Power Converter for MW Scale Wind Energy

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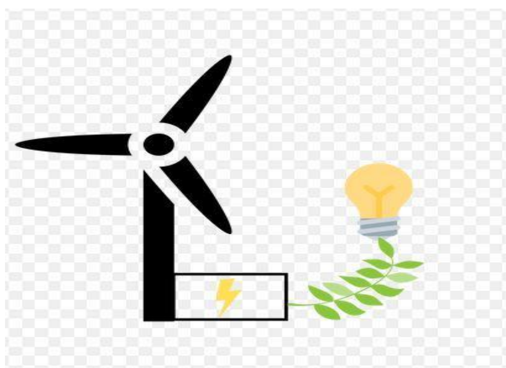

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1. Introduction:

Wind turbine is one of the cleanest renewable energy, and it's one of the fastest growing industrial among all the sources of renewable energy. Wind turbine converts the mechanical energy caused by the wind to electrical energy. That electrical energy can be used in a residential area like a house, or it can be used in a business area, like supplying malls with electricity. In order to convert from those two types of energy, a device called "converter" is used. Converters are usually made with rectifier (convert AC voltage to DC voltage) and inverter (convert DC voltage to AC voltage). Since wind is unpredictable and it changes over time, and that caused the generator to produce different values of voltage and frequency, so the converter changes the voltage and frequency that produced from the generator to a fixed voltage and fixed frequency. Fixed voltage and fixed frequency mean that the voltage and frequency do not change over time even if the turbine run with different speed.

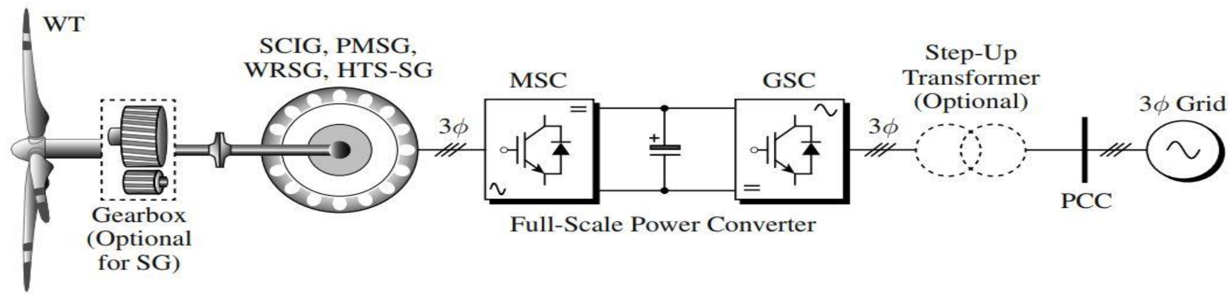
The team task is to build and test an NPC (Neutral Point Clamped) converter. NPC converter considers as a three-level converter, which means the output has three stages, which increase the efficiency and reduces the power losses. NPC converter is rectifier and inverter, the rectifier is used to convert the AC voltage that produced from the generator to DC voltage then convert that DC voltage to AC voltage with a fixed voltage and fixed frequency. Since the wind is unpredictable, the team will not be able to test the converter unless it is windy outdoors. In order to fix that problem, a motor is used as a wind source, and that motor is controlled by an AC drive, which controls the motor speed and frequency. The motor shaft is attached to the generator, so when the motor runs at different speeds and frequencies, the shaft of the generator will start rotating with the same speed as the motor and the generator produce the same voltage and frequency as the motor.

As shown in figure 1, the construction of the wind turbine. Since the team is working in a closed lab, the team replaced the blade and gearbox with a three-phase grid, AC drive and motor, which would be the wind source. The variable AC voltage and variable frequency that produced from the generator will convert to a fixed DC voltage by the rectifier then convert it to fixed AC voltage and fixed frequency. After that it will go through an inductor to reduce the harmonics (harmonics causes the voltage and current to be distorted), after filtering the harmonics, a transformer used as isolation between the converter side and the grid side and to step-up the voltage value if needed.

NPC converter can handle up to 6 Megawatts and 4000 V, but since it's cannot be produced in the laboratories, the team would be using 5 Kilowatts to test the NPC converter, and use the transformer as isolation between the voltage coming from the converter and going back to the grid. Although the power that going back to the grid is lower than the power that came from the grid, the team would be able to test the converter at any time use the grid and the motor instead of the wind turbine blades.

Some of the coolest features are:

- Uses motor and generator as a wind source
- Handle MW scale wind energy
- Return more than 90% of the power used back to the grid



[1] Figure 1: Type 4: WECS

2. Client's Problem: Mohammad Alenezi

Since wind turbine is one of the fastest growing industries in renewable energy sources, and every year lots of countries install wind turbines, and they intended to use those wind turbines as their main source of energy, and countries like Denmark gets more than 42 percent of their electricity demands. Also, there more than 80 countries that use wind energy, but only 29 of them uses more than 1 GW wind power. So, there are lots of manufacturers who produce different types of wind turbine construction, with a different power rating. Dr. Yaramasu is the only instructor at Northern Arizona University who specialized in power electronics, and he has done lots of research on different types of wind turbines. As of today, there are no manufacturers that produce an NPC (Neutral Point Clamped) converter, and the client (Dr. Yaramasu) is exploring research on the behavior of that specific converter. So, the team is asked to build an NPC converter with current and voltage sensors that used to measure the current and voltage input and output, while examining the behavior of the converter by doing experiments to gather results throughout the duration of the semester. The design of the NPC converter needs to be simple and easy design so that it would be easy to explain and view of the overall design, which makes it more convenient for the business industrial.

The project is time-consuming and requires a lot of effort, therefore the client asked the team for help on this project to finish it quickly and gather results. Also, one of the requirements is to use a frame that can fit 58.5 inches by 22 inches board, which can hold all the components vertically as shown in figure 2. The reason behind using a frame with wheels on it is for easy movement and view of the components. Finally, the simplicity of the project's design and the gathered results of the experiments will be proper to upload in an academic paper to be published about the NPC converter.

3. Design Process: Hamad Abdulmalek

Throughout the semester we worked on different aspect of the project, first we had to do a research and test the two-level converter so we could understand the properties of the two-level converter, then we can move to the next stage which is the NPC converter, the NPC converter is a three-level converter, we had to work on a three subsystem first, we had to work on the motor/generator, and since we are working on a close lab, we cannot use a wind turbine inside the lab, and we cannot have a constant wind speed, we need to create a MATLAB code that will control the speed and the frequency of the motor/generator, so we can test the NPC converter anytime at different speed and frequency, and that bring us to the second subsystem which is soldering the voltage and current sensors, the voltage and current sensors will let us measure the voltage and the current coming from the generator to the power converter then measure the voltage and current that coming from the power converter to the grid. Also, we need to solder 12 gate drives, the gate drives will provide circuit isolation and controllability over the rectifier and inverter.

And for subsystem 3 we had to place the IGBTs in an even spaces on the heatsinks, then we need to drill a holes on the heatsinks, so it will distribute the heat and decrease the power losses as much as possible, we have 6 IGBTs 3 of them will act as a inverter which will convert the AC power to DC power, and the other 3 will act as a rectifier, the rectifier will take the DC power coming from the inverter and change it back to AC power.

and after finishing all the subsystem we need to connect everything's together we need to connect the motor/generator to the AC drive which will be connected to the 3-phase grid, and the motor/generator is connected to the current sensor, the current sensor is connected to the inverter, from the inverter to the rectifier, and the send it back to the grid

4. Project Constraints: Abdullah Alghasab

In Subsystem one which is the motor/generator that will act as a wind source in our project since we are working in a closed lab and we have no wind. After implementing the MATLAB code that will measure the speed of the motor/generator (speed of wind) we were worried that they are not running at the same speed, that was one of the constraints. The way we measure the speed of the motor and generator is using the dSpace, which is a tool that we are using to measure the frequency speed, current, and the voltage we are getting from the generator. During the testing the motor/generator speed we got a huge different value comparing to the speed we set to the value showing in dSpace which was one of the challenges we had, because the subsystem one is playing a major rule in our project. So, we had to fix this problem by attaching the motor and generator tight together so they can run at the same speed, which was our goal in this subsystem. The second constraints was to use the Yaskawa 100 Drive tool that control the frequency speed of the motor/generator, this was imposed by the client and none of the group member was familiar with using this tool, so the client had to provide us the manual for the Yaskawa drive in order to understand the way it works and how to implement the speed using it. The third constraints was to use the dSpace, this was one of the client requirement to use the d-Space which is the tool used for calculating the values we get from the motor/generator which is connected directly from the generator to the dSpace, this was imposed by the client to get familiar in using the tool by group members. After we set the percentage of the frequency speed manually using the Yaskawa tool we check the values showing in the dSpace to make sure that we are getting the target results we are looking for.

The second subsystem is the voltage/current sensors, which will be used in the project in order to control the voltage and the current values implemented. The first constraint in this subsystem was soldering the interface boards for the voltage and current sensors, because some of the group members have no any experience in soldering so we had to learn that by ourselves due to the client asked us to solder that using the proper tools for soldering provided in the AMPERE Lab in the SICS building. The second constraint was that one of the channels in the interface board have been damaged, so we had to test all the components in the interface board including the capacitor and resistor. Because we cannot figure out which channel got damaged, also we want to make sure that we are not getting a short circuit in the board we soldered. The solution we came up with was to desolder the damaged channel and replace it with a new one. The third constraints were that we got delayed by the client in providing us with the 12 gate drives we required to use in our project, that will used to modify and give us a controllability over the power signal. Due to the gate drives delayed by the client it caused a delay in our plan for the semester, so we had to jump to the subsystem 3 in order to save some time waiting the client to provide us the 12 gate drives that we need. After we got the gate drives from client to be solder, we had to set extra meetings in order to get back on truck in our plan we have set.

Finally, our third subsystem is the Neutral Point Clamped converter (NPC), which is the major part that needs to be built in our project. The first constraint was that the client has changed the heatsink size and the IGBT/Diodes to a smaller size as a new smaller solution for the project that causes changed in the way of wiring the converter and a change in the circuit design too. The second constraint is drilling the heatsink to place the IGBT's on it, in this task we have to make sure that we are getting an even space between the IGBT's, because any error hole may cause a power loses in our converter as mentioned by the client. The third constraints was to place the board vertically in a frame imposed by the client and we were worried that it causes a wire loses while placing it in the frame, so we had to make sure that the converter wiring are tight and strong before we placing it, in order to avoid the wiring loses.

5. Metrics of Success (WBS): Fahad Alazemi

Through the semester the WBS changed several times based on order delays and client request. Before writing the WBS the team decided to divide the task in each subsystem so that every member in the team be responsible for individual task that way we made sure that everyone participate in this project with the knowledge of every subsystem. The first WBS the team wrote was estimating that the final design finishes before spring break, but some stuff broke down and changed, like, the heat gun for soldering did not work properly so the team had to order a new one, and the board size change, at the start the team used a 50 inch by 50 inch board with no frame, but as the client requested, the final design need to be display vertically with a frame that has wheels for easy movement and fit 58.5 inch by 22 inch board, which is the minimum size that can fit all the components.

Although some part changed and other got delay, the team doubled the meetings to keep the completion date of the final design before the spring break. After changing the size of the board and receiving the heat gun, the gate drives in second subsystem were missing, and the team discussed that issue with the client, so the team did not have the exact time of delivering the gate drives, so the team moved on and start working on third subsystem then to the final design, where the team left empty spaces for the gate drives until they arrive, and kept postponing the due of the final design until Wednesday April 3, where all the gate drive arrived.

6. Status of Planned Features (WBS):

Section	Activity	Description	Deliverables	Depend on section	Responsibility
1.Sub 1					
1.1	MATLAB Coding	Calculate the speed of the motor and the generator.	Create a Simulink code	Non	Mohammad and Hamad
1.2	Testing	Calculate the speed of the motor and the generator	The speed of the motor matches the speed of the generator	1.1	Abdullah and Fahad

2.Sub 2					
2.1	Soldering Gate Drive	Control and modify the signal from the Rectifier	6 Gate Drives for the Rectifier.	Non	Mohammad
2.2	Soldering Gate Drive	Control and modify the signal from the Inverter	6 Gate Drives for the Inverter.	Non	Abdullah
2.3	Testing the Gate Drive	The Gate Drives are controlling the Rectifier	All the Gate drives works properly	2.1	Hamad
2.4	Testing the Gate Drive	The Gate Drives are controlling the Inverter	All the Gate drives works properly	2.2	Fahad
2.3	Soldering PCB board	Measure the voltage across the converter	Soldering the voltage sensor	Non	Hamad
2.4	Soldering PCB board	Measure the input and output current	Soldering the current sensor	Non	Fahad
2.5	Testing the sensors	Testing the voltage sensor	Accurate reading for the voltage with small offset.	2.3	Mohammad
2.6	Testing the sensors	Testing the current sensor	Accurate reading for the current with small offset.	2.4	Abdullah
3.Sub 3					
3.1	Drilling	Drill the holes on the heatsink for the Rectifier	Even space between the devices on the heatsink	Non	Abdullah
3.2	Drilling	Drill the holes on the heatsink for the Inverter	Even space between the devices on the heatsink	Non	Fahad
3.2	Testing and installing the Rectifier	Testing the Rectifier which is used to converter AC to DC	Change the voltage from AC to DC	3.1	Mohammad
3.3	Testing and installing the Inverter	Testing the Inverter, which is used to converter DC to AC	Change the voltage from DC to AC	3.2	Hamad
4.Final Design					

4.1	Wiring	Connecting the Rectifier to the Gate Drives	- Strong/Tight wiring - Easy to track	2.1 and 3.2	Mohammad
4.2	Wiring	Connecting the Gate Drives of the Rectifier to the Interference board	- Strong/Tight wiring - Easy to track	2.1	Abdullah
4.3	Wiring	Connecting the Inverter to the Gate Drives	- Strong/Tight wiring - Easy to track	2.1 and 3.3	Fahad
4.4	Wiring	Connecting the Gate Drives of the Inverter to the Interference board	- Strong/Tight wiring - Easy to track	2.1	Hamad
4.5	Testing	Testing the Final Design which is NPC converter	- safety - simple design - 90% or more efficiency	All section	All team member

6.1. Subsystem 1:

This subsystem is about the motor/generator that playing a major rule in our project, since we are working in a closed lab the motor/generator will act as a wind source in our project. The movement of the motor generates a mechanical power that causes a movement in the generator, which is converting it into an electrical power, due to the rotor shaft that restrained them together as showing in the figure below. So, the motor is acting as the wind turbine blades that move due to the wind speed, in our lab we get the power from the grid and control the frequency speed of the motor using AC drive tool. The target we have set in this subsystem was to test the motor and generator and make sure that they are running at the same frequency speed by applying the frequency speed using the AC drive and check the values in the dSpace that is connected directly with the generator output. We have set two tasks, the first task was to write MATLAB code in the dSpace to calculate the output frequency speed of the motor and generator, the second task was to test the experiment and check the dSpace results if the frequency speed of the motor matches the speed of the generator before the group member start working in the upcoming subsystem. Also, the team completed this subsystem’s tasks and the progress have took three days to get it done.

3-Phase Grid

AC Drive

Motor and Generator

6.2. Subsystem 2:

this subsystem is based on soldering the interference board, voltage and current sensors, and the gate drives, the voltage and the current sensors will measure the voltage and current across the converter, and the gate drives will give us controllability over the IGBTs, and the interference board will send the signal coming from the gate drives to the D-space, and from D-space to the MATLAB, the team divided the soldering so everyone would work on one of the boards Fahad was working on soldering the current sensors, it took him 3 days to finish from soldering the current sensors, Hamad did the voltage sensors it also took him 3 days, Mohammad soldered 6 gate drives, and Abdullah did the other 6 gate drives, the voltage and the current sensors were finished early because we had all the components, but the gate drives were not available so we had to wait for them to arrive so we could finish them, so Mohammad and Abdullah started testing the voltage and current sensors, and after receiving 9 out of 12 of the gate drives we did fished from them, and we waited another week to receive the las 3 gate drives and because of that the final design was delayed.

Current and Voltage Sensors

6.3. Subsystem 3:

For subsystem 3, the team required to build a Neutral Point Clamped converter (NPC) that converts the AC power to DC power and DC back to AC power and return it to the grid. In this subsystem we have come up with four tasks that needs to be done in a specific time to start working on the final design. In the first task we need to drill holes on the heatsink and place the IGBTs and diodes with respecting the spaces between the IGBTs to be even for the wiring purposes for the rectifier(generator side), which will be responsible for converting the AC power getting from the generator to a DC power. Also, the second task is drilling but for the inverter (grid side) which will be responsible for converting the DC power getting from the rectifier to an AC power and send it back to the three-phase grid. The third and fourth task was testing the IGBT's for the rectifier and inverter and make sure that they are working for both side of the converter before we start working on the final design since the subsystem 3 is our final process before the final design. The status of this subsystem is completed, and the group member spent 7 days working on this subsystem in order to get it done.

6.4. Final Design:

Finally, before starting on the final design the group member has went through all the previous subsystem again and test them to ensure that we are ready for the final design process. The main goal in this process is to connect all the subsystems together that will represent our final design which is the wind power converter. In this subsystem we have come up with five tasks, four tasks for wiring and one final task for testing the final design. The first and second tasks is for the rectifier (generator side), which is connecting the rectifier to the gate drives and then connecting the gate drives to the interface board that will convert the AC power getting from the generator to DC power, which is the upper side of the final design showing in the figure below. The third and fourth tasks showing below which are the lower part in board that will act as an inverter that is responsible for converting the DC power getting from the rectifier to an AC power (grid side). For all the previous tasks the group members need to make sure that all the wires are properly connected strongly and tight because the one of the client requirements was to place the board vertically in a specific frame size for marketing purposes. Currently, the group members are pretty much done with the final design and completed the first four tasks so far, and we are waiting for the client to present during the testing which is the final task in the final design process. Because one of the client requirements is that he needs to be attending during the testing process of the final design and get his permission.

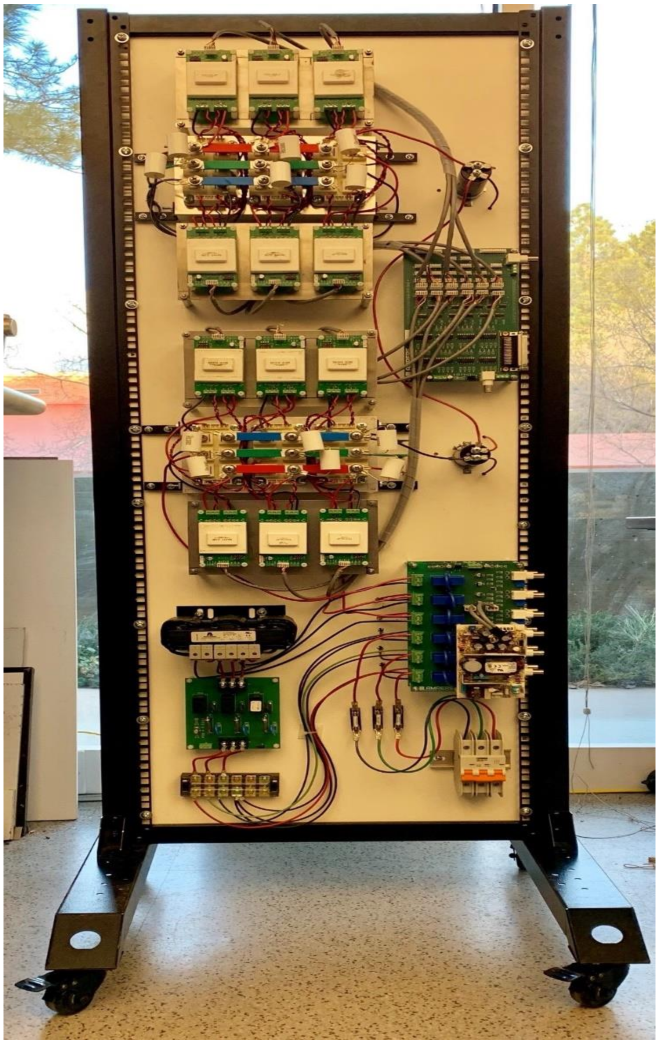


Figure 2: Final Design

7. Conclusion:

To sum up, we are working on a power converter called neutral point clamped (NPC) converter, the client is interested in testing the NPC converter because there are no manufacturers that produce NPC converter for wind turbine, the team was working on 3 subsystem, the first subsystem was creating a MATLAB code that will control the motor/generator speed and frequency, which will be our wind source since we are working on a close lab, and the second subsystem was soldering the voltage and current sensors, 12 gate drives, and interference board, we need the voltage and the current sensors to measure the voltage and current across the IGBTs, the gate drives will control the IGBTs and send the signal to the D-space and from D-space to the MATLAB code, and the third subsystem is building the inverter and rectifier, the inverter will convert the AC power to DC power, and the rectifier will convert the DC power coming from the inverter to DC power. the team faced many problems but what affected us most was the delay of the gate drives; the team was expecting to finish the final design before spring break but because of that we delayed the final design, so we have less time to test the project.

8. References:

[1] Y. Venkata & W. Bin. “BASICS OF WIND ENERGY CONVERSION SYSTEMS (WECS)”.