A FUTURISTIC APPROACH TO SEAMLESS POWER CONTROLLING, MONITORING AND DEMAND MANAGEMENT

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Abstract**—**As renewable energy sources become increasingly integrated and smart grid technologies advance, there is a critical need for innovative approaches to effectively manage power distribution, while also ensuring efficient monitoring and responsiveness to fluctuating demands. This paper presents an advanced approach to demand-side management (DSM) and control strategies within smart microgrids (SMGs) to enhance energy efficiency and address challenges such as voltage and frequency regulations, CO2 emissions, peak-to-average ratio (PAR), and the stochastic nature of renewable energy sources (RESs). Leveraging Internet of Things (IoT) capabilities, the proposed strategy integrates a two-level genetic algorithm (GA) optimization and time-of-use pricing (ToU) for cost-effective energy management. Additionally, an improved PID-based mixed sensitivity H-infinity (PID-MSH∞) control scheme is employed to regulate SMG voltage and frequency in islanded mode, ensuring compliance with IEEE Standard-1547 and enhancing customer service quality while facilitating DSM. Experimental validation on a lab-scale prototype demonstrates the efficacy of the proposed strategy in reducing energy costs, emissions, and PAR while achieving optimal DSM and regulatory performance. Furthermore, the paper discusses the necessity for coordination between renewable power generation units, energy storage systems (ESSs), and the grid to address intermittency challenges, proposing a smart grid architecture with embedded microgrids and introducing a "Micro-grid Key Elements Model" (MKEM) to facilitate smooth integration and virtualization testing. Simulation results underscore the benefits of renewable energy integration and the stabilizing role of battery storage systems in grid operations.

keywords: Smart Grid, Renewable Energy Integration,Energy Storage Systems, Demand Response,Advanced Monitoring Systems.

1. INTRODUCTION

The Paris Agreement aimed to combat climate change by transitioning from hydrocarbon-based power generation, but evidence of this shift remains elusive[1]. The European Union faces challenges in transitioning to a sustainable low-carbon economy, but has set ambitious renewable energy targets for 2030. Countries like Germany have embraced renewable energy expansion, and solar photovoltaic installations have surged globally, indicating a shift towards cleaner and more reliable energy sources.The integration of renewable energy sources (RESs) into power systems aims to reduce greenhouse gas emissions and provide socioeconomic benefits. However, intermittent PV power generation presents grid stability challenges and operational complexities. Decentralized PV generation and energy storage systems (ESSs) are proposed to mitigate these issues and improve grid reliability. The integration of renewable power generation units at different scales introduces dispatchability and control challenges, especially in micro-grid applications.

Energy storage systems (ESSs) are essential for stabilizing grid operations and managing PV variability. Sizing ESSs helps mitigate intermittency and fluctuation in PV power generation. Integrating these systems requires coordinated efforts in power electronics and system design. Smart grid architectures, incorporating bi-directional communication and advanced controls, facilitate the integration of RESs into existing power grids. Models like the Smart Grid Architecture Model (SGAM) provide frameworks for designing resilient and efficient grid systems.Micro-grids are a decentralized alternative to traditional energy systems, offering economic benefits and improved resilience. They can provide reliable renewable energy and are enhanced by control strategies and modeling techniques. The proposed smart grid architecture incorporates embedded micro-grids with hierarchical controllers to address communication challenges and financial considerations.

Modern power systems integrate renewable energy sources into micro-grids and smart grid architectures to reduce emissions, improve reliability, and embrace sustainable energy sources. However, challenges like PV variability, grid stability, and communication complexities persist. Innovative solutions like energy storage and hierarchical control systems are crucial for overcoming these obstacles and realizing the potential of renewable energy integration.

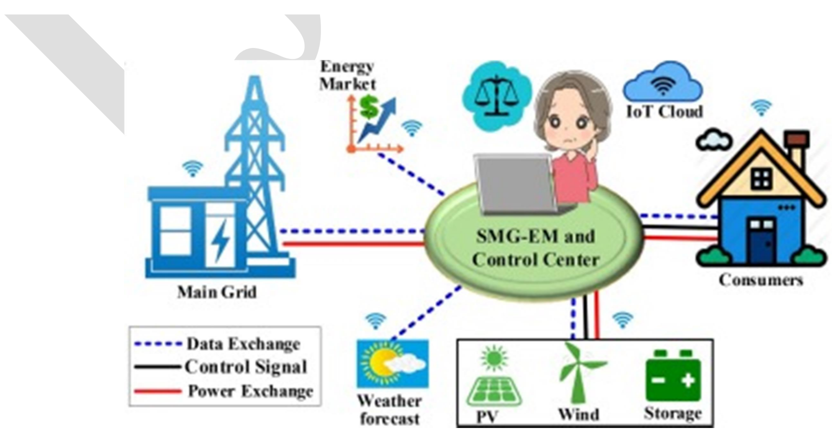

Fig 1:Smart Grid

This paper presents a proposed system structure and IoT platform for SMG energy management, a control system for SMG, a problem optimization algorithm, simulation and experimental validation results, and concludes with a discussion of the results in Section 4. The structure and IoT platform are presented in Sections 2 and 3.

2. RELATED WORKS

In [6], a microgrid system incorporating wind, tidal, and pumped hydro storage was suggested and devised to diminish greenhouse gas emissions. Conversely, the industrial plan for Ouessant Island encompasses a diesel generator, PV system, TT, and Li-ion battery setup. Hence, an isolated microgrid comprising a PV system, TT, diesel generator, and Li-ion battery has been formulated to fulfill the island's electricity requirements.Within the domain of optimizing energy storage systems (ESSs) in microgrids, the research [7] distinguishes itself through its inventive utilization of genetic algorithms. It delves into energy management within hybrid microgrids, presenting methodologies aimed at optimizing battery efficiency and longevity. Through comprehensive simulations, the study demonstrates notable enhancements over conventional approaches, thereby establishing its pioneering role in ESS optimization.

In [8], the focus is on planning microgrids in places that are cut off from larger energy networks. The study introduces a method that considers multiple goals and uses optimization algorithms. It emphasizes the benefits of making microgrids more independent while also reducing costs. Overall, it provides a comprehensive approach to planning microgrids that are sustainable and efficient in isolated areas. [9] study helps us better understand how to keep the electrical system stable in microgrids by using batteries for energy storage. They ran detailed simulations in different situations, showing how storage systems can effectively deal with the ups and downs in renewable energy sources.This study's method, combining risk analysis and reliability assessment, stresses the need for thorough strategies to maintain consistent electricity in microgrids. Study [10] stands out in smart microgrid research by exploring energy management with IoT integration. It introduces a unique approach by using a hybrid PV/wind and piezoelectric energy system, evaluated with ThingSpeak and MATLAB tools, to improve smart microgrid efficiency. Similarly, Study [11] implements an optimized energy management system for a hybrid microgrid, employing a cost-effective IoT communication platform. It emphasizes the practicality and adaptable security of this intelligent hybrid microgrid solution, advancing efficient technology development. Additionally, in IoT system security, References [12,13] discuss formal verification and validation techniques, addressing key challenges and proposing future directions to enhance interconnected system security.

3.PROPOSED METHODOLOGY

Our proposed system is a Prediction system for residential energy management. Herewe use an Arduino microcontroller which controls and monitors a system which is utilized for Energy consumption optimization. This work presents an IOT-based machine learning solution supporting a new intelligent system for energy management within a specified time window to reduce costs. The primary difference between the two systems is that this one closes the loop and involves the user in making decisions based on alerts and messages generated by data analytics. Smart meters can be used to do this. The goal of this project is to create a system for the home that tracks each device's energy usage and graphically displays it. The three categories covered by the proposed design's elements include utilities, which are installed computational systems that allow for the processing and analysis of data obtained from customer smart meters. Network that allows internet-enabled devices to send and receive consumer data in both directions. The major restrictions in the Energy Management system are precise metering, energy monitoring, and the use of visual data for consumer load profiles.

AMR devices frequently broadcast consumption (use) data to the energy provider, therefore human meter readings are typically not necessary. Energy usage data analysis guarantees that more accurate bills are issued to clients for their consideration.

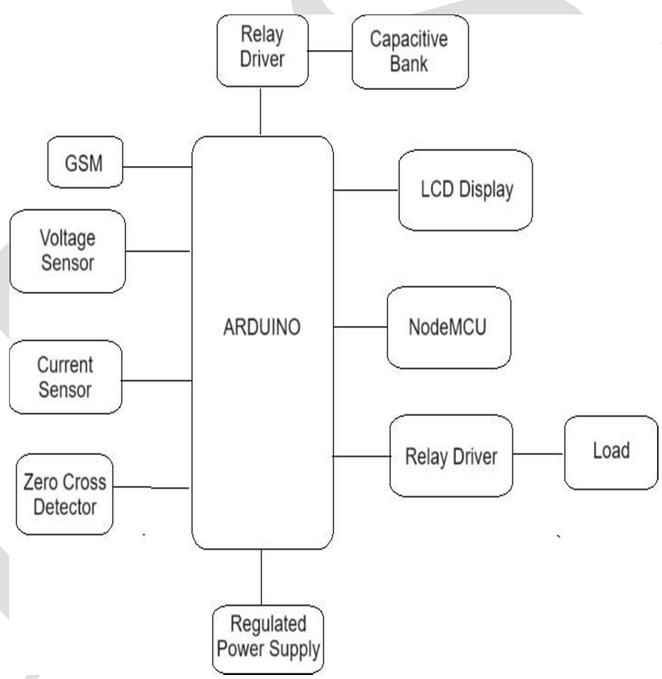

Fig 1. BLOCK DIAGRAM DESCRIPTION

In this proposed system, predictive analysis-based home energy management is suggested. The control and monitoring system is based on the pic microcontroller. To compute through the use of current and voltage sensors, energy consumption by load is estimated.The microcontroller calculates and measures the different load voltage. The Controller and IoT module are interfaced, and the Controller is used to update the web server with new information regarding the energy usage of homes. For this IOT module,we used Node MCU. By setting a username and password, the user connects our controller kit to the IoT server through this module.. Calculating the cost analysis of the power used is the second step.

The user receives a notice whenever the load consumption exceeds the limitations. And then the specific load is controlled by using the node MCU.Our project's overall progress is shown on an LCD panel. Periodically, the online server receives live energy consumption readings from the Smart energy meter, and the details are updated in a centralized database.

The web server is built, and an interface is established so that users may track each appliance's use over time from anywhere and at any time.When a message is sent to the GSM modem, it relays the message to the microcontroller, which then responds by dialing the pre-programmed mobile number. If a customer doesn't pay their bills, the power department will shut off their supply and send them a due bill by SMS after updating the readings on the electricity board.

A. Advanced Control Algorithms

In the world of managing energy, advanced control algorithms are introducing a new way to handle power smoothly, keep an eye on it, and manage demand effectively. These clever algorithms use modern technologies like artificial intelligence, machine learning, and predictive analytics to make power usage smarter in real-time. They gather data from various sources like IoT devices, smart meters, and weather forecasts to adjust energy consumption patterns dynamically, matching the supply and reducing waste while improving efficiency.

One big advantage of these advanced control algorithms is their knack for offering detailed insights into how energy is used, both on a large scale and in tiny details[11]. By looking at past data and learning from real-world experiences, these algorithms can spot trends, unusual occurrences, and areas where energy use could be better. This precision allows organizations to come up with focused plans for balancing loads, reducing peaks, and responding to changes in demand, which ultimately saves money and helps the environment.

Plus, integrating these advanced control algorithms into smart grids and energy management systems gives stakeholders more power and flexibility than ever before. Through centralized platforms, users can keep tabs on power use and manage it from afar, whether it's across different devices, buildings, or whole regions, all in real-time. This smooth integration makes it easier to make proactive decisions, improves the stability of the grid, and ensures that electricity is always available when needed, setting the stage for an energy infrastructure that's stronger and more sustainable in the future.

B. Real-time Monitoring Systems

Real-time monitoring systems are changing the game when it comes to managing our power usage and keeping an eye on demand. These systems are like high-tech guardians, using gadgets like IoT sensors, data crunching, and cloud technology to instantly track how we're using energy. By watching our power consumption in real-time, these systems help us make quick, smart decisions to use energy more efficiently, matching what we need with what's available.One big plus of these real-time monitoring systems is their ability to spot when things aren't running smoothly with our energy usage. They gather data from all over, like smart meters and sensors, and can instantly see if something's not right. This means they can jump into action fast to fix problems, like if a piece of equipment is acting up or if there's suddenly a big surge in demand. By nipping issues in the bud, these systems help us keep things running smoothly and use energy more effectively.

These monitoring systems aren't just reactive - they're proactive too. By crunching through past data and using clever algorithms, they can predict what our energy usage might look like in the future. This means energy providers and grid operators can plan ahead, getting ready for changes in demand or even preventing problems before they happen. It's like having a crystal ball for our energy needs, helping us build a more reliable, affordable, and eco-friendly energy system.The energy supply layer brings together renewable energy sources, battery energy storage, and the utility grid, combining them to meet the required energy demands. This layer is responsible for generating the necessary energy to fulfill the load requirements. Within the energy appliances layer, all system load appliances are included, equipped with the necessary hardware to monitor and control their status. The network layer manages the communication protocol among the interconnected appliances within the SMG. Meanwhile, the energy management layer oversees the operation and service of load appliances, adhering to Time of Use (ToU) pricing principles to lower energy costs, reduce CO2 emissions, and minimize Peak-to-Average Ratio (PAR). The control system layer ensures stable SMG voltage and frequency, accommodating any fluctuations in load. Finally, the IoT service layer acts as a repository for information and data gathered from the energy supply systems and appliances, conducting data analysis to optimize appliance usage.

C. Data Acquisition

This study proposes a data acquisition approach for IoT networks, utilizing a supervisory control and data acquisition (SCADA) system. The system uses a LabVIEW data logger and a dedicated weather station to collect data, which is then recorded in the microgrid's primary server. The SCADA system performs essential processes such as retrieving data from the Modbus TCP/IP communication protocol, storing data in a Citadel database, and visualizing the recorded data.

The SCADA interface allows users to monitor and control the entire power system, including individual equipment components. However, external network monitoring of the microgrid is strictly prohibited due to security concerns. The study aims to provide a solution by leveraging ThingSpeak's capabilities to acquire data from the SCADA system via MATLAB, using the Modbus communication protocol as an intermediary conduit. The data is then transmitted to the IoT web platform, enhancing overall monitoring capability and improving data accessibility.

Three communication channels are established through the ThingSpeak open access platform. Channel 1 provides online monitoring of the microgrid's photovoltaic system, while Channel 2 allows for data acquisition of energy consumption demand profiles for homes located far from the microgrid.

D. ARDUINO

The microcontroller PIC16f877a is one of the most renowned microcontrollers in the industry. This microcontroller is very convenient to use, the coding or programming of this controller is also easier. One of the main advantages is that it can be write-erased as many times as possible because it uses FLASH memory technology. It has a total number of 40 pins and there are 33 pins for input and output.

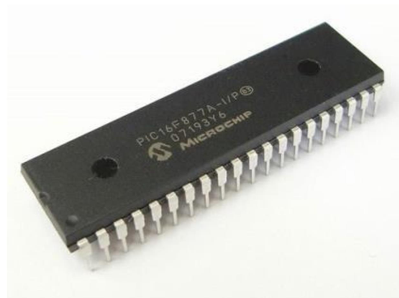

Fig 2. MICROCONTROLLER

E. NODE MCU

The Node MCU (Node Micro Controller Unit) is an open-source software and hardware development environment built around an inexpensive SoC called the ESP8266. TheESP8266, designed and manufactured by Es press if Systems, contains the crucial elements of a computer: CPU, RAM, networking (WiFi), and even a modern operating system and SDK. That makes it an excellent choice for the Internet of Things (IOT) projects of all kinds. As a chip, the ESP8266 is also hard to access and use.

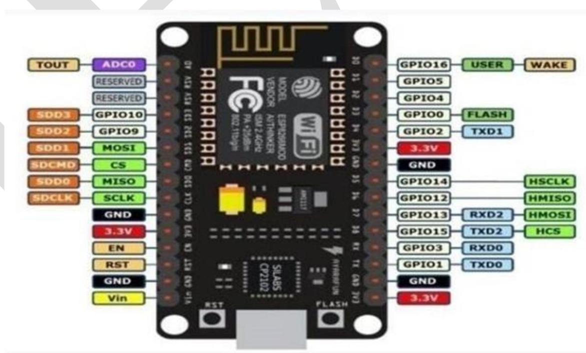

Fig 3. NODE MCU

F GSM MODULE

The GSM system is the most widely used cellular technology in use in the world today. It has been a particularly successful cellular phone technology for a variety of reasons including the ability to roam worldwide with the certainty of being able to operate on GSM networks in exactly the same way - provided billing agreements are in place.

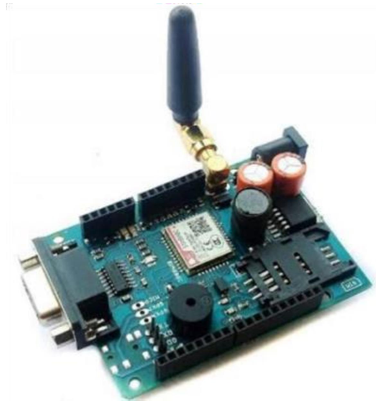

Fig 4. GSM Module

G. REGULATED POWER SUPPLY

A regulated power supply is an embedded circuit; it converts unregulated AC (alternating current) into a constant DC. With the help of a rectifier it converts AC supply into DC. Its function is to supply a stable voltage (or less often current), to a circuit or device that must be operated within certain power supply limits. The output from the regulated power supply may be alternating or unidirectional, but is nearly always DC (direct current).[1] The type of stabilization used may be restricted to ensuring that the output remains within certain limits under various load conditions, or it may also include compensation for variations in its own supply source. The latter is much more common today.

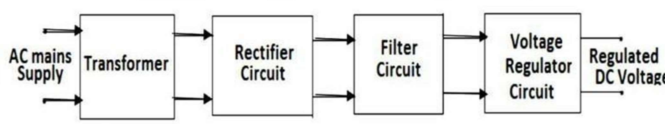

Fig 5. Regulated Power supply

4. RESULTS AND DISCUSSION

The experiment involved collecting data from a meteorological station, revealing peak solar power reaching 1200 W/m2 and fluctuating temperatures between 12 and 20 °C. The study location, near the equator, had stable PV power and temperature patterns. Three channels on the ThingSpeak platform were used to monitor the PV system, displaying solar power, temperature, modeled PV power, and actual PV power generated in the laboratory.Using thing speak the output will be predicted per day and also for a month by consumption of voltage.By Blynk app for energy demand control there are two control units one is for 50 watts and another one is 100 watts which can be controlled by mobile.

Fig 5. PV system for real time monitoring

A study validated a supervision model for PV systems by comparing it with three stable days of generation. The results showed that the model effectively characterized and controlled PV system behavior, enabling efficient internet-based monitoring and control. The model showed a significant correlation with observed real-world behavior, indicating a significant advancement in microgrid management and demand analysis. These findings set the stage for more rigorous and resilient methodologies for real-time analysis through network-based systems.

The monitoring system introduced in this study has the potential to significantly impact renewable energy integration and remote microgrid management. It uses IoT and ThingSpeak to provide real-time analysis of key parameters, such as solar radiation, temperature, and power generation, providing valuable insights into renewable energy sources' behavior. This information aids in informed decision-making and ensures the reliability and longevity of PV system components. The system's integration with ThingSpeak allows for remote accessibility, overcoming geographical constraints in microgrid management. The system also includes energy consumption data from the Pzem004t energy monitor, enhancing its capacity to manage demand effectively.

The system's reliability and correctness are ensured through formal verification and validation techniques. This method systematically analyzes and validates the functionality of the IoT services integrated into the system, reducing errors and enhancing robustness. It also helps identify and mitigate potential security vulnerabilities, enhancing the system's resilience against cyber threats.

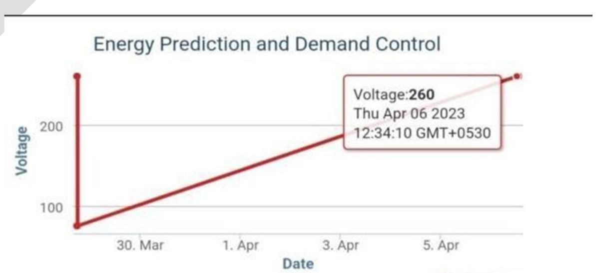

Fig 6. LabView for real time monitoring

The proposed model, built upon the IoT platform, supports up to 80 IoT devices. To improve monitoring and management, the inclusion of more variables, such as frequency, voltage, and harmonics, could enhance the operability of the microgrid. Future studies will analyze these aspects to further enhance the system's effectiveness.

5. CONCLUSION

This paper proposes an advanced control and optimal DSM scheme for Solar Microgrid (SMG) using IoT and GA optimization techniques. The DSM system aims to improve SMG energy cost, emission cost, and PAR by enhancing voltage and frequency under different system load operations. IoT is used to communicate between the central controller, generating units, and load appliances. The proposed DSM and control scheme is implemented using MATLAB/Simulink® to a hypothetical SMG, including different generating units and load appliances.Experimental prototypes are established to validate the proposed DRP. The proposed EMS scheme reduces SMG energy cost, emission cost, and PAR by 26.4%, 60.7%, and 55.9%, respectively, compared to SMG operation without EMS. In the case of BESS charging and discharging based on the real price signal of the utility, system performance is improved by 27.9%, 52.7%, and 40% for energy cost, emission cost, and PAR, respectively.The IoT platform improves data execution time, minimizes required memory size, and reduces response time. The proposed controller effectively regulates SMG voltage and frequency to nominal values under different load demands and operating conditions. Experimental validation shows that the proposed DRP scheme can improve SMG load profiles considering additional changes in SMG demands and generations.

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