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A Grid Modernization and The Transition To A Decentralized Energy Landscape

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Abstract *– This paper explores the critical steps in grid modernization and the transition to a decentralized energy landscape, addressing the challenges and opportunities for achieving a resilient, efficient, and sustainable energy system. As energy demands evolve and renewable energy sources proliferate, there is a growing need to modernize traditional grid infrastructure to accommodate decentralized energy systems, including microgrids, distributed energy resources (DERs), and transactive energy platforms. This study provides an overview of key technologies, such as smart meters, advanced distribution management systems (ADMS), and energy storage solutions, which enable real-time energy monitoring, flexible energy distribution, and enhanced grid resilience. Additionally, the role of digital innovations like the Internet of Things (IoT), blockchain, and artificial intelligence (AI) in facilitating grid decentralization and enabling secure, transparent energy transactions is examined. The findings highlight both technical and policy-based strategies for overcoming the current grid's limitations and outline best practices for achieving a seamless transition to a decentralized energy model. By exploring case studies and emerging trends, the paper underscores the potential of a modernized, decentralized grid to meet future energy needs, drive environmental sustainability, and empower energy consumers.*

Keywords: Grid Modernization, Decentralized Energy Systems, Microgrids, Distributed Energy Resources (DERs), Transactive Energy, Smart Meters, Advanced Distribution Management Systems (ADMS), Energy Storage Solutions

I. INTRODUCTION

Resources are distributed across political boundaries. These resources, which are replenished over time, include solar irradiance, wind, tidal forces, and geothermal heat, among others. Currently, Reconstitutes approximately 25% of the world's total electricity generation, with hydropower contributing 16% and newer technologies adding around 3%[2-5].

In a smart grid, all entities in the power flow (as depicted in Fig. 1.3) generate data about power demand and usage. This data can be analysed to provide end-users with efficient energy management solutions.
Furthermore, smart grid allows utilities to forecast future energy needs based on end-user consumption patterns[6-8]. As a result, by forecasting consumer load requirements, the gap between demand and supply can be minimised by managing their demand response optimally [9]. Demand response, in general, refers to changes in user load demand as a result of the utility's policies [10]. Demand response management is critical in developing countries like ours to manage load demand because energy generation resources are limited and demand is rapidly increasing.

The micro-level of smart grid begins with smart homes in the residential sector, which are the largest electricity consumers. As a result, managing their demand response can be beneficial in balancing the overall load on the smart grid.

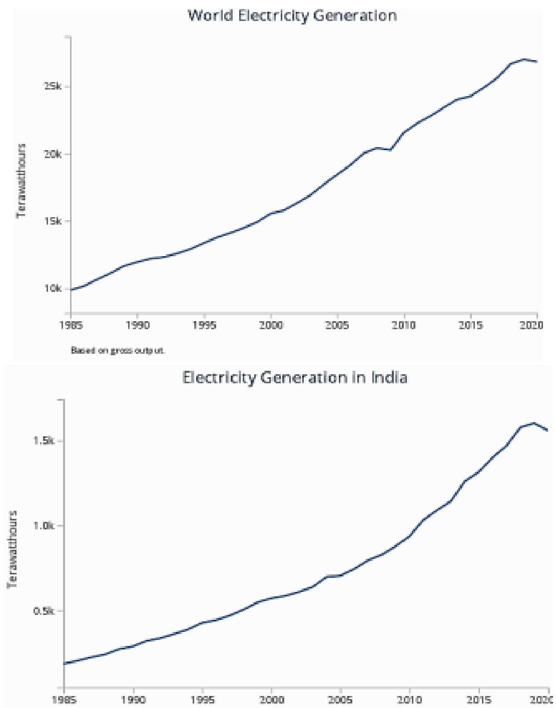


Figure 1: Global and Indian Electricity Generation

If the smart home understands its current and future energy needs, it can provide an energy consumption curve to the grid, which can then plan distribution based on its available generation resources. As a result, the smart grid can use its energy more efficiently based on the needs of its users. Once the energy has been dissipated to various smart homes, the appliances can be controlled using home area networks (HANs) to balance the load based on the power supplied by the grid. Furthermore, distributed energy resources (DERs) such as PV panels can be used in smart homes or smart grids to manage partial load demand, reducing the load on the smart grid.

These technologies are especially beneficial for rural and remote areas, where energy access is often critical for human development. Figure 1.2 shows the proportion of in total electricity generation, both globally and in India. Additionally.

II. Grid Modernization

Grid Modernization(GM) refers to the smart updation of the electric grid infrastructure to address the evolving energy needs of the 21st century and beyond. This process encompasses the integration of advanced technologies, innovative solutions, and scientific advancements to enhance the grid's resilience, reliability, and security. One of the primary goals of grid modernization is to create a more efficient distribution system. This includes the deployment of smart grid technologies that facilitate real-time monitoring and control of electricity flow. Smart meters, sensors, and automated systems enable utilities to better manage energy distribution, quickly identify outages, and optimize energy delivery to consumers. Another critical aspect of grid modernization is the incorporation of energy storage solutions. As RE sources, such as solar and wind, become more prevalent, energy storage systems play a vital role in balancing supply and demand.

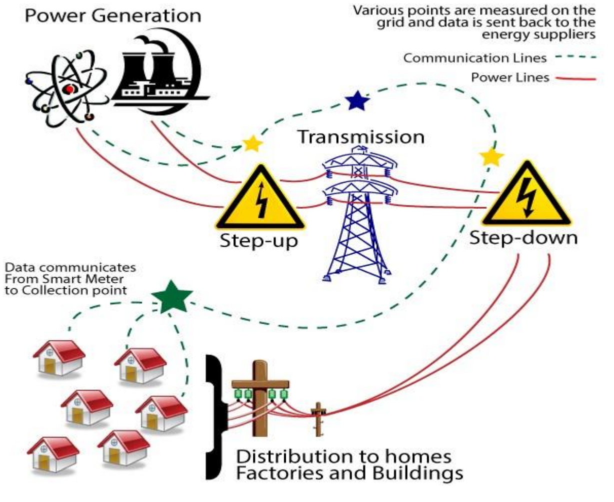


Figure 2: Grid Modernization

Control and management of the electric grid are also significantly enhanced through modernization efforts. Advanced data analytics and artificial intelligence applications allow for improved decision-making processes. Utilities can leverage these technologies to predict energy usage patterns, enhance grid performance, and proactively address potential issues before they escalate into larger problems.
Moreover, grid modernization emphasizes the importance of security. As the grid becomes more interconnected and reliant on digital technologies, safeguarding against cyber threats and physical vulnerabilities is paramount. Implementing robust cybersecurity measures and developing protocols to ensure the integrity of the grid are essential components of this modernization effort..

III. Method

This paper investigates the application of fuzzy logic to optimize and manage hybrid power systems, which integrate various energy sources such as solar, wind, and conventional fossil fuels. The primary goal is to leverage the strengths of fuzzy logic to handle the uncertainties and variabilities associated with generation, thus enhancing the overall reliability and efficiency of these systems.

At the heart of this approach lies the development of a fuzzy logic controller (FLC), designed to effectively manage the distribution of energy among the different sources. The fuzzy logic controller utilizes a fuzzy inference system (FIS) that employs linguistic variables and fuzzy rules for decision-making under uncertain conditions. The inputs to the fuzzy logic controller include parameters such as solar output levels (denoted as S), wind output levels (denoted as W), state of charge of the battery (denoted as SOC), and load demand levels (denoted as D).

To construct the rule base for the fuzzy logic controller, a comprehensive set of fuzzy rules will be formulated, derived from expert knowledge and practical insights. These rules may include conditional statements such as:

- If S is low and W is high, then prioritize wind energy.
- If SOC is low and D is high, then discharge the battery.
- If S is high, then direct excess energy to charge the battery.

The performance of the fuzzy logic controller will be evaluated through simulations conducted in MATLAB/Simulink, examining various scenarios to assess the FLC's performance under different conditions, including fluctuations in REgeneration and load demand. Key performance metrics will include system efficiency (η), energy reliability, and response times, formulated as follows:

$$\eta = \frac{E_{output}}{E_{input}} \times 100$$

Where E_{output} is the total energy output from the system and E_{input} is the total energy input. Finally, the effectiveness of the fuzzy logic controller will be evaluated based on the simulation results, focusing on metrics that quantify reductions in energy loss and improvements in system responsiveness to changes in load and generation. In the concluding phase, the developed fuzzy logic controller will be implemented in a real-time hybrid power system to assess its practical applicability and robustness under real-world conditions, ultimately aiming to enhance adaptive energy management in hybrid systems.

Figure 4 displays the configuration of the EMS built for this study. This EMS uses a fuzzy controller as its foundation, but in this case, the controller also needs to manage the BESS SOC. Three inputs and two outputs make up the fuzzy logic system that was used in this study:

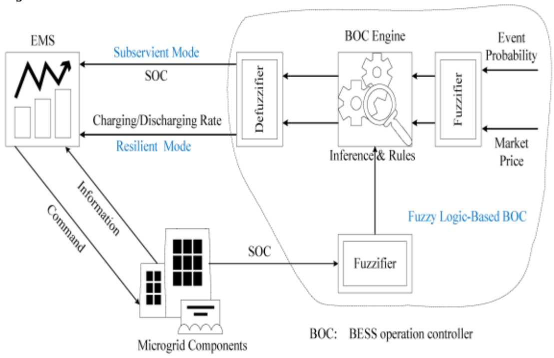


Figure.3. Configuration of the FCS

IV. Result

This is hybrid model basically depend upon renewal energy and constant generate high quality output from the source.

In proposed work designed hybrid power system. That is connected battery, PV and Wind. Here show basic parameter of the system in table 4.1.

This is result section for proposed model. Here we are analysis our proposed architecture design and analysis with different operation like source variation and load variation.

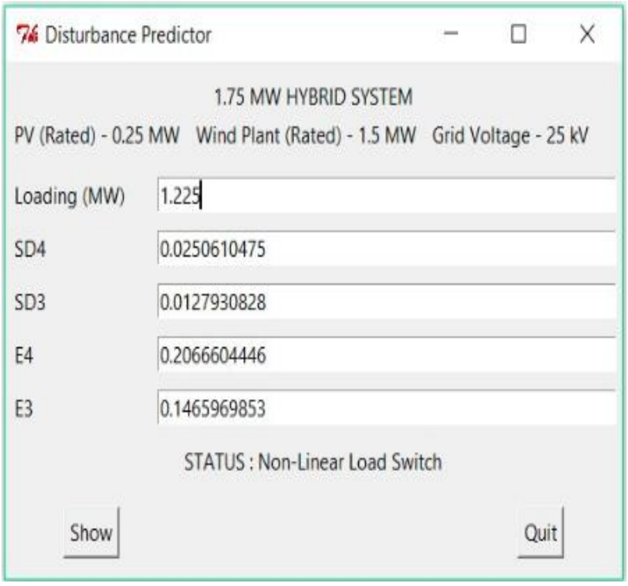


Figure. 5: Disturbance Predictor Window

Figure 5 is show Disturbance Predictor Window. In this there are different parameters values are shown. The values are PV is 0.25MW, wind plant is 1.5MW, grid voltage is 25kV.

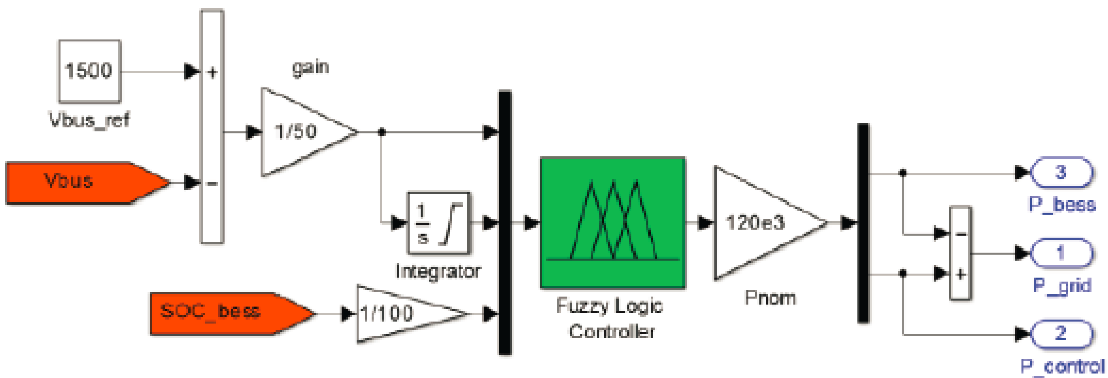


Figure. 4 Fuzzy logic implementation

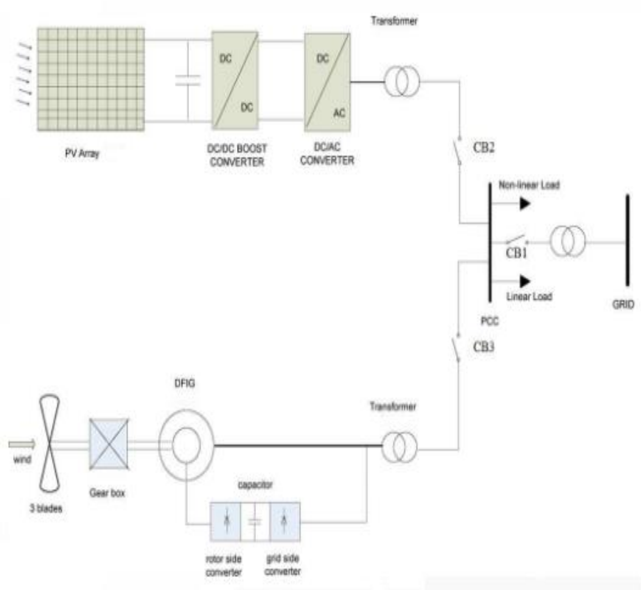


Figure 6: sub model of proposed system

Figure 6 shows the sub model of proposed system. In this some module use PV Array, DC-DC Boost converter, DC/AC converter, transformer etc.

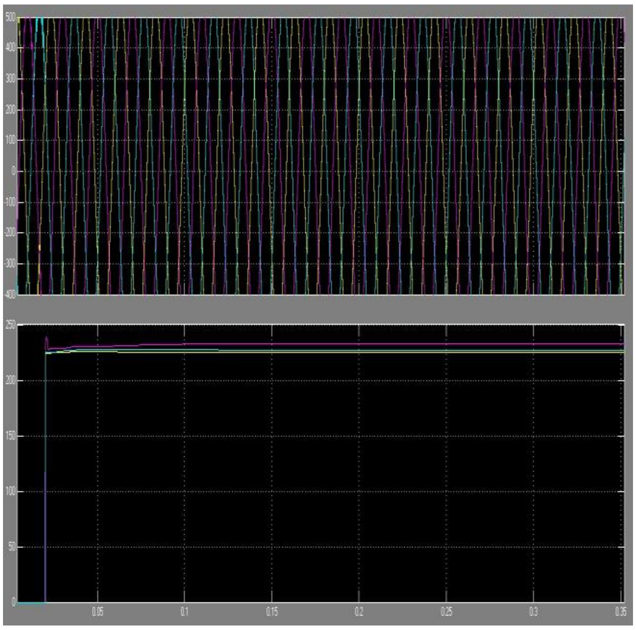
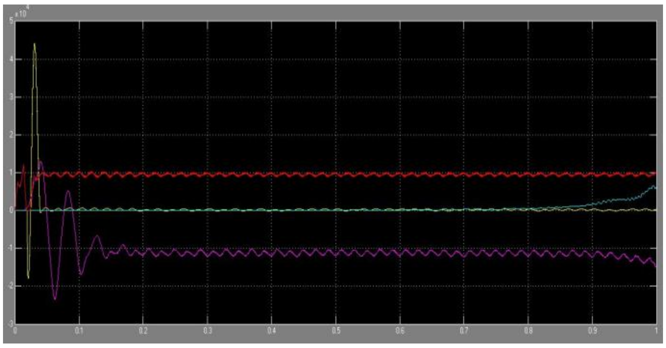
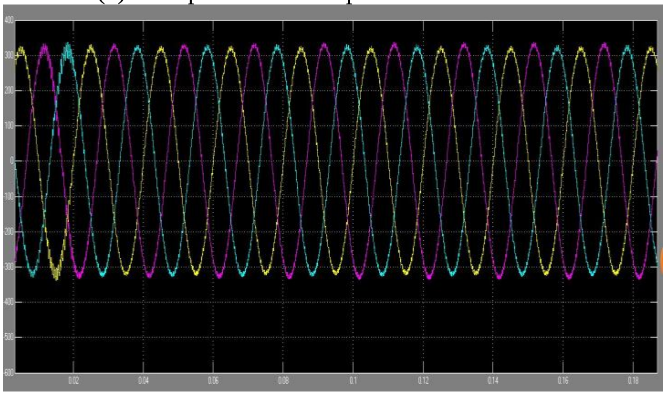


Figure. 7: PWM output of proposed model

Figure 7 shows PWM out of the proposed model. In this figure, PWM controls the voltage and current of the proposed model. This is a system associated with fuzzy to control power quality as shown in the figure5.1



(a)Load power with respect to all source



(b)Voltage

Figure 8: Load power with respect to all source (a) Load power and source power(b) Output voltage

Figure 8 shows the power generation by renewal energy source in a proposed model and load requirement power. where (a) the Charging station required power with respect to source power generate by the renewal source (b) Stable voltage generate by fuzzy login in the proposed system.

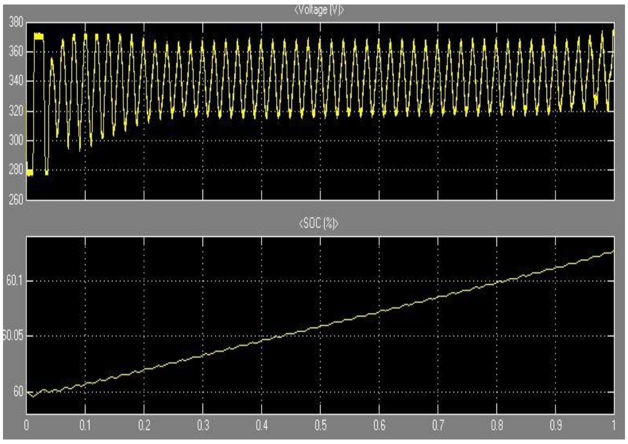


Figure 9: Soc Condition of Battery

Figure 9 shows the state of charge of the battery and voltage of the battery which is used as a source in the proposed model.

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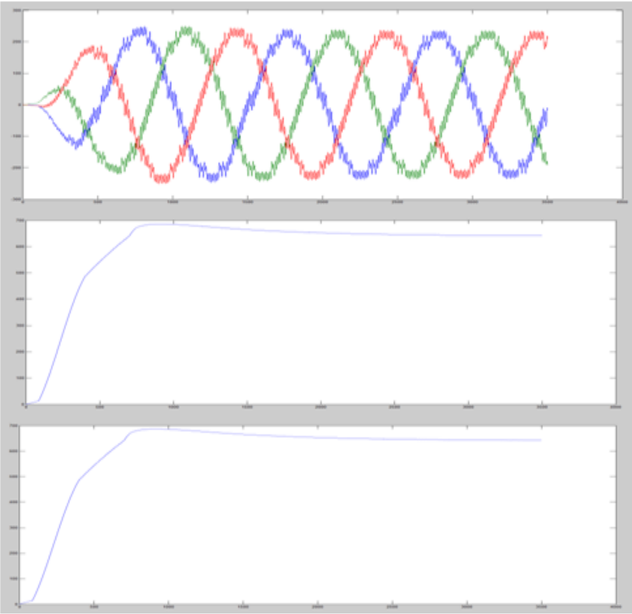

Figure 10 Power Generation of hybrid System

Figure 10 is show smooth power generation with respects EV's load. In this x direction is time and y direction is show voltage and current. Upper figure is show output generation of source and lower section is output of source.

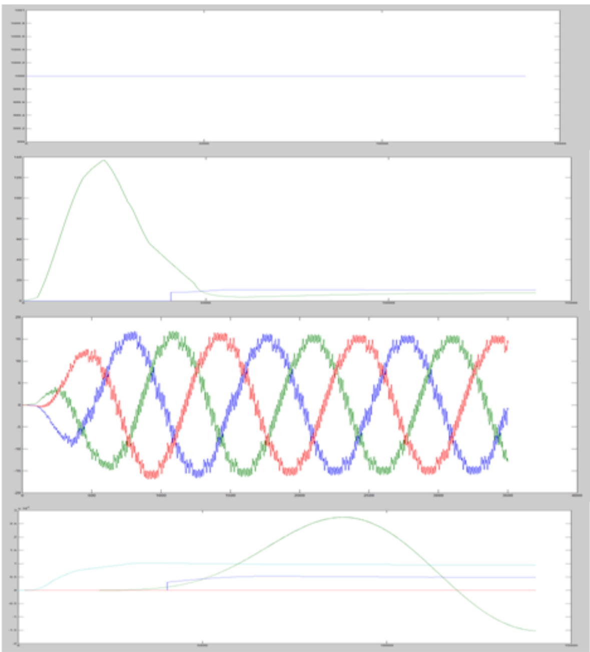

Figure 11 Model with PV and Wind

Figure 11 is show simulation result when PV and wind is connected with EV's charging station. Figure 5.10 is complete model simulation that is show when both renewal energy source connected and charge electrical vehicle and how much power which source generate to maintain power quality in proposed system x dimension show time and y dimension their respective parameter output .

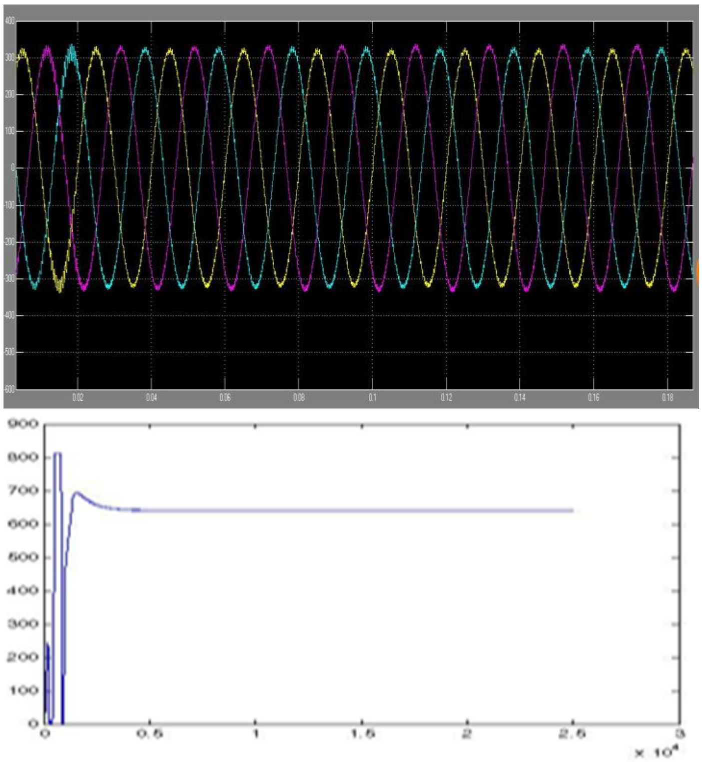

Figure 12 Active power

Figure 12 is show proposed hybrid model active power also shows this condition simulation output of proposed model. This simulation is proving that if change load and source output generation is no change in waveform pattern.

V. Conclusion

This paper focuses on the development of a hybrid renewable energy-based charging station that integrates photovoltaic (PV) and wind energy as primary power sources, with battery systems serving as an alternative source of direct current (DC) power. The proposed model outlines the architecture of a DC hybrid system that utilizes both solar and wind energy inputs to create a reliable and efficient charging solution.

In this work, we detail the control logic employed in the hybrid setup, which incorporates advanced charge control mechanisms for the battery bank using a Fuzzy Artificial Neural Network (ANN). This intelligent control system plays a pivotal role in monitoring error signals and optimizing battery performance, ensuring that the battery bank is effectively utilized for controlled charging. The Fuzzy ANN adapts to varying environmental conditions, allowing for efficient energy storage and management based on real-time data inputs..

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