AI Applications in Load Scheduling and Energy Management Systems

7th SEM

Introduction to Smart Grids and AI

What is a Smart Grid?

- **Definition:** An electricity network based on digital technology that uses two-way communication to supply electricity efficiently
- **Key Features:**
  - Real-time monitoring and control
  - Bidirectional power flow
  - Integration of renewable energy sources
  - Advanced metering infrastructure
  - Demand response capabilities

Why AI in Power Systems?

- **Traditional Challenges:**
  - Increasing energy demand
  - Integration of renewable sources
  - Grid stability and reliability issues
  - Complex optimization problems
  - Real-time decision making requirements

Fundamentals of Load Scheduling

What is Load Scheduling?

- **Definition:** The process of optimally distributing electrical load across time and resources to minimize costs and maximize efficiency
- **Objectives:**
  - Minimize total operating costs
  - Reduce peak demand
  - Improve voltage regulation
  - Balance supply and demand
  - Integrate renewable energy sources

Types of Load Scheduling:

- **Unit Commitment (UC):** Determining which generators to turn ON/OFF
- **Economic Dispatch:** Allocating power output among committed units
- **Demand Response:** Managing customer electricity usage

AI Techniques in Power Systems

- **Machine Learning Approaches:**

1. Supervised Learning

- **Applications:** Load forecasting, demand prediction
- **Algorithms:** Neural networks, SVM, decision trees
- **Example:** Predicting next-day electricity demand using historical data

AI Techniques in Power Systems

2. Unsupervised Learning

- **Applications:** Pattern recognition, anomaly detection
- **Algorithms:** Clustering, PCA
- **Example:** Identifying unusual consumption patterns

3. Reinforcement Learning

- **Applications:** Real-time control, optimization
- **Algorithms:** Q-learning, Deep Q-Networks (DQN)
- **Example:** Dynamic voltage control in microgrids

Load Forecasting Using Machine Learning

Short-Term Load Forecasting (STLF)

- **Time Horizon:** Few hours to few days
- **Accuracy Requirements:** High (MAPE < 3%)
- **Applications:** Daily operational planning

Machine Learning Models:

Artificial Neural Networks (ANN)

- Multi-layer perceptron
- Accuracy: ~98% (MAPE: 1.975%)

Load Forecasting Using Machine Learning

Long Short-Term Memory (LSTM)

- Handles sequential data
- Superior performance for time series

Support Vector Machines (SVM)

- Good for non-linear problems
- MAPE: ~1.46%

Input Parameters:

- Historical load data
- Weather conditions (temperature, humidity)
- Day type (weekday/weekend/holiday)
- Economic indicators

Energy Management Systems (EMS)

Smart Energy Management Functions:

- **Demand Prediction:** AI-based forecasting of energy requirements
- **Optimization Control:** Minimize waste and maximize efficiency
- **Real-time Response:** Automatic adjustment to grid conditions

AI-Enhanced EMS Components:

- **Predictive Analytics:** Forecast energy demand and supply
- **Optimization Algorithms:** Genetic algorithms, PSO, ant colony
- **Real-time Control:** Adaptive control systems
- **Decision Support:** Multi-criteria optimization

Energy Management Systems (EMS)

Benefits:

- Energy cost reduction: Up to 22.96%
- Improved grid stability: 96.25%
- Reduced energy wastage: 12.96%

Demand Response Optimization

What is Demand Response?

- **Definition:** Changes in electric usage by end-use customers in response to price signals or incentive payments

AI in Demand Response:

- **Dynamic Pricing:** Real-time electricity pricing based on demand
- **Load Shifting:** Moving non-critical loads to off-peak hours
- **Peak Shaving:** Reducing maximum demand during peak periods

Demand Response Optimization

AI Algorithms Used:

- **Machine Learning:** Pattern recognition for consumer behavior
- **Reinforcement Learning:** Adaptive pricing strategies
- **Deep Learning:** Complex demand pattern analysis

Load Categories:

- **Non-curtailable:** Critical loads (hospitals, data centers)
- **Deferrable:** Flexible timing (EV charging, HVAC)
- **Curtailable:** Can be temporarily reduced (industrial processes)

Reinforcement Learning in Power System Control

RL Framework for Power Systems:

- **Agent:** Control system (EMS, voltage regulator)
- **Environment:** Power grid state
- **Actions:** Control decisions (generator output, load switching)
- **Rewards:** System performance metrics (stability, cost)

Reinforcement Learning in Power System Control

Applications:

- **Voltage Control:** Maintaining voltage within acceptable limits
- **Frequency Regulation:** Load-frequency control
- **Power Flow Optimization:** Minimizing transmission losses
- **Multi-Agent Reinforcement Learning (MARL):**
- **Decentralized Control:** Multiple agents controlling different grid components
- **Coordination:** Agents learn to cooperate for optimal system performance
- **Scalability:** Suitable for large, complex power systems

Microgrid Energy Management

Microgrid Components:

- **Distributed Generation (DG):** Solar PV, wind, fuel cells
- **Energy Storage Systems (ESS):** Batteries, supercapacitors
- **Smart Loads:** Controllable appliances and systems
- **Energy Management System:** Central controller

AI Applications in Microgrids:

- **Optimal Power Scheduling:** Minimize total operating cost
- **Renewable Integration:** Manage uncertainty in renewable generation
- **Grid Synchronization:** Seamless transition between grid-connected and islanded modes

Microgrid Energy Management

Optimization Objectives:

- Minimize total operating cost (TOC)
- Maximize voltage regulation (VR)
- Reduce power losses
- Improve system reliability

Deep Learning Applications

Advanced Neural Network Architectures:

1. Convolutional Neural Networks (CNN)

- **Application:** Energy demand pattern recognition
- **Advantage:** Spatial feature extraction

2. Recurrent Neural Networks (RNN/LSTM)

- **Application:** Time series forecasting
- **Advantage:** Sequential data handling

3. Deep Reinforcement Learning (DRL)

- **Application:** Real-time grid control
- **Advantage:** Learning optimal policies through interaction

Deep Learning Applications

ORA-DL Framework:

- **Energy Demand Prediction Accuracy:** 93.38%
- **Grid Stability Improvement:** 96.25%
- **Energy Wastage Reduction:** 12.96%
- **Resource Distribution Efficiency:** 15.22% improvement

IoT Integration in Energy Management

IoT-Enabled Smart Grid:

- **Smart Meters:** Real-time energy consumption monitoring
- **Sensors:** Temperature, voltage, current, frequency measurements
- **Communication Networks:** Ethernet TCP/IP, wireless protocols
- **Edge Computing:** Local data processing for faster response

Benefits of IoT Integration:

- **Real-time Monitoring:** Continuous system observation
- **Predictive Maintenance:** Early fault detection
- **Enhanced Security:** Distributed sensing for anomaly detection
- **Improved Efficiency:** Optimized resource allocation

IoT Integration in Energy Management

Challenges:

- **Data Security:** Cybersecurity threats
- **Communication Latency:** Real-time requirements
- **Scalability:** Managing large number of devices
- **Interoperability:** Standard protocols and interfaces