A Review of Load Demand Estimation and Prediction Models (LDEPMs) For Microgrid Projects

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Abstract— **The global shift towards sustainable and reliable energy sources projects has prompted an increasing focus on load demand estimation and prediction. These projects can potentially transform the lives of millions by providing access to electricity. The purpose of this review article is to keep readers up to date on the most recent developments in load demand estimation and prediction for microgrid projects, in order to ensure optimal power management. This review article will serve as a basis for evidence-based decision-making and provide significant insights for policymakers, researchers, and professionals engaged in the building and sustainability of micro-grid initiatives in rural communities. The study highlights how crucial it is to make the choice of selecting relevant input variable (factors) of a load demand estimation and prediction model (LDEPM) as rational selection of input variables (factors) based on experience could be imperative. The study also centered on employing robust data pre-processing techniques, utilizing advanced methodologies. The study highlights the benefits of optimizing load demand estimation and prediction models for energy management, system efficiency, and reliability using artificial intelligence methods and its integration with machine learning and other metaheuristic techniques for improved prediction accuracy. The study also emphasizes on the need for risk management for load demand estimation and prediction models to ensure reliable and sustainable energy supply. Findings from the studies will serve as a basis for evidence-based decision-making and offers important insights to practitioners, researchers, and policymakers involved in the development and sustainability of microgrid initiatives in rural locations.**

Keywords— Microgrid, Prediction Models, Planning, Sustainability, Load Demand, Rural Community.

I. INTRODUCTION

Despite the United Nations' seventh objective of universal access to electricity for all United Nation, many cities and villages around the world continue to have restricted access to electricity [1, 2]. This has resulted in most remote areas experiencing blackouts and having restricted access to electricity from the power system [3].

In the past, the majority of developing countries that made an effort to improve access to electricity did so primarily through grid extension, emphasizing communities closer to the grid or larger urban areas while excluding a sizable portion of the population residing in inaccessible rural areas [4]. This has proven to be expensive and challenging while also leaving those remote communities that are inaccessible in blackouts, hence the urgent need to deploy microgrid projects especially to the rural communities that are inaccessible as a result of difficult geographical location and bad road network linking those communities. In deploying these microgrid projects, there is the need for accurate load demand estimation and prediction models (LDEPMs).

Utilities require planning at several levels of the power system if they are to ensure continuity of supply and fulfill the objective of universal access to electricity for everyone. In order to attain these sustainable power supply, load demand estimation and prediction becomes crucial [5-8].

While, conventional power systems networks have various measures for mitigating power imbalance issues through frequency regulations of inertia and prime movers, renewable energy based microgrids on the other hand often lacks inertia and hence relies on accurate load demand prediction to ensure power balance.

Many microgrid projects have failed due to power imbalances resulting from the microgrid generating more or less power than it can consume [9, 10]. Power imbalances overload strained the microgrid, thereby increasing operational costs, and resulting in frequent blackouts which eventually result in total system collapse [11, 12]. This has created so much fears for many investors, a drop in economic activities for the rural dwellers benefiting from the microgrid, as well as inadequacy of information for planning and decision making.

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Also, different load demand estimation and prediction models have been developed for microgrid, these models often rely on the data from urban and industrial microgrids. However, the load profile and usage patterns in microgrids projects of rural communities have shown departure due to different factors (input variables).

A precise and accurate load demand estimation and prediction tool is needed to ensure effective power management, which can provide financial benefits for consumers and the power industry, as well as to predict the quantity of electricity that must be supplied by existing power generation resources for their steady and profitable operation [13]. As a result, consumers and power utility companies would pay less for electricity, which might promote economic growth.

Load demand estimation and prediction models (LDEPM's) can help improve the reliability of microgrids. This can reduce the number of power outages, which can lead to increased productivity and reduced costs for businesses, hence attracting investments in microgrids thereby creating jobs and boosting the local economy [14].

The intent of this review article is to keep readers up to date on the most recent developments in load demand estimation and prediction for microgrid projects in rural communities, in order to ensure optimal power management.

II. CONTRIBUTIONS OF THE REVIEW PAPER

Previous research has contributed significantly to academics' understanding of load demand estimation and prediction for microgrid projects, however, there are limited studies discussing the selection and ranking of influential input variables affecting load demand in the design of LDEPM's. There is also a limited study on the load profile of rural microgrids and the integration of multiple pre-processing techniques for more robust data pre-processing models. Despite the advantages of artificial intelligence, such as sensitivity, adaptability, uncertainty handling, interpretability efficiency, and high prediction accuracy, there is limited research on its integration with other metaheuristics techniques and machine learning algorithms for better load demand estimation and prediction in rural communities. Additionally, risk management and mitigation strategies in LDEPM's are scarcely reported in literature before now.

To bridge the aforementioned gap, this paper provides an in-depth review of load demand estimation and prediction models classification based on time horizon and modelling technique, procedures for load demand estimation and prediction, review of related work on load prediction of microgrid projects, after which research gaps from related work as well as conclusion for future work will be drawn.

This paper will serve as a basis for evidence-based decision-making and provide significant insights for policymakers, researchers, and professionals engaged in the building and sustainability of microgrid projects in rural communities.

III. SYSTEMIC LITERATURE REVIEW

The detailed and predefined procedure for finding, evaluating, and synthesizing prior research on the topic of LDEPM's for microgrid projects in rural communities is described by Figure 1, to minimize bias and ensure the trustworthiness of the review.

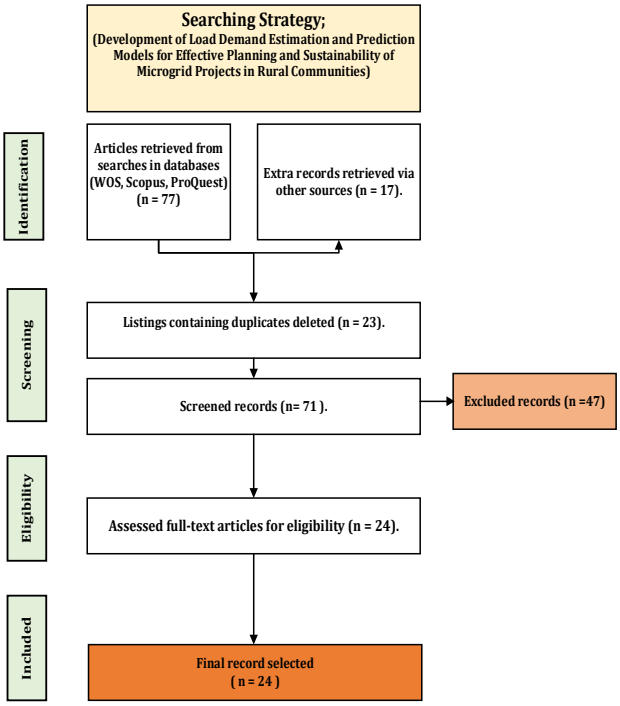

Figure 1: PRIMA Model for Paper Selection

IV. CLASSIFICATION OF LOAD DEMAND ESTIMATION AND PREDICTION MODELS

There are several ways to estimate and predict the load demand for microgrid systems which can be classified based on time horizon and modelling techniques. Each of these methods has its own set of advantages and disadvantages as presented in Figure 2 and Figure 3 respectively with the hybrid methods presented in Table 1.

Table 1: Hybrid Method of Load Demand Prediction

Hybrid models with two Methods	Ref
SVR-LSTM	[15]
HHO-FFN	[16]
DA-SVM	[17]
Fuzzy and Fuzzy-PSO	[18]
GA-PSO-ANFIS	[14]

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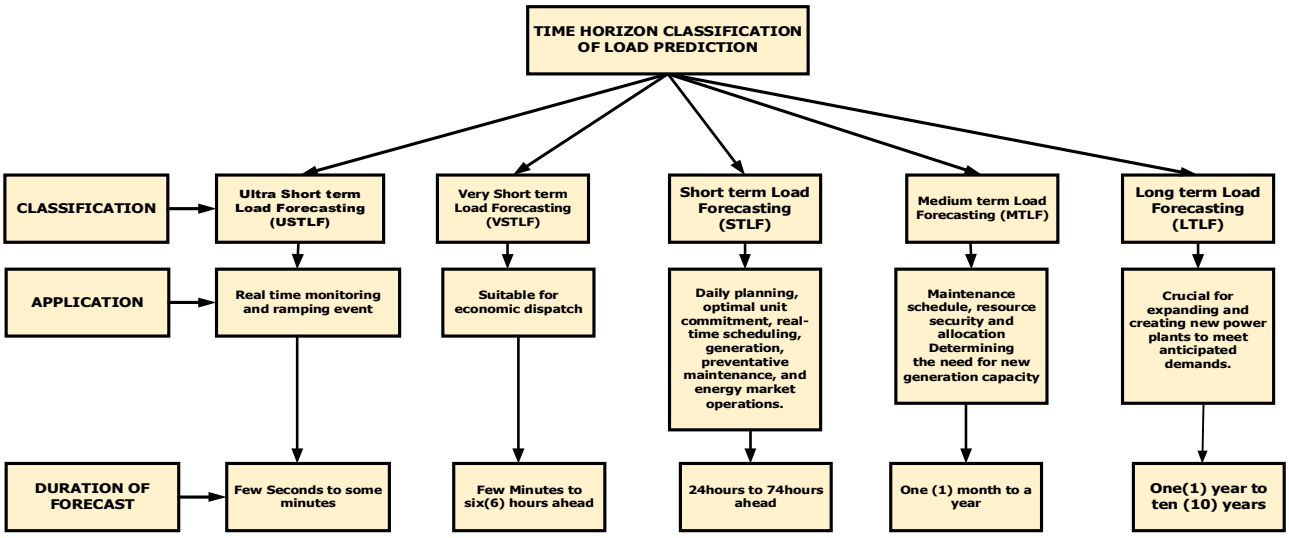

Figure 2: Classification of Load Prediction Based on Time Horizon

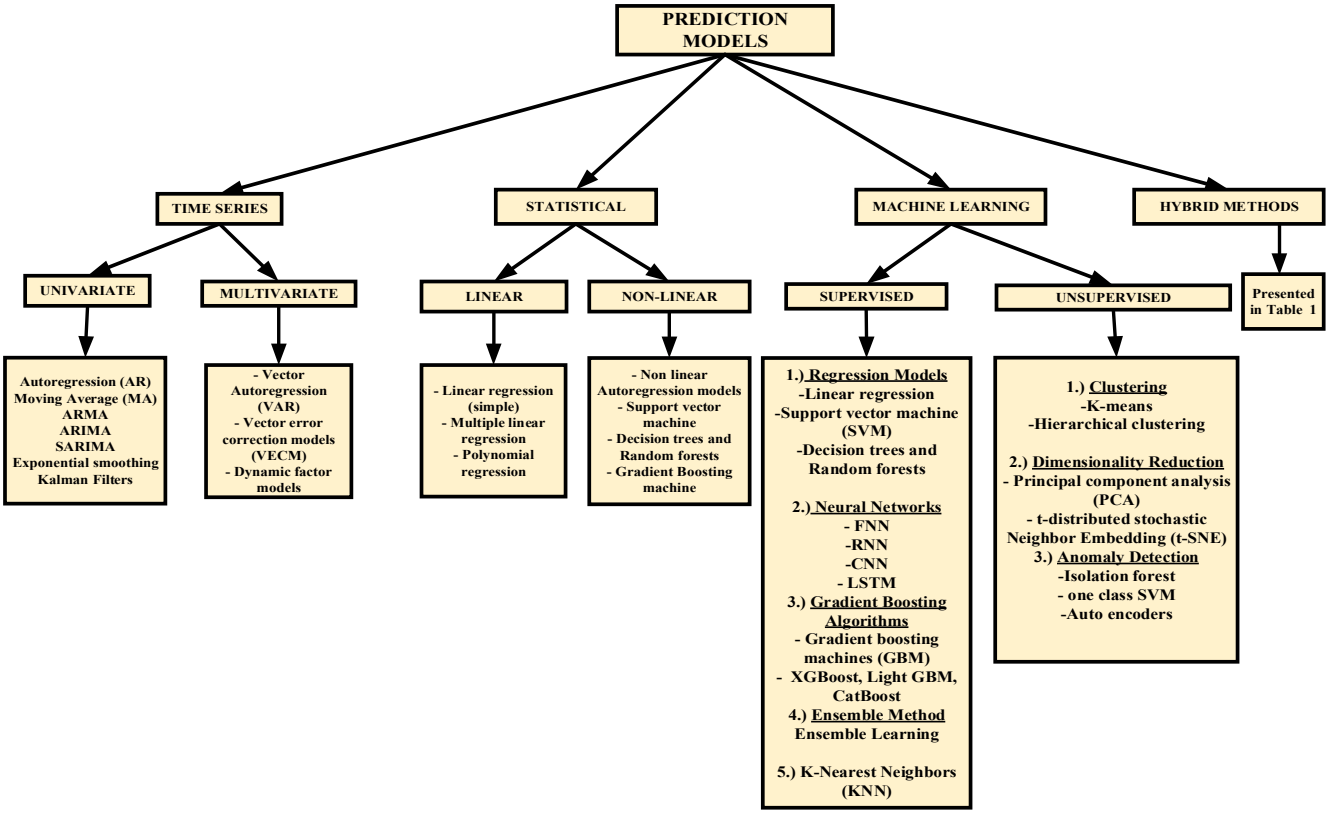

Figure 3: Classification of Load Prediction Based on Time Horizon

V. THEORETICAL FRAMEWORK FOR THE DESIGN OF LDEPM'S

As stated in the work of Al Mamun, et al. [19] there are various phases and stages to designing an accurate LDEPMs. The specific methods and techniques used in each stage or phase will vary depending on the specific microgrid project and the availability of data. A structured framework is presented in Figure 4.

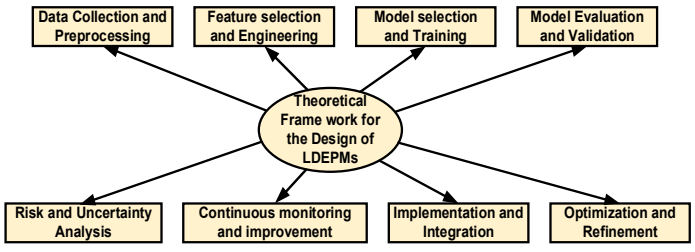

Figure 4: Framework for the Design of LDEPMs

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I. REVIEW OF RELATED WORKS

A short-term load prediction model based on DA-SVM was proposed in [15] for an offshore oil field microgrid. The model outperformed other algorithms, reducing computational time by 50% and achieving an RMSE of 1.5%. However, limitations include relying on industrial microgrid load profiles, limited information on the risk assessment for the LDEPM, no physical implementation or real-data integration, and an unclear selection method for input variables.

Short-term load forecasting for a rural microgrid in Africa via hybrid support vector regression and long short-term memory algorithms (SVR-LSTM) was proposed in [20]. According to the study, the SVR-LSTM model that has the highest correlation coefficient—0.9901—performs better than the LSTM and SVR models, which have correlation coefficients of 0.9809 and 0.9770, respectively. However, a major limitation with the study is that of complexity of the model as well as the authors where mute regarding the risk assement of the LDEPM

Short-Term Load Forecasting of Microgrid Based on Chaotic Particle Swarm Optimization was proposed in the work of [21]. The experimental simulation's results show that the method can improve learning, which raises prediction accuracy, in addition to lowering the probability that the algorithm would reach a local extremum. The model made use of typical load, load from meteorological factors and special load as input to the model without proper description as to why and how the inputs were selected. Also, no data preprocessing technique was mentioned in the study.

A fuzzy-swarm intelligence-based short-term load forecasting model was proposed in [22] to predict microgrid load demand. The model innovatively combined fuzzy logic and PSO, and introduced error correction factors (ECF) to enhance performance. However, the study lacked clarity on input variable selection and data preprocessing techniques, and did not address risk assessment of the LDEPM.

Microgrid Load forecasting Based on Improved Long Short-term Memory Network for a local microgrid in Zhejiang province, China was proposed in [23]. More benefit was shown by the improved LSTM algorithm in terms of accuracy and convergence speed. However, a major limitation of the study was on the Complexity of the model. The authors were also silent on the risk assement of the LDEPM.

Short-term load forecasting for microgrid energy management system using hybrid SPM-LSTM was proposed in [24]. prediction model's input variable selection criteria were not made explicit. Regarding the LDEPMs' risk assessment, the authors remained mute as well.

II. RESEARCH GAPS AND FINDINGS FROM PREVIOUS STUDIES

Previous studies have shown limited research on selecting and ranking input variables that impact load demand in LDEPM's. Traditional methods rely on literature review and expert experience, but a method for analyzing and ranking these factors is crucial. Most research focuses on urban or industrial microgrid load profiles, while rural microgrid load profiles differ due to different factors. There is also limited work on integrating AI with ML and other metaheuristic algorithms for load prediction in rural microgrids. Data-preprocessing techniques need to be integrated to improve robustness and ensure quality and reliability of input data. Physical implementation and integration of prediction models and risk management are also lacking. Addressing these research gaps can provide evidence-based decision-making and valuable insights for practitioners, researchers, and policymakers.

VIII. CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

In conclusion, this study highlights the importance of selecting and ranking relevant factors, employing robust data pre-processing techniques, and utilizing advanced methodologies and risk management for LDEPM's. These findings provide valuable insights for stakeholders involved in energy projects, aiming to address energy access challenges and promote sustainable development in rural communities.

Future studies should focus on developing methods for selecting and ranking input variables, integrating AI and ML in LDEPM's, and implementing risk management strategies to ensure reliable and sustainable energy supply.

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