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Future Load Energy Forecast of Stone-City, Mgbede Community Rural Electrification Scheme

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Abstract- Electrical power system consists of power generation, transmission, and distribution. Rural Electrification is the process of bringing electrical power to rural and remote areas. Rural communities are suffering from massive market failures as the national grids fall short of their electricity demand. This study is focused on the future load energy forecast, and rural electrification system for Stone-City, Mgbede community in Rivers State, Nigeria. The energy forecast for rural electrification indicates a promising trajectory toward increased energy access in underserved regions. The anticipated rise in energy demand, coupled with the deployment of renewable energy sources such as solar and wind, suggests a sustainable path forward. These advancements are poised to significantly enhance the quality of life, economic opportunities, and social services in rural areas. The load forecast for different areas in Stone-City Mgbede Community in Table 5 shows 10 years of energy forecast in the ratio of 5:3:2. However, achieving these goals is not without its challenges. Financial limitations, infrastructure gaps, and technical hurdles must be addressed to ensure the success of rural electrification initiatives. We recommend focusing on policy frameworks that incentivize renewable energy investments, developing robust financing models, and investing in capacity-building programs for local technicians and engineers. Additionally, fostering community engagement and ownership can drive the long-term sustainability of these projects. Looking ahead, the integration of smart grid technologies and energy storage solutions could further revolutionize rural electrification, making it more resilient and efficient.

Keywords- Energy Forecast, Future Load, Stone-City Mgbede Community, Rural Electrification, National Grids

I. INTRODUCTION

The electrification of rural communities is crucial for improving living standards and fostering economic development in these areas (Adebayo & Adeyemi, 2018). Stone-City Mgbede, a rural community located in the Ogba/Egbema/Ndoni local government area of Rivers State, Nigeria has been the focus of various electrification projects in recent years. The introduction of the electrification scheme has not only provided access to electricity but has also enabled the community to utilize modern amenities, healthcare services, education, and communication tools. However, ensuring a reliable power supply requires accurate forecasting of energy demand, as electricity consumption is influenced by various socio-economic, demographic, and technological factors (Bello & Omoniyi, 2020). The ability to predict future energy demand is essential for effective planning of power generation, distribution, and infrastructure development to meet the projected needs of the

community. Electrical power system consists of power generation, transmission, and distribution. Rural Electrification is the process of bringing electrical power to rural and remote areas. Rural communities are suffering from massive market failures as the national grids fall short of their electricity demand. Essentially, the idea of rural electrification refers to the electricity supply to areas outside of cities. However many scholars have given their perceptions in different interpretations.
Stone-City Mgbede is a rural community with a population of approximately five thousand residents. The community includes residential households, schools, healthcare centers, and small industries (Oladele & Ogundipe, 2021). The electrification project in the area began in 2001. Access to electricity has led to various socio-economic improvements within the community. However, ongoing population growth and changes in the community's structure are expected to affect future energy needs. It is essential to consider these factors when projecting future energy demands and aligning them with the overall goals of rural electrification (Ishaku & Ajayi, 2019).

Transformers are electrical machines used in transforming voltages from one level to another level in a power system or electrical instrument. The transformers used in power systems fall into two categories. These are the power transformers used in transmission lines and distribution transformers used in distribution lines. The special transforms used in instruments are called instrument transformers. There are two types according to the electrical parameter it transforms. Those instrument transformers that transform current are called current transformers while those that transform voltage are called voltage transformers. Transformers are by far the most efficient electrical machine. This high efficiency is due to the absence of moving parts (Ijeoma, 2021).

In a power system, high voltages are required for transmission in order to minimize the voltage drop and power loss along the line. Transformers are used in stepping up the generation voltage to transmission line voltage. Transformers used in this way are called step-up transformers. At the distribution end, the transmission line voltages are transformed to low distribution line voltages. The transformers used in this application are called step-down transformers. From the above, we can see that the transformer is a very vital machine in the electrical industry (Gupta, 2013).

Oyejide et al. (2014) explain that rural electrification often impacts greatly in rural lives. Apart from improving the living standards of the dwellers, it is a catalyst for overall rural development. It assists in reducing rural-urban migration which in turn helps alleviate urban congestion and its associated social vices such as poverty and crime. It also helps to promote political stability and increase social virtues such as improved health care delivery, creation of employment, upliftment of the education system, and social cohesion and development in rural communities.

Just as no human can survive without the flow of blood, no nation or city can thrive without reliable electricity. Developed nations have harnessed consistent electricity to achieve and maintain their current status. Today, they enjoy years of uninterrupted power supply, which has enabled their industries, utilities, hospitals, and schools to provide comfortable living conditions for their citizens. No country can transition from underdevelopment to development without access to reliable electricity; without reliable electricity, there can be no development. Sustainable progress has continued to elude Nigeria as a nation due to its lack of dependable electricity (Ibinabo and Ijeoma, 2019).

Electrical energy has countless applications in homes, industries, agriculture, and transportation. In economically developing countries like Nigeria, the demand for electrical power is increasing rapidly. As a result, power distribution networks are becoming heavily loaded, which has made the development of effective protection schemes a significant concern for many substations within these networks. Numerous studies have been conducted on electric power distribution protection, and various solutions have been proposed to enhance the protection of distribution networks (Ijeoma and Amadi, 2024).

Munasinghe (2021) stated that rural electrification, on its own, does not necessarily cause the development of rural areas. He continues by concluding that it can provide a stimulus to economic activity, especially in the service sector and where the necessary conditions are present it can have a major impact on the form that development takes.

Alie (2016) reported that in Costa Rica after the electrification of rural areas particularly dairy and poultry farms used electricity widely. These farms usually switched from their diesel generation to grid electricity. The smaller farms did not use electricity for their farm tasks, only for domestic purposes. Thus, the idea that rural electrification generally enhances productive farming activities was not confirmed.

Stockton (2016) said that the design of a distribution substation and transformers plays a central role. It takes place in several stages in sequence, starting at the generating plant where the voltage is increased for transmission purposes and is progressively reduced in the substation for distribution to household or industrial uses.

According to Pooler (2014), a distribution substation uses a circuit breaker or fuse for the protection of distribution circuits. Substations do not usually have generators, although a power plant may have a substation nearby. Other devices such as capacitors and voltage regulators may also be located at a substation.

II. MATERALS AND METHOD

The energy load forecast for the Stone-City Mgbede community was carried out using a combination of historical data analysis, demographic projections, and energy consumption trends. The study employed the following steps:

Location of Available Grid System

In designing an efficient and reliable electricity supply system, the first step of the project design phase is to locate the nearest available grid system within the area of interest. The community is located some meters away from the existing 11KV grid system in Mgbede Clan in Ogba/Egbema/Ndoni Local Government Area of Rivers State belonging to Oando Energy Resources Nigeria Limited.

Load Survey and Analysis

This involves visitation to Stone-City Mgbede, observing the community conditions, checking topographies, and determining the quantity and characteristics of consumers. The Community consists mainly of a Residential Building, Town Hall, Churches, Schools, and Market. Maximum demand will occur in the evening when all equipment is in operation.

Future Load Forecast

Forecasting future load energy for rural electrification involves predicting the amount of electricity that will be needed to support rural areas over a specified period. This process is crucial for planning and ensuring a reliable supply of electricity. Here are some key steps and considerations involved in creating such a forecast.

Data Collection

- **Historical Load Data:** Collect past energy consumption data.
- **Population and Demographics:** Understand the population growth, age distribution, and migration patterns.
- **Economic Activities:** Analyze the primary economic activities, such as agriculture, small-scale industries, and services.
- **Electrification Rate:** Consider the current level of electrification and future expansion plans.
- **Seasonal Variations:** Account for seasonal changes in energy consumption.

Energy Demand Drivers

- **Household Consumption:** Estimate the energy needs of households, including lighting, cooking, and appliances.

- **Commercial and Industrial Usage:** Predict the energy needs for commercial and small industrial activities.
- **Agricultural Demand:** Consider energy needs for irrigation, processing, and storage.

Technological Advancements

- **Energy Efficiency:** Include potential improvements in energy efficiency through the adoption of modern appliances and equipment.
- **Renewable Energy Integration:** Factor in the potential for solar, wind, or other renewable energy sources.

Policy and Regulatory Environment

- **Government Policies:** Consider government plans and policies for rural electrification and subsidies.
- **Tariff Structures:** Analyze how electricity pricing might affect consumption patterns.

Modeling and Forecasting Techniques

- **Time Series Analysis:** Use historical data to predict future consumption trends.
- **Regression Analysis:** Correlate energy demand with socio-economic variables.
- **Simulation Models:** Create scenarios based on different assumptions about future developments.
- **Machine Learning:** Implement advanced techniques like machine learning for more accurate predictions.

Community Engagement

- **Surveys and Interviews:** Gather insights directly from rural residents to understand their current and future energy needs.
- **Participatory Planning:** Engage the community in planning processes to ensure the forecasts align with their expectations and realities.

Scenario Planning

- Develop different scenarios (e.g., optimistic, pessimistic, and baseline) to account for uncertainties and varying future conditions.

Infrastructure and Supply Constraints

- Consider the capacity of existing infrastructure and the feasibility of expanding the grid or using off-grid solutions.

By integrating these factors, planners and policymakers can develop a comprehensive and realistic energy load forecast for rural electrification. This ensures that the electrification efforts are sustainable and can adequately support the development needs of rural communities.

Design Criteria

To ensure that our design meets technical quality standards, the engineering aspects must adhere to established guidelines and specifications. Below are some key criteria to consider. The community is divided into three areas for effective load balancing.

This paper provides a regression-based forecast of electrical load demand for Stone City, a rural settlement in the Mgbede Community, covering the years 2020 to 2030. The model uses multiple linear regressions to analyze the relationship between load demand and various demographic and socioeconomic factors, including population size, number of households, appliance ownership, income levels, and electrification rates. Accurate load forecasting is crucial for planning rural electrification systems, sizing mini-grids, and making investments in energy infrastructure.

Considering the size of each community area, an allowance of 30% of the known load is allowed for future load demand for ten (10) years in a ratio of

Multiple Linear Regressions

The regression equation is:

$$Load_t = B_0 + B_1 \times P_t + B_2 \times H_t + B_3 \times A_t + B_4 \times I_t + B_5 \times E_t + \epsilon t \quad (1)$$

Where:

$Load_t$: Estimated daily peak load in kW in year t

P_t: Population in year t

H_t: Number of households

A_t: Average appliance ownership per household

I_t: Average income level (proxy for appliance demand)

E_t: Electrification rate (0–100%)

$\beta_0, \beta_1, \ldots, \beta_5$: Regression coefficients

ϵt: Error term (assumed normally distributed)

Table 1: 10-Year Load Forecast for Stone-City, Mgbede Community

Year	Population	Households	Appliances/HH	Income (₦)	Electrification (%)	Forecast Load (kW)
2020	900	150	4	25000	0.2	10
2021	950	160	5	28000	0.3	14
2022	1020	170	6	31000	0.4	18
2023	1085	185	7	33000	0.5	24
2024	1160	195	8	35000	0.6	30
2025	1240	210	9	37000	0.7	36
2026	1320	225	10	39000	0.8	42
2027	1410	240	11	41000	0.85	47.9505
2028	1500	255	12	43000	0.9	53.90099
2029	1595	270	13	45000	0.95	59.85149
2030	1700	290	14	47000	1	65.80198

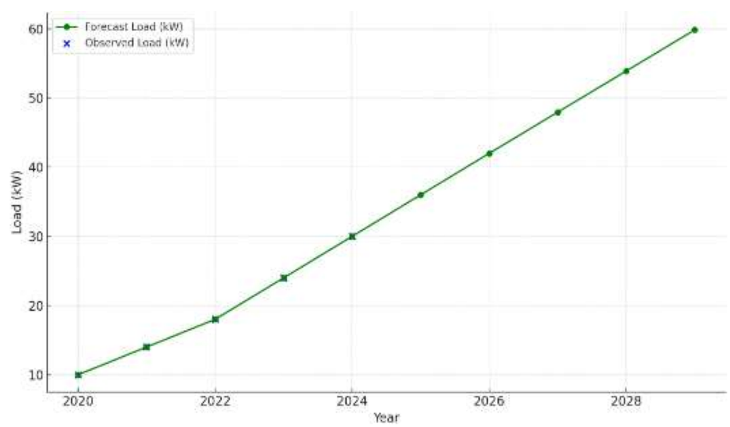

Figure 1: Graph for a 10-year load forecast for Stone-City, Mgbede Community

Table 2: Total Load demand of Stone-City, Mgbede Community Area One

S/N	Category of Buildings	Number of Buildings	Estimate of Consumption Per Category of Buildings (KW)	Initial Total Load Demand Per Category of Buildings (KW)
1	Bungalow	41	5.50	225.5
2	Story Building	2	9.63	19.26
3	Shop	3	1.80	5.4
4	Nursery /Primary School	1	1.3	1.3
5	Secondary School	0	1.3	0
6	Church	3	3.25	9.75
7	Mosque	0	1.7	1.7
8	Mini Industry	1	8.7	8.7
Total				290.21

Table 3: Total Load demand of Stone-City, Mgbede Community Area Two

S/N	Category of Buildings	Number of Buildings	Estimate of Consumption Per Category of Buildings (KW)	Initial Total Load Demand Per Category of Buildings (KW)
1	Bungalow	36	5.50	198
2	Story Building	1	9.63	9.63
3	Shop	5	1.80	9
4	Nursery /Primary School	0	1.3	0
5	Secondary School	0	1.3	0
6	Church	2	3.25	6.5
7	Mosque	0	1.7	0
8	Mini Industry	3	8.7	60.9
Total				277.09

Table 4: Total Load demand of Stone-City, Mgbede Community Area Three

S/N	Category of Buildings	Number of Buildings	Estimate of Consumption Per Category of Buildings (KW)	Initial Total Load Demand Per Category of Buildings (KW)
1	Bungalow	45	5.50	247.5
2	Story Building	0	9.63	0
3	Shop	7	1.80	12.6
4	Nursery /Primary School	0	1.3	0
5	Secondary School	1	1.3	1.3
6	Church	3	3.25	9.75
7	Mosque	1	1.7	1.7
8	Mini Industry	1	8.7	8.7
Total				281.55

$$Load\ Factor = \frac{Average\ demand}{Maxmum\ demand} \quad (2)$$

$$Anual\ Load\ Factor = \frac{Number\ of\ units\ actually\ supplied\ in\ a\ year}{Maxmum\ power\ demand\ \times 8760} \quad (4)$$

$$Load\ Factor = \frac{Units\ generated\ in\ a\ given\ period}{Maxmum\ demand\ \times\ Number\ of\ hour\ of\ operation\ in\ a\ given\ period} \quad (3)$$

Table 5: Load forecast for different areas in Stone-City, Mgbede Community

S/N	Different Areas of the Community	Total Load Demand per area (kW)	15% Forecast for 1st phase (5 years)	10% Forecast for 2nd phase (5 years)	5% Forecast for 3rd phase (5 years)	Total load demand for the community in 10 years (kW)
1.	Area one	290.21	43.53	29.02	14.51	376.97
2.	Area two	277.09	41.56	27.71	13.86	359.72
3.	Area three	281.55	42.23	28.16	14.08	366.02

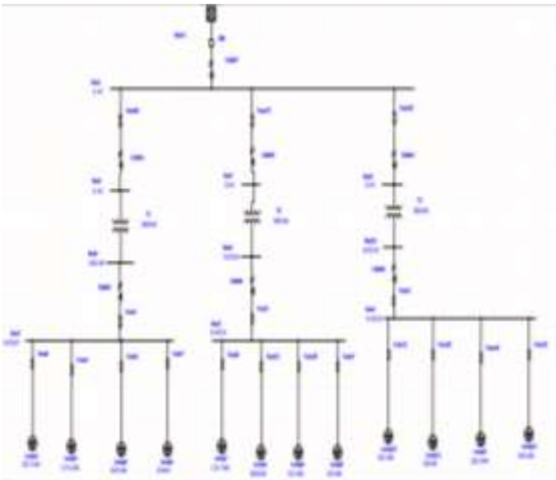

Figure 2: Singe Line Diagram

III. RESULTS AND DISCUSSION

The forecast presented in Table 1 and Figure 1 indicates a steady increase in electrical load over the next decade. This rise is primarily driven by population growth, increased appliance usage, and the expansion of electrification. By 2030, the estimated peak load is projected to exceed 65 kW, which is more than six times the estimated demand recorded in 2020. This information will be instrumental in planning and optimizing rural mini-grid systems, ensuring that they are scalable, reliable, and cost-effective.

Load flow simulations produce results based on single line diagrams and generate reports that detail calculated bus voltages, including their magnitude, angle, current, and power flow throughout the electrical network. The output data for different equipment configurations was analyzed using the ETAP Load Flow Result Analyzer, which presents the information in a concise and summarized format. To ensure proper operation, the sizing of transformers, bus bars, and circuit breakers should be carried out through load balance studies in conjunction with the aforementioned software simulations.

Load Flow

Load flow studies must include calculations and diagrams that illustrate the distribution of loads under anticipated abnormal operating conditions, such as the loss of a generator, feeder, or transformer due to faults or maintenance. System losses should also be calculated and shown on the diagrams. As part of the load flow studies, voltage drop and voltage regulation calculations must be conducted. These calculations will establish the voltage profile of the network under both full load and light/no load conditions.

The results from these load flow studies will be used to verify the following:

- System voltage profile and phase angles
- Transformer ratings and loadings
- Power losses
- Transformer tap settings and ratings

Load Flow Studies

Load flow studies are conducted to determine all bus voltages, branch power factors, currents and power flows within the electrical system. The load flow reports will detail the magnitude of active (real) power and reactive power supplied by transformers, feeders, and bus bars, along with the total connected load. Load flow diagrams will be created for both the main and essential systems, indicating kilowatts (kW), kilovolt-amperes reactive (KVAR), bus bar voltages, and voltage phase angles.

IV. CONCLUSION

The future load energy forecast for the Stone-City Mgbede Community Rural Electrification Scheme highlights the need for proactive planning and investment in energy infrastructure. By incorporating population growth, energy consumption trends, and technological developments into the forecasting model, this study provides valuable insights into the community's long-term energy requirements. The findings of this research can assist policymakers, energy providers, and local authorities in making informed decisions that ensure a sustainable, reliable, and affordable energy supply for the Stone-City Mgbede community (Oladele & Ogundipe, 2021; Sambo & Oparaku, 2017). Rural Electrification is the process of bringing electrical power to rural and remote areas. Rural communities are suffering from colossal market failures as the national grids fall short of their electricity demand. The energy forecast for rural electrification indicates a promising trajectory toward increased energy access in underserved regions. The anticipated rise in energy demand, coupled with the deployment of renewable energy sources such as solar and wind, suggests a sustainable path forward. These advancements are poised to significantly enhance the quality of life, economic opportunities, and social services in rural areas. Load forecast for different areas in Stone-City, Mgbede Community in Table 5 shows 10 years energy forecast in ratio of 5:3:2. However, achieving these goals is not without its challenges. Financial limitations, infrastructure gaps, and technical hurdles must be addressed to ensure the success of rural electrification initiatives. It is imperative that stakeholders, including government bodies, private investors, and local communities, collaborate effectively to overcome these obstacles. To support this endeavour, we recommend focusing on policy frameworks that incentivize renewable energy investments, developing robust financing models, and investing in capacity-building programs for local technicians and engineers. Additionally, fostering community engagement and ownership can drive the long-term sustainability of these projects. Looking ahead, the integration of smart grid technologies and energy storage solutions could further revolutionize rural electrification, making it more resilient and efficient. With continued innovation and dedicated effort, the vision of universal energy access in rural areas is within reach, paving the way for a brighter and more equitable future.

Recommendations

- **Sustainability Focus:** The energy supply should be diversified by incorporating renewable sources, such as solar and wind, to reduce reliance on non-renewable fuels.
- **Energy Efficiency Programs:** Community-wide initiatives aimed at promoting energy-saving practices should be implemented. These initiatives will encourage the use of energy-efficient appliances and help reduce per capita energy consumption.
- **Community Awareness:** Educational programs should be introduced to inform the community about the benefits of energy efficiency and renewable energy sources, thereby enhancing participation in energy conservation efforts.

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