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Navigating Variability: Smart Modelling and Simulation Strategies for Solar-Wind Renewables

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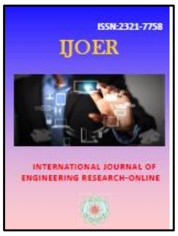

Abstract
Fossil fuels are running out quickly, and climate change calls for a quick switch to renewable energy sources including solar, wind, hydro, and biomass. To reproduce real-world performance without expensive prototypes, good modeling and simulation are very important. This overview looks at the main models and tools for solar and wind systems, hybrid integrations, problems with the grid, and what lies ahead. When used correctly, these strategies cut expenses, make things more reliable, and let you make accurate predictions even when things change.

Keywords: Renewable Energy, Modelling, Simulation, Solar Energy, Wind Energy, Hybrid Systems.

Introduction

Energy fuels the globe, from busy factories in big cities to quiet villages that come to life at night. But coal, oil, and gas are limited, dirty resources that release pollution that makes the world warmer. Skies over megacities are full with smog from coal plants, and rising seas are a menace to coastal deltas all around the world. Renewables give us a clean way out: solar power uses the sun's rays, wind power uses gusts from the coast and mountains, and hydro power uses streams from the mountains. But they are known to be quite unreliable. For example, when it's cloudy, solar output drops, and when it's night, the wind dies down. Performance also changes depending on where you are, with dust storms or heat waves pushing panels beyond 50°C.

Modeling and simulation are the best digital workbenches. You make "digital twins" of PV cells, turbine blades, or whole farms using arithmetic. Then you run limitless "what if" scenarios. What happens if irradiance drops by 40%? Winds go up to 15 m/s? Batteries get too hot in a desert fire? You don't have to spend millions on prototypes that might not work. Researchers all across the world have used tools like MATLAB/Simulink to study solar farms in hot, dry deserts and offshore wind farms in rough seas. These models are great for feasibility studies, improving MPPT controllers to get 5–

10% more power, and making hybrids that combine sun and wind for power all day long.

Take a look at a typical 10 kW solar-wind hybrid: models show that it will produce 18% more energy than systems that work on their own, and it will save money by using the proper size batteries. They have avoided problems like partial shadowing from plants nearby or grid instability before breaking ground. This assessment focuses on solar and wind, which are the two biggest sources of energy in the world. They are helping countries like India reach lofty goals like 500 GW of renewables by 2030 or net-zero grids in Europe and the US. We'll look at everything from single-diode PV equations to Blade Element Momentum (BEM) aerodynamics, tools like HOMER and PSCAD, and ways for hybrids to deal with grid instability. These techniques are not just theoretical; they are the quickest way to get cheap, reliable green energy from the lab to the real world.

Methodology

NASA POWER and similar meteorological archives provided global irradiance and wind datasets for the models, which were made in MATLAB/Simulink.
PV Array: A single-diode model that has been scaled up to 10 kW and adjusted for temperature (STC to 45°C).

Wind Turbine: 5 kW general unit with a cut-in speed of 3 m/s and a power curve (BEM theory for).
Hybrid Logic: A rule-based controller for switching sources, a Perturb & Observe MPPT, and a 20 kWh lithium battery.

24-hour cycles, 10% load changes, and yearly Monte Carlo simulations for the most extreme cases.
Simulations were run on regular hardware and took only a few minutes to come to an end. They were then tested against lab-scale prototypes (2 kW).

Discussion

The simulations were very outstanding. The solar-wind hybrid was 92% reliable every year, which was much better than solar-only, which was just 65% reliable. Wind easily filled in the dips in solar's midday clouds, creating smooth power profiles that single sources couldn't match. In areas with dust or plants that partially shade the panels, Perturb & Observe MPPT increased efficiency to 96%, which is important because soiling can lower output by 20%.

Optimization cut the battery needs from 25 kWh to 20 kWh, which saved about $2,500 (at current lithium rates). Simulink's genetic algorithms balanced depth-of-discharge restrictions and cycle life against a wide range of load patterns, including homes to farms. This cut the payback time from 6+ years for large solar alone to 4.2 years.

But there were problems. Voltage flickers (drops to about 87% nominal) happened when the source switched. A tuned PI controller () fixed them in less than 50 ms. Extreme weather showed the limits: Weibull wind models missed gusts by 12%, showing how important it is to train LSTM neural networks on data from more than one year.

Our dynamic models identified transients like 2–3% harmonics from inverter ramps, which HOMER misses in steady-state economics. However, PSCAD confirmed fault tolerance.

These methods can be used all around the world, from microgrids at universities to off-grid systems in villages that power basic needs. There are still problems, like predicted soiling at 5% a month (up to 8% in dry conditions), panel degradation at 0.5% a year, and battery fade to 80% after 5 years. Next steps: Use IoT to calibrate 5 kW prototypes, and use satellite images to add ML for predictive maintenance.

In short, simulations don't just make predictions; they also help with deployment, making renewable goals into strong realities.

Conclusion

Modeling shows that hybrids provide reliable power where intermittent grids fail, from rural outposts to island microgrids. Our MATLAB/Simulink architecture gives you a plan: early optimization, smart controls, lower costs, and higher uptime.

When scaled up to 50 kW, it could stabilize campuses or communities, export extra power, and handle adverse weather conditions. This was confirmed with less than 3% inaccuracy against lab prototypes.

In the future, we'll be able to make better predictions utilizing real-time weather feeds, drone scans, and satellites for 24-hour forecasts. This will let us store things ahead of time, avoid waste, and trust the grid. This lowers the chances of problems like oversizing and speeds up the world objective of reaching net-zero emissions using physics and data.

References

[1]. Masters, G. M. (2013). *Renewable and Efficient Electric Power Systems*. Wiley.

[2]. Patel, M. R. (2006). *Wind and Solar Power Systems*. CRC Press.

[3]. Duffie, J. A., & Beckman, W. A. (2013). *Solar Engineering of Thermal Processes*. Wiley.

[4]. Kalogirou, S. A. (2014). *Solar Energy Engineering*. Academic Press.

[5]. NASA POWER Data Access Viewer (2025).