



Smart Controller for Wind-Solar Hybrid System under Grid Connected Operations

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Abstract: The major sources of energy that are available for the consumption are Coal, Natural gas and the oil reserves. But with the current consumption rate of energy these natural reserves won't last long. This reason made the world to take up renewable energy sources for a nonpolluting and clean environment. The Solar and Wind energy systems are ones which are often used and a lot of research is going on in the field of both wind and solar energy systems. The hybrid energy system of wind and solar has tremendous research potential and has got its own advantage over other sources of energy.

When two or more power sources are connected to form a hybrid system, it becomes essential to control the power flows of each of them depending upon the input and output conditions. Hence there is a need for a smart controller which can continuously monitor and control the overall hybrid system.

Keywords: wind energy, solar energy, hybrid, MPPT, chopper, three phase inverter, grid connection.

I. INTRODUCTION

In the present day world there is a huge demand for renewable energy resources as the non-renewable energy resources are becoming extinct and costly. But these renewable energies are not available at all times. Consider for example, the solar power and wind power. These are complementary since sunny days are usually calm and strong winds often occur on cloudy days or in night times [1]. Hence in order to obtain power all the time, there is a need for adding up of these complimentary resources. Thus the hybridisation of these complimentary energy resources like solar and wind resources will result in continuous power availability and results in a better utilization of power.

The renewable energies being available freely must be utilized properly to extract maximum power from them. In order to control these different energy resources and again connecting them to the grid requires an efficient controller.

Presently there exist solar and wind energy systems which are separately connected to the utility grid. This paper presents the concept of a hybrid system of both of these systems. The advantage of choosing this combination of energy source is that maximum energy can be extracted at all times.

II. BLOCK DIAGRAM OF SOLAR-WIND HYBRID SYSTEM

The block diagram of a solar wind hybrid system is as shown in Fig.1.

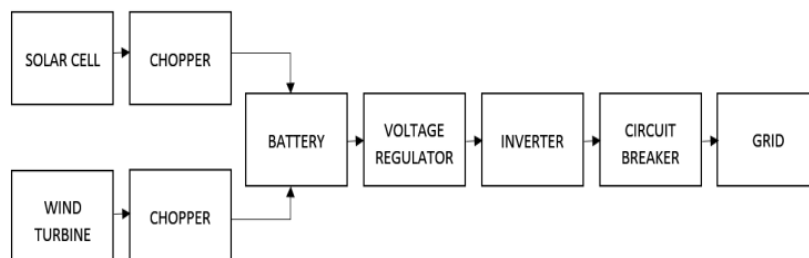


Fig. 1: Block diagram of solar-wind hybrid system connected to grid

Choppers are used after the solar and wind systems to control the output voltage of solar and wind. A battery is used in order to provide a continuous power to load as wind and solar energies are uncertain during islanding operation. However the usage of batteries for large scale power generation is not possible. A voltage regulating chopper is used to monitor the output level of the voltage which comes out of inverter in order to match it with that of the grid voltage. An inverter converts a DC voltage to an AC voltage in a proper phase sequence, so that

the obtained output is in phase with the grid voltage. Circuit breaker is used to connect the solar wind hybrid system to the grid to synchronise the generated power with the grid.

III. CONTROL OF SOLAR ENERGY

A solar cell basically is a p-n semiconductor junction. When exposed to the light, a DC current is generated. The generated current varies linearly with the solar irradiance [2]. The equivalent electrical circuit of an ideal solar cell can be treated as a current source parallel with a diode shown in Fig 2.

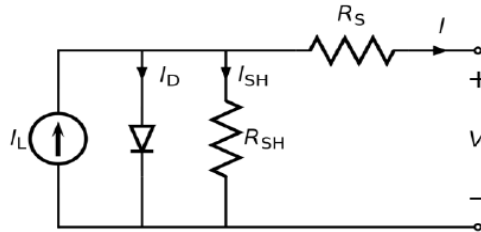


Fig. 2: Equivalent electrical circuit of a solar cell

The I-V characteristics of the equivalent solar cell circuit can be determined by following equations. The current through diode is given by:

$$I_D = I \left(e^{\frac{q(V+IR_S)}{kT}} - 1 \right)$$

While, the solar cell output current:

$$I = I_L - I_D - I_{sh} = I_L - I \left(e^{\frac{q(V+IR_S)}{kT}} - 1 \right) - \frac{V + IR_S}{R_{sh}}$$

Where:

I : Solar cell current (A)

I_{sh} : Light generated current (A) [Short circuit value assuming no series/ shunt resistance]

I_D : Diode saturation current (A)

q : Electron charge (1.6×10^{-19} C)

k : Boltzman constant (1.38×10^{-23} J/K)

T : Cell temperature in Kelvin (K)

V : solar cell output voltage (V)

R_s : Solar cell series resistance (Ω)

R_{sh} : Solar cell shunt resistance (Ω)

The current versus voltage curve for the solar cell is as shown in the Fig 3.

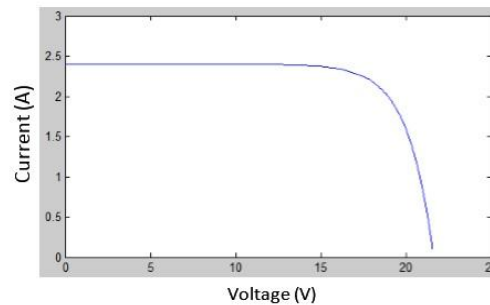


Fig. 3: IV characteristics of a solar cell

The power delivered by the solar module depends on the irradiance, temperature, and shadowing conditions. The solar cell has a nonlinear characteristic, and the power has a Maximum Power Point (MPP) at a certain working point (Fig 4), with coordinates V_{MPP} voltage and I_{MPP} current [3]. Since the MPP depends on solar irradiation and cell temperature, it is never constant over time; thereby Maximum Power Point Tracking (MPPT) should be used to track its changes. Maximum Power Point Tracking (MPPT) is becoming more and more important as maximum energy extracted from the solar cell.

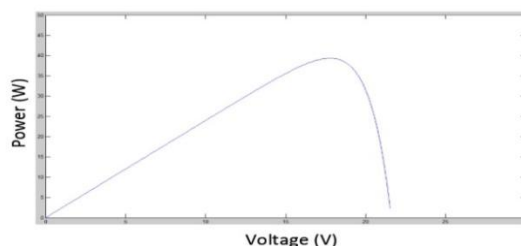


Fig. 4: PV characteristics of a solar cell

Hence the smart controller must be capable of determining the MPPT voltage and current for a given condition.

IV. CONTROL OF WIND ENERGY

The Wind energy is one of the fastest growing renewable energies in the world. The generation of wind power is clean and non-polluting; it does not produce any by-products harmful to the environment. For a particular wind speed, there is a specific turbine rotational speed which generates the maximum power. The maximum power point tracking (MPPT) for each wind speed increases the energy generation. However, the MPPT control for each wind speed generates the output power fluctuations. But, the introduction of fuel cells and flywheels has reduced the above problem [4].

The power versus wind speed curve for the wind turbine is as shown in the Fig 5.

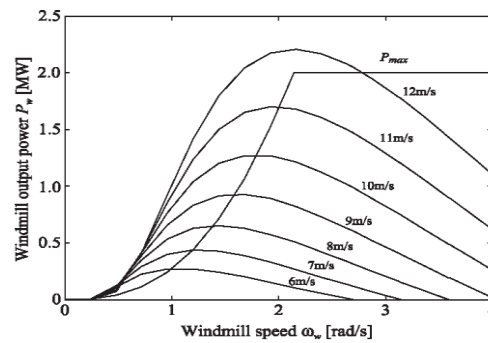


Fig. 5: Power-wind speed characteristics of a wind turbine

The wind mill speed of the wind turbine can be varied by varying the pitch angle. Also from Fig 5 it can be noted that for a particular wind speed there will be a particular wind speed for which the power is maximum. Hence the smart controller must be capable of determining the pitch angle to extract maximum power under a given condition.

V. CONTROL OF POWER FROM AND TO BATTERY

A battery is used in order to provide a continuous power to load as wind and solar energies are uncertain. A battery being a chemical device has some restrictions while operating it such as the minimum and maximum State of Charge (SOC), maximum charging and discharging currents and so on [7]. Hence the smart controller must be capable of controlling all these requirements.

VI. VOLTAGE REGULATOR CONTROL

The output voltage generated from the inverter must be of same level as that of the grid in order to synchronise to the grid. If there is a difference in voltage levels of the generated voltage and the grid voltage, then there will be a flow of huge inrush currents which may cause damages. The magnitude of inrush current for a difference voltage of ΔV and for a sub-transient reactance of X_d'' is:

$$I_{inrush} = \frac{\Delta V}{X_d''}$$

A chopper is used as voltage regulator to vary the DC input of the inverter so as to vary the output voltage level of inverter in order to match with grid level. Also after the synchronisation to the grid, the voltage regulator can be designed to increment the output voltage level of the inverter in order to supply the reactive power required [5]. Smart control has to perform all these functions by controlling the chopper action.

VII. INVERTER CONTROL

A three phase inverter is used just after the voltage regulating chopper in order to supply the power to the local loads and also to the grid.

In order to connect the solar-wind hybrid system to the grid, the generated voltage must be in phase with the grid voltage. Hence inverter control is made such that it takes the grid voltage as the reference and generates control pulses to the inverter, so that a voltage having same phase sequence and same frequency as that of the grid voltage is generated.

Once the solar-wind hybrid system is connected to the grid, the power angle (δ) of generated voltage must be increased slightly, in order to ensure that all the generated power (P) flows to the grid [6] according to the equation shown below.

$$P = \frac{EV}{X} \sin \delta$$

The smart controller must be capable of increasing the power angle of generated power after connecting to the grid.

VIII. CIRCUIT BREAKER CONTROL

The circuit breaker is controlled to not only clear the faults but also to connect/disconnect the solar-wind hybrid system to the grid, only if the generated voltage is in synchronism with the grid.

It will check the RMS values of both grid voltage and hybrid system voltage and will connect the hybrid system to the grid only when magnitude and the phase sequence are matching.

IX. FUNCTIONS OF THE SMART CONTROLLER

The functions of a smart controller are as follows:

- ✓ Control of solar and wind chopper by implementation of MPPT algorithm for the utilization of the maximum power generated from the solar module and wind turbine.
- ✓ Monitor the charge & discharge of the battery for its safe operations.
- ✓ Monitors the output voltage level of the three phase inverter and adjusting it continuously to the grid voltage level by controlling the voltage regulating chopper.
- ✓ Once the system is connected to the grid, reactive power management is done by controlling the terminal voltage of the system by controlling the voltage regulating chopper.
- ✓ Monitoring the output frequency of the three phase inverter and adjusting it continuously to the grid frequency by controlling the inverter action.
- ✓ Also when the system is connected to the grid, controls the active power flow by controlling the power angle of the hybrid system.
- ✓ Controls the circuit breaker depending on islanded or grid connected operation
- ✓ Under the grid connected operation it monitors the output voltages of the system and grid voltage and connects both of them only when the voltages are synchronous to each other.

X. SIMULINK MODEL OF THE SOLAR-WIND HYBRID SYSTEM CONNECTED TO THE GRID

Simulink model [9] of the solar wind hybrid system connected to the grid is as shown in Fig 6. It consists of a smart controller which controls the overall functions of the hybrid system. The block diagram of the controller is as shown in Fig 7. The MPPT control of the controller is based on perturb and observe algorithm [8]. The V_{MPPT} and power extracted from solar cell for the given variation in irradiance is as shown in Fig 8. The battery management system is modelled to control the charge and discharge rates of the battery in order to improve the life of the battery.

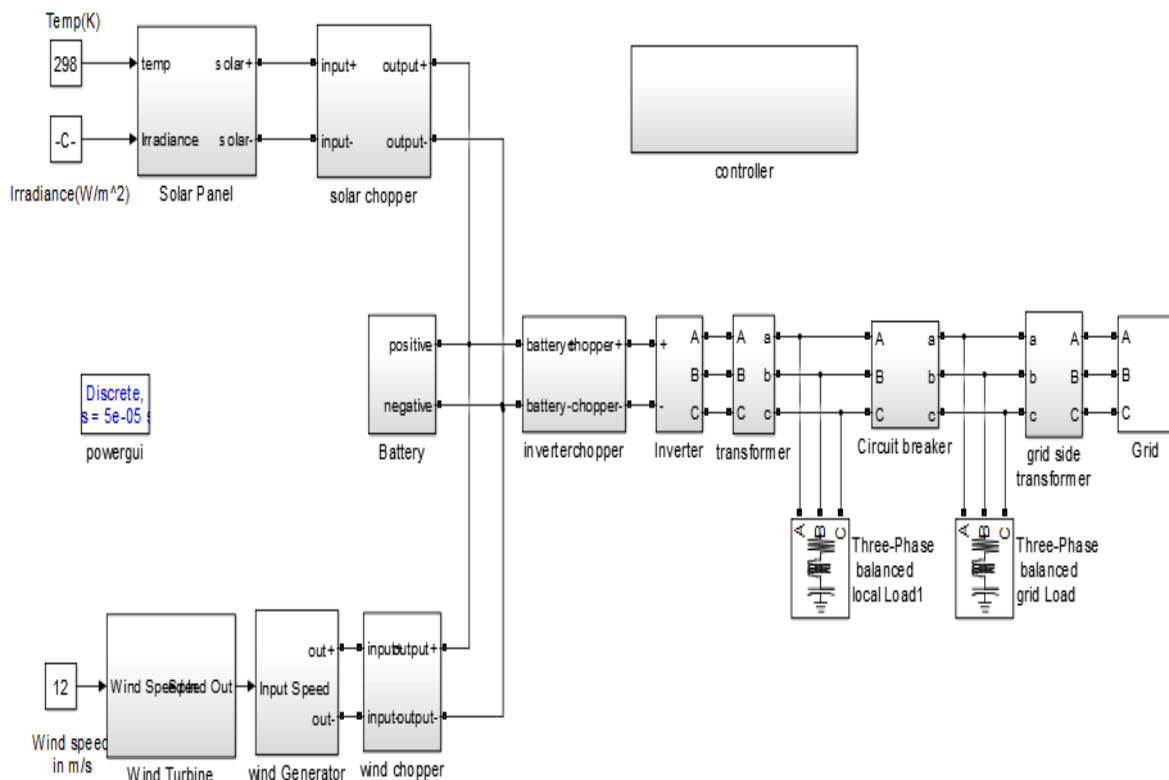


Fig. 6: Simulink model of solar wind hybrid system connected to grid

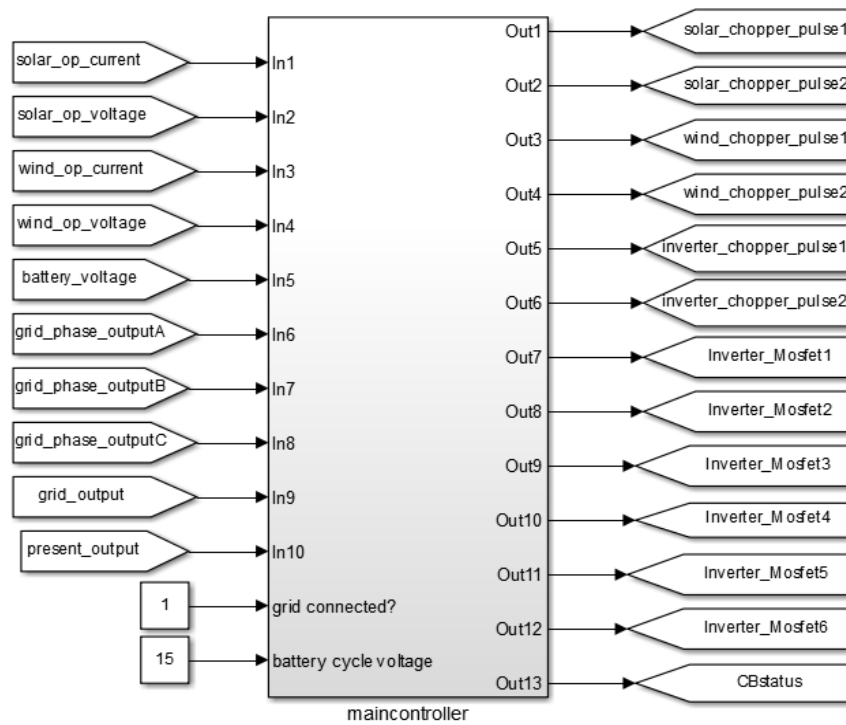


Fig. 7: Smart Controller for solar wind hybrid system connected to grid

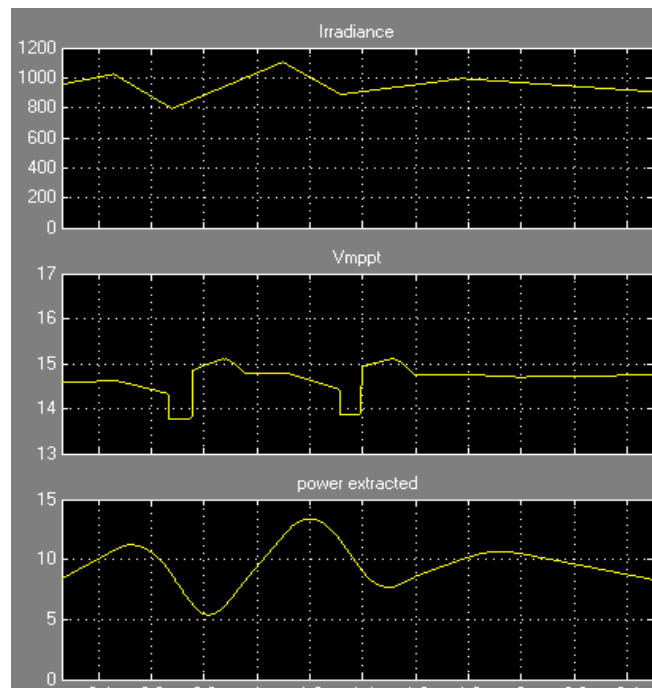


Fig. 8: Variation of V_{MPPT} and power extracted with respect to variation of Irradiance due to
 Voltage regulating chopper is used to regulate the voltage level at the output of the inverter with respect to the voltage variations at the grid. Controller calculates the duty cycle by taking the values of input voltage (V_i), required output voltage (V_r) and actual output voltage (V_a). The calculated duty cycle is given by:

$$d = \left(\frac{13}{270} \right) \frac{V_r}{V_i} + 0.01(V_r - V_a)$$

Where $(V_r - V_a)$ represents the error and the number 0.01 represents the minimum change of duty cycle, the number 13 represents the maximum battery voltage and the number 270 represents the maximum grid voltage (under over voltage condition). The inverter control uses the grid voltage as the reference for producing pulses

for the semiconductor devices of inverter, thus the produced 3 phase voltage will be in phase with the grid voltage.

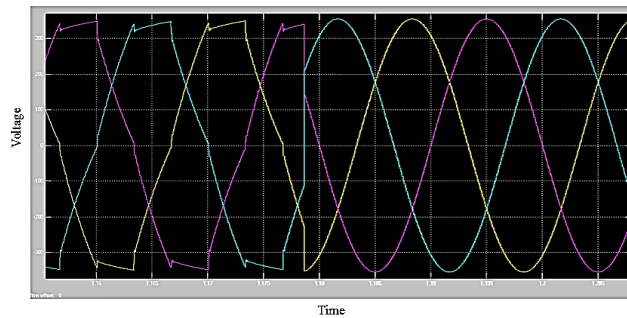


Fig. 9: Voltage waveform of the hybrid system at the time of synchronization to the grid

Circuit breaker is modeled to connect the hybrid system to the grid when the RMS voltages of both grid and hybrid system are nearly close. The voltage waveform of the hybrid system at the time of synchronization to the grid is as shown in the fig. 9.

XI. CONCLUSION

The background study regarding the working of the solar cell and wind turbine has been done. The requirement of hybridization and the challenges involving the hybridization are discussed. The control strategies involved in the hybrid system and the hybrid system connected to the grid are discussed. Model of the proposed system has been realized with the help of Simulink and the expected results are observed.

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