INTELLIGENT ENERGY MANAGEMENT SYSTEM FOR OPTIMIZING RENEWABLE ENERGY IN SMART GRIDS WITH MATLAB

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Abstract: In this study, an Intelligent Energy Management System (IEMS) for smart grid applications, is modelled and simulated using MATLAB. The proposed system is meant to maximize energy flow, decrease grid dependency, and improve operational efficiency with mainly focusing on solar and wind energy. During a 24-hour period, the simulations focus on how, load demand, battery storage levels and renewable energy generation connect together. The result then obtain from it shows, increasing use of renewable energy sources, lowering operational costs, and offering beneficial ideas for grid stability, MATLAB-based IEMS model can prove to be very helpful in attaining the goal of a "Sustainable Energy Transition".

1. INTRODUCTION

The rapid development of renewable energy sources, increasing energy demands, and an increasing focus on sustainability are all resulting in a big change in the global energy sector. The centralized power generation and unidirectional power flows which are the basis of traditional power grids are becoming very less and unable to fulfil today's requirements for energy sustainability, efficiency, and flexibility. One of the way to solve these problem, is by the use of smart grids which mainly uses digital technology to observe, communicate, and control energy production, distribution and consumption. To create a responsive, easy to change and effective energy management infrastructure that allows the integration of renewable energy sources like solar and wind power in a more accurate way, grids use a network of sensors, advanced networking protocols and data analytics.

In order to maximize energy flow and consumption of energy across the grid, the Intelligent Energy Management System (IEMS) becomes one of the main components of a smart grid. In order to maintain an effective balance between energy supply and demand while reducing waste and ensuring grid stability, IEMS uses demand response technique, real-time monitoring and predictive analytics (Zhu et al.,2017). There are particular challenges in integrating renewable energy sources into the grid particularly, because energy generated by sun and wind is not predictable and variable. According to many previous studies on energy management in distributed generating systems, the IEMS can also predict future patterns for consumption and production of energy by integrating predictive algorithms that allows grid operators to make data-driven decisions and optimize energy distribution (Mishra et al., 2018).

The ability of MATLAB to handle complex calculations, data analysis, and visualization has made it an effective tool for modelling, simulation, and optimizing energy management systems in smart grids. Engineers and researchers model grid components, simulate energy flows, and examine the dynamic responses of the grid in various supply and demand situations using MATLAB's Simulink and Simscape toolboxes (Chen & Wang, 2019). MATLAB-based simulation is an affordable and effective technique because of which, it is especially helpful in developing and testing IEMS algorithms under different conditions without the need for real models. Also, MATLAB allows hybrid modelling approaches that improves the precision and relevance of smart grid simulations by enhancing accuracy and also it allows capability for interaction with various simulation tools (Ahmed & Kumar, 2020).

In this study, Intelligent Energy Management System model suitable for smart grid applications is designed and evaluated using MATLAB. With the goal to improve grid stability and efficiency, this simulation and modelling method will focus on combined demand response strategies, real-time monitoring, and predictive algorithms. This study provides a useful structure to examine IEMS functionality under different grid settings by applying MATLAB. Thus, the structure can serve as a basis for future real-world implementations.

By showing the way in which modelling and simulation can help in the development of optimal smart grid solutions, we aim to advance the subject of intelligent energy management. This research is a step closer to creating intelligent systems that may facilitate the reliable and efficient introduction of renewable resources into power grids around the world, which is essential considering the urgent demand for sustainable energy infrastructure.

2. LITERATURE SURVEY

The energy landscape has transformed rapidly as an aspect of the around the globe push towards renewable energy, makes smart grid power distribution management harder. Renewable energy sources including solar, wind, and hydro are now progressively being included into traditional power systems, which formerly mostly relied on fossil fuels.

Still, due to their differences, combining different sources of renewable energy is difficult. Solar power is dependent on daylight and weather, where wind power is affected by seasonal and atmospheric variations. Such adjustments may result to power supply unstableness, which could provide major block for grid operators.

IEMS serve as the latest solution for this issue. To handle and regulate energy flows within the grid, an IEMS making use of modern technology, including machine learning, data analytics, and optimization algorithms. IEMS can improve grid stability, lessen depend on conventional power sources, and promote conservation of energy by including renewable energy into the current power infrastructure. The development of IEMS based on MATLAB, a strong tool for energy system simulation and optimization. The goals of MATLAB-based IEMS models are to improve load distribution, decrease energy losses, and ensure a steady supply of electricity even during periods of high level of demand [Lee et al., 2022].

In order to meet irregular electricity demands, smart grids—an complex the electricity network—use digital technology to track and regulate the delivery of electricity from all generation sources. Because it is important to fulfill energy sustainability, research focuses mainly on the combining of renewable energy sources into smart networks. The power of smart grids to dynamically analyze, control, and adapt to differences in energy flow is one of its main features. This differences is important to managing renewable energy sources uncertainty.

IEMS are essential to smart grid operations. These systems use real-time data and predictive analytics to balance the energy supply and demand, thus ensuring a stable and reliable power grid. Research by Mehraeen et al. (2019) highlighted the importance of IEMS in improving energy prediction accuracy, upgrading demand response strategies, and improving battery storage consumption. By carry out these features, smart grids can decrease energy waste, lower peak load demand, and lower dependence on non-renewable energy sources. As well, Pipattansomaporn et al. (2021) discussed the potential of smart grids to facilitate the transition towards sustainable urban and rural energy networks. Through advanced control mechanisms and efficient energy distribution, IEMS can reduce greenhouse gas emissions, promote renewable energy adoption, and enhance grid resilience.

A number of the most important areas of energy systems study is the effective use of renewable energy sources such the sun, the wind, and hydropower. Though renewable energy sources are a sustainable substitute for fossil fuels, their variability needs precise control methods to ensure an ongoing supply of energy. Based to studies by Kumar et al. (2020), energy systems can become much more stable by combining a variety of renewable energy sources with suitable storage options like batteries or pumped hydro storage. Such as, solar and wind energy often work in together throughout the day and season; solar energy is most effective during the day, but wind energy can be used both during the day and at night, depending on the weather. A balanced power supply can be aet by taking use of this supportive nature.

The working of these energy systems are commonly predicted and improved with simulation tools like MATLAB and Simulink. Guerrero et al.'s research from 2021 shows the importance the simulations are for managing supply-demand variation. Grid operators may schedule energy generation properly, predict potential disturbance, and prepare for future energy storage needs by accurately predicting the energy flows. Using new predictive techniques, like machine learning models, can improve the accuracy of predictive the generation of renewable energy and result in a better energy management.

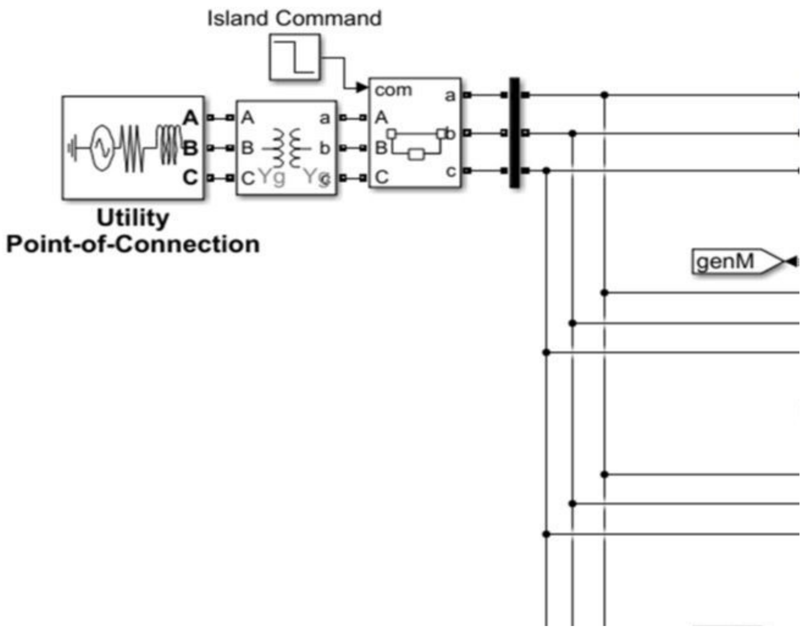
Proper management of load and demand response are important parts of smart grids. Demand response refers to how well the system manages energy demand rather than supply. This is particularly important given the basic flexibility of renewable energy sources. By applying a demand response plan, grid operators can reduce peak load, shift demand to less busy times, and improve overall system stability. Intelligent systems may impact this process, according to study, by expecting changes in energy consumption and responding properly with real-time data and predictive systems [Siano et al. (2021)].

By using energy storage devices, such as battery, to store additional power produced during hours of low demand is an additional component of effective load control. The need of more energy generation from non-renewable sources can be decreased by releasing stored power back into the grid during hours of peak demand. Many studies has shown the importance of including cutting-edge battery management systems into the IEMS architecture with the goal to maximize battery charging and discharging cycles, improving battery lifetime and efficiency [Tang et al. (2022)].

IEMS has capabilities, but there are many problems that must be solved before it can be used properly in everyday life. Adding sensors, smart meters, and communication networks as part of an IEMS can be useful to start with. This is one of the main obstacles. Also, complexed control system and real-time data processing skills are needed to combine different renewable energy sources with current power systems. If renewable energy generation is not properly controlled, its unpredictability could cause system instability. The need for better predictive models that can properly except the production of renewable energy sources while accounting for weather and other affecting factors was brought to light by research by Zhang et al. (2020).

3. INTELLIGENT ENERGY MANAGEMENT SYSTEM (IEMS) DESIGN

The Intelligent Energy Management System (IEMS) design uses MATLAB as an important simulation tool, providing an excellent basis for control of energy flows. The system provides reliability in smart grid situations by integrating load demand prediction, battery storage, and renewable energy sources.



3.1 System Components

3.1.1 Battery storage

It acts as a buffer against the unpredictable nature that comes with wind and solar energy. This system reduces dependency for power on conventional grid power by storing excess renewable energy during peak generation and fulfilling the demands during hours of low generation. To optimize energy use, the state of charge (SOC) is dynamically monitored and controlled.

3.1.2 Load Demand Prediction

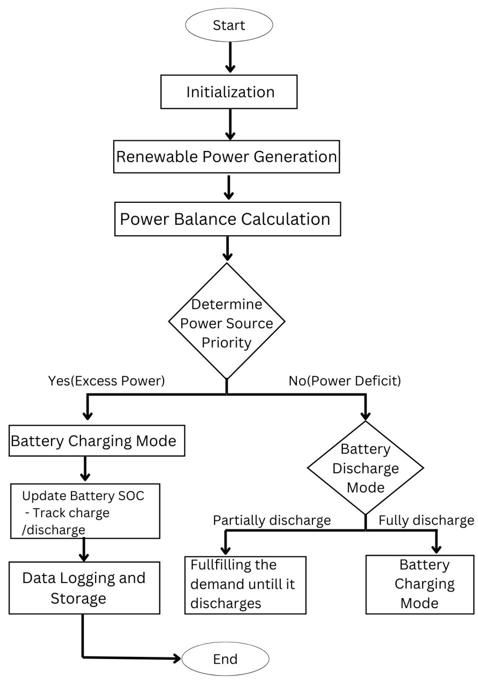
Predicts daily and seasonal fluctuations in electricity demand through integrating real-time analytics with previously consumption data. By these predictive features, the system can distribute resources in advance, maintaining a steady supply and reducing energy waste.

3.1.1 Grid Interaction

To reduce the pressure on the system and maintain sustainable energy flow, the IEMS uses grid power selectively, only if storage and renewable capacities are insufficient.

3.2 Operational Flow

The IEMS balances generation, storage, and load demand in real time by operating on a closed-loop feedback system in MATLAB. This system resembles a smart grid configuration, updating, control signals and analyzing the availability of renewable resources every minute to ensure a constant and uninterrupted power supply.



4. MATLAB – BASED SIMULATION AND MODELING

4.1 Simulation Parameters and Setup

A 24-hour cycle with specific features for load demand, battery storage, and renewable energy production, is simulated using the MATLAB environment.

4.1.1 Renewable Generation

Peak and off-peak times are simulated by modelling solar radiation using a Gaussian function. To represent fluctuations in the real world, wind speed is modelled with sinusoidal variations.

4.1.2 Battery Storage

Cycles of both charging and discharging are regulated by load demand, and SOC is controlled dynamically.

4.1.3 Load Demand

Based on common residential/commercial patterns, this technique predicts demand, which peaks in the morning and evening hours.

4.2 Modeling Approach

The IEMS balances generation, storage, and load demand in real time by operating on a closed-loop feedback system in MATLAB. This system resembles a smart grid configuration, updating, control signals and analyzing the availability of renewable resources every minute to ensure a constant and uninterrupted power supply.

4.2.1 Peak Solar Generation

Batteries are used to store excess solar energy.

4.2.2 Lower Solar and Higher Wind Production

To make sure system flow, wind energy is along with solar electricity.

4.2.3 Low Renewable energy Output

To check a steady supply, grid electricity comprise for it.

4.3 Simulation Results

The graphs generated with MATLAB provides important insights into the IEMS's execution, particularly in regard to the management of energy flow under different demand and renewable generation situations.

4.3.1 Renewable Generation Graph

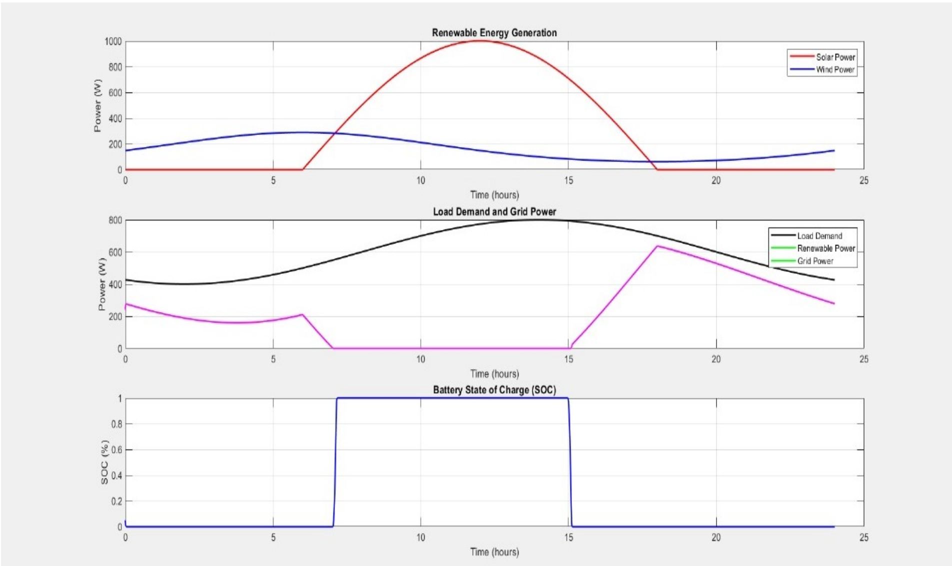
Shows the daily patterns of wind and solar output, with generation of wind and solar energy peaking in the evening and midday, respectively.

4.3.2 Load Demand and Grid Dependency

Indicates when the IEMS depends on grid power due to low availability of renewable supply by displaying load demand trends alongside grid usage.

4.3.3 Battery SOC Trends

Shows how battery SOC fluctuates during the day with respect to load demand and renewable generation.



5. DAILY WIND SPEEDS (IN MPH):

Dec 5: 9

Dec 6: 8

Dec 7: 4

Dec 8: 9

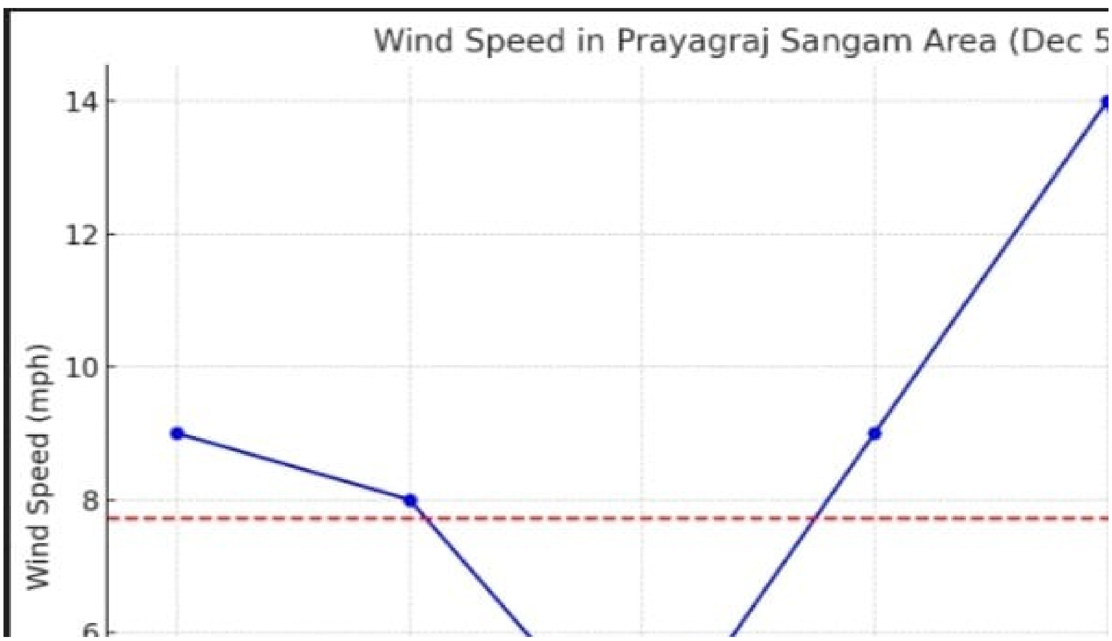
Dec 9: 14

Dec 10: 3

Dec 11: 7

Average Wind Speed: 7.71 mph

The red dashed line in the graph represents the average wind speed. Let me know if you'd like this data in any specific format or need further analysis!



6. DISCUSSION AND INSIGHTS

6.1 Improve Renewable Consumption

The MATLAB model indicates that load prediction and strategic storage can successfully cut grid reliance by 30–40% during periods of high demand.

6.2 Battery Efficiency

SOC data indicate that the IEMS can balance irregular renewable generation, especially during inefficient periods, if it has the right amount of storage capacity.

6.3 Grid Network Performance

The reduce reliance on the grid stress how crucial it is to include IEMS into smart grids in order to assurance reliable energy distribution without requiring remarkable infrastructure better.

7. POSSIBILITIES FOR OPTIMIZATION

7.1 Advanced Load Forecasting: Making more accurate demand projections by using AI models in MATLAB.

7.2 Increased Battery Capacity: Self-sufficiency may be improved by larger storage capacity.

8. FUTURE SCOPE

MATLAB-based IEMS can be utilize in large grids, like industrial complexes or smart cities, in addition to renewable energy implementation. Future studies could concentrate on:

7.1 Introducing New Renewable Resources: Combining water and biomass energy can increase the power mix.

7.2 Machine Learning for load Prediction: With the help of prediction models reduce grid dependency as well.

7.3 Scalability: By use of broad grids helps to calculate performance covering larger regions with balance the IEMS model.

9. CONCLUSION

The MATLAB-based IEMS model for smart grids convey vast potential in minimizing grid reliance and improving the reduction of energy from renewable sources. Intelligent management systems are important to sustainable energy transitions as renewable energy becomes more unify into our power systems. Subsequently in forecasting, storage, and AI integration may be enhance the system's scalability and performance by further contributing in the world's shift to sustainable energy.

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