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Simulation of Grid Integrated with Wind Farm

S. K. Awaze, Sarika Shelke, Shaikh Mohammad Talha, Shaikh Mubin
Department of Electrical Engineering
Dr. Vithalrao Vikhe Patil College of Engineering, Ahmednagar, Maharashtra, India

Abstract: *This project investigates the integration of a large-scale wind energy farm into an existing power grid and its impact on grid reliability. Using PowerWorld Simulator, the study models the IEEE 9-bus system enhanced with wind and renewable energy resources. Key performance indicators such as voltage stability, frequency response, power flow, and contingency scenarios are analyzed under varying wind generation levels. The research employs the zone branch methodology to segment the power distribution system into protected zones, facilitating a detailed reliability assessment. The role of compensating capacitors is also examined to understand their influence on system reliability indices. Results demonstrate both benefits and operational challenges posed by renewable energy integration, highlighting strategies to improve grid resilience. The findings underscore the importance of reliability analysis in planning and designing modern power distribution systems incorporating renewable energy resources..*

Keywords: Wind turbines, power system dynamics, PowerWorld Simulator, reliability analysis, zone branch methodology, renewable energy resources.

I. INTRODUCTION

The growing emphasis on reducing greenhouse gas emissions and transitioning toward sustainable energy solutions has led to the widespread adoption of renewable energy technologies. Among these, wind energy has emerged as a prominent contributor due to its eco-friendly nature, cost-effectiveness, and scalability. However, the integration of wind farms into existing power grids presents unique challenges, primarily due to the variability and unpredictability of wind patterns, which can cause voltage fluctuations, frequency instability, and difficulties in load balancing. This research project focuses on simulating the impact of wind energy integration on power grid reliability using PowerWorld Simulator, a powerful tool for modeling and analyzing complex electrical systems. A modified IEEE 9-bus test system is utilized to study the dynamic behavior of the grid under different wind power scenarios. The simulation evaluates various performance indices such as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI) to quantify the reliability of the grid. Furthermore, the project applies the Zone-Branch Methodology to segment the network into protective zones, allowing for localized fault analysis and enhanced fault isolation strategies. The role of reactive power compensation, through the use of capacitors and advanced power electronic devices like Voltage Source Converters (VSCs), is also examined in improving voltage stability. Mitigation strategies such as Battery Energy Storage Systems (BESS) and Flexible AC Transmission Systems (FACTS) are analyzed for their effectiveness in supporting grid stability under fluctuating wind conditions. By combining theoretical concepts with simulation-based analysis, this study provides valuable insights into the operational challenges, reliability considerations, and potential solutions for effectively integrating wind energy into modern smart grids. The findings are intended to guide future planning and policy decisions related to renewable energy deployment and grid modernization.

II. METHODS AND MATERIAL

1. Overview of wind farm System

Integrating both distributed renewable energy resources (DRERs) such as solar and wind and energy storage devices (SDs) into a conventional power grid significantly enhances system reliability something clearly demonstrated on the IEEE 9 bus test network. In a comparative analysis of three configurations, the system featuring both DRERs and SDs

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delivered more dependable power supply, reduced greenhouse gas emissions and energy wastage, and achieved marked improvements in key reliability metrics (SAIFI, SAIDI, CAIDI, ASAI) compared to setups lacking these integration.

II. ACTUAL SYSTEM MODEL

2.1 Case 1= System Diagram (Blackout/without capacitance)

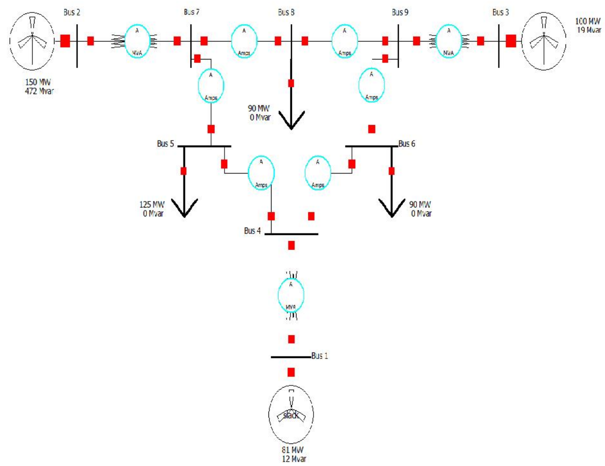

Fig 2.1. Simulation of Wind farm integrated smart grid (Blackout/without capacitance)

This power fig 3.1 illustrates a stable and balanced grid integrated with three wind energy sources at buses 1, 2, and 3. The wind generators supply a total of 331 MW of active power along with significant reactive power support, especially from Bus 2, which provides 472 MVar. The generated power is efficiently distributed to major load centers located at buses 5, 6, and 8, consuming 125 MW, 90 MW, and 90 MW respectively. Power flows through a well-connected network of buses and transmission lines, with directional arrows indicating smooth and stable operation.

2.2 Case 2= System Diagram (Without capacitance)

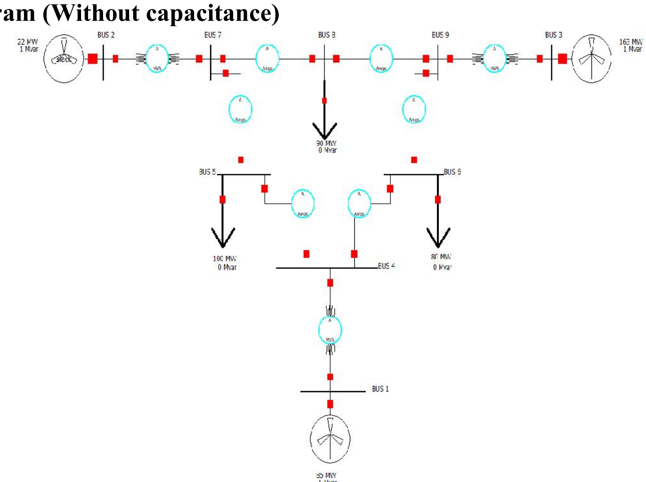

Fig 2.2. Simulation of Wind farm integrated smart grid (Blackout/without capacitance)

The fig 2.2 shown represents a 9-bus power system designed for analysing power flow and evaluating system reliability using simulation tools like PowerWorld Simulator. This system consists of three main components: power generators, electrical loads, and interconnected transmission lines. Three generators are installed at Bus 1, Bus 2, and Bus 3,

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supplying 85 MW, 22 MW, and 163 MW respectively, each contributing 1 Mvar of reactive power. The total power generated is 270 MW, which precisely matches the total load demand of the system.

2.3 Case 3= System Diagram (With Capacitance)

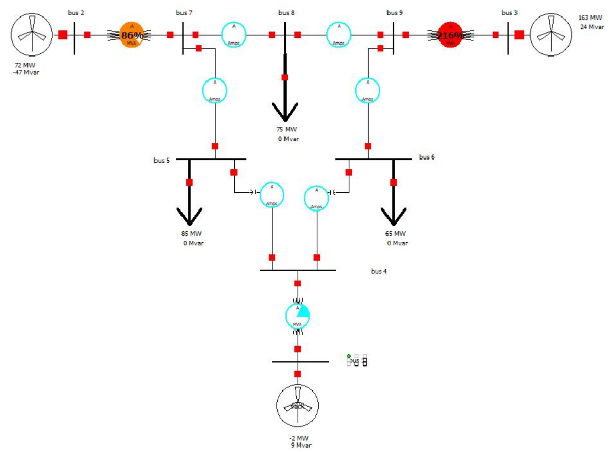

Fig 2.3 Simulation of Wind farm integrated smart grid (With capacitance)

The depicted 9-bus power system represents a realistic interconnected network used for transmission system planning, reliability analysis, and stability studies. The system includes three generators, three main load centers, and several interconnected transmission lines across nine buses. Generation is located at Bus 1, Bus 2, and Bus 3, while major load centers are placed at Bus 4 (indirectly), Bus 5, Bus 6, and Bus 8. The power system topology is meshed, allowing power to flow in multiple directions and providing redundancy. However, the diagram reveals signs of system stress, particularly overloading at certain key branches.

III. RESULTS AND DISCUSSION

The simulation of wind energy integration using the IEEE 9-bus test system in PowerWorld Simulator revealed important insights into grid performance under variable wind generation. Key reliability indices SAIDI (System Average Interruption Duration Index), SAIFI (System Average Interruption Frequency Index), CAIDI (Customer Average Interruption Duration Index), and ASAI (Average Service Availability Index) were calculated for systems with and without reactive power support (capacitance).

Result of simulation

1. Reliability Main Concept and Indices

SAIDI= System Average Interruption Duration Index

SAIDI = Sum of Customer Interruption Durations per reporting period / The total Number of Customers Served per reporting period

SAIFI= System Average Interruption Frequency Index

SAIFI = Total Number of Customer Interruptions per reporting period / Total Number of Customers Served per reporting period

CAIDI= Customer Average Interruption Duration Index

CAIDI = Sum of customer interruption durations per reporting period / Total number of customers interrupted per reporting period

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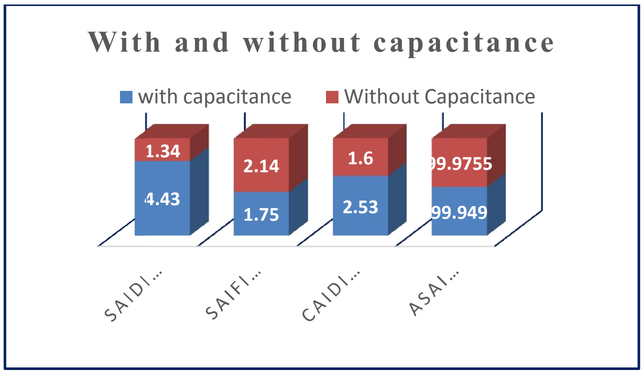
ASAI = Average Service Availability Index
ASAI= Customer-hours of service availability / Customer-hours demanded

2. Interruption Result (Without Capacitance)

Sr. No	Index	Without Capacitance	With Capacitance
1	SAIDI	4.43	1.34
2	SAIFI	1.75	2.14
3	CAIDI	2.53	1.60
4	ASAI	0.99949	0.999755

Table 1: Without and With Capacitance values



Graph 1: Interruption Result (Without and With Capacitance)

IV. CONCLUSION

This study effectively demonstrates the impact of integrating wind energy farms into conventional power grids using PowerWorld Simulator. The simulation results highlight both the opportunities and challenges associated with wind power integration. Key reliability indices such as SAIDI, SAIFI, CAIDI, and ASAI were evaluated under various conditions to assess grid performance with and without wind energy inclusion. It was found that while wind energy significantly contributes to sustainable and cleaner power generation, its inherent variability introduces potential risks such as voltage instability, frequency deviations, and line overloading. However, the simulation also revealed that with appropriate mitigation strategies including the use of compensating capacitors, battery storage systems, and reactive power compensation the reliability and stability of the grid can be substantially improved. Overall, the project confirms that strategic planning, proper system design, and real-time simulation tools are crucial for ensuring reliable grid operation in the era of renewable energy. The findings serve as a valuable resource for grid planners and engineers aiming to integrate wind energy while maintaining robust and stable power system performance.

REFERENCES

[1]. Ghania, S. M., Mahmoud, K., & Hashmi, A. M. (n.d.). A reliability study of renewable energy resources and their integration with utility grids.
[2]. V. Vivek and C. P. Das, "Reliability Analysis using Renewable Energy sources" International Journal of Mechanical and Industrial Engineering, Vol. 1, no. 1, pp. 47–50, Jul. 2011, https://doi.org/10.47893/IJMIE.2011.1011.
[3]. A.M. Huseynov and O.B. Azdkhanov, "Development of Intellectual Information measuring system for Azerbaijan Power system regain reliability control," in morden electric power system, Wroclaw, Poland, Sep.2019, PP. 1-3.
[4]. M.Rausand and A. Hoyland, system reliability theory: Model Statical method, and applications, 2nd editions. Hoboken, NJ, USA: John Wiley & Sons, 2003.

[5]. M.Xie, Y. S. Dai and K.L. Poh, computing system reliability models and analysis. New York, NY, USA: Kluwer Academic Publisher,2004.

[6]. J. N. Sheen, Applying Fuzzy Engineering Economics to Evaluate Project Investment Feasibility of Wind Generation, WSEAS TRANSACTIONS on SYSTEMS, Issue 4, Volume 8, April 2009.

[7]. T. Gjengedal, Large Scale Integration of Wind Power and the Impact on Power Systems, 2nd WSEAS/IASME International Conference on Renewable Energy Sources, Corfu, Greece, 26. 10.2008.

[8]. T. Ackermann, Wind Power in Power Systems, John Wiley & Sons, USA, 2005. [4] M. Stiebler, Wind Energy Systems for Electric Power Generation, Springer, Berlin, Germany, 2008.

[9]. J. Smith, Reliability, Maintainability and Risk: Practical Methods for Engineers including Reliability Centred Maintenance and Safety-Related Systems, 8th ed. Butterworth-Heinemann, 2011.

[10]. R. N. Allan and R. Billinton, Reliability Evaluation of Power Systems, 2nd ed. New York, NY, USA: Springer, 2013.