

# ***Abstract***

In today's world, one of the most important parameters deciding the global growth is determined by its per capita energy consumption. Energy in the form of electricity plays a vital role in day-to-day life. An unbalanced growth between the highly developed and economically backward countries makes the energy consumption scenario even worst. Rapid industrialization and urbanization lead to exponential growth in power consumption. Although power planning is drawing significant attention, the country is facing a persistent power crisis since last few years.

Meeting the ever-growing load demand and managing grid stress has become a significant challenge in today's world. The load demand fluctuates due to various factors, including human habits, economic growth, the acceptance of new technology advancements, geographical location and demographic cycles etc. Utility sectors have provided data indicating that in some countries, more than 25% of total energy is consumed by the domestic sector. Additionally, significant energy consumption in the commercial and agricultural sectors highlights the diverse energy needs across the economy, underscoring the need for improvements in the transmission system. The present energy transmission system often suffers from significant losses and the growing stress on the grid necessitates a shift towards more efficient energy management solutions. This is where microgrid becomes inevitable, as they can reduce transmission losses as well as grid stress through localized energy management. While traditional consumers rely mostly on grid energy and they never become part of the load management initiatives, in recent past consumers have been part of the generation by feeding their own generated electricity from roof top PV or wind to a storage system or directly to the grid. This has been a smart move towards load management initiatives. These consumers are called prosumers. Prosumers not only generate their own energy but also contribute demands to the system, creating a more dynamic energy ecosystem, by transitioning consumers, mostly domestic consumers into domestic prosumers where they play a pivotal role in addressing the current power scenario. This has helped in developing a dynamic, robust, yet flexible Energy Management System. Microgrid plays a significant role in providing capacity addition to generation in local grids by integrating Renewable Energy. Prosumers connected to microgrids contribute to a more stable and resilient energy system by providing additional generation capacity and demand response capabilities. The localized nature of microgrid ensures that the energy produced by prosumers is used efficiently within the community, reducing the need for long-distance transmission and optimizing local-level energy management. The growth of prosumers and microgrids encourages technological

innovation in energy storage, smart grid technologies and the energy management system. Both prosumers and microgrids empower communities to take control of their energy future, promoting sustainability and self-sufficiency. Factors that dictate energy management includes Load Forecasting, Load Profiling, Load Scheduling etc. Load forecasting plays vital role for the efficient and reliable operation of modern energy system. They enable effective integration of renewable energy sources, enhance grid stability, contribute to cost savings and sustainability goals. This is essential for meeting the growing demands and challenges for the energy sector.

To achieve an efficient energy management system, an accurate forecasting, load profiling and load scheduling based on tariff and Renewable Energy availability is utmost important. Various forecasting techniques have been studied and analyzed for load forecasting, including Time Series Analysis and Artificial Intelligence based methods. Auto Regressive Integrated Moving Average (ARIMA) and Auto Regressive Integrated Moving Average with exogenous variables (ARIMAX). ARIMA, ARIMAX are classical techniques, time series analysis whereas Artificial Neural Network (ANN), Wavelet and Artificial Neural Network (WANN) and others are AI based. Each technique has its own benefits. ARIMAX models are faster and requires less computational power compared to Long Short-Term Memory (LSTM) and ANN model, making them suitable for applications with limited resources.

Load scheduling, like load forecasting is an utmost important part of energy management system. Load scheduling involves strategically planning and controlling the distribution of electric loads to optimize energy usage and cost. Effective load scheduling aims to balance supply and demand, minimize energy cost, reduced peak load and enhance the reliability of the existing system. The present work proposes to develop a Load Management System which is meant for different kind of loads at present mainly with their prediction, Time of Use and followed by Renewable Energy availability and integration. A case study was needed to understand the nature of domestic load variation pertaining their time of use in a day, run time etc. We have explored various feature selection techniques to select appropriate parameters for scheduling household appliances and Energy Storage Systems (ESS) and found that Weighted K nearest neighbor method (WKNN) excels in selecting features compared to Complex Tree, Gaussian SVM (State Vector Machine) and Bagged Trees method, which in turn contributes towards an efficient Energy Management System (EMS). The reliability and sustainability of an EMS can be enhanced by incorporating ESS. ESS helps to balance supply and demand, maintaining grid stability by storing excess energy during low demand and releasing it during high demand leading to cost savings. On the other hand, ESS facilitates the

integration of renewable energy sources, which are intermittent by nature. The integration of renewable energy sources into the existing grid presents both advantages and disadvantages. On the negative side, the most well-known disadvantage is the stability issue, due to the intermittent nature of renewable energy, which can affect grid reliability. However, on the positive side, renewable energy offers a crucial solution for reducing dependence on coal, lowering carbon emissions and promoting environmental sustainability. Proper utilization of renewable sources can also provide economic benefits, particularly through participation in the electricity trade market.

In this context, tariff structures play a crucial role by encouraging efficient energy usage and helping to balance the integration of renewable sources into the grid, ensuring both economic and operational sustainability. It plays a crucial role in shaping energy consumption patterns and cost management. Time Of Use (TOU), Demand Charges, Real Time Pricing (RTP) are the different tariff schemes which have been studied and implemented in the designed EMS.

Finally, a Tri-Optimized Tariff (TOT) has been proposed, an AI-based dynamic scheme that supports cost optimization, load balancing and promotes energy efficiency among prosumers. The demand profiles of residential prosumers are influenced by geographic conditions and demographics, making the use of an appropriate optimization technique essential to the design and operation of the energy management system. It drives efficiency, cost effectiveness and sustainability ensuring that energy resources are utilized optimally while meeting the demands of reliability, environmental standards and economic feasibility. Implementation of robust optimization methods is essential for modern energy management in the face of increasing energy demand and the transition towards renewable energy sources. In this context, we have explored various optimization techniques, culminating in the development of a hybrid technique merging Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) etc and finally, we have proposed a novel hybrid synergic swarm approach that incorporates the strength of PSO and ACO with a specific focus on addressing Multiple Knapsack problems (MKP). The effectiveness of the proposed technique has been tested in IEEE 33 bus system which is commonly used for power flow analysis due to its moderate size and complexity, making it manageable for testing different algorithms and techniques. The outcome demonstrates the efficiency and real-world potential of our model. We have conducted a case study and developed an AI based Strategic Residential Load Management System (SRLMS) showing cost effectiveness and improved energy performance index (EPI) for prosumers. This work encourages the development of a harmonious relationship between utility sectors and prosumer