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Small Scale-Wind Power Dispatchable Energy Source Modeling

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Abstract

Due to the importance of Wind energy as an intermittent renewable resource in Micro-Grids applications; this paper is proposed. So this research proposal seeks to model and analyze components of a wind turbine generator (WTG) system to store energy and supply loads with the stored energy. Focus is placed on the storage of energy into a lead acid battery and using the battery with the inverter as a dispatchable energy source. The storage device and inverter acts as a steam power plant generator. The small-scale system consists of wind turbine, wind generator, loads, dc-dc converter, ac-dc inverter, controller and battery. We use the desired power value delivered to each load to determine characteristics of the wind turbine system. Some characteristics are: wind speed, power, and charging / discharging characteristics for the battery are presented. We build the proposed real system to present a system with its components in details on a small scale. Such model' components are tested together with other distributed system models in order to evaluate and predict the overall system performance. The proposed research presents to show an operational wind power system, for a small-scale micro-grid application. The experimental test-bed is implemented to supply the Neural Network model with its real training data. Using the Artificial Neural Network (ANN), with feed forward back-propagation technique to introduce discharging ANN model with Time as input and Voltage, Ampere-hours and Power (Watt) as outputs. ANN network consists of two layers one hidden with log-sigmoid function (has two neurons) and the second with pure-line function (has three neurons). This is done to make benefits from the ability of neural network for interpolation between points and also curves. ANN model with Back - Propagation (BP) technique is created with suitable numbers of layers and neurons. The model is checked and verified by comparing actual and predicted ANN values, with good error value and excellent regression factor to imply accuracy.

Keywords: *Wind power, generator, Model, Small-Scale, Artificial Neural Network, and Simulink.*

1. Introduction

Renewable energy is a fast progressing area of engineering with great strides being made daily to improve the green energy output across the world. One area of renewable energy that presents great opportunities as a source of clean energy is wind energy [1]. Wind power capacity in the U.S. has reached more than 65 GW in 2014, which is up from 61 GW in 2013. The average power consumption for the state of Georgia for a month is 1098 kWh. Wind energy generation has attracted much interest in the last few years due to it being a clean and renewable energy source [2]. Doubly-Fed Induction Generators (DFIGs) have some advantages over synchronous and induction generators when used in wind farms, such as variable speed operation, active and reactive power control, and lower converter cost [3].

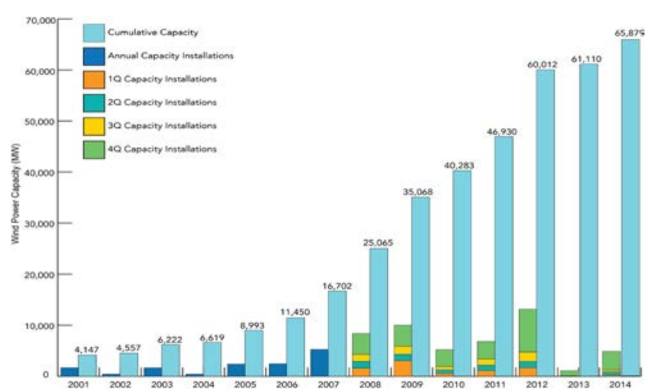

Fig. 1 U.S. progression in wind power capacity and how quickly it is advancing [1].

We decided to pick a project that would promote sustainability in areas with access to sufficient wind. One downside to using the wind as a source of energy is the fact that it is an intermittent source of energy. This is why we decided to use a battery as a storage device to store the available energy. This battery is then a dispatchable source of energy that can be disconnected from the system and used for power during the time that wind speed is not sufficient enough to produce enough power for the desired load. The idea for our project is to construct a system that is capable of harnessing energy from the wind and supply it to a home to decrease the cost of electricity on a monthly basis. Using less electricity from a power plant will save money over the course of years while also supporting a sustainable world. Power plants that burn fossil fuel to create power are the leading cause of carbon dioxide emissions in the United States. By using wind to cut down on energy consumption from the main grid families across the United States can help to promote a cleaner environment and a more sustainable future for the earth. Having a battery as a dispatchable source of energy allows a system that uses a wind turbine generator to act as a micro grid, meaning that a home could run off of the wind turbine and battery when energy is available but could also use power from the main grid when the available renewable energy is not sufficient. Having the resources necessary to create energy more naturally is a powerful thing and more people across the world should be knowledgeable about the positive effects intermittent dispatchable sources of energy could have on a home and the environment.

A small scale hardware model of the actual system is gathered and implemented. In order to gather data and show how a generator connected to a battery and charge it. Next, an inverter changes the output voltage of the battery from DC to AC. Finally, a load is connected after the inverter to gather data and show how the stored energy could be used to supply the load for a certain amount of time. For this research we use a 50 watt wind turbine generator with a built in controller to charge a small 12 volt battery. A digital multimeter will be capable of being moved before and after the battery to measure charging and discharging characteristics of the battery. To discharge the battery we have a 150 watt inverter connected to the battery to allow AC voltage to be used to power a small home lamp or other small home appliances.

2. Technical Description:

Our project has been constructed based on a small-scale model that we used to charge and discharge a 12-volt battery. This part of project is to model a small-scale WTG system for demonstration purposes and to show charging and discharging characteristics of a lead-acid battery. After completely a large amount of research about wind turbines and battery storage we compiled a list of components that would be needed to construct this small-scale model. When we received the items for our small-scale model, we began to put the turbine together. We then had to construct a small stand for the WTG to sit on. We reviewed the specifications of the turbine we purchased, and decided to build a stand out of common PVC pipe. This decision worked out very well in the construction of the stand due to its durability. PVC is also very easy to cut and put together with couplers, so we decided on a design for a stand and then constructed it out of several couplers and PVC pipe. We then made the necessary electrical connections from the WTG to the battery and then to the inverter. During our testing of the charging and discharging of the battery, we only connected the components necessary for each test. We used an in-line ammeter before and after the battery to provide us with different characteristics including amperage output (A), load wattage (W), amp-hours (Ah), time (T), and voltage (V). The small-scale model was a great add-on to our project to show how the system works for a demonstration purpose.

2. Small-Scale Model

For this part our project we decided to build and model a small-scale wind turbine generator system. We wanted to be able to charge and discharge a 12-volt lead-acid battery to show how the system works. After discussing options with Dr. Shahat, we decided to purchase a 50-watt DC output wind turbine kit. We also purchased a 12-volt lead-acid battery from the same company that sold the turbine kit. The other components we wanted our design to have were an inverter to supply AC power, a inline multimeter to show charging and discharging characteristics, and a load. This kit came with the turbine, generator, a housing for the generator, tailfin section, blades, and a hub. We then constructed the turbine, and after that was completed we had to construct a small stand to hold the turbine off the ground. We made this stand out of ¾" PVC pipe because this material is easy to work with and would be strong enough to hold our small turbine. Once, we had the turbine system designed and built, we then made the electrical connections between the turbine, inline meter, battery, and inverter. Below are a few photos from the design of the small-scale model.

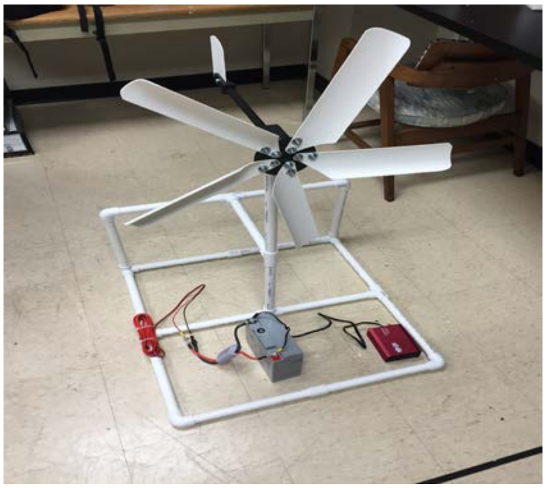

Fig. 2 Overall design of our small-scale model

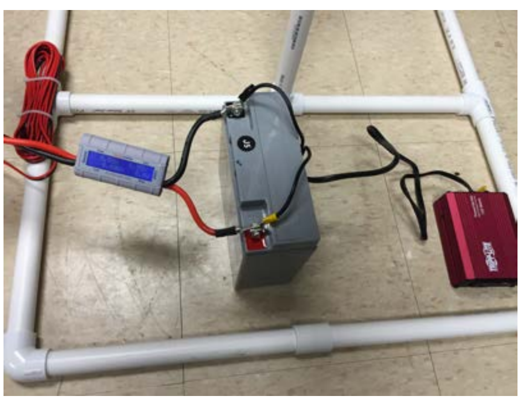

Fig. 3 Picture of inline multimeter, 12-volt battery, and inverter

Project Software and Hardware Used:

1. Computer with Matlab Software
2. Simulink
3. 50 Watt Wind Turbine Generator
4. 150 Watt Inverter
5. 12 Volt Lead-Acid Battery
6. Digital and In-Line Multimeter
7. Wind Speed Meter
8. 12' of 3/4" PVC Pipe
9. 4 X 90 Degree PVC Connectors
10. 2 X T PVC Connectors
11. Phillips-Head Screw Driver
12. Cordless Power Drill
13. Handheld Saw
14. 6 Wire Connectors
15. 4 X 1/4" Bolts and Washers
16. 4 X 1/4" Ring Terminal Connectors
17. Industrial Fan
18. Desk Lamp with 2 X 13 Watt Light Bulbs

The wind turbine came with an incased generator, a hub, 6 blades, bolts, nuts, washers, and wiring to connect to the battery. Using super glue we connected the hub to the generator. The next step was to screw the blades onto the hub, using a Phillips-head screwdriver and the bolts, nuts and washers provided. Once the turbine was assembled we had to build a stand to be able to hold the turbine up when testing the system. To do this we purchased 12 feet of PVC pipe, four 90 degrees and two T connectors. We then used a handheld saw to cut the PVC into pieces that fit the design we had in mind for our stand.

Fig. 4 Construction of PVC stand for small-scale model

Once the stand was constructed we had to connect all components of the system. The first thing we did was run the wiring from the wind turbine through the PVC out of a hole we drilled at the bottom of the stand. When wiring the system we used ring terminal connecters to connect the wiring between the wind turbine and battery and between the battery and inverter. By doing this we were capable of moving an in-line multimeter before and after the battery to measure charging and discharging characteristics. The wiring was then run from the wind turbine to the multimeter and then to the battery using a screwdriver and bolts, nuts and washers. After the battery was charged connections were made from the battery to the multimeter and then to the inverter so that a load could by plodded in. All permanent connections were made using plastic cased wire connectors and ring terminal connectors on the in-line multimeter were used to be able to place it where we needed to obtain data in the system at that time. Finally, we used an industrial fan and a wind speed meter to run the turbine and our desired wind speed and obtain data throughout the battery charging process. Once the battery was charged a desk lamp with a 36 watt light bulb was plugged into the inverter to test the discharging of the battery from the system.

Fig. 5 Photo of in-line multimeter before the battery

Equipment, Software and Materials:

i. 50-Watt Wind Turbine Generator Kit
ii. 12- Volt DC Battery
iii. PVC Pipe
iv. Inverter
v. Anemometer
vi. Digital Multi-meter
vii. Ammeter
viii. Wiring and Terminal Connectors
ix. Matlab- Simulink

3. ANN Model and Results

3.1 Discharging Characteristics

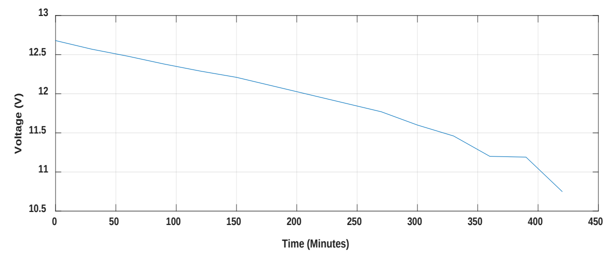

Fig. 6 Measured Discharging Battery Voltage with Time

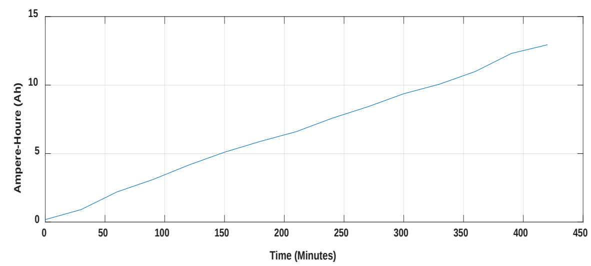

Fig. 6 Measured Discharging Battery AH with Time

3.2 Charging characteristics

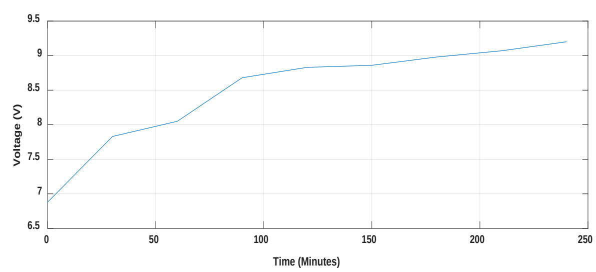

Fig. 7 Measured charging Battery Voltage with Time

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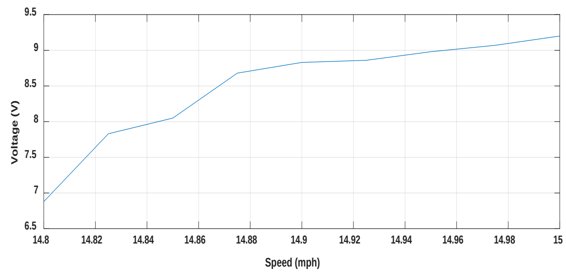

Fig. 8 Measured charging Battery Voltage with Wind Speed

3.3 ANN Model

Using the Artificial Neural Network (ANN), with feed forward back-propagation technique [4]-[8] to introduce discharging ANN model with Time as input and Voltage, Ampere-hours and Power (Watt) as outputs. ANN network consists of two layers one hidden with log-sigmoid function (has two neurons) and the second with pure-line function (has three neurons). This is done to make benefits from the ability of neural network for interpolation between points and also curves. ANN model with Back - Propagation (BP) technique is created with suitable numbers of layers and neurons. The results obtained are sufficiently accurate to apply the models involving less computational efforts. The model is checked and verified by comparing actual and predicted ANN values, with good error value and excellent regression factor to imply accuracy. Finally, the algebraic equations could be deduced to use it without training the neural unit in each time or using the Simulink model.

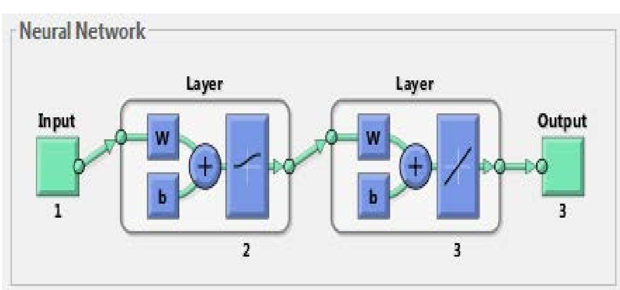

Fig. 9 A schematic diagram of ANN model

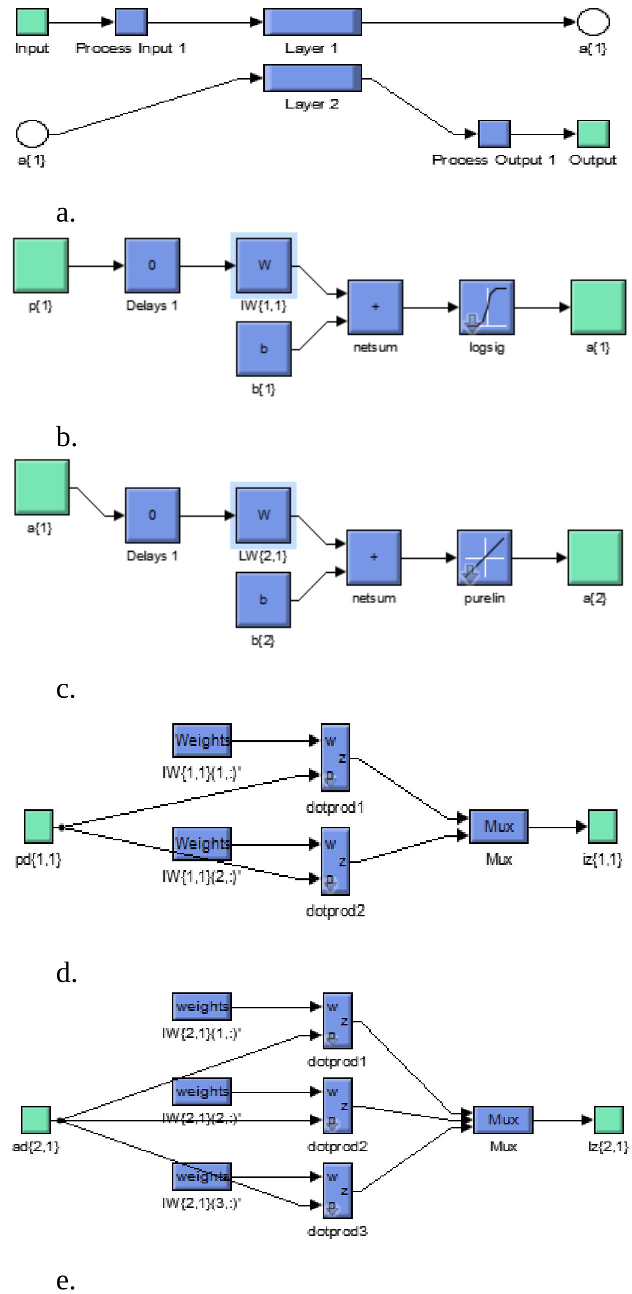

Fig. 10 Full detailed ANN Simulink Model (a. Two Layers constructions; b. Hidden Layer with log-sigmoid function; c. Output Layer with Pure-Line function; d. 1st Layer weights for the two neurons; e. 2nd Layer weights for the three neurons)

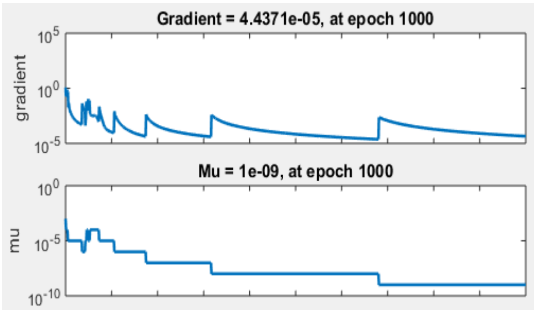

Fig. 11 Training state and error for ANN Model

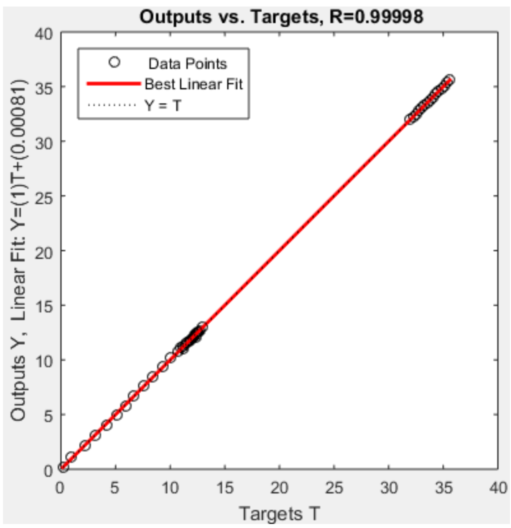

Fig. 12 Output VS Target for the ANN Model Accuracy (Regression = 0.99998)

4. Conclusion

Renewable energy has become an exponentially growing resource in today's world. Wind power, solar power, and other renewable resources help to supply the need of electric power for communities, businesses, and residential homes in the form of micro-grids. These micro-grids can be connected or disconnected from the main electric grid and can result in a more reliable and higher quality of power than the traditional grid. Our project was to seek and model the wind turbine generator system, and from this project we were able to simulate a wind turbine generator system to act similar to micro-grid. The small-scale model we designed and constructed for demonstration purpose turned out very well. We were able to model charging and discharging characteristics of a 12-volt lead-acid battery. This small model is implemented to supply the Neural Network model with its real training data. Using the Artificial Neural Network (ANN), with feed forward back-propagation technique to introduce discharging ANN model with Time as input and Voltage, Ampere-hours and Power (Watt) as outputs. ANN network consists of two layers one hidden with log-sigmoid function (has two neurons) and the second with pure-line function (has three neurons). This is done to make benefits from the ability of neural network for interpolation between points and also curves. ANN model with Back - Propagation (BP) technique is created with suitable numbers of layers and neurons. The model is checked and verified by comparing actual and predicted ANN values, with good error value and excellent regression factor to imply accuracy. Finally, the algebraic equations could be deduced to use them without training the neural unit in each time or using the Simulink model.

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