# Hybrid Renewable Energy Systems: Hybridization and Advance Control

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**Abstract**

*As world's power consumption is increasing regularly and consequently, demand for more power generation is inevitable. So this power demand can produce by Renewable energy resources up to some significant percentage of total demand. Wind turbine technology combined with solar photovoltaic (PV), as a hybrid system, can play an effective role to overcome our future energy consumptions with a cost effective energy conversion system. Integration of both resources is highly appreciated for providing a reliable power source to the world. In this paper hybrid energy system is discuss briefly, based on wind and solar photovoltaic. Next, integration schemes are illustrated by help of schematic diagrams, at last use of advance control techniques and their performance are given with future challenges.*

**Keywords**

*Renewable energy system, Photovoltaic, Wind turbine, Control system, integration schemes.*

## I. Introduction

The use of Renewable energy power generation is motivation for reduction of $CO_2$ emissions which is highly dangerous for the human health and quality of man's life. It is expecting that it will play an important role in power production and development. As the global demand of electric energy is increasing gradually and the main resources of electric energy, like oil and gas, are decreasing with the time. Renewable energy sources can provide a significant percentage of the total demand. The renewable energy can be sub-divide into two categories: RE power generation, like photovoltaic (PV), biomass, wind, and alternative generation of energy, such as fuel cell, micro turbine and which are efficient and clean source of energy.

The photovoltaic (PV) and the wind turbine technology is most attractive technologies among all other renewable energy technologies. The modern development in the field of wind turbines started in 1980's with a few sites of Kilo-W range units to multi-Mega-W units. The world trends towards this technology can be seen by global wind report 2012 which indicates that the wind power market grew by 10% of 2011. It is nearly about 45Giga-W wind turbine power brought online [1]. Overall renewable power capacity increases up to 1,470GW in 2012, about 8.5% as compared to 2011 worldwide. 39% of RE power capacity added in year 2012, with 26% of the accounts of solar Photovoltaic (PV) [2].

In general, the main courage behind the development of AE/RE energy system is their perceived advantages such as improved power quality and the reliability, reduced emission of $CO_2$ and combining of power operations and heat to the increase efficiency of the system. In the last half century, many researches have been done in RE/AE area on feasibility study, control, modeling and the experimental work and the integration of the systems, e.g. [3]-[4].

The wind and the solar PV technology are gaining much attention of the researcher and the investor as an alternative source of electric energy. The intermittent nature of RE resources such as wind and solar, hybrid combinations of these resources with their efficient generation technology can make the whole system more reliable and improve the system performance.

Generally, hybrid energy system convert all individual system's output into electrical form and stores it in another form like thermal, mechanical compressed air and chemical. Final output is ready to be use for any kind of load. Good reliability and improved operational performance can be achieved by proper selection of technology and unit sizing while hybridization and designing of such systems.

The integral and the essential part of a hybrid Renewable-energy (RE) system are the types and the capacity of storage. With storage of high capacity, energy can be used for long period of time but the response time is slow. Access-based storage can be used for gaining fast response. With proper storage and renewable energy resources, any kind of combination of RE technology could make hybrid power system. The summary of different RE power generation technologies with proper storage schemes for hybrid systems are given in Table 1.

This paper reviews the literature on principles of wind energy and solar Photovoltaic (PV) and its use as hybrid renewable energy system with different configuration, integration schemes and the motivation for use of advance control system techniques in it.

Table 1 : Different Re Power Generation Technologies With Storage Devices

| Main RE Technologies | Energy Storage Types |
|---|---|
| Biomass | Battery |
| Geothermal | Compressed air |
| Solar PV | Battery |
| Wind turbine | SMES |
| Ocean tidal/ wave | Hydrogen |

## II. Renewable Energy Resource

Two main renewable energy resources are briefly described. They are wind turbine and Photovoltaic.

### A. Wind Power System

Wind turbine system is used to produce electric power from wind by converting the linear motion of air in to rotational energy for driving generator. Wind turbine capture the power of air using blades, designed aerodynamically, and changes it to rotational power as illustrated in the fig.1. There are two types of turbines for wind, one is horizontal-axis-wind-turbine (HAWT) which is most popular and other one is vertical-axis- wind-turbine (VAWT). Horizontal-axis WT has typically three blades. As of 2013, Danish Company Ventas is the leading world's biggest wind turbine

manufacturer [5].
The wind turbine power is given below:

$$P = \frac{1}{2}\rho\pi C_p v^3 R^2 \quad (1)$$

$C_p$Where R is the radius of turbine, v is the air speed, $C_p$ is the power coefficient, is $p$ density and R is the radius of turbine. In a pitch-controlled WT, $C_p$ , a representation of power conversion efficiency, is the function of the blade pitch angle (β) and the tip-speed ratio ($\lambda$ ). $\lambda$ is the ratio of speed of tip of turbine blades to the wind speed, which is given below:

$$\lambda = R.\Omega/v \quad (2)$$

Here $\Omega$ is the wind's rotational speed.
There are some major issues which leads the maximum power coefficient down then the desired.

- Wake rotation behind the rotor
- Non-zero aerodynamic drag
- The tip loss and the limitation of number of blades.

Some limitations and critical conditions are also available which will take the system towards destruction. It is essential to make such control which will restricts the more power when the wind speed is higher than a specific limit to avoid damage to electronics as well as infrastructure. A wind turbine has been designed in such a way that maximum power can be converted in all air speeds. To suffer in danger conditions, it should be too heavy. The high cost of such infrastructure can be compensated by extra power production. The maximum power usually achieves at much low wind speed; the rated speed is of 9-12 m/s. The maximum achievable power extraction by a wind turbine (WT) is nearly 59% of total theoretical calculated wind power [6].

## B. The Photovoltaic Cell

Sun is the origin for all renewable energy sources (RES). Solar energy has energy in form of radiations. Mainly, photovoltaic (PV) and concentrated solar power (CSP) used for production of electric energy. In Photovoltaic (PV), by using semiconductors, electric power is produced by sun's radiations on PV cell which convert it in to direct current (DC). Photovoltaic (PV) is getting more attention from the world as an alternative way of power because of the advancement in the technology and the continuous reduction of the cost. It is becoming the main RES of the future.
PV modules have no any moving parts like generator that's why its wear-and-tear cost is very low. It has lifetime of more than 25 years however 25% of nominal value may be reduced in power generation capability. PV cell model is shown in Fig 1. Details of different technologies, basics and physics of photovoltaic (PV) cells can be found in a many textbooks such as [7] and [8]. The global total capacity of solar PV is more than 100 GW in 2012[9].

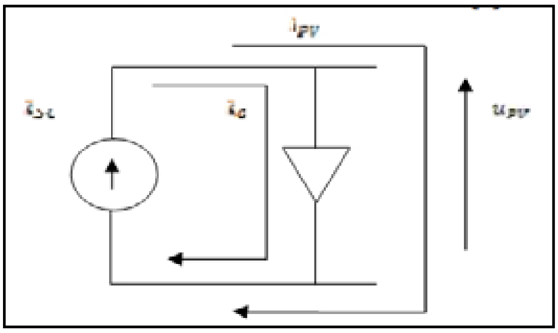

Fig. 1 : Electrical model of Solar PV cell

Concentrated Photovoltaic (CPV) technology generates electric power by using principles of optics. Lenses are arranges in such a way that large amount of solar radiations are concentrated on small area of the photovoltaic material. In this technology, manufacturing cost reduces as well as the area becomes small. Detail of CPV technology can be found in [7].
CPV is classified into three types such as low concentrating photovoltaic (LCPV) with concentration factor less than 10 suns; medium concentrating photovoltaic (MCPV) with factor between 10 and 300 suns and third class is high CPV with factor of more than 300 suns. MCPV systems have disappeared from the market because of its complication as it requires two axis solar tracking and cooling [10]. According to the Kurtz [10], ten years ago these concentrator cell was just 30% efficient compared with now 40% and with a potential to approach 50% in next year's. Silicon cells have efficiency more than 26% while in multi-junction compound cells have 45% as given in reference [2].
Photovoltaic (PV) modules are made up series connected 36 to 72 cells. Electrical model is shown in fig. Series connection of the cells gives high voltage across the terminals with the current determine by the weakest cell. This weak-cell causes reduction of available power which can be improved by using bypass diodes across the cells but this will drop the terminal voltage. PV modules output is mainly determine by the angle of incident radiation and characterized by an I-V curve. The power of module is dependent on operating point and the maximum power point (MPP), near the knee of I-V curve which gives maximum power. By increase of light intensity, photocurrent will be increase and open-circuit voltage will be decrease [11]. Power electronic and control techniques are used in renewable energy system for conversion of power from one form to another form.

## III. Hybrid System Configuration

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## A. Integration Schemes

To form a Hybrid Energy System, it is essential to have standard procedures and frameworks while dealing with different types of renewable energy resources as these sources have different operation and other characteristics. A renewable energy hybrid system is the integral of RE sources with energy storage, loads and a grid, which is optional, having capability to operate autonomously. There are many integration techniques available in the literature to form a hybrid system from renewable energy sources. These integration techniques can be divided into three categories: AC, DC and hybrid-coupled [12]-[15]. Following is the brief description of the schemes.

### 1. DC-Coupled Systems:

In this type of hybrid systems the different renewable sources, like photovoltaic and wind turbine, are interfaced to a main DC link by PE circuits. Solar photovoltaic can connect to DC link directly or through DC-to-DC chopper. Similarly DC load also may connect to main DC link directly or by chopper (DC/DC Converter) for an appropriate voltage level. AC loads can also supplied by using DC-to-AC inverter or utility grid. DC coupling is simple because there is no need of synchronization like ac to integrate different RE sources. DC-Coupled system's schematic is shown in fig. 2. DC coupling have some drawbacks such as if the power inverter (DC/AC Converter) is out of service then system cannot have any backup to provide AC power supply. To overcome the situation, several inverters with low rating can be connected in parallel and synchronized it with utility grid. A control scheme is also needed for proper power sharing to different power inverters [16].

### 2. AC-Coupled systems

AC-coupled systems are classified into two parts. One is power frequency AC- coupled systems and the other is HFAC coupled system.

#### i. PFAC-Coupled systems:

In this type of hybrid systems the different renewable sources, like photovoltaic and wind turbine, are connected to a main power frequency AC bus by power electronic interfacing circuits. Coupling inductors is used between Power Frequency AC bus and the electronic circuitry for power management. Power Frequency AC-coupled system's diagram is shown in fig. 3.

#### ii. HFAC-Coupled systems:

The different renewable sources, like photovoltaic and wind turbine, are connected to a main High frequency AC bus by power electronic interfacing circuits. High frequency loads are connected to this system. The schematic of High Frequency AC-coupled (HFAC) systems are shown in fig. 4.

#### iii. Hybrid-coupled systems:

In hybrid-Coupled system, many RE sources are interfaced to different AC or DC bus. Hybrid-coupled system's schematic is shown in fig. 5. Here RE sources can be connected directly to the main AC or DC link without any interfacing circuits which results in cost reduction and high energy efficiency. Energy management and control becomes more complex because of hybridization.
Different coupling techniques find its own application according to the suitability with the system. DC-coupled system is best choice where dc loads are more and DC sources are the main source of power and if AC loads are mostly driven and main power source is AC then AC-coupled system will be the best choice. If the major sources of power are AC and DC then hybrid-coupled system will become the best choice for integration.

### B. Optimal Unit sizing

A solar photovoltaic and wind systems will generates electricity during sunny and windy days only and it can't supply continues power to the load. Hence, a combination of solar and wind will improve the power output and system reliability. So, a proper optimization is necessary to ensure the size of photovoltaic and wind turbine. Several techniques of optimization have been developed and presented. Traditional sizing methods for wind and solar systems are based on some data information like long term weather forecast, wind speed and solar radiation. Where such information is not known, artificial intelligence are used there. Dufo-López et al. [17] have done much work on optimization for the design of hybrid Photovoltaic-wind systems with a control strategy for production of hydrogen. They gave a result that only in high wind speed, the hydrogen could be economically viable for selling. Kolhe et al. [18] proposed a physical model of hybrid PV-wind system with battery storage. The proposed system can be interfaced with remote monitoring and control system.

## IV. Control Strategies And Challeges

Renewable power energy systems are fundamentally reliant on control systems, communications and computation to ensure efficient operations stability and reliability. From last 25 years, extensive research has been devoted to improve the efficiency of solar-wind power systems in terms of optimization and control system. These researches cover the area related to this

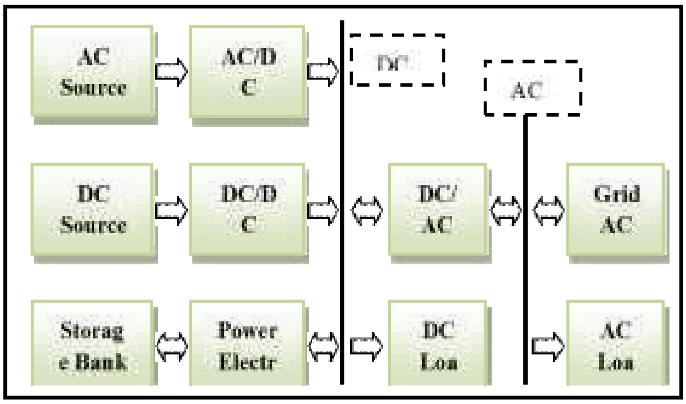


Fig. 2 : Schematic Diagram of DC coupled system

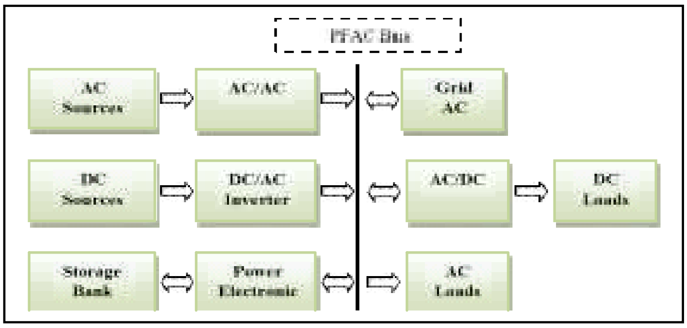


Fig. 3 : Schematic Diagram of PFAC coupled system

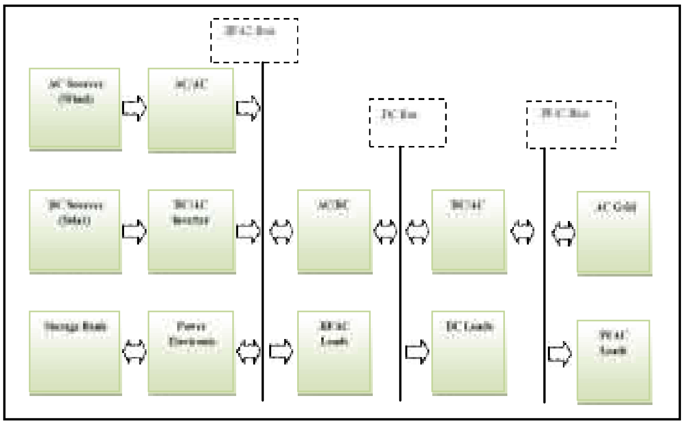

Fig. 4 : Schematic Diagram of HFAC coupled system

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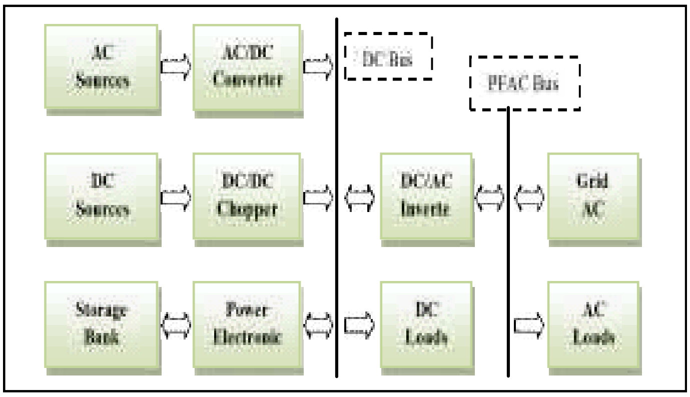


Fig. 5 : Schematic Diagram of Hybrid coupled system

fields are modeling and simulations, classical proportional-integral-derivative control (PID), model- based predictive control (MPC), cascade control (CC), integral model control (IMC), Optimal control (LQG), neural network control (NNC), and non-linear control (NC) [20]. In each year more than $170 Million is spending on research and development of solar photovoltaic (PV). The main challenges are improvement of system performance, cost reduction and power storage methods [21].

Liu et al. [22] proposed a hybrid micro grid to reduce multiple conversion stages with one stage, concluding that hybrid grid may be able to reduce the stages but there appeared many practical problems for applying system on current ac dominated infrastructure. Huang et al. [23] pointed out that speed of response for duty cycle of DC/DC converter is comparatively faster in maximum power point tracking (MPPT) control process. They also highlighted that the charging current of battery changes with adjustment of duty cycle automatically. Many different control techniques can be implemented for good performance of the hybrid systems. More development is needed in advance control to encounter the power quality of the hybrid RE system. The short time fluctuations can be handled by the advance fast response control such as automatic generation control and flexible AC transmission system.

## V. Conclusion

This paper has provide the basic concepts for the photovoltaic (PV) and the wind turbine. Different integration schemes are illustrated by the help of schematic diagrams for hybrid renewable power energy system. Optimal unit sizing has discussed briefly and shows some methods which will be helpful for optimal selection. Finally, the advance control work which has been done by the researcher in this field are shown. Motivation and challenges are also mentioned to improve the interest for researcher. Challenges arepoint out to develop the advance techniques to overcome the different technical issues, like short and long term frequency and voltage fluctuations, MPPT, reliability and stability of the hybrid RE system.

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