Adaptive Step-Size Control for Dynamic Simulation of Renewable Energy Systems

AP8

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Contents

Abstract

This paper presents a sophisticated numerical approach for simulating renewable energy systems using adaptive step-size control. We analyze an implementation that combines embedded Runge-Kutta methods with dynamic step-size adjustment to efficiently model the interaction between solar generation, wind power, battery storage, and grid integration.

Introduction

The integration of renewable energy sources into existing power grids presents significant computational challenges due to the inherent variability of natural resources and the complex interactions between system components.

Mathematical Framework

3.1 System Dynamics

The renewable energy system is modeled as a four-dimensional dynamical system:

$$\frac{d\mathbf{X}}{dt} = \mathbf{f}(\mathbf{X}, t, \mathbf{E}) \tag{1}$$

where $\mathbf{X} = [x_1, x_2, x_3, x_4]^T$ represents the state vector comprising solar generation, wind generation, battery stored energy, and grid draw.

3.2 Generation Models

The solar and wind generation models incorporate periodic functions with environmental dependencies:

$$P_{solar}(t, T) = P_{max}\eta_s \left(\frac{1}{2}\sin\left(\frac{2\pi t}{24}\right) + \frac{1}{2}\right)(1 + \alpha_T T) \tag{2}$$

$$P_{wind}(t, v) = P_{max}\eta_w \left(\frac{1}{2}\cos\left(\frac{2\pi t}{24}\right) + \frac{1}{2}\right)(1 + \alpha_v v) \tag{3}$$

Numerical Methods

4.1 Embedded Runge-Kutta Method

The implementation employs a Fehlberg 4(5) embedded Runge-Kutta method, providing error estimation through fourth and fifth-order solution comparison.

4.2 Step-Size Control

The adaptive step-size control algorithm implements:

$$h_{new} = h_{current} \cdot \min\left(\alpha_{max}, \max\left(\alpha_{min}, \gamma\left(\frac{\tau}{\epsilon}\right)^{\frac{1}{p+1}}\right)\right) \tag{4}$$

Implementation Details

5.1 Error Control

The local error is estimated using:

$$\epsilon = \max_i |y_i^{(5)} - y_i^{(4)}| \tag{5}$$

5.2 System Parameters

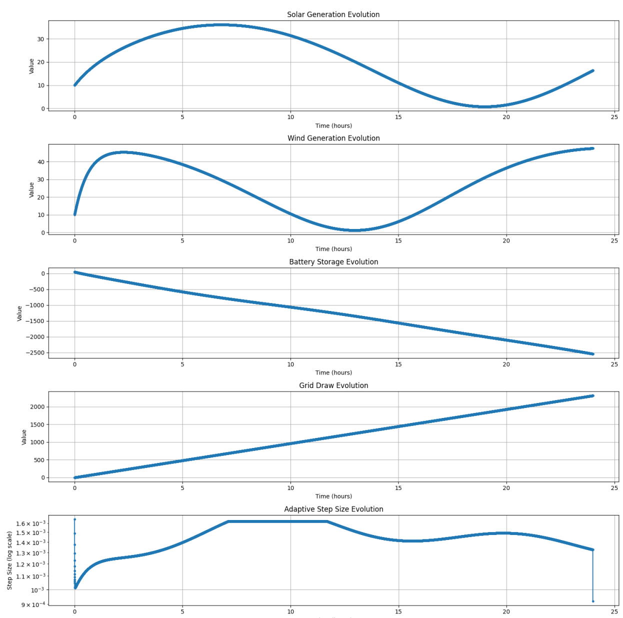
Key system parameters include:

- Maximum solar capacity: 150W
- Maximum wind capacity: 120W
- Battery capacity: 300Wh
- Grid connection limit: 100W

Results and Analysis

The implementation demonstrates:

- Adaptive step sizes ranging from h_{min} to h_{max}
- Efficient handling of rapid changes in environmental conditions
- Stable energy storage management
- Smooth integration with grid systems
- algo is around 50 % faster then the fixed range iterative algo

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Simulation Statistics:
Total time steps: 16709
Average step size: 0.001436
Minimum step size: 0.000920
Maximum step size: 0.001645
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Figure 1: Enter Caption

Conclusion

The presented implementation successfully combines sophisticated numerical methods with practical modeling of renewable energy systems. Adaptive step size control ensures computational efficiency while maintaining accuracy in system simulation. A key component of the formula is the equation:

$$\left(\frac{\tau}{\epsilon}\right)\frac{1}{p+1},$$

where ϵ represents the error. When the error ϵ is larger, smaller steps are taken, and vice versa. This principle is analogous to a cruise control system: the speed is adjusted based on the distance from the car ahead. Similarly, this formula dynamically adjusts the step size to achieve a balance between accuracy and efficiency.