

INFORMATION ABOUT THE RESEARCH RESULTS

Thesis name: ENHANCING WIND POWER PROFITABILITY IN THE ELECTRICITY MARKET

Major: Electrical Engineering.

Specialized code: 9520201

Full name of the doctoral candidate: Dinh Ngoc Sang

Scientific supervisor: Assoc. Prof. Dr. Truong Viet Anh

Assoc. Prof. Dr. Duong Thanh Long

Training Institution: Ho Chi Minh City University of Technology and Engineering

1. Summary of the Thesis

Over the past decades, renewable energy—particularly wind and solar power—has achieved significant progress due to strong support mechanisms aimed at accelerating the transition toward sustainable energy systems. In Vietnam, preferential feed-in tariff (FIT) policies have played a crucial role in promoting wind and solar power projects. However, in line with the inevitable evolution of electricity markets, increasing competition is gradually replacing direct support policies. This transition imposes an urgent requirement on investors to carefully assess financial risks, especially as the inherent uncertainty of renewable energy sources poses substantial technical and economic challenges, affecting power system stability as well as investment performance. In this context, numerous studies have focused on technological improvements and financial optimization solutions to enhance the competitiveness of these emerging energy sources, including the application of advanced forecasting methods, the development of optimization algorithms, and the formulation of financial investment strategies. Nevertheless, existing review studies indicate that many issues remain open, and further research and innovative approaches are still required to effectively promote the global transition toward sustainable energy systems.

Based on this context, and with the objective of improving investment efficiency in the wind power sector, the study develops two main research directions: MODEL DEVELOPMENT and METHOD PROPOSITION. First, the study focuses on probabilistic modeling of wind power uncertainty in electricity markets. Composite probabilistic models are developed to capture unexpected fluctuations in wind generation. Coordination models are then formulated for different bidding mechanisms in the day-ahead market, where each model represents a specific coordination scenario among wind farms or between wind power and other generation sources. Based on these models, the actual revenue variability of wind power producers under each bidding mechanism is evaluated considering wind uncertainty, thereby identifying effective coordinated bidding models for wind power investors. Second, the study proposes methods to increase wind power revenue under the newly developed modeling framework, contributing to enhanced investment efficiency. As coordination among multiple generation sources leads to high-dimensional problems with exponentially increasing computational complexity under uncertainty—particularly in large-scale power systems—two solutions are proposed. The first applies artificial intelligence to enhance metaheuristic optimization by integrating LSTM networks into genetic algorithms and particle swarm optimization, improving convergence speed, forecasting accuracy, and robustness against local optima, and enabling optimal wind power bidding strategies in coordinated generation models. The second solution emphasizes the deployment of energy storage systems to expand existing wind farms, combined with the optimal utilization of transmission transformers to maximize marketable wind

power. Financial evaluations indicate that expanding existing wind farms yields higher economic efficiency than investing in new wind power projects.

During the research process, simulation experiments conducted on standard IEEE test power systems produced effective results with clear practical significance. First, the integrated probabilistic models and experimental framework demonstrated high effectiveness, as the coordination of wind farms with thermal power sources and energy storage systems increased the available generation capacity from 55 MW to 95 MW, while improving wind power plant operating profits by up to 132% compared with conventional models. Second, the newly proposed hybrid algorithms (LSTM–GA and LSTM–PSO), tested on optimization models that explicitly consider wind power uncertainty, exhibited superior performance relative to traditional approaches, achieving a 12–20% increase in wind power generation, a corresponding revenue improvement of approximately 7%, and about a 22% reduction in computational cycles compared to conventional methods. In addition, these algorithms help wind power investors stabilize bidding power variability in electricity markets. Third, in terms of investment efficiency, the proposed solutions that enhance the utilization of energy storage systems significantly improve the financial performance of wind farm expansion projects, with the potential return on investment increasing by up to 5.64 times compared to new project development, corresponding to an improvement in financial efficiency from 4.4% to 24.8%, thereby strengthening investor confidence and promoting the sustainable development of wind energy.

2. Novel Contributions of the Study

The study makes three main contributions to the scientific community, with the following notable novelties.

(i) Probabilistic modeling of wind power uncertainty as a foundation for coordinating generation resources in competitive electricity markets. The research develops and proposes models that enhance wind power investment efficiency under highly uncertain conditions, which otherwise place wind generation at a disadvantage compared to more stable conventional power sources in competitive market environments.

(ii) The proposal of novel hybrid techniques that integrate Long Short-Term Memory (LSTM) networks into the optimization processes of Genetic Algorithms and Particle Swarm Optimization. The newly developed LSTM–GA and LSTM–PSO algorithms demonstrate clear advantages by embedding artificial intelligence into conventional optimization structures. Their application to wind power uncertainty problems in electricity markets provides effective solutions for improving wind power performance and investment efficiency.

(iii) The proposal of a solution that enhances the use of energy storage systems and optimizes transmission transformers to efficiently expand existing wind farms, rather than developing new projects that are often constrained by land acquisition and compensation issues. The integrated storage-based model, which explicitly considers wind power uncertainty, enables optimal utilization of transmission transformers and significantly increases investment benefits without the need for additional transmission expansion.

The research results have also contributed to the publication of 12 scientific papers in academic journals, including four articles ranked Q1–Q2 in ISI- and Scopus-indexed journals.