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# The Energy Stream Analysis Method for Integrated Energy Systems

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**Abstract:** This research presents a novel method for analyzing energy flows in integrated energy systems (IES) using a likelihood-based approach. The proposed method incorporates the concept of Probabilistic Load Flow (PLF) from power systems into the analysis of IES likelihood energy flow points. By assessing the qualitative impact of uncertainties on the probability distribution of the state quantities in integrated energy systems encompassing electricity, air, and heat, this method enables a comprehensive evaluation of the load and output of wind electric fields. The outcomes of this research contribute to establishing a solid foundation for real-time network planning, steady-state analysis, optimized operation, control, and safety analysis of integrated energy systems.

***Keywords:*** *Integrated energy system, Likelihood analysis, Energy flow, Probabilistic Load Flow, Qualitative assessment, Probability distribution, Wind electric field, Network planning, Steady-state analysis, Optimized operation, Control, Safety analysis.*

## Introduction

The development of integrated energy systems (IES) has gained significant attention in recent years as a means to achieve a more sustainable and efficient energy infrastructure. These systems integrate multiple energy sources, such as electricity, air, and heat, to meet the diverse energy demands of various sectors. However, the successful integration and operation of IES pose several challenges, particularly in dealing with uncertainties and variability associated with renewable energy sources. To ensure the reliable and optimal operation of IES, it is crucial to understand the probabilistic behavior of energy flows within the system. Traditionally, power systems have relied on the Probabilistic Load Flow (PLF) method to assess the probabilistic behavior of electricity networks. However, the application of PLF to the analysis of IES is not straightforward due to the presence of multiple energy carriers and the interconnected nature of these systems. This research aims to bridge the gap between power systems' PLF and IES analysis by proposing an integrated energy system likelihood energy stream analysis method. The primary objective is to incorporate the concept of PLF into the The proposed method holds great promise in enhancing the planning, operation, and control of IES in real-time

analysis of likelihood energy flow points within IES. By doing so, this research seeks to enable a qualitative assessment of the probability distribution of state quantities in IES, including the load and output of wind electric fields. The figure (**Fig.1**) shows a synopsis of sustainable energy development.[2]

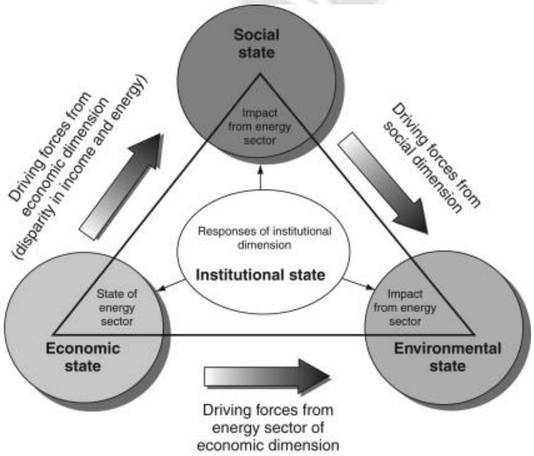


*Fig.1:Synopsis of Sustainable Energy Development*

scenarios. It offers a comprehensive framework to evaluate the uncertainties and variability associated with renewable energy sources, enabling more accurate estimation of energy flows and system performance. Moreover, the outcomes of this research will provide a solid foundation for various aspects of IES management, including network planning, steady-state analysis, optimized operation, control strategies, and safety analysis. By addressing the challenges related to probabilistic analysis in IES, this research contributes to the overall advancement of integrated energy systems and their integration into the existing energy infrastructure. The findings will guide decision-makers, energy planners, and system operators in making informed decisions for the effective integration and utilization of diverse energy sources, leading to a more sustainable and resilient energy future.

**Related Work**

Integrated Energy Systems (IES) have emerged as a crucial component in the transformation of energy resource systems towards economic efficiency, environmental protection, and sustainability. Among various primary energy sources, natural gas has gained prominence due to its abundant reserves, economic viability, and environmental benefits.[1] The increasing share of combined cycle gas turbine (CCGT) generation in the overall energy mix further emphasizes the need to study the interdependencies between the power system (Electric Power System, EPS) and natural gas system (Natural Gas System, NGS). Furthermore, the integration of multiple energy resources, including electricity and natural gas, through energy hubs (Energy Hubs, EB) is expected to foster deeper coupling between EPS and NGS.[2] The formation of Integrated Energy Systems (IES), which combine EPS, NGS, and potentially other energy systems, represents a crucial path towards achieving a more efficient, environmentally friendly, and economically viable energy resource system transformation. Existing literature on IES research can be broadly categorized into several aspects: 1) IES modeling and energy flow analysis, 2) IES coordinated planning, 3) IES coordinated operations, 4) IES market regulations and game theory, and 5) IES fail-safe analyses.[3] Notably, IES involves a significant number of uncertain factors, including fluctuations in electric and gas loads, intermittent renewable energy sources, generator and circuit failures, market uncertainties, and more. Analyzing the impact of these uncertainties on IES planning, optimization, market dynamics, and reliability is crucial. However, traditional deterministic analysis methods are inadequate to meet the demands of IES analysis due to their inability to handle uncertainties effectively.

In EPS, the probabilistic nature of input stochastic variables can be addressed through Probabilistic Load Flow (PLF) methods, which lay a solid foundation for quantitative analysis and assessment of uncertain factors in EPS.[4] Various PLF solution approaches, such as simulation, analytic methods, and approximation methods, have been developed. Monte Carlo simulation is commonly used to evaluate the accuracy of PLF methods, while cumulates method offers high computational efficiency in analytic approaches.[5] Approximation methods, such as point estimations, provide advantages in handling input variable correlations without requiring precise knowledge of their functional relationships. While Probabilistic Load Flow has been extensively studied in EPS, research specifically focused on the probability analysis of energy flows in IES, known as probability tide analysis, is relatively scarce both domestically and internationally.

**Research Objective**

The objective of this research is to develop an integrated energy system likelihood energy stream analysis method that integrates the concept of Probabilistic Load Flow into the analysis of IES likelihood energy flow points. This method aims to assess the qualitative impact of uncertainties on the probability distribution of state quantities in integrated energy systems, specifically focusing on the load and output of wind electric fields. The research aims to provide a foundation for real-time network planning, steady-state analysis, optimized operation, control, and safety analysis of integrated energy systems.

**Method-Analysis of the Integrated Energy System**

This research presents a detailed analysis of a novel method called the Integrated Energy System Likelihood Energy Stream Analysis Method. The method is designed to assess the probability distribution of energy flows within integrated energy systems (IES). The research focuses on the following steps involved in the method: Power System Mesomeric State Modeling: The first step of the method involves modeling the mesomeric state of the power system (Electric Power System, EPS). For each branch road (ij) that transmits electricity within the EPS, the active power (Pij) and reactive power (Qij) are determined. The equations for calculating Pij and Qij take into account various parameters such as conductance (gij), susceptance (bij), node voltage amplitude (V), and phase angle (θ). The conductance and susceptance values are derived from the equivalent circuit of the branch road, while gsi and bsi represent the conductance and susceptance on the i-side of the node, respectively.

Qualitative Assessment of Uncertain Factors: In integrated energy systems, various uncertain factors significantly impact the system's performance. These factors include load fluctuations, intermittent renewable energy sources, generator and circuit failures, and market uncertainties. The method incorporates a qualitative assessment of these uncertain factors to analyze their influence on the integrated energy system. By considering the probabilistic nature of these factors, the method enables a more comprehensive evaluation of the system's performance and reliability.

Probability Distribution Analysis: The likelihood energy stream analysis method focuses on evaluating the probability distribution of energy flows within the integrated energy system. It takes into account the uncertain factors identified in the previous step and analyzes their impact on the system's overall performance. By considering the probabilistic behavior of energy flows, the method provides insights into the system's resilience, stability, and efficiency. This analysis serves as a foundation for further network planning, steady-state analysis, optimized operation, control strategies, and safety analysis of the integrated energy system.

Application in Real-time Scenarios: The proposed method is designed to be applicable in real-time scenarios, allowing for dynamic monitoring and analysis of the integrated energy system. By continuously assessing the likelihood energy stream and updating the probability distribution based on real-time data, the method enables timely decision-making for system operators and energy planners. This real-time application enhances the system's flexibility, adaptability, and resilience in response to changing conditions and uncertainties. The diagram below (**Fig.2**) shows the energy management in microgrids with renewable energy sources.

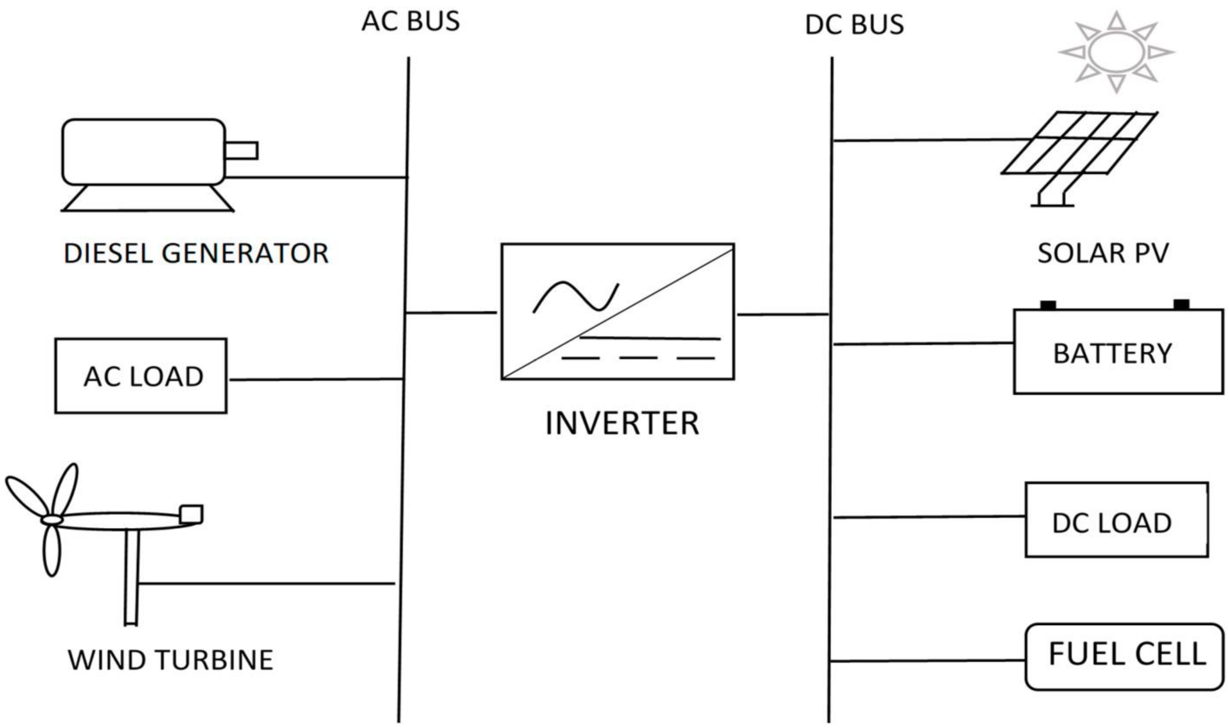


*Fig. 2: Energy Management in Microgrids with Renewable Energy Sources*

Overall, this research contributes to the field of integrated energy systems by introducing a novel method for likelihood energy stream analysis. By integrating probabilistic analysis techniques from power systems and addressing the unique challenges of IES, the method provides valuable insights into the behavior and performance of integrated energy systems. The outcomes of this research have implications for network planning, steady-state analysis, optimized operation, control strategies, safety analysis, and the overall transformation towards more efficient, sustainable, and resilient energy systems.

## Conclusion

In conclusion, this research has presented a comprehensive analysis of the Integrated Energy System Likelihood Energy Stream Analysis Method. The method offers a novel approach to assessing the probability distribution of energy flows within integrated energy systems (IES), taking into account the uncertainties and fluctuations associated with various factors. By incorporating power system mesomeric state modeling, the method captures the intricacies of energy flow within the power system (EPS). The qualitative assessment of uncertain factors, including load fluctuations, intermittent renewable energy sources, and market uncertainties, provides valuable insights into the system's performance and reliability.

The probability distribution analysis conducted in this research enhances our understanding of the probabilistic behavior of energy flows in IES. By considering the probabilistic nature of these energy flows, decision-makers and energy planners gain a more accurate understanding of the system's resilience, stability, and efficiency. This analysis serves as a foundation for network planning, steady-state analysis, optimized operation, control strategies, and safety analysis in real-time scenarios. The application of the likelihood energy stream analysis method in real-time scenarios enables dynamic monitoring and decision-making for system operators and energy planners. By continuously assessing the likelihood energy stream and updating the probability distribution based on real-time data, the method enhances the flexibility, adaptability, and resilience of the integrated energy system. The outcomes of this research contribute to the advancement of integrated energy systems by providing a robust and effective analysis method for probabilistic assessment. The method fills a gap in existing literature, where the impact analysis of uncertain factors on IES has received less attention compared to electric power networks. The research lays the groundwork for further exploration and implementation of probabilistic analysis techniques in IES, guiding future network planning, steady-state analysis, optimized operation, control strategies, and safety analysis. Overall, the Integrated Energy System Likelihood Energy Stream Analysis Method presented in this research offers a valuable tool for understanding and managing uncertainties in IES. By considering the probabilistic behavior of energy flows, the method supports the transformation towards more efficient, sustainable, and resilient energy systems. The findings of this research have far-reaching implications for energy planners, system operators, and decision-makers involved in the integration and utilization of diverse energy sources within integrated energy systems.

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