistant Professor, Department of Electrical and Electronics Engineering, Avanthi Institute of Engineering & Technology, Makavarapalem, India
[2]UG Student, Department of Electrical and Electronics Engineering, Avanthi Institute of Engineering & Technology, Makavarapalem, India

***Abstract*: One of mankind's greatest needs is a reliable and sustainable supply of electricity. Conventional, non-renewable energy resources such as coal and nuclear fuel have long been used to generate electricity, but these resources are depleting with continued use, which has shifted attention toward renewable sources such as wind, solar and tidal energy. This paper presents the design and implementation of a portable hybrid power system that combines solar and wind energy to generate reliable, sustainable electricity. Wind and solar energy are attractive because of their abundance, availability and ease of harnessing, but each is intermittent on its own: wind power is available only when the wind blows, and solar power only when the sun shines. Combining the two sources, together with a charge controller, improves availability and reliability, since one source can compensate when the other is insufficient. The prototype uses a 20 W monocrystalline solar panel and a small wind-driven dynamo as the two energy sources, each protected against reverse current by a diode, feeding a DC-DC buck-boost converter that supplies a constant input to a PWM solar charge controller. The charge controller regulates the charging of a 12 V lead-acid battery, whose output can supply DC loads directly or be converted to 220 V AC through an inverter. The system is intended for domestic, agricultural and remote-area use where a continuous grid supply is unavailable or unreliable.**

***Keywords*: Solar energy, wind energy, hybrid power system, photovoltaic panel, wind turbine, charge controller, buck-boost converter, battery storage, inverter.**

1. Introduction

Generation of electric power is essential for any country moving towards industrialization and a higher level of technological advancement. Constant availability of electricity is an important need that must be met to make day-to-day living more comfortable, and providing that constant supply is a goal that most countries pursue.

Electricity can be generated from conventional, non-renewable resources such as coal, petroleum and nuclear fuel, or from non-conventional, renewable resources such as wind, solar and tidal energy. Renewable resources are generally pollution-free, economical and naturally replenished, and are therefore inexhaustible in a way conventional resources are not. Wind power is generated by using airflow to mechanically drive a generator; it is plentiful, widely distributed and produces no greenhouse-gas emissions during operation. Solar power is generated by converting sunlight into electricity, either directly through photovoltaics or indirectly through concentrated solar power; photovoltaic systems use solar panels, on rooftops or in ground-mounted farms, to convert sunlight directly into electric power through the photovoltaic effect.

Solar and wind energy are commonly harnessed independently, but when the two are combined, the resulting arrangement is called a hybrid power system. Hybrid power systems combine two or more modes of renewable generation typically solar photovoltaic and wind to give increased efficiency and a better balance of supply, since a stand-alone system built around only one resource performs poorly whenever that resource is unavailable: a solar-only system produces little on a stormy day or at night, and a wind-only system produces little when the air is still.

A. Objective

The objectives of this project are:

- To design and implement a solar–wind hybrid power system.
- To use the complete system domestically to provide sustainable electricity irrespective of changes in weather conditions.
- To ensure that the system is available for use throughout the day.

B. Scope

The project is divided into the design and implementation of a functional wind generator to harness wind energy, and the design and implementation of a solar power system. A charge controller receives the DC outputs of the solar and wind subsystems and regulates the charging of the battery, preventing overcharging. An inverter converts the battery's DC output to AC so that ordinary AC loads, such as lamps and fans, can be powered, while DC loads can be connected directly to the battery output.

C. Significance

Growing use of electrical and electronic devices is increasing the demand for energy worldwide, while concerns about global warming and the environmental costs of conventional generation continue to grow. Renewable resources used in

*Corresponding author: petla.dorababu@gmail.com

isolation only produce power when the corresponding resource is available, which is a significant limitation. A hybrid system in which solar and wind sources back each other up – since their peak outputs tend to occur at different times of day and year – addresses this limitation, requires little maintenance, and provides a more continuously available supply than either source alone.

2. Literature Survey

With growing concern over global warming and the depletion of fossil-fuel reserves, wind and photovoltaic energy are, after hydro power, the resources with the greatest potential to meet energy demand. Wind energy can supply large amounts of power, but its availability is highly unpredictable; solar irradiation is present throughout the day but varies with sun intensity and cloud cover. The common drawback of both is their intermittent nature, which by itself makes either one unreliable. Combining the two intermittent sources, together with a charge-control stage, has been shown to improve power-transfer efficiency and reliability, since one source can compensate when the other is insufficient [1]–[4].

Several hybrid wind/photovoltaic systems with charge control have been reported in the literature. Balaji Damodar and Sethil Kumar proposed a high step-up converter for hybrid solar/wind systems [1]. Rakesh Kumar Shah surveyed wind–solar hybrid energy-conversion systems and summarised the converter and control topologies used in them [2]. Malik Elamin reported a hybrid wind–solar electrical power system built and evaluated at the University of Khartoum [3]. Sandeep Kumar and Vijay Garg described a hybrid PV solar/wind/fuel-cell system aimed at improving reliability of supply [4]. Most systems in the literature use a separate DC-DC boost converter connected between each energy source and the charge controller, so as to present the charge controller with a constant input; some works instead combine the sources at the DC end with a simpler multi-input structure built as a fusion of the buck and buck-boost topologies, which avoids the passive input filters otherwise needed to remove the current harmonics that shorten generator lifespan and increase heating losses. The present work follows the more common approach of a shared buck-boost stage feeding a single PWM charge controller.

3. Proposed System

The proposed system integrates a solar panel and a wind-driven dynamo so that the two sources back each other up and together give more continuous power than either alone. Each source is connected through a diode, which blocks reverse current from flowing back into the source, to a shared DC-DC buck-boost converter that presents a constant input to a PWM solar charge controller. The charge controller regulates the charging of a 12 V lead-acid battery. The battery can supply DC loads directly, or its output can be converted to 220 V AC by an inverter to supply AC loads. The complete arrangement is shown in Fig. 1.

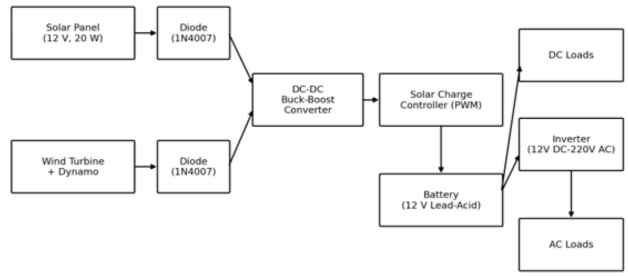

Fig. 1. Block diagram of the proposed hybrid solar–wind power generation system

The solar panel used is rated at 12 V, and works on the photovoltaic effect: when light is incident on the panel, electrons in the valence band absorb energy and are excited into the conduction band, and those that reach a junction are accelerated by a built-in potential, generating an electromotive force and hence an electric current. The wind subsystem converts the kinetic energy of the wind into electrical energy through a turbine and a dynamo. The buck-boost converter, built around a MOSFET switch (IRF250N), inductor, capacitor and diode, keeps the combined input to the charge controller within the required range regardless of which source is currently dominant. Table 1 lists the components used in the prototype.

4. Solar Energy Subsystem

A. Photovoltaic Principle

A photovoltaic (PV) module is a packaged assembly of solar cells, typically arranged in a 6×10 grid. A single solar cell cannot supply an electronic device with enough voltage and power on its own, so cells are connected in series to raise the voltage and in parallel to raise the current, building up to the panel and array level shown in Fig. 2. Each cell is made of a semiconductor, usually silicon: light striking the cell frees electrons in the semiconductor, and the cell's built-in electric field forces those electrons to flow in a particular direction; metal contacts on the top and bottom of the cell then draw this current for external use. A solar photovoltaic cell is essentially a P-N junction: electrons diffuse from the N-type layer to the P-type layer until this diffusion is balanced by a drift current

Table 1
List of components

S.No.	Component	Range	Type	Qty
1	Solar panel	12 V, 20 W	Monocrystalline	1
2	Dynamo	6–38 V, 2400–9000 RPM	Motor / generator	1
3	Buck–boost converter	12 V, 35 W	Digital, PWM	1
4	Solar charge controller	12 V, 35 W	PWM	1
5	Battery	12 V	Lead–acid	1
6	Inverter	220 V, 200 W	DC to AC	1
7	Diode	1N4007, 30 V	PN junction	2
8	Connecting wires	–	–	As required

across the depletion region, which is why, in darkness, a photovoltaic cell behaves like a reverse-biased diode.

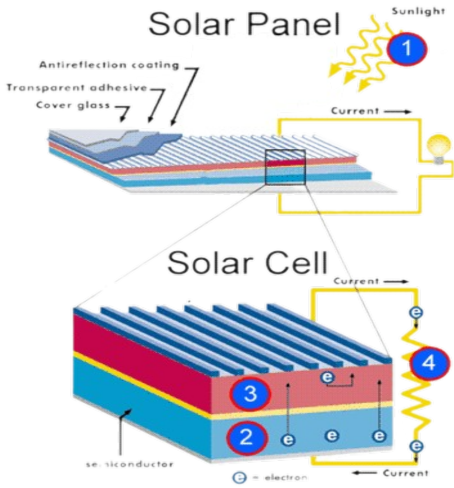

Fig. 2. Development of a photovoltaic system, from cell to module

B. *Types of Solar Panels*

Almost all commercial photovoltaics are based on some form of silicon, and panels are usually classified as monocrystalline, polycrystalline or thin-film, in decreasing order of silicon purity and, generally, of efficiency and cost. Monocrystalline panels, shown in Fig. 3, are cut from cylindrical silicon ingots and are recognisable by their uniform colouring; they have the highest efficiency (typically 15–20%), the smallest footprint for a given output, and the longest warranted life, but are the most expensive and can fail across their whole circuit if even partially shaded. Polycrystalline panels are made by melting raw silicon, which is cheaper but slightly less efficient and less space-efficient. Thin-film panels are made by depositing photovoltaic material on a substrate; they are inexpensive and flexible but require the most area for a given output and generally degrade faster. The prototype described here uses a 20 W monocrystalline panel for its higher efficiency at a small physical size.

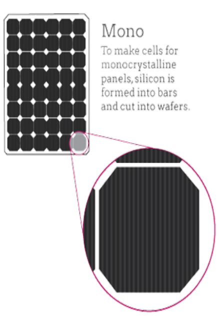

Fig. 3. Monocrystalline silicon solar panel

5. Wind Energy Subsystem

A. *Wind Turbine*

A wind turbine converts the kinetic energy of the wind into rotational kinetic energy in the blades, and then into electrical energy through a generator. The energy available depends on the wind speed and the swept area of the blades; from the kinetics of moving air, the power in the wind is proportional to the cube of the wind speed ($P = \frac{1}{2}\rho A v^3$, where ρ is air density, A is the rotor swept area and v is wind speed), so the turbine and generator are rated for the minimum and maximum speeds expected at the site. Wind turbines are classified by the orientation of their rotor shaft.

Horizontal-axis wind turbines (HAWT), Fig. 4, carry the rotor shaft and generator at the top of a tower and must be pointed into the wind, using a wind vane on small turbines or a wind sensor and servo motor on larger ones; most HAWTs use a gearbox to convert the slow rotation of the blades into a faster rotation suited to the generator. Vertical-axis wind turbines (VAWT), Fig. 5, have a vertically arranged rotor shaft and do not need to be pointed into the wind, which is an advantage where wind direction is variable; their generator and gearbox can also be placed near the ground, which simplifies maintenance.

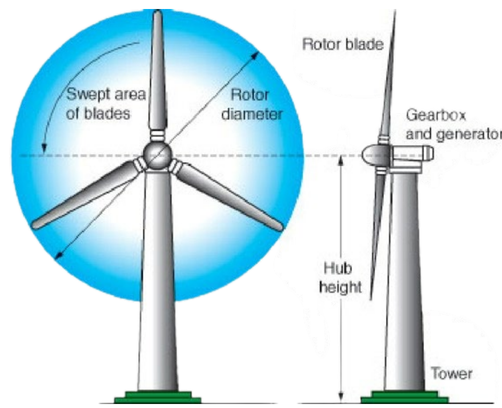

Fig. 4. Horizontal-axis wind turbine (HAWT)

Fig. 5. Vertical-axis wind turbine (VAWT)

B. *Dynamo*

Fig. 6. Dynamo used as the wind-driven generator

The prototype uses a small dynamo as its wind generator (Fig. 6). A dynamo is a DC generator built around two permanent magnets and a rotating coil, with a commutator that reverses the connection to the external circuit every half-cycle so that the output current does not alternate; this makes it well suited to low-power applications such as battery charging. The unit used is rated at 6–38 V DC, with a speed range of 2400–9000 RPM, in a 6 × 2 cm steel housing weighing about 200 g.

6. Power Conditioning and Storage

A. Protection Diode

A 1N4007 diode is placed between each source and the buck-boost converter to block reverse current from flowing back into the solar panel or the dynamo. The 1N4007 is a silicon PN-junction diode rated for 1 A of continuous forward current, with a surge rating of up to 30 A; it conducts when the anode is more positive than the cathode and blocks conduction, aside from a small leakage current, in the reverse direction. Fig. 7 shows its V–I characteristic: forward current rises sharply once the forward voltage exceeds the device's threshold, while reverse current stays negligible until breakdown.

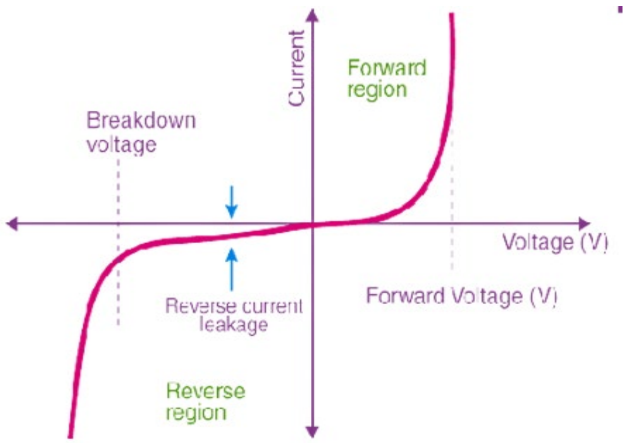

Fig. 7. V–I characteristic of the 1N4007 protection diode

B. DC-DC Buck-Boost Converter

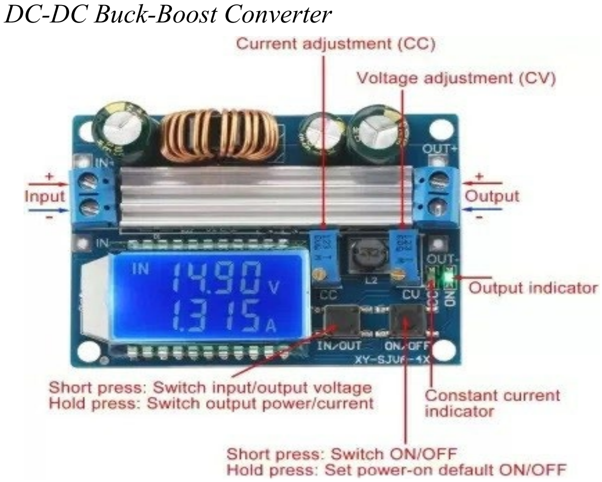

Fig. 8. DC-DC buck-boost converter module used to condition the combined source input

The buck-boost converter (Fig. 8) is a DC-to-DC converter whose output voltage magnitude can be either less than or greater than its input, depending on duty cycle, with input power equal to output power under ideal (lossless) conversion. In step-up (boost) operation Vin < Vout and Iin > Iout; in step-down (buck) operation Vin > Vout and Iin < Iout. A single inductor stores energy from the input while the switch is on and releases it to the output while the switch is off, and the output capacitor is sized so that its RC time constant is large compared with the switching period, keeping the output voltage effectively constant. The converter used is rated for a 0–35 V input, 1.3–30 V / 3 A output, about 92% conversion efficiency at a 150 kHz switching frequency, with load and voltage regulation of ±0.5% and ±2.5% respectively.

C. Solar Charge Controller

The regulated output of the buck-boost converter feeds a PWM solar charge controller, which keeps the battery from overcharging. An unregulated "12 V" panel can put out 16–20 V, well above the roughly 14–14.5 V a lead-acid battery needs to reach full charge, so without regulation the battery would be damaged; the controller also opens the circuit to stop reverse current flowing back into the source array whenever no power is being generated. Fig. 9 shows the functional blocks of the controller used: operational amplifiers continuously monitor panel voltage and load current, LED indicators report full charge, undercharging, overload and deep-discharge conditions, and a MOSFET switch cuts off the load under low-voltage or overload conditions. The unit used is rated for a nominal 12/24 V battery, operates from 0 °C to 50 °C, and measures 13.3 × 7 × 3.5 cm.

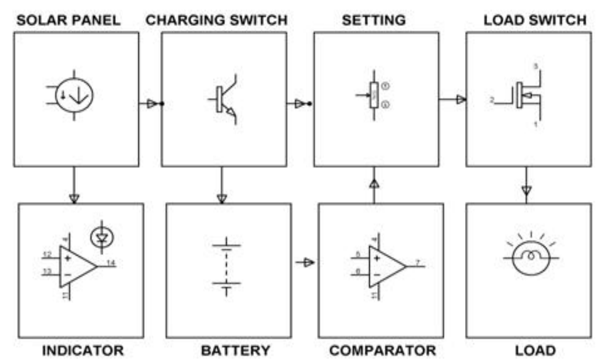

Fig. 9. Functional block diagram of the PWM solar charge controller

D. Battery

Fig. 10. 12 V lead-acid battery used for energy storage

A 12 V, 4 Ah sealed lead-acid battery (Fig. 10) stores the charge delivered by the controller and supplies the load between charging periods. Charge is stored and released through the chemical reactions in the battery's cells, which drive a flow of electrons through the external circuit. The spill-proof, absorbed-glass-mat (AGM) construction tolerates a tilted mounting position, gives low self-discharge, and includes a flame arrestor for added safety.

E. Inverter

A 200 W inverter (Fig. 11) converts the battery's 12 V DC output to 220 V AC so that ordinary AC appliances can be run from the stored charge; DC loads can instead be connected directly to the battery. The inverter itself supplies no power of its own – the energy still comes from the battery – and includes overload, low-battery and reverse-connection protection.

Fig. 11. 12 V DC to 220 V AC inverter

7. Applications

The loads that the system can supply fall broadly into domestic AC loads, commercial loads, remote-location loads, street lighting, agricultural loads and small-scale industrial loads. Because the two sources back each other up and the battery buffers their combined output, the system is particularly suited to locations where the electrical grid is unreliable or entirely absent, such as remote or rural sites.

8. Results and Discussion

The prototype was assembled from the components listed in Table I and tested with the solar panel and dynamo feeding the shared buck-boost converter and charge controller. The buck-boost stage held its output within the specified range across the 0–35 V input swing produced by the two sources, so the charge controller consistently saw a suitable input for regulated charging of the 12 V battery regardless of which source was momentarily dominant. The protection diodes prevented either source from being back-fed by the other or by the battery. On the output side, the battery successfully supplied DC loads directly and, through the inverter, 220 V AC loads, with the inverter's overload and reverse-connection protection operating as expected during testing. Because the peak output of the solar panel occurs during daylight hours while the dynamo can contribute whenever wind is available, the combined arrangement gave a more continuous supply to the battery than either source used alone.

9. Conclusion

Hybrid solar–wind power generation is an effective alternative to conventional energy resources, with greater overall efficiency than either source used alone. It is suited to domestic, commercial and agricultural loads, to street lighting, and to remote locations that the grid struggles to reach, where generating power close to where it is used reduces transmission losses and cost. Because it produces no emissions and no harmful waste, the approach is also environmentally favourable. With only an initial investment required and a long operating life, the system offers a reliable, cost-effective and scalable route to sustainable electricity generation, including eventual integration with grid supply for larger-scale generation.

10. Future Scope

The prototype points to several directions for further work: reducing unit cost through larger-scale production of the components; extending the architecture toward grid-connected operation for larger amounts of power; and encouraging wider adoption of non-conventional energy resources, particularly in remote locations that are otherwise difficult for the grid to serve.

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