Iowa State University

Hybrid Wind and Solar Generation System

Design Document

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Summary

The project is a functioning hybrid generation system. The goal of the project is to use both wind and solar power to reliably and efficiently power a small load, as one might see in a small household. A photovoltaic array will be used to generate solar power. A motor, whose speed is governed by wind speed readings, will simulate a wind turbine to produce power. Both generation systems will have separate power electronics to convert from DC and AC as needed, as well as altering the waveform to suit the load. A battery bank will be used to store charge in order to maintain constant power to the load when weather conditions are not optimal.

System Design

System Requirements

Photovoltaic Array

The amount of power generated by the photovoltaic array is dependent on the amount of solar irradiance received by individual solar cells. Our generation will have two solar panels, size currently unknown. Nominal voltage and current measurements will be done in the testing phase.

Boost Converter

The boost converter requires an input voltage and a duty cycle for its switch. The duty cycle will be assigned by the Maximum Power Point Tracking system, which will use the perturbation and oscillation method to get closer to maximum power. The boost converter keeps the system as close to the voltage that achieves maximum power as possible.

Induction Motor

The amount of power generated by the induction motor is dependent on the wind speed readings taken by the anemometer. A higher wind speed results in a higher rotation and more power. A lower wind speed has the opposite result in the wind system. The induction motor is mechanically coupled to the permanent magnet generator and thus their rotational speeds will be the same.

Inverters

The inverter will convert our DC power to AC for the load. Each inverter requires a DC power input. A pulse-width-modulator regulates the switching in the inverters to output a 60 Hz waveform for the load.

Load

The load will draw only real power, approximately 400 Watts. A series of light bulbs and fans will be used to obtain this value. The load will be connected in series with the battery bank as well as to the output of the generation systems. Switching will be utilized to select which source will be drawn from depending on certain conditions: the current output of the photovoltaic system, the current output of the wind system, and the charge of the battery.

Battery Bank

Several 12 V batteries will be connected in series to achieve the desired nominal voltage level for the bank. The battery bank will be connected in parallel to the inverter and load in order to store charge at the desired level of voltage and feed the load when necessary. A switching mechanism will be used to determine which of the generation systems is charging the battery, and when to disconnect the battery when fully charged.

PI Controllers

Controllers will be used to compare voltage or current levels at certain points to determine switching behavior for the different generation cases.

System Description

This hybrid wind and solar generation system uses two types of sustainable energy to power a small load. The project is a proof of concept for this dual-generation system on a small scale. The solar power is generated by a photovoltaic array. This is connected to a boost converter with Maximum Power Point Tracking (MPPT) capability to adjust the voltage of the photovoltaic system to achieve maximum power. The AC motor governing the generator is connected to a controller that takes wind speed readings from an anemometer. This simulates the functionality of a wind turbine. Both forms of generation then power a battery bank and connect to an inverter to power the AC load. Direct load connection, battery charging, discharging, and other responses will be determined by various controllers and switches. Figure 1 shows a block diagram of the proposed system.

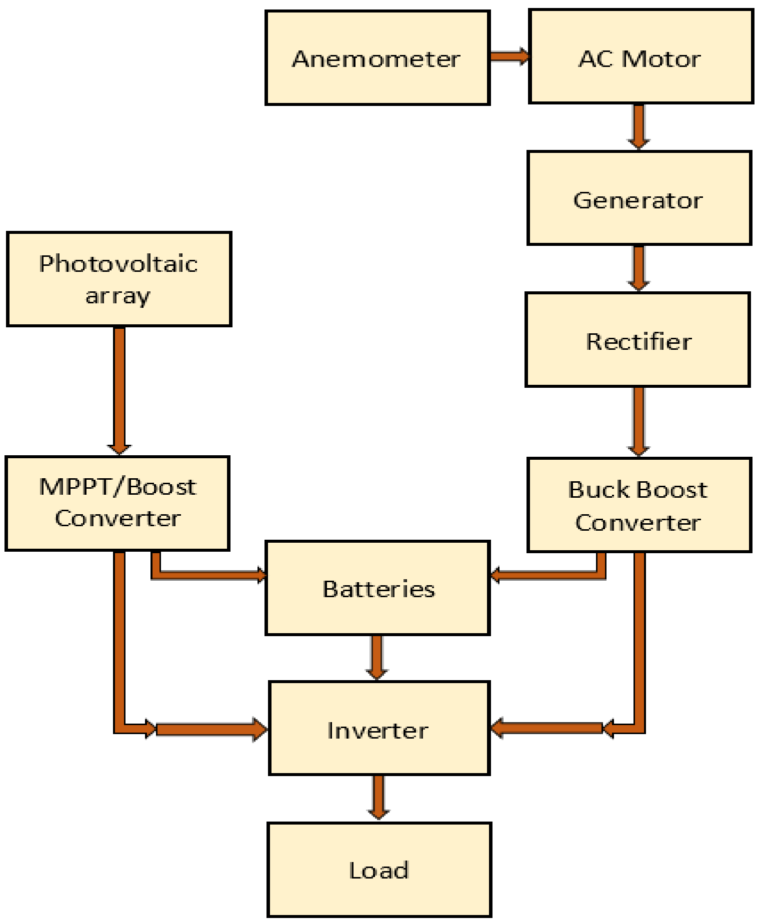

Fig. 1: Block diagram of the hybrid generation system

Detailed Design

I/O Specifications

The input and output specifications for the project as a whole is to generate enough electricity from renewable solar and wind sources to power a 400 W load. Solar power is obtained from a PV panel. Wind electricity will be simulated rather than harnessed from a wind turbine because code violations prevent any kind of wind turbine from being in the Coover area. An induction motor that is mechanically coupled to a wind turbine generator spinning at a rate proportional to the current wind speed readings will simulate an operational wind mill. These two sources together will provide for the 400 W load.

Hardware Specifications

This project is done in two parts, the first half in Matlab Simulink and the second half in hardware implementation. In the solar design of our hybrid system a PV panel generates electricity which is sent through a boost converter and Maximum Power Point Tracking (MPPT) system to maximize DC power. This max DC power is then put into an inverter which converts the DC power to AC power. The AC power then feeds the load. A battery bank will be integrated to store excess power and supply extra power when needed.

One individual solar cell provides approximately .5 volts a peak irradiance. A typical solar panel will have 36 solar cells connected in series which can provide up to 18 volts, however some of this voltage is lost due to heat. The boost converter should increase voltage input to the value specified by the MPPT. The MPPT will select a voltage value that will provide the corresponding maximum power. The stand-alone inverter will convert from generated DC to AC.

The wind section of the hybrid system replaces a typical wind mill with an induction motor that is mechanically coupled with the wind turbine generator. The wind turbine generator is a permanent magnet machine. This means that the magnetic field across the rotor is created from permanent magnets rather than a coil excited by a DC current. The speed of the induction motor will be determined by readings from an anemometer. A particular wind speed will correspond to a particular amount of power that would otherwise be generated by the wind turbine generator under typical operation. The wind speed data will be converted into an rpm value. The rpm value will then be converted to a voltage that will be applied to the input leads of the motor.

As the induction motor and the wind turbine generator are mechanically coupled, they will spin at the same rotational speed. The voltage generated by the wind turbine generator is then rectified and filtered to a DC voltage. The DC voltage is then sent through a buck/boost converter to maintain a constant DC voltage. A regulated DC voltage is imperative in order to supply the battery bank with safe and reliable power. An inverter will then convert the DC voltage to single phase AC to drive the load.

Interface Specifications

The final project will be completely autonomous. The hybrid generation system will be designed to be used in isolated areas and require little to no user interaction outside of installation.

Simulations and Modeling

Simulations for each hardware component will be done in Matlab Simulink prior to any implementation. Both the solar and wind parts of the hybrid system must be successfully simulated individually and then integrated into one model and simulated again before moving to hardware. Each major component of the solar and wind design is included in the simulation. The input will be approximated as realistically as possible, and the output must be maintained at 400 W. Scenarios which result in a load less than and greater than the generated solar and wind power will also be considered to simulate real world situations. In summary, expected values of voltage and current for the input and output of each component must be known before hardware testing can begin.

Featured below in figures 2-4 are displays of the Matlab simulation of the PV system.

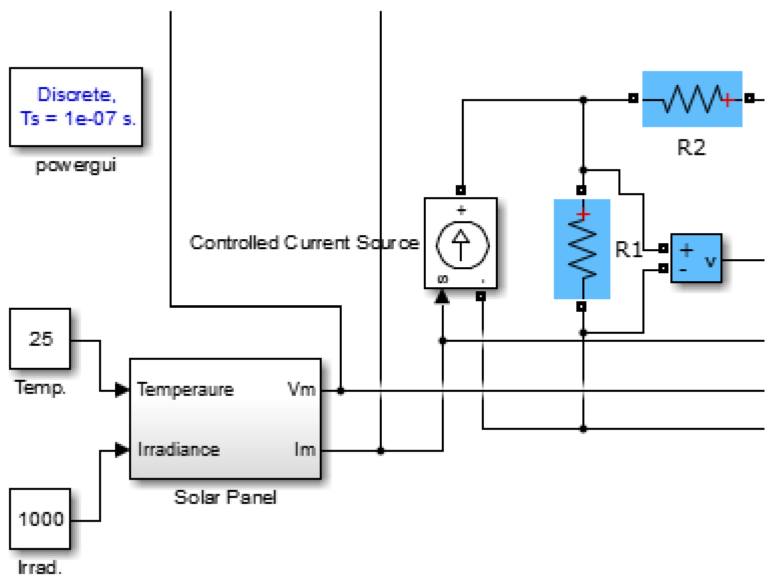

Fig. 2: Function simulates the solar panel output characteristics, and current divider inputs to boost converter

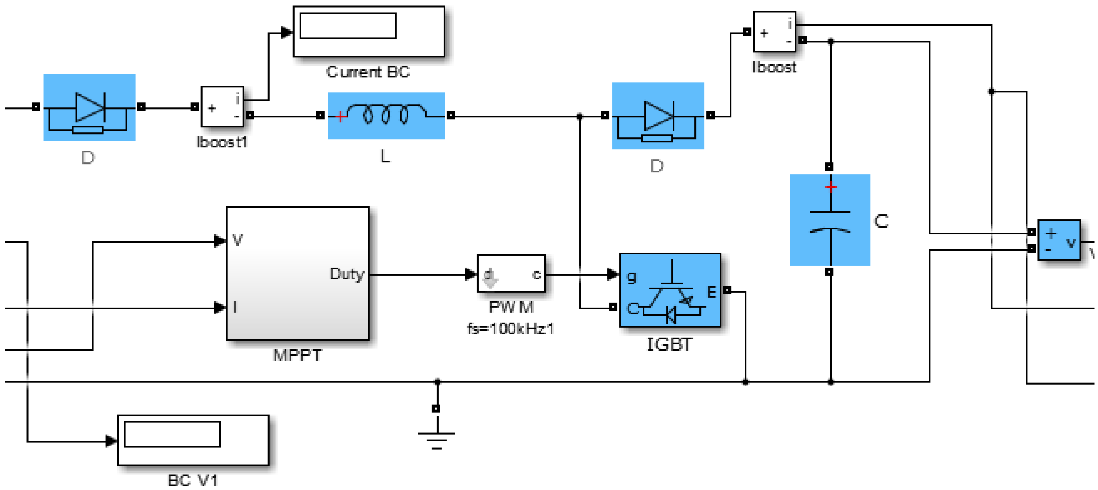

Fig. 3: Boost converter steps voltage up or down. MPPT determines the duty cycle of switch to control.

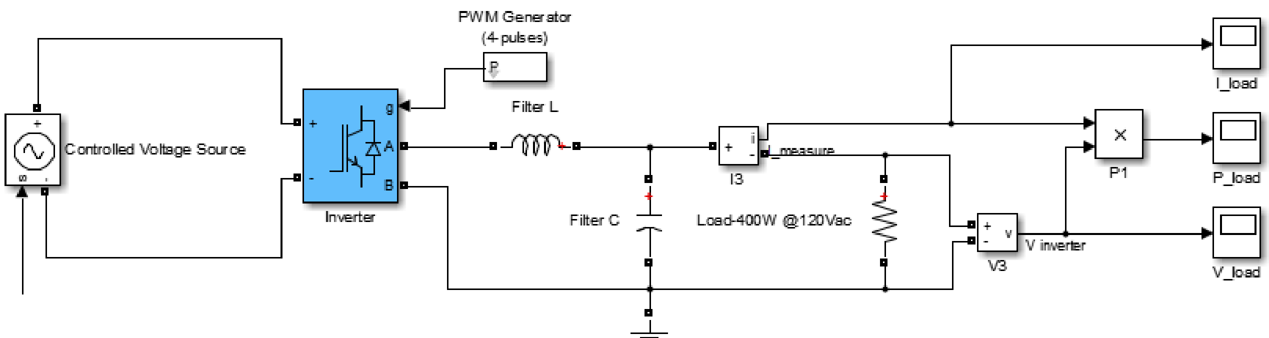

Fig. 4: Output voltage from the boost converter is given to inverter to convert to AC power. An LC filter alters the waveform for the AC load

Below is a figure of the induction motor mechanically coupled with the permanent magnet generator. For testing purposes, the input voltage to the induction motor is a constant three phase voltage source. In practice, this will be swapped with a device that converts the wind speed measured from the anemometer to an rpm value and from an rpm value to a three phase voltage magnitude. The three phase load is also for testing purposes only. The load will ultimately be connected at the output of the inverter.

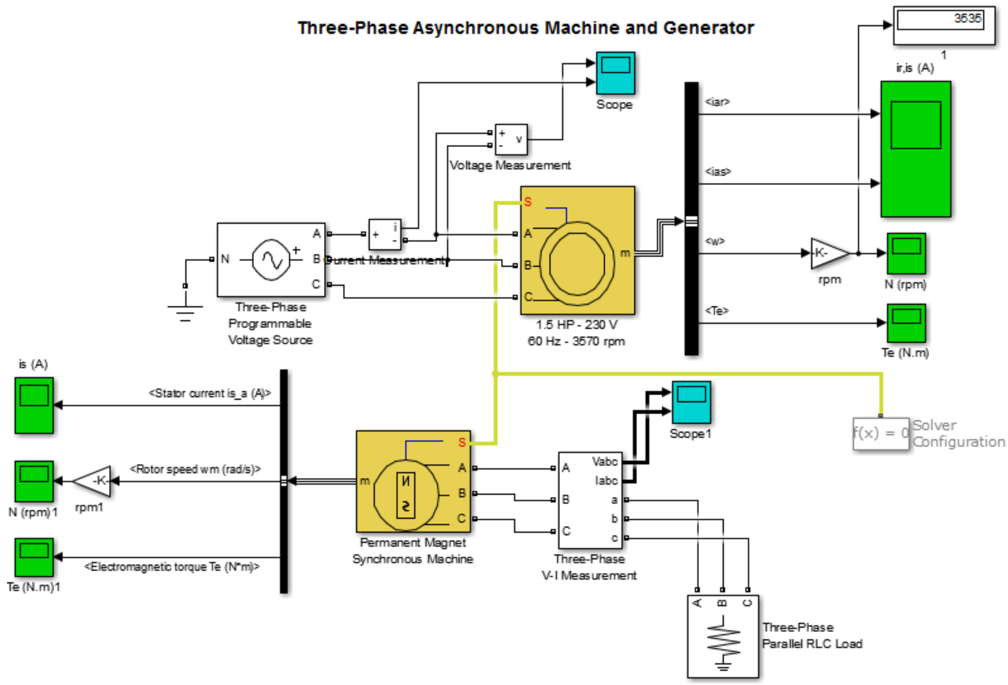

Fig. 5: Simulink simulation of the induction motor mechanically coupled with the permanent magnet generator

Figure 6 depicts the rectifier portion for the wind generation section. For testing purposes, the three phase voltage source models the output of the generator.

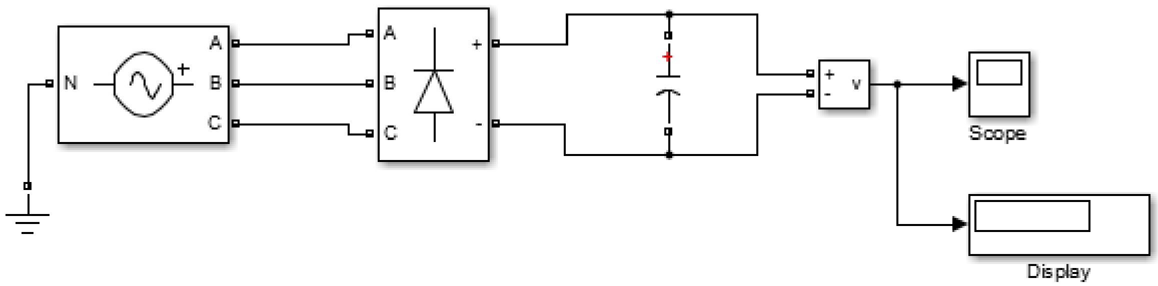

Figure 6: Simple rectifier converts 3 phase voltage to DC voltage

Figure 7 depicts the buck converter for the wind generation section. The purpose of the buck converter is to take the varying DC rectified voltage, step it down to the voltage of the batteries (24V), and maintain a constant 24V DC output voltage. For testing purposes, the DC voltage source models the output of the rectifier. Resistor R_{Load} is also in place for testing purposes only. The final design will only include R_{Load} at the output of the inverter.

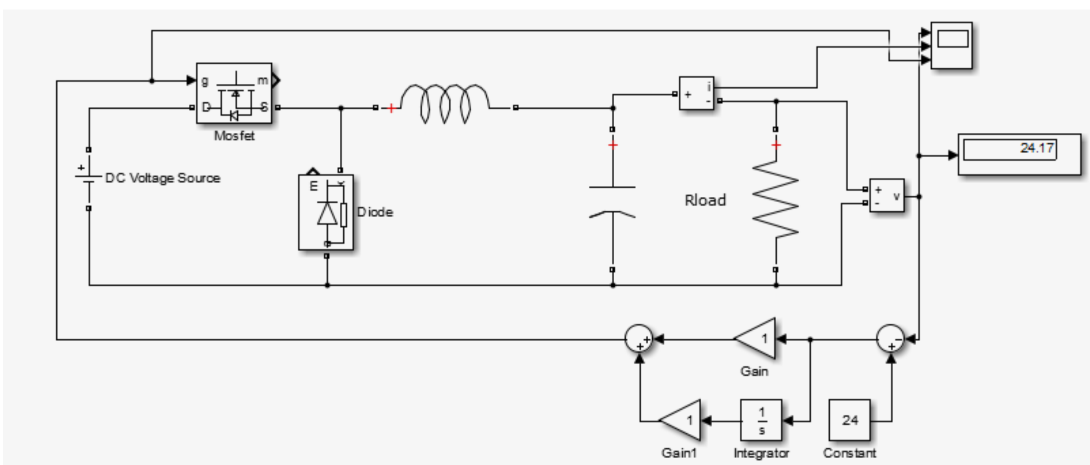

Figure 7: Buck converter reduces input DC voltage to a constant 24V DC

The output of the buck converter will also be tied in parallel with the reserve battery bank. At this point, the wind generation system will be tied to the solar generation system. Control will be in place to monitor the output of the reserve battery bank. The wind generation and solar generation systems will share a single inverter. The purely resistive load will be connected to the output of the inverter.

Testing Procedures

In general, we are going to test solar part and wind part separately before we test the final hybrid design. This way it is easier for us to locate issues and simplifies the testing procedure. By simulating the input and output power for each component of the design in Matlab, we will gain an idea of what we need to obtain from the hardware. Additionally, the simulation gives us expected output to help prevent the overburdening of valuable electrical components.

In the solar design, the major devices we have are solar panels, Maximum Power Point Tracking (MPPT) system, boost converter.

Major components in the wind design are the induction motor, permanent magnet generator, maximum power point tracking (MPPT), rectifier, buck/boost converter.

Both systems will connect to the same battery bank, inverter, and loads.

There are numerous solar cells that make up our solar panels. The number of cells in parallel and series give us an expected voltage and current for certain conditions. There are many commercial MPPT controllers optimized for solar charge, such as Victron Energy MPPT 75/15 solar charge controller, that we may use in our design. The boost converter often comes with the MPPT, such as the SPV1020 solar boost converter.

The inverter for solar charge as well as the battery bank are also available in the electronics market, but we will need to build the filter by ourselves in order to meet the specific frequency requirement. We are planning on using a passive RLC filter.

An important consideration with the pseudo wind generation is that the input potential power (measured wind speed) will need to equal the output power of the induction motor. This will be key to maintaining a design closest to having the blades of the windmill spin the rotor of the wind turbine generator itself. Each component of the system will need to be tested individually. This testing will be done both in simulation and with the hardware. We need to be able to expect the output for a given input into each component. This knowledge, will be very helpful when it comes to troubleshooting problems when combining each part into the whole system.

After we have all of the components, we will individually test the input and output waveform characteristics as per our simulations and compare to the expected values. Next we will physically connect them and perform further output measurements sequentially. The functional systems will be put outside to test its generation under various real conditions. Here we will observe actual power output from the input of solar irradiance and wind speed.

Closing Documents

Schedule

Figures 2 and 3 describe the basic project outline for the first semester and second semesters, respectively.

	August	September				October					November				December		
Task Description	25-29	1-5	8-12	15-19	22-26	Sept. 29- 3	6-10	13-17	20-24	27-31	3-7	10-14	17-21	24-28	1-5	8-12	15-19
Project Selection/Team meeting/Introduction																	
Background Research																	
Initial Software Simulation																	
Develop Project Plan																	
Software Simulation and Component Testing																	
Acquire Component Data																	
Part Acquisition and Hardware Preparation																	

Fig. 2: First semester schedule

	January			February			March				April				May		
Task Description	12-16	19-23	26-30	9-13	16-20	22-27	2-6	9-13	16-20	22-27	30-3	6-10	13-17	20-24	27-1	4-8	11-15
Solar Cell Testing																	
Induction Motor Testing																	
PMSG Testing																	
Converter Testing																	
Anemometer Testing																	
Battery Testing																	
Rectifier Testing																	
Inverter Testing																	
TroubleShooting/Assembly																	
Final Assembly/Assembly/Testing																	
Present																	

Fig. 3: Second semester schedule

Challenges

When it comes to hardware, we have proposed several devices to implement our design. One of the implementation issues that may happen is the power output may exceed the ratings of the device being used, and damage may occur. This can result in project delays and additional costs to replace equipment. Simulation and testing is done in order to prevent this.

Another challenge is anticipating the output of the various power electronics. Though the goal of the simulation is to give us values to expect, differences in practice and theory will always occur. Once again, there is a risk to the functionality and potentially damage to each device.

Project Deliverables

The following is a list of milestones to be reached as we progress through the project.

- A fully functioning solar generation simulation which includes: PV cells, MPPT/boost converter, battery, inverter, and a load.
- A fully functioning wind generation simulation which includes: (insert wind components)
- The simulated solar design modeled and tested in hardware so that a load of up to 400 W can be provided for.
- The simulated wind design modeled and tested in hardware so that a load of up to 400 W can be provided for.
- A fully functioning solar/wind hybrid generation simulation which is comprised of the two previous simulations.
- The hybrid design modeled and tested in hardware so that a load of up to 400 W can be provided for.

Conclusion

This project is designed to be completed by the end of two semesters. Our work in the first of these two semesters focused largely on simulation and gaining an overall understanding of the project. As a group we have been very successful in our simulations, and now that we have working designs for both solar and wind generation we are preparing to work with hardware next semester. The project focuses on design and testing a system rather than producing a final product. At the end of next semester our goal is to be able to demonstrate a working model which powers a load by combining both solar and wind generation.

Team Information

Our project is split into two teams: the solar team and the wind team. Each team is responsible for software, hardware, and general knowledge for their field. All team members are seniors in electrical engineering.

Solar Team

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