Abstract

Rapid integration of renewable energy sources (RES) into modern power grids introduces challenges such as intermittency, demand-supply imbalances, and grid instability. Artificial Intelligence (AI) has emerged as a transformative tool to address these issues through advanced forecasting, real-time control, and optimization. This 2-part review article aims to guide researchers and practitioners toward leveraging AI for a sustainable energy transition. In part 1, key AI techniques, including machine learning (ML), deep learning (DL), and reinforcement learning (RL), applied in smart grids for RES management were reviewed. We also analyzed applications such as demand-side management, fault detection, energy storage optimization, and peer-to-peer (P2P) trading. Here, in part 2, challenges like data privacy, model interpretability, and scalability are discussed, along with future trends like edge AI and quantum computing as well as future directions.

Motivation

The motivation for this review, as mentioned also in part 1, stems from the urgent need to address three critical challenges in modern power systems: (1) intermittency management which is solar and wind generation are inherently variable, requiring advanced forecasting and balancing mechanisms, (2) grid stability where high RES penetration can lead to voltage fluctuations and frequency instability, and (3) demand-supply matching which is real-time alignment of generation with consumption becomes increasingly complex with decentralized resources.

This paper aims to provide a comprehensive review of AI applications in smart grids for renewable energy management. Specifically, in part 1, we categorized and explained key AI techniques and applications being used in smart grid operations, and now in part 2, we identify current challenges and limitations in AI deployment for grid management, and outline promising future research directions in this area. The scope of this review encompasses time horizons from very short-term (millisecond-level control) to long-term (planning and investment decisions), spatial scales from individual DERs to entire transmission networks, and all major AI approaches currently being applied in power systems. Fig. 1 illustrates a graphical summary of AI challenges and future directions in smart grids for renewable energy management.

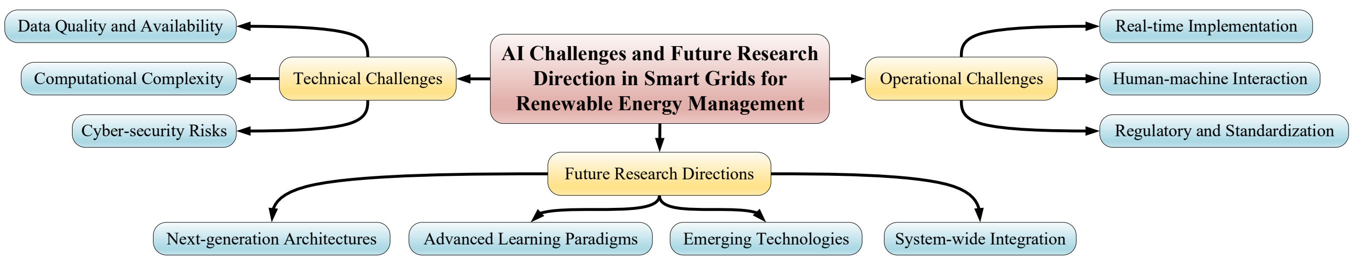

Fig. 1. Artificial intelligence challenges and future reserach directions in smart grids for renewable energy management.