Design and Simulation of a 500 MW wind firm for H_2 project near Stephenville, Newfoundland.

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***Abstract*—Achieving stabilization in atmospheric carbon dioxide (CO_2) level is deemed an imperative measure to secure a sustainable future. Hydrogen systems emerge as a promising solution that can provide both immediate and long-term emission reductions to accomplish this goal. The emission benefits of hydrogen technologies stem from not only the heightened efficiency associated with hydrogen-based energy conversion, but also from the consideration of hydrogen as an energy carrier and industrial feedstock within a larger energy system. Given Canada's abundant energy resources and leadership in hydrogen technologies, the country is well-positioned to spearhead the transition to a hydrogen economy. In this context, World Energy GH_2 Inc. ($WEGH_2$) proposes developing, constructing, operating, and decommissioning onshore wind farms and one of the first commercial scale "green hydrogen" and ammonia production plants powered by renewable wind energy in Canada. The anticipated initial electricity demand for hydrogen production is expected to be around 500 MW. In this paper, we propose the establishment and accordingly, design, simulate and result analysis of an onshore Wind Farm on the Port au Port Peninsula, NL, and on the Newfoundland mainland, which is northeast of the isthmus at Port au Port. The primary objective of this proposal is to meet peak load demand for hydrogen production using green energy.**

Keywords—Green Hydrogen, WPP, PMSG, MPPT, PO, NLC, Converter, Inverter, Controller, Homer Pro, MATLAB-Simulink.

I. Introduction

World Energy GH_2 is a consortium of four Canadian partners with strong regional expertise, proposing the construction and operation of a wind powered green hydrogen/ammonia facility on Newfoundland's west coast in the province of Newfoundland and Labrador (NL). The project, named **"Nujio'qonik GH_2"**, will include a 0.5 GW hydrogen production facility at the Port of Stephenville and 500 MW of onshore wind power generation on the Port au Port Peninsula, connected through supporting infrastructure and transmission systems. Hydrogen will be produced via electrolysis powered by wind energy, ensuring the fuel remains emission-free. Green hydrogen refers to hydrogen generated exclusively using renewable energy sources like wind power.

The wind farm will transmit power through one or more project-owned transformer substations linked to both the hydrogen/ammonia plant and the NL Hydro Transmission System [1]. Fig.1 provides an overview of the stages of a green hydrogen/ ammonia project.

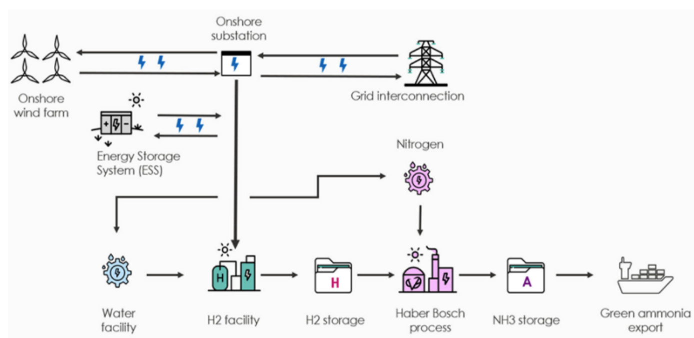

Fig. 1. Framework of Project Energy and Storage Flow.

At the plant, renewable electricity will split water into hydrogen, which will then be converted into ammonia. The expected annual output is approximately 206,000 metric tonnes of hydrogen or 1.17 megatonnes (Mt) of ammonia, which will be exported to international markets via the Port of Stephenville's existing marine terminal [2]. Fig. 2 shows the location of the project on the western coast of the Island of Newfoundland.

Fig. 2. Project and Proposed Wind Farm Location.

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The project reflects advancements in integrating renewable energy sources like wind power into power grids. Wind power, a highly reliable and sustainable energy source, has been seen global growth due to its cost-effective and low environmental impact. Control systems are crucial in wind power applications, with permanent magnet synchronous generators (PMSGs) frequently employed to convert wind energy into electricity. Traditional proportional-integral (PI) controllers are widely used to control wind energy conversion systems (WPP) but can struggle with delayed power tracking and fluctuations around the maximum power point. To overcome these challenges, maximum power point tracking (MPPT)-based intelligent control models have been developed, enhancing system efficiency and stability without requiring precise system models or additional sensors [3-5]. Fig. 3 represents a block diagram of PMSG based Wind Turbine.

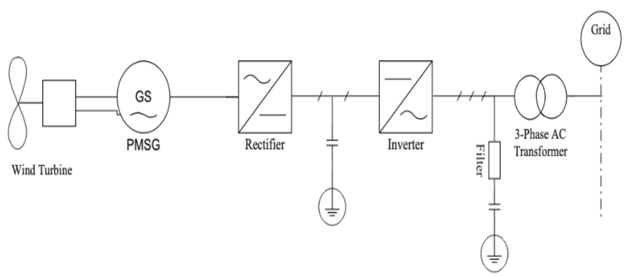


Fig. 3. A Typical Block diagram of PMSG based Wind Turbine.

II. Wind Turbine Sizing and Specification

The **Port au Port Peninsula** (French: *péninsule de Port-au-Port*; Mikmaq: *Kitpu*) in Newfoundland and Labrador is a triangular peninsula located on the island's west coast. The selection of wind turbines based on the **Wind Map of Port au Port Peninsula** (shown in Fig. 4) is critical to optimizing the project's efficiency. This map provides essential data on average wind speeds, directions, and meteorological factors, helping tailor turbines to local conditions. Based on the various data of wind map, two turbine models have been selected for optimization purpose:

- **Enercon E-126** – 7.58 MW
- **Vestas V164** – 8 MW

Fig. 4. Wind Map of The Port au Port Peninsula.

The power curves and detailed specification of the selected wind turbines has been illustrated in the figures and tables below.

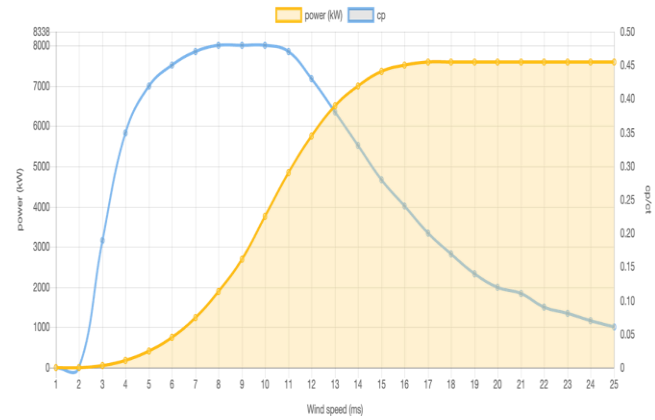


Fig. 5. Power Curve of Enercon E-126 - 7.580 MW Wind Turbine.

TABLE I. TECHNICAL SPECIFICATION

Enercon E-126-7.580 MW Wind Turbine	
Rated Power	7.500 kW
Rotor Diameter	127 m
Hub height	135 m
Wind zone: (DiBt)	WZ III
Wind class: (IEC)	IEC/NVN IA
Turbine concept:	Gearless, variable speed, single blade adjustment.
Rotor type:	Upwind rotor with active pitch control
Rotational direction:	Clockwise
No. of blades:	3
Swept area:	12,668 m^2
Blade material:	GRP (epoxy resin); integrated lightning protection
Rotational speed:	Variable, 5 – 11.7 rpm
Pitch control:	ENERCON single blade pitch system, one independent pitch system per rotor blade with allocated emergency supply.

TABLE II. TECHNICAL SPECIFICATION

Vestas 164 - 8 MW Wind Turbine	
Rated Power	8,000 kW
Cut-in wind speed	4.0 m/s
Rated wind speed	13.0 m/s
Cut-out wind speed	25.0 m/s
Rotor Diameter	164.0 m
Swept area	21,124.0 m^2
Rotational direction	Clockwise
No. of blades	3
Manufacturer	Vestas
Power density 1	378.7 W/m^2
Power density 2	2.6 m^2/kW

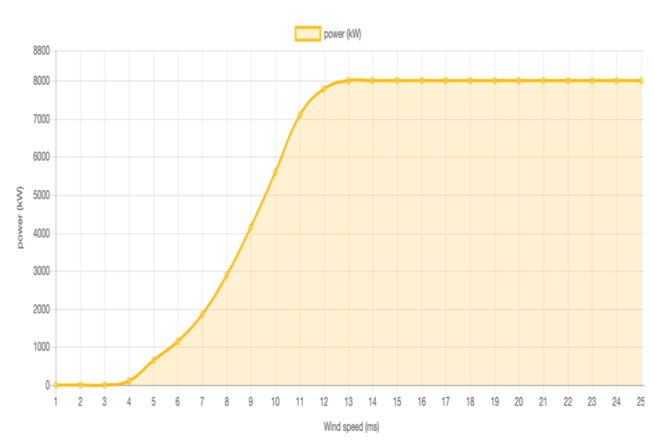
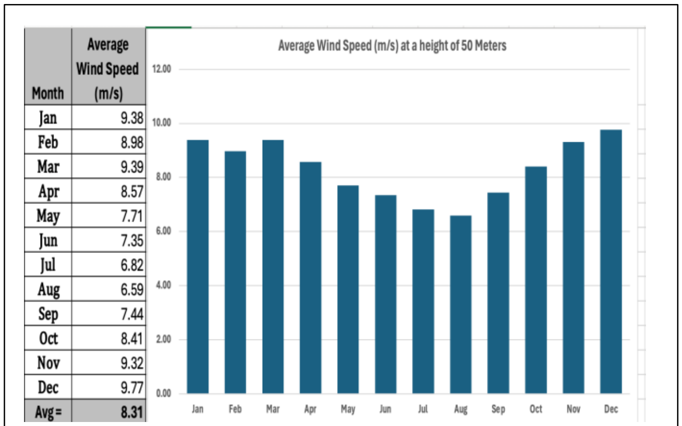


Fig. 6. Power Curve of Vestas 164 - 8 MW Wind Turbine.

III. SYESTEM STEADY STATE MODELING

A. Wind Resource Assessment

HOMER Energy software offers a robust framework for evaluating wind resources and assessing the feasibility of wind energy projects. It effectively integrates site-specific data such as weather patterns, topography, and historical wind data to support precise energy planning and optimization. For this project, Cape Saint George, Newfoundland, Canada, was chosen as the site for wind resource assessment using HOMER Energy. Historical data from the Stephenville Airport Station provided key insights into local wind conditions (shown in Fig. 7).



Month	Average Wind Speed (m/s)
Jan	9.38
Feb	8.98
Mar	9.39
Apr	8.57
May	7.71
Jun	7.35
Jul	6.82
Aug	6.59
Sep	7.44
Oct	8.41
Nov	9.32
Dec	9.77
Avg =	8.31

Fig. 7. Wind Resource Historical data from Stephenville Airport Station.

B. Load Profile

The load profile for the World Energy GH_2 Project, with an average power demand of 500 MW, plays a critical role in planning and optimizing the project's energy infrastructure. With 12,000,000 kWh of daily energy consumption, the GH_2 project demands a consistent and reliable power supply to support green hydrogen production. The load profile, shown in Fig. 8, provides the foundation for sizing the energy infrastructure, ensuring a reliable supply that aligns with global sustainability goals.

C. Project Sizing, Modelling, and Analysis

HOMER Energy's steady-state modelling serves as a cornerstone of the GH_2 Project, facilitating an in-depth analysis of voltage levels and system stability when integrating wind energy. The software's optimization process focuses on identifying the most cost-effective and environmentally sustainable energy mix through simulations and sensitivity analyses. The analysis, optimized for a 500 MW load, identified that installing 195 Vestas 164-8 MW wind turbines is the most effective solution. This configuration is projected to meet 84.8% of the project's energy demand, with the remaining 15.2% to be sourced from the grid, ensuring continuous supply. The optimized design also allows for surplus capacity, with 45.7% of excess generation available for potential grid sales, enhancing the project's economic viability. Furthermore, the minimal excess electricity (2.39%) demonstrates operational efficiency, minimizing waste and optimizing resource utilization. With renewable penetration between 80-100%, the project significantly reduces dependence on nonrenewable energy sources, reflecting a strong commitment to environmental stewardship and sustainable energy transition. The results from the steady state analysis have been shown in Fig. 9.

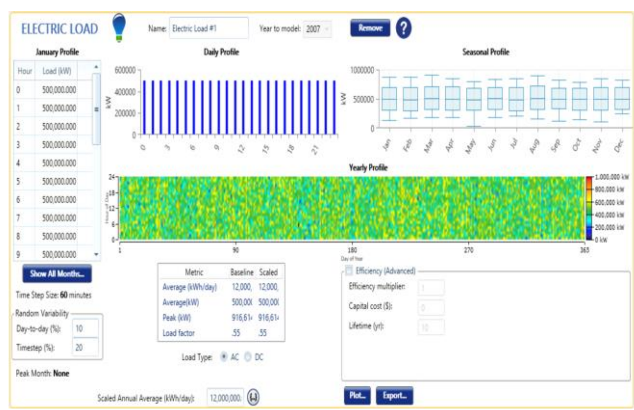


Fig. 8. Load Profile for the World GH_2 Project in Homer Pro software interface.

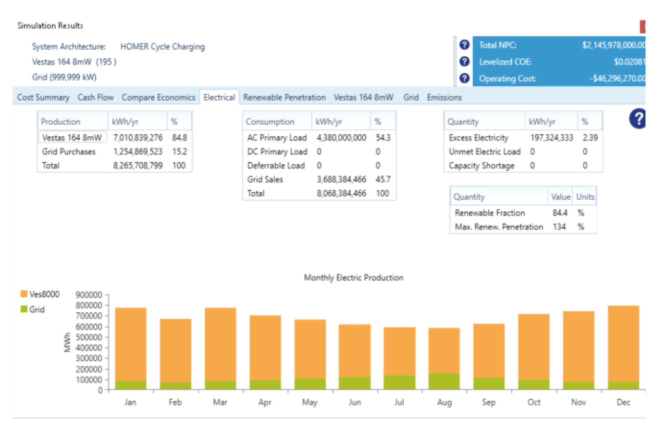


Fig. 9. Simulation Result with Electrical Parameters.

IV. System Dynamic Modeling, Simulation and Analysis

Our approach leverages MATLAB's advanced functionalities to conduct a comprehensive examination of wind farm components, including turbines, generators, and power electronics. The analysis integrates critical factors such as meteorological data, which provide insights into wind speed and direction impacts on turbine performance, and topographical considerations that affect wind flow. Additionally, turbine characteristics such as blade profiles and pitch angles are incorporated to enhance power output accuracy. This model aims not only to simulate power generation but also to analyze the wind farm's performance under diverse operating conditions.

A. *Dynamic System Model and Design*

Wind energy, derived from solar heating, Earth's rotation, and surface irregularities, offers efficient energy transmission when wind turbines are properly connected to the grid [6,7]. A typical wind power system utilizes a dual-stage converter configuration (AC/DC and DC/DC) and a DC/AC inverter, shown in Fig. 10, enabling turbines to supply reactive power for voltage support and maintain alignment with local load demands.

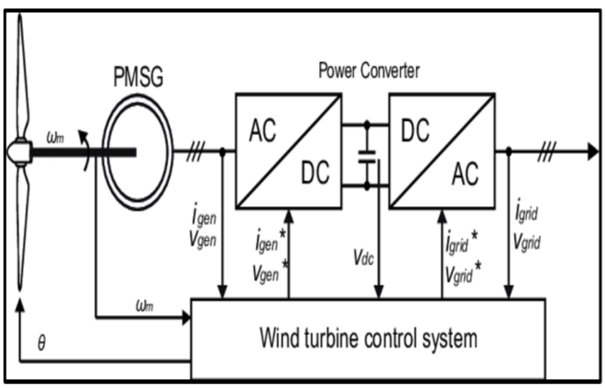


Fig. 10. PMSG-Based Wind Energy Conversion System (WPP) Block Diagram.

B. *Intelligent Control and Permanent Magnet Generators*

Traditional controllers, such as proportional-integral (PI) or proportional-integral-derivative (PID) controllers, often require precise system models and can struggle with parameter variations. In contrast, modern intelligent control techniques, such as fuzzy logic control (FLC), enhance system performance without needing exact models [8], [10-11].

Permanent Magnet Synchronous Generators (PMSGs) are widely adopted in wind turbines due to their high efficiency. The relationship between rotor speed and electrical frequency in a PMSG is given by:

$$f = \frac{p.n_s}{120} \quad (1)$$

where f is the frequency (Hz), n_s is rotor speed (RPM), and p represents the number of poles.

PMSG-based systems utilize machine-side (AC/DC) and grid-side (DC/AC) converters. The machine-side converter tracks the maximum power point (MPP), ensuring stable power output despite varying wind speeds.

C. *Wind Turbine Dynamics and Power Coefficient*

The power generated by a wind turbine can be expressed as:

$$P_m = \frac{1}{2} C_p(\lambda, \beta) * \rho * A * V_w^3 \quad (2)$$

where C_p is the power coefficient, ρ is air density, $A=\pi R^2$ is the swept rotor area, V_w is wind speed, λ is the tip-speed ratio, and β is the blade pitch angle. The theoretical maximum C_p value, known as the Betz limit, is 0.593, although achieving this in practice is challenging. The mechanical torque is calculated as:

$$T_m = \frac{P_m}{\omega_m} \quad (3)$$

where T_m is torque and ω_m is rotor speed. Synchronous motors are used for constant speed operation with controllable power factor through field current variation.

D. *Converters and Control Techniques*

Efficient power conversion is crucial for WPPs. Two converter technologies have been implemented in this analysis process.

1) Generator-Side Converter (DC-DC Boost Converter with MPPT Controller): The boost converter extracts maximum power from the turbine by dynamically adjusting to wind variations using the Perturb and Observe (PO) method. Fig. 11 shows the flowchart for PO algorithm of MPPT Controller. The system's size and cost can be lowered by employing the boost converter instead of a transformer [12]. Additionally, the converter boosts voltage levels for compatibility, increasing simplicity, and reducing the need for transformers [14].

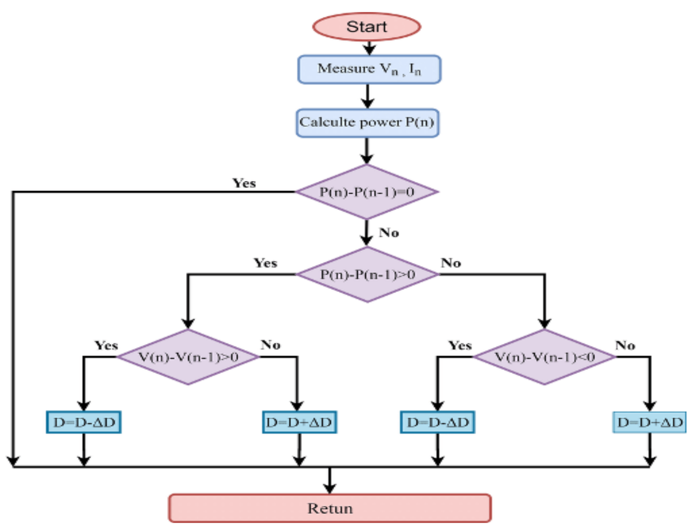


Fig. 11. Flowchart of Perturb and Observe (PO) algorithm of MPPT Controller.

2) Grid-Side Converter (Modular Multilevel Converter with Nearest Level Modulation): This converter maintains grid stability, manages reactive power, and ensures compliance with power quality standards. For this project, we implemented a Modular Multilevel Converter (MMC) with Nearest Level Modulation (NLM) to enhance switching precision. In the context of MMC, the Phase Shift Carrier (PSC) PWM technique is commonly used, facilitated by its simple implementation with digital signal controllers (DSC). PSC PWM ensures uniform carrier waves with consistent mean value, frequency, and amplitude, with each wave separated by a phase angle of 2/n [15]. This configuration optimizes power flow and improves system reliability, making it ideal for the grid integration of wind farms. Fig. 12 shows the position of the converters and controllers in the wind turbine model.

V. MATLAB Simulation, Result Analysis

A. *MATLAB Simulation of Wind Turbine with PMSG Generator with MPPT Controller*

Parameters of Wind Turbine and PMSG System used for simulation are as follows:

TABLE III

TECHNICAL SPECIFICATION	
Rotor Radius (R)	0.856 m
Power Coefficient (C_p)	0.41
Air Density (ρ)	1.225 kg
Rated Power (Pn)	1 kW
Rated Torque (Tn)	17.61 Nm
Stator Resistance (Rs)	0.0485
Stator dq-axis Inductance	0.000395
Number of pole pairs	3
Moment of Inertia	0.0027 Kg/m^2
Flux Linkage	0.20675 wb

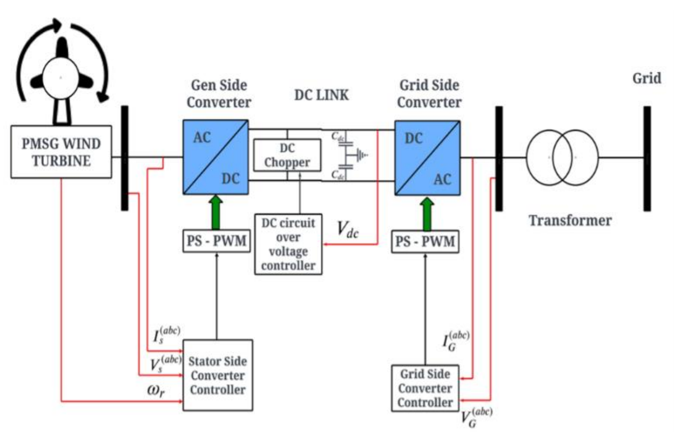


Fig. 12. A description model of wind turbine with various Converters and Controllers.

The Simulink model of a PMSG-based wind turbine with controlled converters omits pitch control for simplicity, setting the pitch angle to 0°. MATLAB-based PID control with MPPT provides a realistic performance simulation, optimizing energy extraction under varying wind conditions. Results (Fig. 13) show an increase in load-side voltage from 259.9V to 268.9V, with minor ripples mitigated by a filter circuit. Performance significantly improves compared to simulations without MPPT integration.

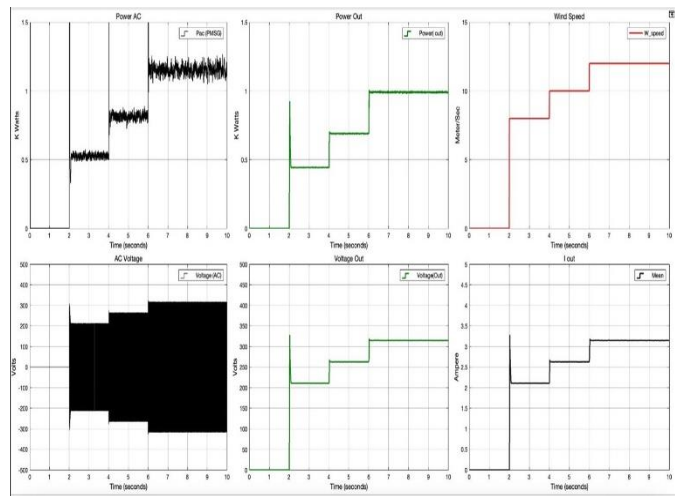


Fig. 13. Simulation Results of PID-Controlled PMSG-Based WPP (with MPPT): (a) AC Power Input, (b) DC Power Output, (c) Wind Speed of the Turbine, (d) Input Voltage, (e) Output Voltage and (f) MPPT Pulse.

B. *MATLAB Simulation of Wind Farm with MPPT Controller and Modular Multilevel Converter with NLM Control.*

During the simulation, nine levels of MMC were considered, which is a significant factor in ensuring accurate results (shown in Fig. 14). For each phase, a total of eight MMC submodules have been considered to ensure that the output is as close as possible to the desired result. It is noteworthy that the V_{out}, or output voltage, closely matches the desired output, indicating that the simulation has been successful. The results of the simulation for the Modular Multilevel Converter with Nearest Level Modulation are shown in Fig. 15. The output voltage (V_{out}) consists of a total of nine voltage levels and is quite similar to the desired sinusoidal output. Additionally, the Total Harmonic Distortion (THD) of the simulation has also been checked and found in the range of 11.54.

VI. Conclusion

In summation, the proposed Nujio'qonik GH_2 initiative presents a compelling endeavor in leveraging renewable energy resources, particularly facilitating green hydrogen production through wind power. The sophisticated system dynamic model crafted using MATLAB-Simulink modelling provides invaluable insights into the operational dynamics and performance of the 500 MW wind farm located near Stephenville, Newfoundland.

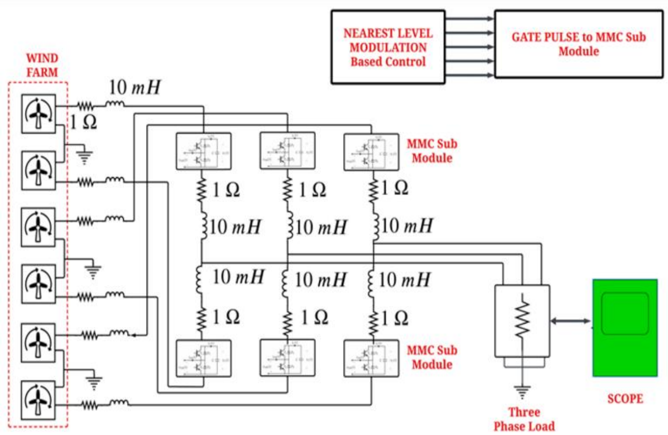


Fig. 14. Simulink Model Block Diagram for Nine-level Modular Multilevel Converter.

The implementation of advanced electronics along with control and protection systems is critical for enhancing the efficiency, reliability, and safety of large-scale wind energy projects. A comprehensive project report on this subject has been created, which emphasizes this fact. Through meticulous analysis and simulation using MATLAB Simulink, the report has demonstrated the efficacy of MPPT-based converter controllers, nearest level modulation- based inverter controllers. These technologies are designed to optimize power generation, grid integration, and fault management within wind farms. The MPPT-based converter controller is specifically designed to extract the maximum amount of power from the wind, while the nearest level modulation-based inverter controller enhances grid compatibility and stability.

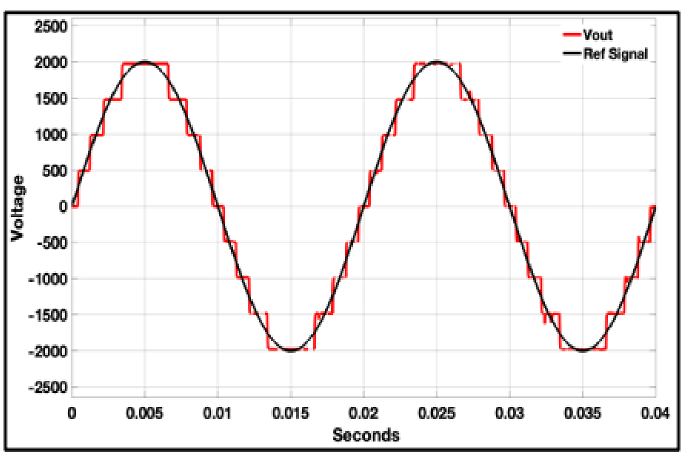


Fig. 15. Simulation result of Nine level Modular Multilevel Converter with Nearest Level Modulation Control.

This project report will be of significant value to stakeholders in the renewable energy sector, providing insights into cutting edge technologies and best practices for the development of large-scale wind energy projects. The report also paves the way for the successful deployment of renewable energy systems and fosters sustainable energy solutions in regions such as Stephenville, Newfoundland. Such regions are poised for the integration of hydrogen production alongside wind energy generation. Overall, this project report serves as a valuable resource for the renewable energy industry, demonstrating the importance of advanced control and protection systems in optimizing large-scale wind energy projects.

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