MINISTRY OF INDUSTRY AND TRADE

ELECTRIC POWER UNIVERSITY

ĐẠI HỌC ĐIỆN LỰC
ELECTRIC POWER UNIVERSITY

DINH VAN THIN

PROPOSED MODELS FOR DESIGNING WIND TURBINE BLADES AND INSTALLED CONFIGURATIONS OF ONSHORE WIND FARMS IN VIETNAM

Major: Energy Engineering

Code: Pilot

SUMMARY OF DOCTOR OF PHILOSOPHY THESIS

IN ENERGY ENGINEERING

Hanoi – 2026

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SCIENTIFIC SUPERVISORS:

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CONTENTS

THESIS OUTLINE

The thesis studies the construction of wind turbine blade profile and turbine installation configurations design models in onshore wind farms in Vietnam.

The main contents of this thesis are divided into 04 chapters, including: Chapter I is Introduction and Overview; Chapter II is Methodology; Chapter III is A proposed model for designing wind turbine blade profiles; Chapter IV is A proposed model for designing installed configurations of onshore wind farms.

This thesis uses 70 symbols and abbreviations; 08 tables and 69 images to describe the theoretical contents, models and obtained results. All parts of the thesis are presented in 136 pages.

INTRODUCTION

Research reasons:

Currently, the climate change processes are taking place at a faster rate and the scope of influence has spread globally. The consequences of climate change are increasingly serious, especially the problems of rising temperatures and air pollution. According to the WMO report [1], the average global air temperature in 2024 has increased by 1.55°C compared to the period 1850 - 1900. The main cause of global warming is due to the concentration of greenhouse gases such as CO_2, CH_4 and N_2O in the air being too high. These substances are mainly created from the burning of fossil fuels such as coal, gasoline, and oil to produce electricity and serve human transportation. The more developed a country is, the greater the demand for electricity and transportation fuels. No country is left out in the fight against climate change.

At COP26, Prime Minister Pham Minh Chinh pledged that Vietnam will develop and implement strong measures to reduce greenhouse gas emissions, aiming for net zero emissions by 2050. Vietnam has taken many specific actions to implement this commitment.

Through the statements and the revised National Power Development Plan VIII, Vietnam will maximize the development of electricity from renewable energy, continuing to increase the proportion of renewable energy in the power source structure. Specifically, promoting the development of onshore, nearshore and offshore wind power in line with the absorption capacity of the grid systems, reasonable transmission costs associated with ensuring operational safety and economics, making the most of the existing grid infrastructure. Total onshore and nearshore wind power capacity will reach about 26,066 MW - 38,029 MW in 2030, 84,696 MW - 91,400 MW in 2050. Total offshore wind power capacity for power generation will reach about 6,000 MW - 17,032 MW in the period 2030 - 2035 and about 113,503 MW - 139,097 MW in 2050. Offshore wind power capacity for new energy production will reach about 15,000 MW in 2035 and about 240,000 MW in 2050 [4]. According to EVN's report on April 30, 2025 [5], the total capacity of onshore and nearshore wind power plants with COD is only 1,214.5 MW and no offshore wind power plants have been deployed. Clearly, the Vietnamese Government needs to take stronger and more practical actions to achieve the commitments and goals in the revised National Power Development Plan VIII.

According to the Government's viewpoint stated in the revised National Power Development Plan VIII, the planning of power source projects must have a long-term, effective and sustainable vision. Power development must be based on the principle of optimizing overall factors of power sources, transmission and distribution in conjunction with ensuring energy security and environmental protection. However, wind power projects that have been deployed in practice still have many shortcomings, such as the lack of a national-level master plan; have not mastered the technology of surveying, designing, manufacturing, installing, operating, maintaining, and processing wind turbines; completely dependent on foreign consulting, investment, and equipment supply companies. As a result, some new wind power plants have had incidents and accidents such as broken turbine blades, generator explosions, operating below design capacity, etc. or some wind power plants have transferred ownership to foreign corporations after successfully signing power purchase agreements (PPA). This leads to low investment efficiency, causing energy insecurity and reducing people's confidence in wind power projects in general.

Based on practical issues and the desire to master the technology, the thesis was carried out with the title "PROPOSED MODELS FOR DESIGNING WIND TURBINE BLADES AND INSTALLED CONFIGURATIONS OF ONSHORE WIND FARMS IN VIETNAM". This thesis is a scientific work that can be used as a reliable reference source, helping managers and investors make more accurate decisions in the stages of survey, planning, site selection, turbine design and turbine installation configuration of onshore wind farms, suitable for terrain characteristics, infrastructure and wind resources.

Research Objectives:

The objective of this study is to develop models for designing turbine blade profiles and turbine installation configurations of onshore wind farms in Vietnam. The models are used to determine the development areas, turbine blade profiles and turbine installation configurations of onshore wind farms. Thereby, contributing to improving the operational efficiency of the farms by maximizing the Annual Electricity Production (AEP) value and ensuring the Levelized Cost of Energy (LCOE) consistent with the current Electricity Purchase Price (EPP) in Vietnam.

The scope of the thesis is wind power generation technology using three-bladed horizontal axis turbines. The research object of the thesis is the small horizontal axis turbine blade profiles and the installation configurations of onshore wind farms in Vietnam.

METHODOLOGY

Theoretical basis:

This thesis uses a number of theories and numerical simulation models, including:

- GIS and CFD models to study, evaluate and select potential areas for onshore wind farms. The results from this simulation model will determine the terrain and wind resource characteristics such as terrain elevation and roughness, average wind speed and turbulence intensity as input parameters for the turbine blade profile and installed configuration design models in onshore wind farms.

- BEM and BOM theories combined with PM, LLFVWM and CFD simulation models to study the blade profiles and operating parameters of wind turbines according to wind resource characteristics with the goal of achieving the largest power coefficient (C_P).

- BEM and Jensen theories combined with GIS and CFD simulation models to study the design of turbine installation configuration in wind farm areas with the goal of achieving the largest AEP value and reasonable LCOE value.

Research methods:

To carry out the research contents in the thesis, a number of research methods have been used, including:

- Method of searching, collecting and processing information and data online: This method is used to solve problems related to data sources such as terrain characteristics, infrastructure, wind resources, turbine design parameters; theoretical basis of BEM, BOM, AEP, WL and LCOE; theoretical basis and data library of GIS, CFD, PM and LLFVWM models.

- Physical simulation method: Using different physical theories to describe, analyze and interpret the movement and interaction processes of air flows under different specific conditions. Physical conservation equations are the basic foundation for analytical models, numerical simulation models such as GIS and CFD. The terrain features, infrastructure, wind resources in the area of interest will be built and displayed on digital maps based on BlenderGIS, QGIS or Ansys CFX, Fluent. Then, create 2D, 3D models of the objects. These models will be used to simulate wind interaction processes under different conditions. From there, the interaction processes, wake effects, energy losses when the wind blows through this area will be determined. These results are used to calculate the operating parameters of the turbines, thereby evaluating and selecting suitable turbine installation locations in the surveyed areas.

- Statistical method: This method is based on large historical data to make forecasts. This method is performed according to time series analysis to build wind speed frequency distribution functions by area or wind speed distribution functions according to terrain height at different locations. These functions will provide important input data for design calculations and CFD simulation models.

- Analysis method:

+ BEM, BOM theories combined with PM, LLFVWM, CFD models to study and design wind turbine blade profiles according to terrain characteristics and wind resources in the surveyed areas. From there, the analysis determines the most suitable turbine blade profile.

+ BEM, Jensen theories combined with GIS, CFD models to study turbine installation configurations in wind farm development areas to achieve the largest AEP and reasonable LCOE. Finally, the analysis determines the most suitable turbine installation configuration for the entire wind farm development area.

This thesis combines the above methods to collect values and results according to the research objects. Then, these results will be analyzed, evaluated and compared with experimental and practical values in some specific cases.

SOME MAIN RESULTS

Model simulating wind speed changes according to terrain and altitude:

Vietnam has a territory stretching from North to South, the terrain is mainly mountainous. The terrain altitude increases gradually from East to West. Wind direction changes seasonally and regionally, mainly in the Southwest and Southeast directions, sometimes in the Northeast direction.

When the air flow moves, the characteristics of the wind resource will depend greatly on the terrain characteristics. Because air is a type of fluid, the properties and shape of the fluid often depend on the surrounding environment. The moving air flow will continuously change its state with three forms: laminar flow, transition flow and turbulent flow. In each state, important properties such as direction, density, viscosity, etc. will change accordingly. Therefore, the same initial wind resource, but when moving to different terrain areas, almost all of their properties will be changed. Therefore, detailed and specific studies are needed for each area according to the terrain characteristics and wind resources to ensure that all processes occurring are calculated in advance and ensure that the turbines will exploit the highest energy efficiency throughout the operating life of the wind farms. To accurately describe the airflow processes, it is necessary to clarify some important initial parameters such as: direction, speed and turbulence intensity of the airflow entering the farm area; the surrounding ground surface layer, in direct contact with the airflow, is often called the Boundary Layer. At the surface in contact with the Boundary Layer, the airflow velocity will be 0. The roughness of the Boundary Layer will greatly affect the formation of friction with the air layer in direct contact, thereby creating turbulence, vortex and reverse airflow as illustrated in Figure 3.1. This leads to loss of airflow energy and other problems such as vibration (fatigue problem), noise (health problem) for the turbines during operation. It is necessary to clearly define the width of this interaction zone to avoid unnecessary impacts and losses on the actual operation of the turbine.

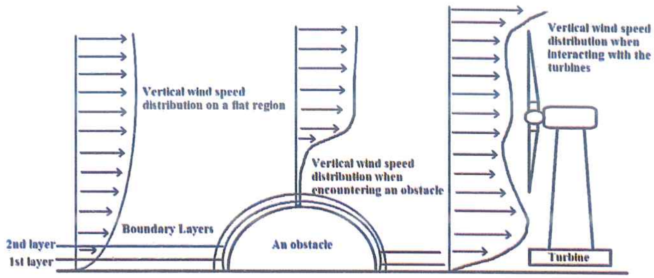
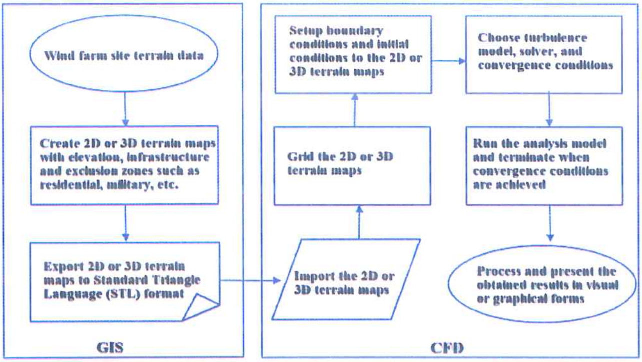


Figure 3.1. Illustration of the wind speed distributions

Vietnam's territory is mainly mountainous, with large elevation differences. Therefore, it is necessary to conduct research for each area where the farm is expected to be built to determine the most accurate wind speed distribution. The flow chart analyzing the terrain and wind resources characteristics in the area corresponding to a wind farm is shown in Figure 3.2.

The GIS – CFD model proposed in this study can help select the most suitable areas and locations for developing onshore wind power projects in Vietnam. The results obtained from this model include the location and terrain characteristics of the farms, wind speed distributions according to terrain and elevation, which is an important basis for conducting further design studies on turbine blade



profiles and turbine installation configurations in farm areas.

Figure 3.2. The flowchart analyzes terrain characteristics and wind resources

A design model for wind turbine blade profiles:

GIS – CFD model allows to determine the terrain characteristics and wind resources at each location in the wind farm development area. The wind speed distribution function and turbulence intensity with height are important bases for selecting or designing suitable wind turbines.

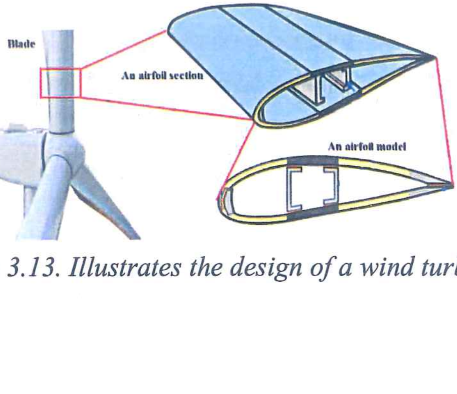
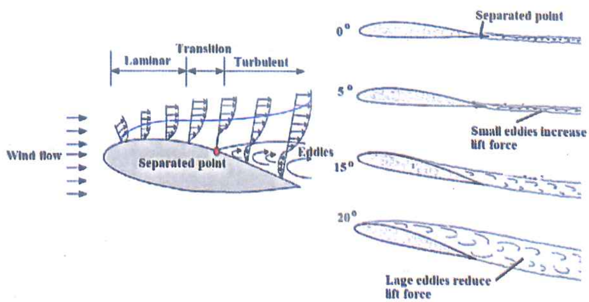


Figure 3.13. Illustrates the design of a wind turbine blade

Wind turbine blades are usually designed from many different airfoil sections. The airfoil sections will be placed at different positions, thicknesses, lengths and twist angles to create a complete blade profile. When the incoming wind interacts with the airfoil surface, depending on the wind speed, AoA, size and surface roughness, different phenomena will occur as illustrated in Figure 3.14. If the airfoil models are designed with the appropriate size and AoA value for the incoming wind speed, it will create the largest lift force and the smallest drag force, then the C_l/C_d ratio will reach the largest value. Conversely, if the airfoil size or AoA value does not



match the characteristics of the incoming wind, it will create large drag force and reduce lift force, resulting in a low C_l/C_d value.

Figure 3.14. Illustration of the interaction processes of incoming flow with an airfoil

When the incoming wind interacts with the turbine blade below the AoA value, each airfoil section will catch the wind at a different angle. The C_P of the entire blade will depend on the C_l/C_d value of each airfoil section. Therefore, to design a complete blade, it is necessary to study airfoil models. Then, the airfoil models with the highest wind energy extraction efficiency will be combined to create the optimal blade profile based on the BOM theory. The optimal blade profile is the one with the highest C_P value. The detailed model for designing the turbine blade profiles is shown in Figure 3.15

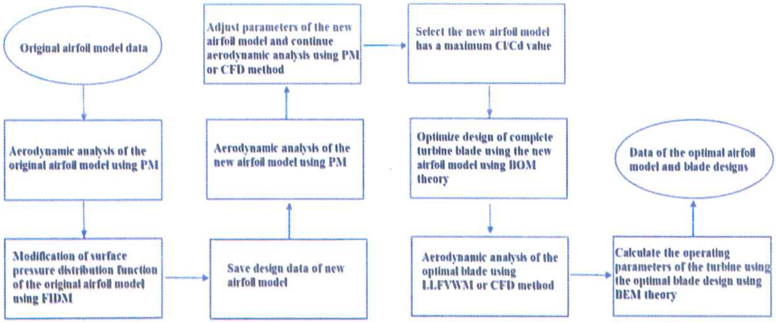


Figure 3.15. The flowchart of the optimal blade design model

The optimal design model of the turbine blade profiles includes 11 steps as follows:

- The 1st step: Select an airfoil model with high wind energy exploitation efficiency - Original airfoil model.

- The 2nd step: Analyze the aerodynamics parameters of the original airfoil model in the wind speed region of interest using the PM. The results are the lift coefficient, drag coefficient, lift to drag coefficient ratio when operating in the wind speed and the graph or function of wind speed distribution or wind pressure on the surface of the original airfoil model.

- The 3rd step: Modify the graph or wind speed distribution function or wind pressure distribution function on the surface of the original airfoil model to obtain a new graph or pressure distribution function with the largest difference between the upper and lower surfaces of the original airfoil model. The result is to obtain a new wind speed distribution function or new wind pressure distribution function. Then, a new airfoil profile will be created based on the new wind speed distribution function or new wind pressure distribution function using the FIDM.

- The 4th step: Save the data of the new airfoil profile with a suitable name or identification number.

- The 5th step: Analyze the aerodynamics parameters of the new airfoil model in the same wind speeds using the PM. The results are the lift coefficient, drag coefficient, lift to drag coefficient ratio. Compare and evaluate the values obtained from the new airfoil model with the original one.

- The 6th step: Continuously adjust the design parameters of the new airfoil model such as MT, MTP, MC and MCP to obtain the new airfoil model profiles. Then, all the new airfoil models are aerodynamically analyzed using PM or CFD methods. The results are obtained lift coefficients, drag coefficients, lift coefficient to drag coefficient ratios of the new airfoil models in the same wind speeds.

- The 7th step: Compare and evaluate the lift coefficient to drag coefficient ratios of the original airfoil model and the new airfoil models, then select the airfoil model with the largest lift coefficient to drag coefficient ratio. The result is to obtain the optimal airfoil model profile in the wind speed region of interest.

- The 8th step: Use BOM theory to arrange the airfoil models according to different size and twist angle parameters to create complete blade designs. Each complete blade design can use several different airfoil types, but it is also possible to use only the airfoil model with the largest C_l/C_d. The result is the turbine blade profiles.

- The 9th step: These new blade profiles are aerodynamically analyzed using LLFVWM or CFD methods to calculate CP values at different wind speeds. The blade profile design with the largest CP value is selected.

- The 10th step: The blade profile with the largest CP is used to create a 3-blade horizontal axis turbine. The BEM theory is then used to determine the turbine operating parameters such as the output electrical power based on the mechanical system and generator parameters. The result is the operating values of the turbine designs under different conditions.

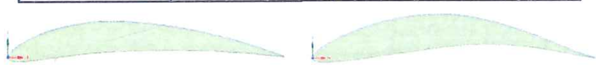
- The 11th step: Compare the power coefficient values of the turbine designs and select the blade design with the largest CP value. The result is an optimal turbine blade design in the wind speed region of interest. Finally, the detailed data of the optimal turbine blade design is exported and given a suitable name.

The optimal design model of turbine blade profiles as shown in Figure 3.15 is then implemented in this thesis. According to the first step in the optimal design model, some original airfoil models with good wind energy exploitation efficiency and are commonly used in the wind power field are selected such as: NACA6409, S1010, S1223. These airfoil designs represent symmetrical and asymmetrical airfoil models.

From the step 2 to step 7, these airfoil models are analyzed by PM or CFD methods to determine the characteristic aerodynamic quantities under operating conditions with wind speeds in the range of 3.0 - 10.0 m/s. The dimensions of the airfoil models will be brought to the standard length of c=1.0 m, and divided equally into 149 panels when using PM. However, because the main wind speed region in Vietnam is in the range of 4.0 - 6.0 m/s. Therefore, the analysis results with this wind speeds will be presented specifically in this thesis. All 03 original airfoil models were analyzed in the same steps and after comparison and selection, 03 new airfoil models were obtained for the corresponding maximum lift coefficient to drag coefficient ratio. The new optimized models were named based on the research cooperation between Electric Power University and Vietnam Academy of Science and Technology: VAST-EPU-N6409, VAST-EPU-S1010, VAST-EPU-S1223.

Table 3.2. Basic parameters of NACA6409 and VAST-EPU-N6409

Parameters	NACA6409	VAST-EPU-N6409
MT	9.00%	10.30%
MTP	30.03%	32.03%
MC	6.0%	7.99%
MCP	40.44%	51.45%



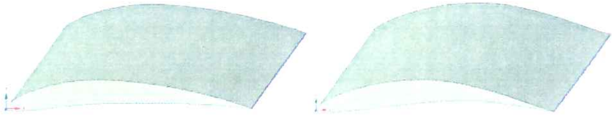


Figure 3.20. Shapes of NACA6409 and VAST-EPU-N6409

Table 3.3. Basic parameters of S1010 and VAST-EPU-S1010

Parameters	S1010	VAST-EPU-S1010
MT	6.02%	8.00%
MTP	23.42%	20.32%
MC	0.00%	5.96%
MCP	0.00%	72.77%

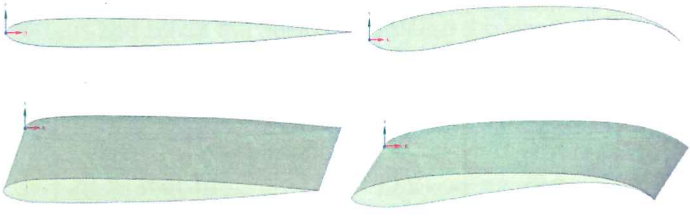


Figure 3.24. Shapes of S1010 and VAST-EPU-S1010

Table 3.4. Basic parameters of S1223 and VAST-EPU-S1223

Parameters	S1223	VAST-EPU-S1223
MT	12.14%	5.0%
MTP	20.12%	19.82%

MC	8.68%	8.16%
MCP	47.45%	48.65%

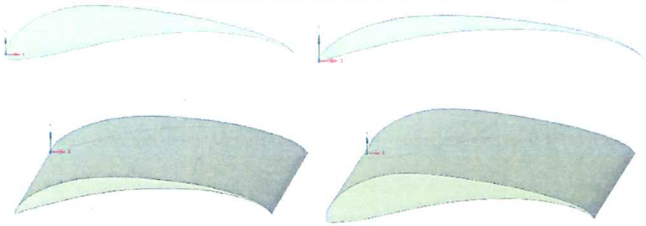


Figure 3.28. Shapes of S1223 and VAST-EPU-S1223

Some aerodynamic analysis results of S1010 airfoil model using CFD numerical simulation model are shown in Figure 3.34.

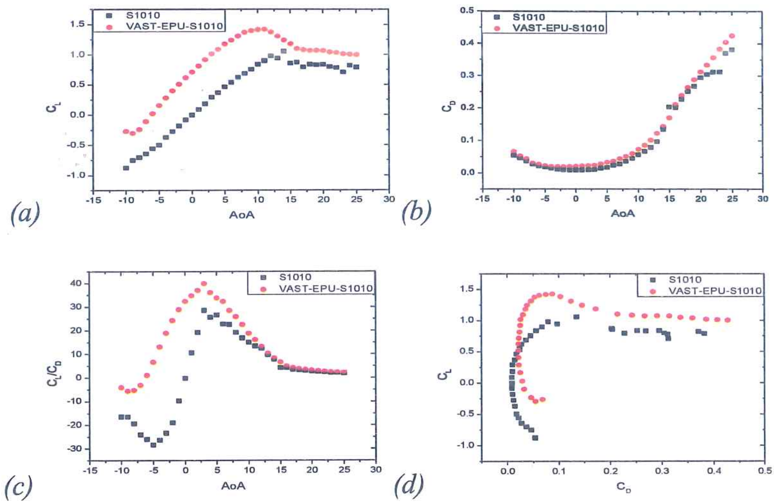


Figure 3.34. Obtained values of C_l (a), C_d (b), C_l/C_d (c), C_l compared to C_d (d) when operating at a wind speed of 5.0 m/s

The results obtained from the CFD analysis models can also be presented as visual images showing the flow passing over the surface of the VAST-EPU-S1010 airfoil, along with the location of the flow separation and the magnitude of the vortices according to the AoA angles. This is a great advantage of the CFD method in aerodynamic analysis problems. These results are shown in Figure 3.37.

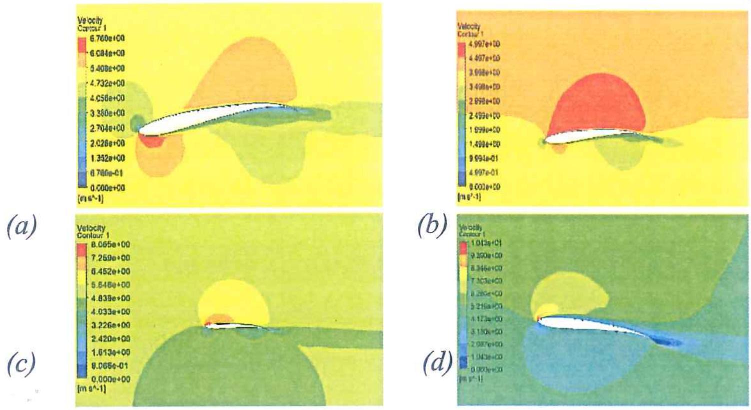


Figure 37. Airflow contours and eddies when interacting with the VAST-EPU-S1010 airfoil surface with angles: AoA=-5° (a), AoA=-0° (b), AoA=5° (c), AoA=10°(d) at a wind speed of 5.0 m/s

According to the design model as shown in Figure 3.15, the first 7 steps help to design the airfoil models for the largest C_l/C_d. From steps 8 to 11, these airfoil models will be arranged according to different sizes and twist angles depending on the rotor radius. The final goal is to find the blade profiles for the largest power coefficients under the specific operating conditions of the turbines. Among the new airfoil models, VAST-EPU-S1223 is continued to be used to design the complete turbine blades based on the BOM theory. The results are shown in Figure 3.41. The maximum output power of the turbine using the 5m long VAST-EPU-S1223 blade is 3.05 kW, with a maximum C_P of up to 50.5%. This C_P value is about 1.59 times larger than that of the original blade model and 1.11 times larger than that of the SG6043 model under the same operating conditions at a wind speed of 5.0 m/s. In fact, the best commercial turbines available today can only achieve C_P values of around 45% to 48%.

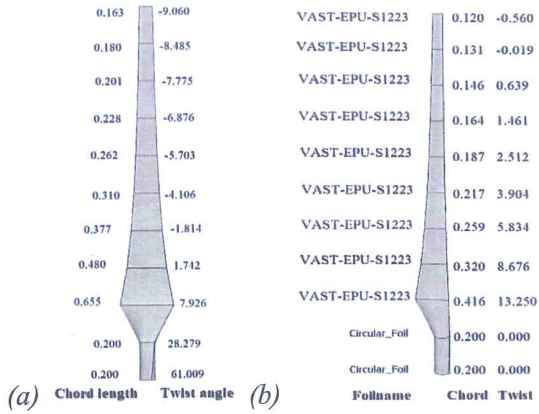


Figure 3.41. Design parameters of 5.0 m long turbine blades using the SG6043 model (a) and the VAST-EPU-S1223 model (b)

Summary: To design or select a turbine suitable for the development area of onshore wind power projects, it is necessary to carry out two main contents including: Determining the terrain characteristics and wind resources in the area according to different locations and heights; calculating the design or selecting a turbine suitable for the terrain characteristics and wind resources to achieve the highest C_P.

For areas with high average wind speeds, turbine blades are often designed longer, the airfoil models used often have large MT and small MC. For actual wind speeds in Vietnam, mainly from 4.5 m/s to 6.5 m/s, the turbine blade length should be designed in the range of 4.0 m to 8.0 m for the greatest efficiency in exploiting wind energy. The airfoil model used should have small MT (MT < 10%) and large MC (MC > 10%). This ensures the highest wind energy extraction efficiency of the turbine.

The design model proposed in this thesis combines the strong advantages of both theoretical and numerical simulation models. The results obtained are highly reliable and intuitive.

A model for designing wind farm installation configurations:

When an onshore area is identified as having potential and planned for wind power project development, it is necessary to exploit the wind energy resources in this area most effectively. The efficiency of wind energy exploitation depends mainly on factors such as wind resource characteristics, turbine design and turbine layout configuration in the wind farm. Wind resource characteristics will change continuously depending on the terrain and turbine layout as analyzed in the previous sections. When the wind collides with obstacles, it will create eddies, causing turbulence and energy loss of the flow, which will eventually reduce the turbine output power. This thesis presents an design model for the turbine installation configuration in an onshore wind farm based on the combination of

GIS, CFD numerical simulation models and BEM, Jensen theories. The objective of this model is to determine the installation configuration of a certain number of turbines in a farm area to achieve the maximum AEP value and a reasonable LCOE value. A reasonable LCOE value means that it must be lower than the EPP currently applied in Vietnam. The flowchart of this turbine installation configuration design model is shown in Figure 4.1.

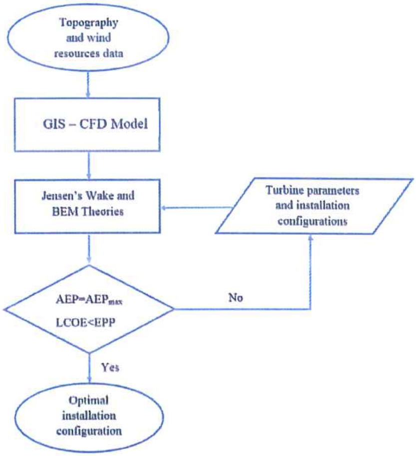


Figure 4.1. The flowchart of the model for designing turbine installation configurations

The proposed model consists of five main processes:

- The 1st process: The terrain and wind resource characteristics in the wind farm development area are collected.

- The 2nd process: Simulate the interaction process of wind resources with the terrain of the farm area under different conditions.

Through the GIS - CFD combined analysis model, wind energy losses due to terrain factors will be determined. The results are wind speed distribution functions at different locations and heights. From there, the types of turbines and the expected installation configurations in the farm area will be determined.

- The 3rd process: Wind energy losses due to turbines with different installation configurations will be determined using Jensen's wake theory. Different configurations will be based on different spaces of turbine rows. The distances will have increasing values from small to large. Then, the actual operating power of the turbines will be determined using the BEM theory.

- The 4th process: The AEP and LCOE values of different turbine installation configurations will be determined in turn according to theoretical functions based on wind resource data after correcting for energy losses caused by terrain and turbine factors. At each installation configuration, the corresponding AEP and LCOE values will be determined. If the AEP of the configuration is larger than that of the previous configuration, the turbine installation configuration will continue to be changed. If the configuration has a smaller AEP than the previous configuration or the distance between turbine rows has exceeded the width of the wind farm area, the configuration change process will stop. At this time, check which configuration gives the largest AEP value and consider the condition that LCOE is smaller than EPP. In the case that the configuration meets the largest AEP but LCOE is larger than EPP, the configuration with the largest AEP will still be given priority. Because the objective function aims at the maximum efficiency of wind energy exploitation.

- The 5th process: Determine the optimal installation configuration which is the configuration that simultaneously satisfies both constraints of the largest AEP and LCOE<EPP. If the analysis results show that LCOE is larger than EPP, this result can be used as a scientific basis to convince state managers such as EVN to adjust the EPP value more appropriately.

This design model is applied to the Khanh Hoa province (Ninh Thuan), around the coordinates (11°27'51.1"N; 109°00'17.6"E). The obtained results are wind speed distributions according to height at different locations in the wind farm as shown in Figure 4.8 and Figure 4.9.

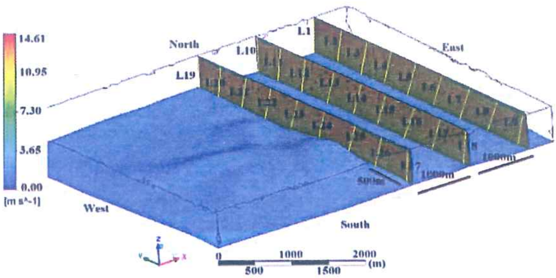


Figure 4.8. Locations surveyed in detail in the model

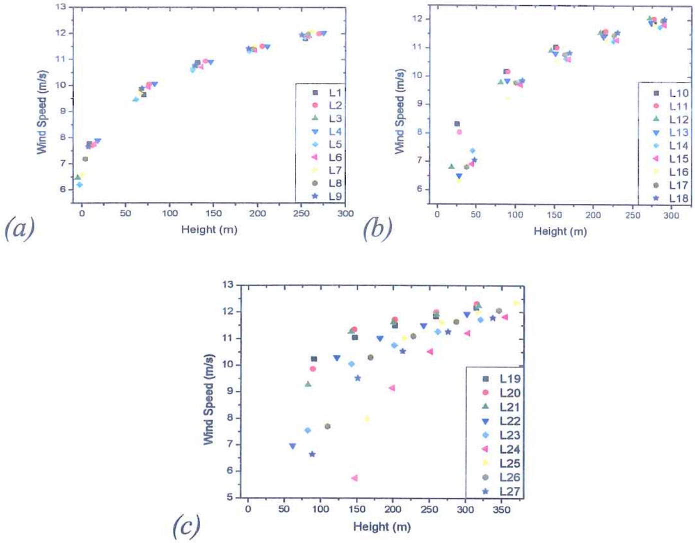


Figure 4.9. Wind speed distributions according to height at different locations

Through the steps shown in Figure 4.1, the most suitable installation configuration of E103 turbines for this farm area is shown in Figure 4.10. According to this configuration, the turbines will be installed in 3 rows perpendicular to the East direction. The distance between the two nearest turbines in the same row is 3Drotor and the distance between the two nearest turbine rows is 10Drotor.

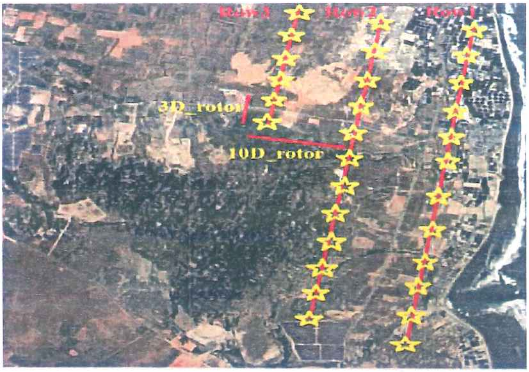


Figure 4.10. Optimum configuration for installing the E103 turbines at the farm area

The proposed new turbine installation configuration gives the AEP value of up to 203.84 GWh/year, about 2.5 times higher than the current configuration. The LCOE value of this configuration is about 79.7$/MWh, equivalent to the electricity purchase price in Vietnam in 2025.

Summary: The wind farm installation configuration design model proposed in this thesis can determine the influence of terrain factors, wind resources, turbine types and turbine installation configurations in the wind farm development area on the AEP value. The goal of this design model is to determine the turbine installation configuration in the farm to achieve the largest AEP value. This model uses GIS-based terrain data sources. Therefore, the farm's terrain surface data such as roughness and elevation are presented visually and clearly. At that time, only wind resource data at a point in the farm area is needed. The CFD method will simulate the entire interaction processes of this wind resource with the specific terrain. From there, the wind resource characteristics at each location in the wind farm area are determined. This is a great advantage of CFD over all other methods. Obviously, the GIS - CFD combined model has many outstanding features in solving the aerodynamic problems of wind farms. Jensen and BEM theories perform calculations to determine AEP based on the results obtained from the GIS - CFD model. The simultaneous combination of theoretical and numerical simulation models makes this design model perfect, and evaluates many different factors affecting the AEP values of onshore wind farms in Vietnam.

CONCLUSIONS

The thesis has conducted research and proposed the models for designing turbine blade profiles and turbine installation configurations of onshore wind farms. These models include three main parts: determining locations with high wind energy potential, turbine blade profiles for the largest power coefficients and installation configurations for the largest annual electricity productions.

These design models include both analytical theories and numerical simulation methods. The theories help determine the relationships between the quantities describing the operation of wind turbines. Simulation models help to correct the values of wind speed, turbulence intensity, wind speed frequency, and wind direction at locations in the wind farm development area. These models are highly suitable and general for actual conditions in Vietnam.

In addition, the boundary conditions of the models are terrain conditions, and the initial conditions are wind resource characteristics. Therefore, these design models only need wind resource data measured at a location in the farm area. Then, the entire processes of movement, interaction and transformation of wind resource characteristics according to the terrain will be accurately described by the GIS - CFD model. From there, some hypothetical risk analysis cases under extreme weather conditions can also be easily identified, helping to minimize problems related to incidents and accidents throughout the life cycle of the turbines. This is also a great advantage of the model compared to other design models.

The design models proposed in this thesis are highly effective and intuitive. However, the participating models such as GIS and CFD are modern, big data models. To use these tools, a computer system with a large enough configuration is required and the person performing these analyses must have sufficient knowledge and experience. Especially experiences in selecting mesh type, meshing, selecting solver, turbulence model in CFD models.

Some new scientific and practical contributions:

- In terms of science: This thesis studies and proposes the design models base on the combination of BEM, Jensen theories and modern numerical simulation models such as GIS, CFD. GIS models use large, high-resolution spatial data sources to accurately determine the terrain characteristics of the wind farm area. CFD models are modern analysis and simulation tools. Systems of conservation equations are used to accurately and visually describe all possible interactions of wind resources in the farm area. Determining meshing methods, choosing turbulent flow models, boundary conditions and initial conditions play a decisive role in the accuracy of the CFD simulation models. The specific parameters of the CFD simulation models used in this thesis are new scientific contributions.

- In terms of practice: Vietnam is strongly developing renewable energy. In which, wind power will contribute a large proportion to the power source structure in the future. Currently, Vietnam is in the process of implementing many onshore and offshore wind power projects. This thesis provides the models for designing blade profiles and installation configurations of onshore wind farms. These models can contribute to the management and investment efficiency of onshore wind power projects in Vietnam. The thesis has contributed 02 new design models, specifically including:

- Proposing the design model of turbine blade profiles according to actual wind resource conditions in Vietnam, in order to obtain the largest power coefficients.

- Proposing the design model of turbine installation configurations of onshore wind farms according to actual terrain and wind resource conditions in Vietnam, in order to obtain the largest AEP values.

Future Work:

The results presented in this thesis are only the first step. In the next steps, research directions related to the selection of materials for manufacturing turbine blades and turbine blade manufacturing technology based on modern technologies such as 3D printing will be prioritized. In addition, studies using artificial intelligence models will also be conducted to compare and verify with the results obtained from the models proposed in this thesis.

LIST OF SCIENTIFIC PUBLICATIONS

1. **Dinh Van Thin**, Le Quang Sang, Chau Dinh Van, Nguyen Huu Duc, *Technology trends in onshore wind turbine design – Performance assessment in Vietnam*, 2nd Asia Meeting on Environment and Electrical Engineering (EEE-AM), Hanoi, Vietnam, 2025, pp. 1-5, IEEE Xplore.

2. **Dinh Van Thin**, Le Quang Sang, Chau Dinh Van, Nguyen Huu Duc, *Study on design of NREL 5MW equivalent turbine blade using VAST-EPU-N6409 airfoil model*, 2nd Asia Meeting on Environment and Electrical Engineering (EEE-AM), Hanoi, Vietnam, 2025, pp. 1-4, IEEE Xplore.

3. **Dinh Van Thin**, Le Quang Sang, Chau Dinh Van, Tran The Vinh, Duc Nguyen Huu, *A proposed airfoil configuration to improve aerodynamic efficiency applied in the design of small wind turbines*, Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, Vol. 133, No. 2, 2025, pp. 140 – 154. https://doi.org/10.37934/arfmts.133.2.140154. ISSN: 2289 – 7879.

4. **Dinh Van Thin**, Le Quang Sang, Nguyen Huu Duc, *Optimization method of wind turbine locations in complex terrain areas using a combination of simulation and analytical models*, IEEE Access, Vol. 13, 2025, pp. 114384 – 114400. https://doi.org/10.1109/ACCESS.2025.3584560. ISSN: 2169 - 3536.

5. Le Quang Sang, Tinnapob Phengpom, **Dinh Van Thin**, Nguyen Huu Duc, Le Thi Thuy Hang, Cu Thi Thanh Huyen, Nguyen Thi Thu Huong, Quynh T. Tran, *A method to design an efficient airfoil for small wind turbines in low wind speed conditions using XFLR5 and CFD simulations*, Energies, Vol. 17, No. 16, 2024, pp. 1 – 19. https://doi.org/10.3390/en17164113. eISSN: 1996 - 1073.

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8. **Dinh Van Thin**, Nguyen Huu Duc, Le Quang Sang, *Aerodynamic analysis of NACA64A010 airfoil using XFLR5 and ANSYS Fluent*, GMSARN International Journal, Vol. 18, No. 2, 2024, pp. 258 – 266. ISSN: 1905 – 9094.

9. **Dinh Van Thin**, Le Quang Sang, Chau Dinh Van, Nguyen Huu Duc, *Modifying NACA6409 airfoil configuration to improve aerodynamic performance in low wind speeds*, 1st Asia Meeting on Environment and Electrical Engineering (EEE-AM), Hanoi, Vietnam, 2023, pp. 1-5, IEEE Xplore. https://doi.org/10.1109/EEE-AM58328.2023.10395332.

10. **Dinh Van Thin**, Nguyen Huu Duc, Le Quang Sang, Doan Van Binh, *Study to evaluate the effect of terrain surface on performance of a wind farm in Ninh Thuan province*, Vietnam, E3S Web of Conferences Vol. 470, 2023, ID. 01038, pp. 1 – 11. https://doi.org/10.1051/e3sconf/202347001038. eISSN: 2267-1242.

11. **Dinh Van Thin**, Nguyen Huu Duc, Le Quang Sang, Evaluating the wind resources in an area that is equivalent to the size of a wind power plant: a methodology, TNU Journal of Science and Technology, Vol. 228, No. 2, 2023, pp. 343 – 351. ISSN: 1859 - 2171, 2374 - 9098; e-ISSN: 2615 – 9562.

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13. **Dinh Van Thin**, Nguyen Huu Duc, Le Quang Sang, *Aerodynamic analysis of NACA6409 airfoil in wind turbine by using Panel method*, TNU Journal of Science and Technology, Vol. 227, No. 8, 2022, pp. 227 – 235; ISSN: 1859-2171, 2374-9098; e-ISSN 2615-9562.