Artificial Intelligence Based Optimization and Control of Solar Energy Harvesting, Utilization, and Storage Systems

Introduction

The increasing global demand for sustainable energy sources has made solar energy one of the most promising renewable energy options. Photovoltaic (PV) systems are widely adopted for power generation due to their modularity, scalability, and low maintenance requirements. However, the efficiency and stability of PV systems are affected by dynamic environmental conditions, load variations, and nonlinear system characteristics. Effective control and management of solar energy harvesting, utilization, and storage are therefore critical to ensure reliable and continuous power supply.

Traditional control and optimization approaches such as perturb and observe or incremental conductance methods exhibit limitations under rapidly changing conditions. In contrast, Artificial Intelligence (AI) techniques provide adaptive and data driven capabilities for real time optimization of energy systems. Deep learning based approaches can model complex nonlinear relationships in PV systems, predict optimal operating points, and manage energy flow intelligently. This research aims to develop an integrated AI based control framework for enhancing solar energy harvesting, utilization, and storage efficiency through intelligent decision making.

Objectives

- To develop deep learning based predictive models for maximum power extraction from photovoltaic systems under varying solar and load conditions.
- To design intelligent control algorithms for efficient power conversion and distribution within solar energy systems.
- To implement AI based strategies for optimal energy storage management including state of charge estimation and charge–discharge control.
- To validate the proposed AI framework through simulation and experimental studies for improved system efficiency, reliability, and adaptability.

Methodology

System Modelling and Simulation

The photovoltaic generation system including PV array, DC–DC converter, inverter, and energy storage components will be modelled using MATLAB/Simulink. Electrical parameters such as current–voltage characteristics, converter switching behavior, and storage dynamics will be represented to capture realistic system performance under different irradiance and temperature profiles.

AI Based Solar Energy Harvesting

Deep learning models will be developed to predict the optimal operating point of the PV system. The AI controller will continuously learn the relationship between environmental inputs and electrical outputs to determine the converter duty ratio that maximizes power generation. The developed model will replace conventional maximum power point tracking algorithms and enable adaptive operation under nonstationary conditions.

Intelligent Energy Utilization

AI algorithms will be employed to manage the distribution of generated energy among connected loads and storage units. The system will utilize forecasted generation and consumption data to schedule power flow efficiently. Reinforcement learning techniques may be explored to achieve real time decision making for load prioritization and grid support.

Energy Storage Management

Machine learning and deep learning models will be developed to estimate the state of charge and state of health of the battery storage system. Adaptive control strategies will be implemented to regulate charging and discharging processes, extending battery life and ensuring energy availability during low generation periods.

Experimental Validation

A laboratory prototype consisting of PV modules, converters, inverter, and battery storage will be developed. The AI based control strategies will be implemented on a digital signal processor or microcontroller platform. System performance will be evaluated using parameters such as energy conversion efficiency, power loss reduction, voltage regulation, and storage utilization.

Expected Outcomes

- Development of a deep learning based intelligent control framework for solar energy systems.
- Improvement in overall energy harvesting and conversion efficiency under dynamic environmental conditions.
- Enhanced storage management with accurate state estimation and extended operational life.
- Establishment of a reliable and self adaptive energy system suitable for smart grids and standalone renewable applications.

Significance

The proposed research contributes to the advancement of intelligent control in renewable energy systems by integrating artificial intelligence with electrical power conversion and management. The outcomes of this work will support the realization of high efficiency, reliable, and autonomous solar energy systems. The developed AI framework can be further extended to hybrid renewable systems, contributing to sustainable energy development and global decarbonization initiatives.