Iowa State University

Hybrid Wind and Solar Generation System

Project Plan

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Overview

Background

A sustainable, off-the-grid generation system is desirable in many situations. Environmental concerns, for example, may turn a consumer away from fossil fuels or natural gas. Connection to a traditional power grid may be costly or impractical for a small or isolated load. Or, the infrastructure in a community may simply not exist to support such a grid. Wind and solar power alike have seen reductions in cost and an increase in popularity around the world in recent years. Whether it is used to make an existing grid more environmentally-friendly or provide power to communities in poorer areas, a hybrid wind and solar generation system has many useful applications. This project is aimed at developing efficient and reliable generation for small-scale loads, as one would see in a typical household.

Problem

The application of both wind and solar generation presents a number of challenges. Both methods of generation are highly dependent on weather conditions. A wind turbine will not meet required loads if there is insufficient wind. A photovoltaic array may not provide adequate power if it is nighttime, or even cloudy. The system will need to be connected and operate in such a way that the two methods of generation can reliably meet load demands, even during adverse weather conditions. The system will need to be simulated throughout the project's lifetime, and these results applied to the actual construction of the hardware itself. The hardware will need to be tested under a variety of conditions. This includes when both systems are generating at ideal power levels, when one is ideal and the other is low, and when both are low.

Objective

The goal of the project is to use wind and solar power to reliably power a 400 watt load, maximum. Both wind and solar systems will be modelled using Matlab's Simulink program, and the resulting model will assist in building the hardware. The hardware project itself will be constructed based on the results of the simulation and tested extensively. The solar generation will be done by a photovoltaic array. The wind generation will be done by a motor coupled to a generator, simulating the effects of a wind turbine based on wind speed readings.

Specifications

When completed, the hybrid generation system should meet several specifications:

- Both solar and wind generation powers a small load (up to 400 Watts)
- Maintains power to load throughout non-ideal weather conditions
- Uses PI controllers to govern battery and generation connection to the load
- Safely charges battery and does not overpower load for excellent weather conditions
- Completely autonomous, functional in isolated areas

Deliverables

The deliverables for this project come in several phases. The first part is to develop simulations for our hybrid solar and wind design. After this model has been simulated thoroughly then we will construct the model with the provided hardware, testing and refining it extensively. The results of these simulations, installation, and tests will be a fully functioning hybrid generation system for our client.

Design

Below is a schematic of the combined wind and solar generation system. The photovoltaic array is connected to a boost converter with maximum photovoltaic power tracking (MPPT) capability. 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.

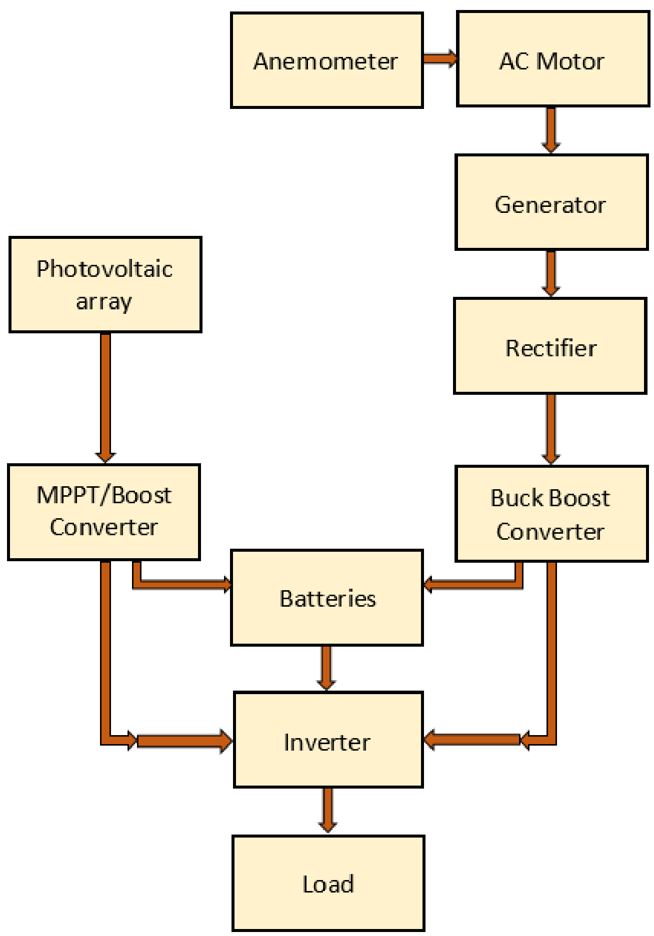

Fig. 1: Block diagram of hybrid generation system

Interface

The final project for demonstration will feature the solar and wind generation systems, battery, and load. The system will be completely autonomous. Amount of power going into the load and battery will be displayed. The hybrid generation system will be designed to be used in isolated areas and require little to no user interaction outside of installation.

For the solar generation system, a photovoltaic (PV) panel generates electricity from the sun, measured in irradiance. This power is then sent through a boost converter in order to adjust the voltage to a level that provides maximum power for the amount of irradiance of the panel for any given time. Adjustments to the boost converter are made by the MPPT, which adjusts the duty cycle of a bipolar transistor. This maximized DC power is then connected in parallel to a battery bank and inverter. The battery bank will be integrated to store excess power and supply extra power when needed. The inverter converts the DC power to AC power. The AC power then feeds the load after going through a simple filter to create a sinusoidal waveform.

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. The wind generation system will be connected to the same battery bank, inverter, filter, and load as the solar generation system.

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.

Work Breakdown

For this senior design project Riley O'Connor will be the team leader, Daoxi Sun and Shihao Ni will be the webmasters, Trevor Webb and Xiaokai Sun will be the communication leaders, and Ben Ryan will be the concept holder. Roles will be changed periodically to allow each member a diverse group experience, at the request of the advisor.

The team leader is primarily in charge of communication with the advisor, client, and group as a whole, as well as appointing tasks for the group each week. The team leader also reviews and edits all major documents before submission. The webmasters' main duty will be to design, update, and maintain the group's website. The communication leaders are in charge of writing weekly reports and other documentation. The concept holder's primary duty is to keep track of new and important information, and to ensure the group is continuously refining aspects of the design. Apart from their appointed roles, each team member is also responsible for reading relevant material, contributing to coursework, and assisting in the simulation and hardware aspects of the project.

The full team was divided into two groups, each containing three people. Daoxi Sun, Riley O'Connor, and Trevor Webb make up the solar team and will focus on the photovoltaic system. Xiaokai Sun, Ben Ryan, and Shihao Ni make up the wind team and will focus on the wind turbine system. Both teams will initially work separately, but will keep each other informed on their portion and work on combining the systems further on.

Validation Testing

The solar part and wind part will be tested 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.

Cost Estimations

All of the cost for the project will be from hardware purchases. The solar team will require the purchase of an MPPT and boost converter. PI controllers, as well as some passive components, will need to be purchased for both systems as well. Overall, we are looking at total purchases under $300 dollars.

Resources

For the hardware aspect of the project, we will use a variety of equipment, including a motor, generator, anemometer, photovoltaic array, boost converter(s), inverter(s), and other power electronics. Various lab equipment will be used to measure output from the hardware. We will use Matlab for some basic simulation before we begin assembly of the hardware. Also, access to online resources will assist us in understanding the project, such as Wolfram Alpha, Mathworks, and scientific 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

Risks

It is very important to be aware of the safety hazards when working with power electronics. Proper workplace attire will be worn at all times, this includes closed toed shoes and clothing of appropriate length. When necessary safety equipment such as gloves, and goggles will also be worn. All safety procedures will be obeyed while in the lab.

Risk to the equipment should also be considered. Developing a thorough and realistic simulation will reduce the risk of damaging the equipment. The equipment that we will be working with is expensive and burning anything out would be a problem. We will avoid the risk of overloading the battery or back feeding power from one generation source to another.

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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