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Design and dynamic simulation of a wind turbine powered electric vehicle charging system

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***Abstract*— These days, electric vehicles (EVs) are popular, and there is a need to increase the number of charging stations for EVs. Newfoundland has considerable potential for wind energy to charge EVs. The design of such a system and its dynamics are described, and simulation results are provided in this paper.**

Keywords*— *electric vehicles, wind turbine, charging station, Homer Pro, Simulink

I. INTRODUCTION

For past decades, humanity faces a wild rise in CO2 and other greenhouse gas emissions, resulting in irreversible consequences. One of the most efficient ways to prevent climate change is replacing fuel cars with electric vehicles(EVs). The EVs are environmentally friendly, quieter, and easier to operate compared to conventional vehicles (CVs).

It should be noted that electric vehicles need electrical power to run, and if conventional power plants are used to provide this energy, it probably results in more air pollution (due to low efficiency at a conventional power plant and power loss at the network). According to what is said, it is wise to use green energy (like PV and WT) to provide power for EVs. This research will design a charging system for electric vehicles based on wind energy for St. John's to achieve this goal.

It goes without saying that St. John's is one of the windiest cities in the world, so it is logical to take advantage of the nature of this city. The average wind speed of St. John's for a period of 12 months between Aug 2020 to Aug 2021 is 24.96 km/h [1].

In this paper, first, Wind turbines and wind energy conversion systems are reviewed. Then, an overview of Electric Vehicle systems and the standard AC and DC Charging systems are provided. The proposed scheme and system sizing using Homer Pro, are discussed in part4. The result of Simulink is provided in part 5. In the end, essential system protection is described.

II. WIND TURBINE

A. Wind turbine classification

There is different structure of wind Turbine which are classified at two types, Horizontal Axis Wind Turbine(HAWT) and Vertical Axis Wind Turbine (VAWT) :

1. Horizontal Axis Wind Turbine: HAWTs are used widely because they tap more wind energy (from only one direction), so make them more economical than VAWT [2]. The main components of HAWT are blades, Nacelle, and foundation tower.

2. Vertical Axis Wind Turbine: although HAWTs are more economical, VAWTs are more portable [2] and take less space to install. These kinds of wind turbines tap wind energy from any direction. VAWT is usually used at stand-alone systems to supply individual households with electricity, heat, and even pumping water [4]. Varies designs of VAWTs are available, like Straight-bladed Darrius VAWT. Table 1 compares the advantages and disadvantages of HAWTs and VAWTs

Table 1: A comparison of 2 types of wind turbine structure

Turbine design	Advantages	Disadvantages
HAWT	• Full range from watt to megawatt • Yaw control [2] • Blades pitch control • More efficient and economical [2]	• Emission of the sound [2] • It is heavier and cannot produce well in turbulent winds [2]
VAWT	• Usually are built in small size, so they easily can be mounted on a rooftop • Simple design (no yaw or pitch) [4] • Gearbox, generator, etc. are installed on the ground (easy to install and maintain)	• Usually are installed low to ground (wind speed is low at ground level) • Not all of the blades produce torque at the same time (Pulsating torque)

B. Typical wind energy conversion systems

On the basis, there are two categories of wind turbines, 1- fixed speed wind turbine 2- variable speed wind turbine. Until the mid-1990s, most of the installed wind turbines were fixed speed ones, based on squirrel cage induction machines directly connected to the grid, and the generation was always done at the constant speed [3]. Today, most of the installed wind turbines are variable speed ones, which are based on three typical electrical systems, 1- permanent magnet synchronous generators (PMSGs), 2- squirrel cage Induction generator (SCIG) 3- doubly-fed induction generator (DFIG). Table 2 shows these configurations:

Table 2: A comparison of varies electrical generation configure

topologies	Advantages	Disadvantages
PMSG & WRSG	• Brushless (requires less maintenance) • Can operate at a full range of wind speed (due to full-scale converter)	• Full converting system
DFIG	• Partial converting system (needs a converter to deal with about 30% of rated power) [3] • Fully Control of active and reactive power independently	• Needs slip-rings • Limited speed (around -30% to +30% of synchronous speed)

III. Electric Vehicle(EV) and Charging System

A. Electric Vehicles (EVs)

There are four types of EVs, including Battery Electric Vehicle (BEV), Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), Fuel Cell Electric Vehicle (FCEV) [5]:

- **Battery Electric Vehicle:** BEVs are the fully electric vehicle which their energy provided only by their rechargeable battery. It means, once the battery is fully charged, it can drive until it uses all battery stored energy. Typically, they can cover 100 km–250 km on one charge [6].
- **Hybrid Electric Vehicle:** HEVs use both an internal combustion engine (ICE) and an electric machine. There are three different configurations, series, parallel, and series-parallel [7].
- **Plug-in Hybrid Electric Vehicle**: In the beginning, PHEV starts at fully electric mode, and all the propulsion energy comes from batteries; when battery energy reaches a specified low level, the ICE starts until the end of the trip [8]. The batteries can be charged through both regenerative braking and plugging in (utility grid).

B. Charging systems

For charging of EVs, DC or AC systems can be used [5]. There is various kind of charging systems for EVs, and they are categorized as level 1, level 2 and level 3 charging (based on level of voltage and current) [9].

- **AC Charging system**: it provides an AC power supply according to the SAE J1772 standard (Society of Automotive Engineers). This system usually uses an on-board charger; it means EV's charger is installed inside the vehicle, and EV is plugged into an AC outlet at the charge station [10]. There is 3 level of AC charging system [5]:
    - Level 1: voltage 120V single phase, the current between 12A to 16A
    - Level 2: voltage between 208V and 240V single phase, current up to 80A
    - Level 3: voltage 208,480 or 600V three-phase, current up to 400A
- **DC Charging system**: it provides a DC power supply according to the SAE EV DC Charging standard. This system usually uses an off-board charger which is fixed at the charging station [10]. Similar to AC charging systems, DC charging systems are at three levels [5]:
    - Level 1: voltage 200V-400V, current up to 80A
    - Level 2: voltage 200V-400V, current up to 200A
    - Level 3: voltage 200V-600V, current up to 400A

IV. Proposed Scheme and System Sizing

So far, the main concepts of wind power systems and EVs are given. This research is aimed to design an EV charging station; consists of a wind turbine and its tower, converter, and battery to provide sufficient power for charging an EV like Kia e-Soul.

A. Main component and specifications

1) Wind Turbine: Wind turbine is the most important part of the system because the wind turbine provides the whole energy. The Bergey EXCEL 10 is selected because:

- A wind turbine with at least 7 KW for its nominal output power is needed to minimize the battery bank.
- The Bergey company is one of the professional companies.
- This is one of the few small wind turbines which has SWCC Certification.

Table 3: The Bergey EXCEL 10 specification

specification	Value
Reference Rated Power	10 kW
AWEA Rated Power	8.9 kW at 11.176 m/s
AWEA Rated Annual Energy	13,800 kWh at 4.9 m/s average
AWEA Rated Sound Level	42.9 dB (A)
Cut-in Wind Speed	2.2 m/s
Cut-out Wind Speed	none
Peak Power	12.6 kW at 12.5 m/s
Max. Design Wind Speed	59.5 m/s
Design Operating Life	30-50 years
Turbine Rotor Diameter	7 m
Nominal output voltage	240 V AC 1phase
Voltage frequency	60Hz

2) Inverter: The inverter is the heart of the system which not only converts AC/ DC in both directions, but also controls the battery's state of charge and adjusts output voltage and frequency. A hybrid inverter named "Schneider - XW Pro 8.5 kW Hybrid Inverter 230V" is chosen for this project. This inverter is used to:

- Convert input 200-240V AC to 48V DC for charging the batteries
- Once the system needs energy from the batteries, it Converts input 48V DC to 230V AC
- It fixes the output voltage with pure sin waveform
- It controls the battery charging process

3) Battery: To build a 48VDC back-up energy system, a series of 4 number 12V batteries is needed. So, Trojan SAGM 12 205 battery is used. This battery has a reasonable capacity and a high lifespan.

4) Load: The aim of this work is that to design a charging station for Kia e-Soul. This is an EV car that is equipped with a 39.2KWh or 64KWh battery. This car supports both AC (Level2) and fast DC charging (Level3) systems.

B. Sizing and analysis

Homer Pro is used for sizing the system. Homer pro is a powerful software for designing an optimum microgrid that provides the models of different wind turbines, solar panels, customized load profiles, and NASA resources data. The simulation properties are as follow:

1. **Location**: A spot at the Avalon Mall parking lot is chosen where it has the least wind obstruction and is easy to install the tower.

Figure 1: Proposed installation location

2. **Load:** the assumption is that one of the Avalon mall employees will charge its EV car for 6 hours, from 9 AM to 2 PM. So the charging station is supposed to handle this demand every day. As mentioned previously, the charging station should provide 7.2KWh to charge the Kia e-Soul
3. **Wind turbine:** as mentioned earlier, Bergey Excel 10 is used which the full model of this WT is available at Homer Pro. The hub height and lifetime are adjusted to 24m and 30 years, respectively.
4. **Battery:** As well as the WT model, Trojan SAGM 12 205 is available at Homer Pro. The string size should be 4 to build a 48V DC bus.
5. **Inverter:** exact model of Schneider - XW Pro 8.5 kW Hybrid Inverter 230V was not available at Homer Pro, So the Schneider Conext XW+8548 is used instead, which has similar properties.

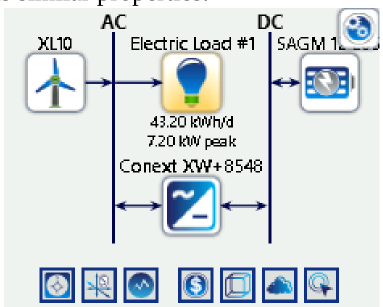


Figure 2: System scheme at Homer Pro

C. Sizing Result

Homer Pro does the calculation, and the result is as follow:

Homer proposed a system consisting of one Bergey Excel 10, a 7.8 kW inverter, and 40 Trojan 205 batteries in 10 strings. The project cost is estimated at 145000 CAD.

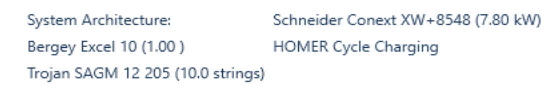
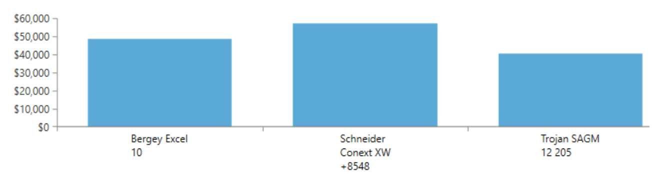


Figure 3: Homer pro analysis result



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Bergey Excel 10	$43,200.00	$0.00	$6,463.76	$0.00	-$1,226.54	$48,437.22
Schneider Conext XW+8548	$31,218.27	$24,125.08	$5,044.68	$0.00	-$3,270.95	$57,117.09
Trojan SAGM 12 205	$22,200.00	$8,902.73	$10,342.01	$0.00	-$1,123.47	$40,321.27
System	$96,618.27	$33,027.81	$21,850.46	$0.00	-$5,620.95	$145,875.58

Figure 4: Project estimated expenses

As shown in Figure 4, batteries have a significant share in expenses, so it is possible to decrease the expenses if they ignore the system back-up or reduce the back-up power. Figure 5 shows that most electric production is during the winter when the wind speed in St. John's is at maximum.

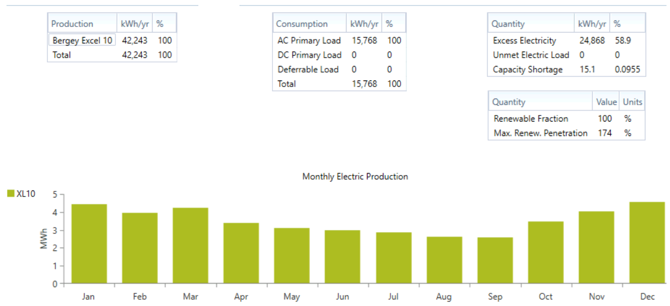


Figure 5: Electrical power flow

V. Dynamic Simulation in Simulink

In the previous section, the sizing and steady-state analysis is done. In this part, we will make a dynamic system model on Matlab Simulink and provide its results. The simulation is done with the help of prepared models, customized models, and modifications on Matlab examples and models.

1) The main components of this system are:

- Wind turbine [11]
- Gearbox [11]
- Permanent magnet synchronous generator [11]
- AC/DC/AC inverter
- Bidirectional DC/DC converter [12].

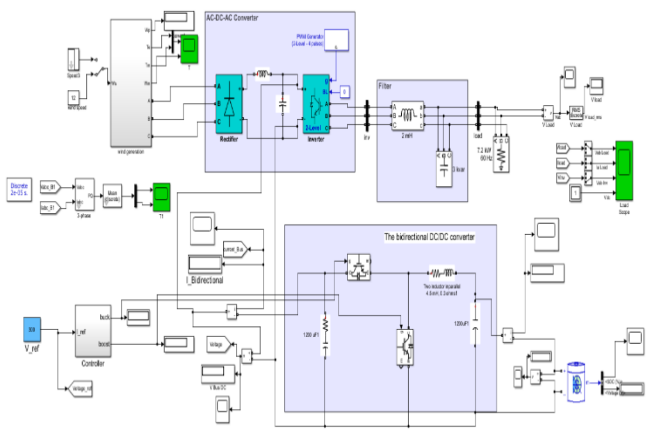


Figure 6: Complete system

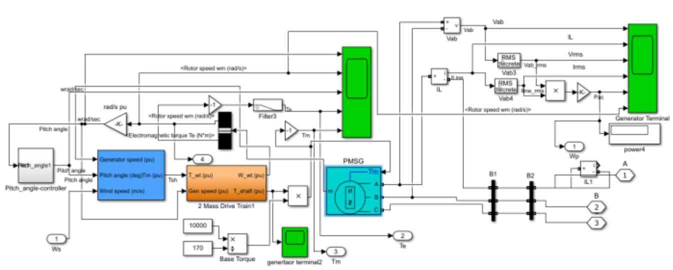


Figure 7: Wind turbine Subsystem consists of turbine, gearbox, PMSG model

2) The Simulink Result:

The main result of dynamic analysis in Simulink are depicted as follows:

Figure 8 shows that after transient time when both electromagnetic and mechanical torque follow each other, the rotational speed reaches to its nominal speed.

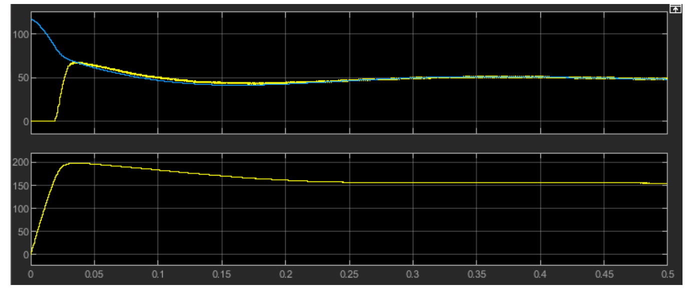


Figure 8: a) Electromagnetic torque (Yellow) and mechanical torque (Blue) b) Rotational speed

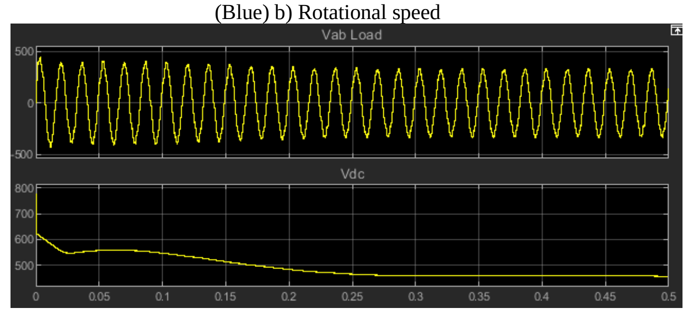


Figure 9: a) Voltage signal of the load b) Current signal of the load c) Output voltage of inverter d) Voltage of DC bus

Also, Figure 9 depicts that after transient time, the load is powered by a pure sinusoidal voltage, and voltage at a DC bus is controlled at a constant value. As a result, the dynamic study of designed an EVs charging station shows that this system is reliable and efficient.

VI. System Protection and Control

All electrical systems need to be controlled and protected to guarantee the system reliability and efficiency. There are some simple but vital protection tools and control system which will be addressed in the following:

A. system protection

a) AC and DC fuse: it is a safety device installed in series to protect the overflow of current.

b) Circuit breaker: A circuit breaker is a safety device that automatically switches off to protect an electrical circuit from damage caused by excess current from an overload or short circuit. It mainly works with electromagnetic principles.

c) Grounding: all standard systems are supposed to provide a grounded wire to protect both humans and the system.

d) Surge and lightning arrester: this device captures the lightning to protect the system from a surge voltage.

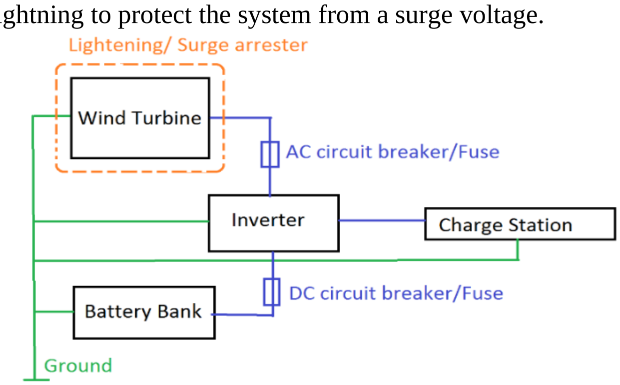


Figure 10: Scheme of protection system

B. *Control system*

the mentioned system is equipped with a small wind turbine and PMSG generator, so there is not yaw or pitch angle controller. Since this system has a battery bank, a control system for batteries is needed; this control system consists of two subsystems:

1. Bidirectional DC/DC controller: this controller adjusts and fixes the voltage at the battery side. Even if the DC bus voltage changes, the battery side voltage remains constant.

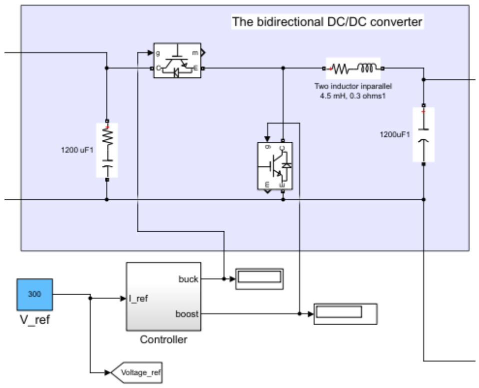


Figure 11: Bidirectional DC/DC control system

2. Battery over charge/discharge controller: this part of the system controls the battery's state of charge to protect the battery against overcharge or over-discharge. When the SOC excide 80%, the battery stops charging, and when the SOC drops under 20%, it prevents the battery from discharging.

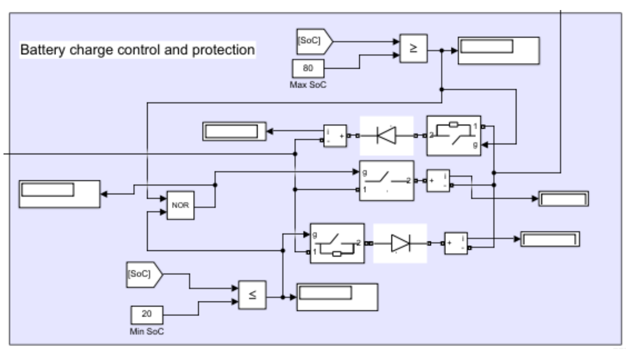


Figure 12: Battery charge control and protection system

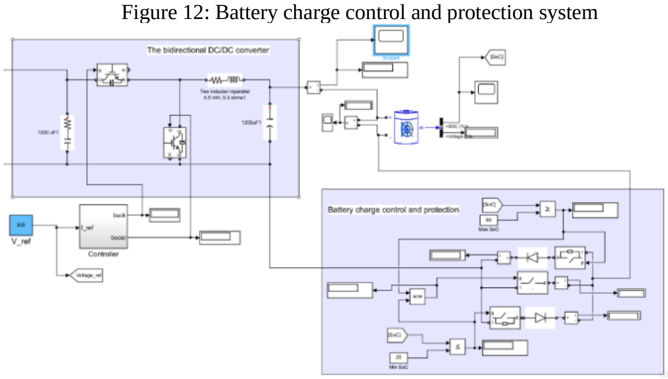


Figure 13: Battery charging system

It should be noted that both mentioned control functions are done by the Schneider hybrid inverter, and figures 11 to 13 depict a simple model of the inverter subsystems.

VII. Conclusion

In this research, a charging station for electric vehicles is designed, and the simulation result is provided. The initial installation cost seems a bit high, so this project might not be economical, but it is quite practical and environmentally friendly. The system consists of a 10 kW wind turbine, an 8.5 kW bidirectional inverter, a battery bank to store energy while the vehicle is on the road.

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