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Original Article

Evaluation of Standalone Power Generators and Distribution Network of Federal Polytechnic Ile-Oluji, Ondo State, Nigeria

Olamiposi Ibukun Dare-Adeniran[1], Thomas Olabode Ale[2], Ifeanyi Charles OJI[3], Opeyemi Amodu Aliyu[4]

[1,2,3,4]*Department of Electrical/Electronic Engineering, Federal University of Technology, Akure, Nigeria.*

[1]*Corresponding Author : oladareadeniran@fedpolel.edu.ng*

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Abstract - *This research evaluates the power infrastructure at the Federal Polytechnic, Ile-Oluji, Ondo state, Nigeria. The polytechnic relies solely on standalone generators because the institution is yet to be connected to the grid. The study aimed to evaluate the current standalone power generators and propose a central powerhouse for efficiency and cost-effectiveness. Key objectives included mapping the existing power infrastructure, evaluating building-specific load demands, identifying challenges with current generators, and proposing optimized power solutions. Data collection involved recording load demands for all campus buildings and measuring current at main generator breakers. To enhance scalability and cost reduction, seven existing generators serving seven different buildings were synchronized. Centralized power placement decisions were influenced by building clusters and space availability. Load flow analysis was conducted using ETAP software, which revealed the network performance to be 46.3% of total generator loading and a maximum voltage drop of 2.32% when all seven generators were synchronized. This configuration met permissible voltage conditions and indicated potential for increased load efficiency. To ensure efficiency and reliability, (4) 350 kVA generators were identified as the optimal combination to power the entire campus, achieving an 82% total generator loading. Economic analysis revealed a capital investment of N39.3b and annual fuel savings of ₦87.2m with a payback period under a year after implementation and an anticipated projected profit of ₦41.2m. The proposed synchronized power model for FEDPOLEL offers enhanced reliability, efficiency, and significant economic benefits. The institution's power needs were met with a return on investment, validating its feasibility and profitability.*

Keywords - *Economic analysis, ETAP software, Grid, Load flow analysis, Standalone generators, Synchronization.*

1. Introduction

In an era defined by increasing demands for reliable and sustainable energy sources, institutions of higher learning stand at the forefront of the challenge. Federal Polytechnic Ile-Oluji, like many educational institutions, is no exception to the need for an uninterrupted and efficient power supply. With the rapid growth of student populations, the expansion of facilities, and the growing reliance on technology for teaching and administrative functions, the Polytechnic faces a critical need to evaluate its power generation capabilities and distribution network.

Educational institutions such as Rufus Giwa Polytechnic Owo, Ondo State, and many others, particularly in developing countries like Nigeria, face energy challenges due to increasing energy demand, unreliable grid supply, and limited access to affordable and sustainable energy sources [24]. These challenges necessitate the evaluation of standalone power generation and distribution systems. Some other institutions rely on renewable energy to ensure uninterrupted power supply, such as solar power and microgrids [12]. However, improvements in operational efficiency and cost savings are particularly important in resource-constrained settings. Evaluating power generation and distribution systems can lead to significant cost savings and operational efficiency improvements for educational institutions [8].

The smooth running of Polytechnic activities depends on an uninterrupted power supply to ensure modern education methods, impacting academic performance and administrative functions [3]. The evaluation of power systems in polytechnics can lead to enhancements in these areas.

Standalone generators are widely employed across various Polytechnics, especially as emergency backup systems. Their operation, when isolated, often entails a robust and reliable power source. However, as demands for power increase, standalone systems may prove insufficient in meeting the requirements, leading to operational inefficiencies and increased costs. To increase efficiency and optimize standalone generating systems, it is necessary to consider a central powerhouse system, also known as a parallel arrangement of generators or synchronization. Among its numerous advantages is the environmental impact of the system of power generation in educational institutions. Evaluating and optimizing systems for cleaner energy sources can reduce carbon footprints and contribute to environmental sustainability [25].

Standalone generator systems have been extensively used for decades as a reliable source of backup in educational sectors. To ensure an enhancement of the performance and efficiency of generators, fuel consumption is one of the key economic values to be accessed in a generator. Mohammadi [23] examined the impact of load variations on the fuel efficiency of diesel generators. The study proposed load management strategies to optimize fuel consumption. According to Johnson [19], the authors investigated the efficiency and emissions performance of standalone diesel generators in remote communities. They emphasized the need for optimizing fuel consumption and emissions control to enhance sustainability.

Ensuring the reliability of standalone diesel generators is essential, especially in applications where power interruptions can have severe consequences. Recent research by Khosravi [20] explores the application of machine learning and predictive maintenance techniques to enhance the reliability of diesel generator systems. Their work demonstrates how data-driven approaches can predict component failures and improve maintenance strategies.

While standalone power generation offers numerous advantages, it is not without challenges. These systems require substantial initial investment, maintenance, and skilled personnel for operation. Inadequate maintenance can lead to system failures. Jallow [18] discussed the importance of proper operation and maintenance of renewable energy systems in educational institutions. Additionally, regulatory and policy challenges can affect the deployment of standalone power generation systems.

A study by Itodo [17] and Goswami [16] evaluates the financial and managerial aspects of the power-generating network to be of great importance as the sustainability and reliability of this system are of great necessity. Understanding the economic implications of standalone systems and parallel arrangements of generators is essential for informed decision-making.

To enhance the optimization of the power-generating network in the educational sector, it is necessary to evaluate standalone systems and parallel arrangements of generators. A recent study by Ahmed [6], titled “Enhancing Power Reliability in Polytechnic Institutions: A Case Study of Parallel Generator Arrangements,” provides valuable insights into the use of parallel generators in Polytechnic institutions. The authors present a case study of a Polytechnic institution that implemented a parallel generator system to improve power reliability. The study highlights the challenges faced, the design and control of the system, and the outcomes achieved. It also discusses the cost-effectiveness and sustainability of the solution.

A study conducted by Olaniyan [27] on “Optimizing Power Generation in Polytechnic Institutions through Parallel Generators” focuses on the optimization of power generation, load management, and the integration of renewable energy sources in Polytechnic institutions. The study suggests that parallel generators can work in conjunction with other energy sources to create more sustainable power systems for Polytechnics.

Parallel arrangements of generators offer a reliable and efficient solution for ensuring uninterrupted power supply. Recent studies indicate the feasibility and advantages of such systems in educational settings, with a focus on sustainability and cost-effectiveness.

Standalone power generation systems have gained prominence in educational institutions due to their ability to provide continuous power supply. These systems often utilize renewable energy sources, such as solar and wind, coupled with backup generators for reliability. A study by Alzubaidi [9] demonstrated the successful implementation of a solar-wind hybrid power system in a university in Iraq, highlighting its potential to reduce electricity costs and environmental impact. Similarly, Adaramola [2] investigated the feasibility of wind power in Nigerian universities, emphasizing the economic benefits and reduced greenhouse gas emissions.

A comparative study by Xie [29] and Fernandes [14] on the performance evaluation of standalone and parallel generators in terms of efficiency, fuel consumption, and reliability highlighted the advantages of parallel arrangements for large load applications, which can be suitable for educational institutions and related sectors. Similarly, an economic analysis by Zhang [31] compared the lifecycle costs of standalone and parallel systems. The research considered factors like initial investment, maintenance, and operational costs, which are paramount to ensuring the sustainability of the system.

Technological advancements are also shaping the evaluation and optimization of diesel generators. Research by Xie [29] and Acker [1] investigates the use of advanced control systems and microgrids to enhance the flexibility and reliability of parallel arrangements. Their work demonstrates how smart grid technologies can improve the responsiveness of power generation systems to varying loads.

According to Dabowsa [13], synchronization was defined as a necessary process of connecting more than one generator to an electrical power system that consists of a generator, transmission line, and supplies many widely distributed loads.

Neshti [26] opined that parallel operation allows operating generators around their rated load resulting in operating with high efficiency.

The study by Su [28] focuses on the integration of renewable energy sources into synchronized parallel systems. This research highlights the potential of hybrid configurations, where diesel generators work in tandem with renewable sources like solar and wind to ensure continuous power supply while reducing carbon emissions.

The parallel arrangement of diesel generators offers scalability and enhanced load-sharing capabilities. Recent research by Zhou [32] investigates load-sharing mechanisms in parallel arrangements, emphasizing the importance of synchronization and control. Their findings highlight the role of advanced control systems in achieving optimal load distribution.

The concept of synchronization of generators has gained traction in recent years, particularly in industries where high power demands are crucial. Research by Zhang [30] delves into the load-sharing mechanisms of parallel generators, emphasizing the importance of precise synchronization and control to achieve optimal load distribution. Their findings highlight the significance of synchronization technology in improving the performance of parallel arrangements.

The Electrical Transient Analyzer Program (ETAP) is a robust and widely used software tool for power system modelling, analysis, and simulation. Its extensive capabilities in both steady-state and transient analysis, coupled with user-friendly features, make it a valuable asset for power engineers and researchers [22]. Despite its complexity and cost, the ability of ETAP to cater for various aspects of power systems positions makes it a reliable choice for those seeking comprehensive power system analysis solutions. In a research work by [11], ETAP software was used to model the existing generating system (operating as a standalone system) and the proposed central system (synchronization method)

Federal Polytechnic Ile-Oluji (FEDPOLEL), as the case study, was established in 2014 and started operation on the 1st of April 2015. The institution moved to its permanent site in 2019 on 152.669 hectares of land located at Ipetu-Ijesa expressway Ile-Oluji, Ondo State, Nigeria. Presently, the institution has three schools with several buildings: The School of Engineering and Architecture, the School of Applied Science, and the School of Business and Management.

Thus, the polytechnic runs twelve academic programs; these programs include Accountancy, Business Administration and Management, Statistics, Science Laboratory Technology, Computer Science, Electrical and Electronics Engineering, Computer Engineering, Civil Engineering, Fisheries Technology, Agricultural Technology, Cooperative Economics, and Architectural Technology [15].

At the time of this research, the institution is not connected to the grid, relying solely on diesel generators. These generators are installed as standalone systems in various buildings: the Administrative building (350 kVA), Polytechnic Library Complex (350 kVA), School of Engineering building (350 kVA), School of Business and Management building (150 kVA), ICT/CBT centre (350 kVA), School of Agriculture building (150 kVA), and Polytechnic Health Centre (150 kVA). Running and maintenance of these generators can be very expensive and yet not put into optimal use, which makes some of the departments settle for inverters as an option, which is quite expensive as well.

The growing demand for electricity as FEDPOLEL expands, coupled with the increasing concerns about environmental sustainability, has driven the need for efficient and effective power generation systems. The choice between standalone power generation systems and parallel arrangements of these generators plays a pivotal role in meeting energy demands.

As the Polytechnic continues to transition toward a more sustainable future, there is a growing need to comprehensively evaluate the performance, efficiency, and economic viability of standalone systems and synchronized generators as a central powerhouse. This case study of power generation and distribution networks offers insight into real-world challenges and best practices [7]. This case study can serve as a reference for similar institutions.

Federal Polytechnic Ile-Oluji and other educational institutions play a vital role in the development and growth of nations. To ensure the seamless operation of these institutions, a reliable power supply and network infrastructure is imperative. In many developing countries, including Nigeria, the power supply from the national grid is often inadequate and unreliable [4]. This necessitates the exploration of standalone power generators and network solutions.

While there is extensive research on standalone generators and distribution networks, there is a gap in understanding how to optimize their use for the specific needs of a Polytechnic like Federal Polytechnic Ile-Oluji. This study could address factors like:

- Understanding the daily and seasonal variations in power needs at the Polytechnic.
- Optimizing generator use for efficiency and cost
- How effectively the standalone generators can be arranged in parallel and integrated with the Polytechnic's existing distribution network.
- Analyzing power losses within the Polytechnic's distribution system and proposing methods for reduction.

By addressing these gaps, this research could provide valuable insights for improving power reliability, reducing costs, and potentially paving the way for a more sustainable energy future at Federal Polytechnic Ile-Oluji.

The research delves into the unique power consumption patterns and needs of the Federal Polytechnic Ile-Oluji; it also focuses on optimizing the power distribution network and standalone generators within the Federal Polytechnic Ile-Oluji. This could involve loss reduction strategies, improved network layout based on the institution's power needs implementation, and cost efficiency.

1.1. FEDPOLEL Electricity Supply Infrastructure

FEDPOLEL is yet to be connected to a 33 kV network from the Ile-Oluji community. However, the electrification installation is in progress at the time of this research, which makes the institution solely dependent on standalone generators, designated in some buildings within the campus, administrative building 350 kVA, polytechnic library 350 kVA, school of engineering building 350 kVA, school of business and management building 150 kVA, ICT/CBT centre 350 kVA, school of agriculture building 150 kVA, polytechnic health centre 150 kVA, All generators are diesel operated.

2. Methodology

The following methods were adopted to achieve the objectives of this research: development of FEDPOLEL power infrastructure as-built drawing of the existing network, evaluation of load demand of existing buildings within the campus, identification of the possible problems of the existing power generating facilities and proposal of a better arrangement for optimal use, A proposed model for all synchronizable generators was carried out with the Load flow analysis performance of the loading system. The impact of the proposed model was validated.

2.1. Evaluation of Load Demand of Existing Buildings in FEDPOLEL

Load demand of all existing buildings within the polytechnic was recorded by acquiring the details on the datasheet of all the generator data. The currents drawn by the connected loads on all the generators were measured using a clamp meter at the main breakers of the generators at all the buildings serviced by the generators. The current measurements were taken at 12 pm and 3 pm of the day for five days, and the maximum values of readings which indicated the peak period were chosen for the model.

2.1.1. Verification of Load Balancing of the Powered Buildings

It is important to verify if the red, yellow, and blue phases of the electrical system are balanced; this is crucial to ensure an even distribution of electrical load and to prevent overloading of any one phase. Balanced phases help in maintaining power quality, reduce the risk of equipment damage as well as the generators, and ensure a stable electrical supply. An alternating current clamp-on meter was used to measure the load currents per phase for October 2023. The load imbalance was calculated using Equation 1.

At I_{ib}> 10% shows the phases are not balanced

$$I_{ib} = \frac{I_{\max(ph)} - I_{\min(ph)}}{I_{\mathrm{Av}(ph)}}\% \tag{1}$$

where; I_{ib} is imbalance current,

$I_{\max\,(ph)}$ is the maximum phase current,

$I_{\min\,(ph)}$ is the minimum phase current,

$I_{Av(ph)}$ is the average phase current.

2.2. Modelling of the Proposed Synchronizable Generators

To ensure the scalability, reliability of the installed standalone generators and, reduce the running and maintenance costs, supply power to some of the buildings that are currently not being powered by the stand-alone generators, the seven available generators differently supplying electricity to seven buildings were arranged in parallel as the case in the University of Gujrat in Pakistan [10].

In order to reduce line losses, the choice of the location of the central power was based on the clustered buildings and the availability of space. To efficiently analyze the modelled network, load flow analysis was carried out using ETAP to determine the line losses, voltage drops and stability of the entire synchronized network.

To ensure better analysis, different scenarios were considered for the proposed modelled networks. The different scenarios are;

- Synchronization of the seven generators with their respective connected buildings,
- Synchronization of the seven generators with all the buildings connected to the synchronized system,
- Synchronization of the possible minimum number of generators needed to be synchronized that will be capable of supplying all the loads (buildings). This was considered for better efficiency, maintainability, and reliability of the entire system.

2.3. Load Flow Analysis

The load flow analysis of the modelled network was carried out using an extended Newton-Raphson algorithm. The mathematical expressions for the Newton Raphson load flow algorithm are expressed in Equations 2 to 23.

Generally, for the typical bus of the power system:

$$\mathrm{I_n} = \sum_{j=1}^{n} \mathrm{Y_{ij} V_j} \tag{2}$$

The polar form is as expressed in the Equation

$$I_n = \sum_{j=1}^{n} |Y_{ij}| |V_j| < \theta_{ij} \delta_j \quad (3)$$

The complex power at bus i is expressed in Equation 4.

$$P_i - jQ_i = V_i * I_i \quad (4)$$

Substituting for I_i:

$$P_i - jQ_i = |V_i| < -\delta_i \sum_{j=1}^{n} Y_{ij} V_j < \theta_{ij} + \delta_j \quad (5)$$

Therefore, separating the real and the imaginary parts, we have Equations 6 and 7, referred to as the Static Load Flow Equations (SLFE):

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (6)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad (7)$$

Where i and j are buses, P_i and Q_i are the active and reactive power at bus i, Y_{ij} is the admittance between buses i and j, V_i and V_j are voltages at buses i and j, θ_{ij} is the power angle between buses i and j, and δ is the state variable.

The Jacobian matrix gives the linearized relationship between small changes in voltage angle $\Delta\delta_i^{(k)}$ and voltage magnitude $\Delta|V_i^{(k)}|$ with the small changes in real and reactive power, $\Delta|P_i^{(k)}|$ and $\Delta|Q_i^{(k)}|$. This is expressed in Equation 8.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 J_2 \\ J_3 J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (8)$$

The diagonal and the off-diagonal elements of J_i are expressed in Equations 9 and 10 as:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j\neq 1} |V_i| |V_j||Y_{ij}| \sin(\theta_{i_j} - \delta_j + \delta_i) \quad (9)$$

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}| \sin(\theta_{i_j} - \delta_j + \delta_i), j \neq i, \quad (10)$$

The diagonal and off-diagonal elements of J_2 are expressed in Equations 11 and 12.

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ij}| \cos\theta_{ij} + \sum_{j\neq 1} |V_i| |V_j||Y_{ij}| \sin(\theta_{i_j} - \delta_j + \delta_i) \quad (11)$$

$$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}| \cos(\theta_{i_j} - \delta_j + \delta_i), j \neq i \quad (12)$$

The diagonal and off-diagonal matrixes of J3 are expressed in Equations 13 and 14.

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j\neq 1} |V_i| |V_j||Y_{ij}| \cos(\theta_{i_j} - \delta_j + \delta_i) \quad (13)$$

$$\frac{\partial Q_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}| \cos(\theta_{i_j} - \delta_j + \delta_i), j \neq i \quad (14)$$

The diagonal and the off-diagonal matrix of J_4 are expressed in Equations 15 and 16:

$$\frac{\partial P_i}{\partial |V_i|} = -2|V_i||Y_{ij}| \cos\theta_{ij} + \sum_{j\neq 1} |V_i| |V_j||Y_{ij}| \cos(\theta_{i_j} - \delta_j + \delta_i \quad (15)$$

$$\frac{\partial P_i}{\partial |V_j|} = -|V_i||Y_{ij}| \sin(\theta_{i_j} - \delta_j + \delta_i), j \neq i \quad (16)$$

The terms $\Delta|P_i^{(k)}|$ $\Delta|Q_i^{(k)}|$ are the difference between the scheduled and calculated values known as the power residuals given in Equations 17 and 18.

$$\Delta|P_i^{(k)}| = P_i^{sch} - P_i^{(k)} \quad (17)$$

$$\Delta|Q_i^{(k)}| = Q_i^{sch} - Q_i^{(k)} \quad (18)$$

The new estimates for bus voltages are by Equations 19 to 21:

$$\delta_i^{(k+1)} = \delta_i^{sch} - \Delta\delta_i^{(k)} \quad (19)$$

$$|\Delta V_i^{(k+1)} = |V_i^{(k)}| + \Delta|V_i^{(k)}| \quad (20)$$

$$|\Delta P_i^{(k)}| \leq \in; |\Delta Q_i^{(k)}| \leq \in \quad (21)$$

2.4. Validating the Impact of the Proposed Model

To achieve this objective, load flow results, overall percentage loading, and efficiency of the generators were considered.

2.4.1. Efficiency of the Generators

Diesel generators typically exhibit their highest efficiency when operating at or near their rated or base load capacity.

This is the point at which the generator is designed to perform most efficiently. Ideally, generators should be loaded to at least 70-80% of their rated capacity for extended periods to achieve peak efficiency [14].

The generator efficiency of the respective standalone generators was calculated using Equation 22. Also, the percentage loading of the generators was computed using Equation 23.

$$G_{eff.} = \frac{G_O}{G_I} X\ 100\% \quad (22)$$

Where;

$G_{eff.}$ is the generator efficiency,
G_O is the generator output, and
G_I is the generator input.

$$G_L = \frac{CL}{GR} X\ 100\% \quad (23)$$

Where;

G_L is the generator percentage loading,
CL is the connected load, and
GR is the generator rating.

2.5. Economic Benefits of the Proposed Model

To consider the economic benefits of the proposed model, the capital investment in the installation of the synchronized system and the reduction in the running cost as a result of the synchronization were reflected. For accurate determination of capital investment, materials costs, installation costs, civil costs, engineering costs, and commissioning costs were considered as expressed in Equations 24 to 29 [17].

2.5.1. Total Costs

Total costs incurred in the installation of the proposed synchronized system were obtained by summing material costs, installation costs, and civil costs.

2.5.2. Material Costs

Material cost was one of the most important aspects of the implantation of the proposed synchronized system. The material costing was done by estimating and calculating the required materials in terms of size, length and quantity. The actual price was requested from the sellers. The sizes of the cables required were obtained by checking for the equivalent cable ratings using the NigerChin cable catalogue based on the ratings of the individual generators and the combined load requirement of the entire synchronized system.

2.5.3. Civil Costs

Civil cost was very fundamental in the course of estimating the proposed capital investment of the proposed model. This covered the excavation and construction of the foundation capable of carrying the weight of the powerhouse and generators. The area required was estimated by considering the length and breadth of the generators and order equipment required to make up the complete system, and this was drawn using AutoCAD.

2.5.4. Engineering Cost

The Engineering cost is 10% of the total costs, as represented in Equation 24

$$E_C = 0.1\ (M_C + I_C + C_C) \tag{24}$$

Where; E_C is the engineering cost, M_C is the material costs, I_C is the installation costs, and C_C is the civil costs.

2.5.5. Commissioning Cost

The commissioning cost, $ComC$ is 1% of the total cost as expressed in Equation 25

$$COM_C = 0.01\ (M_C + I_C + C_C) \tag{25}$$

Where; COM_C is the engineering cost, M_C is the material, I_C is the installation costs, and C_C is the civil costs.

2.5.6. Total Cost of Implementation (TCI)

The total cost of implementation, as expressed in Equation 26

$$I_{TC} = M_C + I_C + C_C + COM_C + E_C$$
$$= 1.11(M_C + I_C + C_C) \tag{26}$$

Where; I_{TC} is the total cost of implementation, M_C is the material costs, I_C is the installation costs, and C_C is the civil costs, COM_C is the engineering cost, E_C is the engineering cost.

2.5.7. Capital Investments

The capital investment is a function of maintenance cost and total cost of investment and is equal to the total cost of implementation [17] as expressed using Equation 27.

$$CI = I_{TC} \tag{27}$$

Where CI is the Capital Investment and I_{TC} is the Total Cost of investment.

2.5.8. Yearly Cost of Fuel Savings

The total yearly fuel savings due to the proposed synchronized model was evaluated over one year in terms of the cost of fueling the redundant generators.

2.5.9. Annual Cost of Fuel Savings

The total cost of annual fuel savings due to redundant generators was obtained using Equation 28

$$AC_{FS} = (\sum_{k=1}^{3} AFC_k \times ARH_k) \times P_D \times 12 \tag{28}$$

Where;

AC_{FS} is the annual cost of fuel savings due to synchronization, AFC_M average fuel consumption per month, ARH_k average running hours per month, and P_D is the price of diesel per litre in Naira.

2.6. Payback Period (PBP)

PBP relates to the years for which the cumulative sum of the annual cost of fuel savings due to synchronization equals CI, and it was calculated using Equation 29 [17].

$$PBP = \tau \leftarrow \sum_{t=1}^{\tau} AC_{Fs(t)} = CI\text{CL} \tag{29}$$

3. Results and Discussion

3.1. Development of As-Built Drawing of the Power-Generating Infrastructure FEDPOLEL

The developed as-built drawing of the Ile-Oluji Generating Infrastructure was done. As extracted from the as - built drawing of the entire existing power-generating infrastructure network, it was noted that all the generators are operating as standalone.

There are seven generators at different locations of the Polytechnic, servicing seven buildings: The first generator located at the administrative building supplies power to the entire four floors of the building; the second generator located at the polytechnic library complex supplies power to four floors of the building; the third generator located at school of engineering supply power to the school of engineering; the fourth generator located at school of business and management building supply power to all the four floors of the building; the fifth generator located at ICT/CBT Complex supply power to the building; the sixth generator located at school of agricultural building supply power to building, the seventh generator located at Polytechnic Health centre supply power to the building.

Grid harmony, system stability, communication channels, robust protection, maintenance needs, and minimizing transmission losses and emissions to ensure smooth operation were considered. Noise, security, and future grid compatibility were also considered for optimal performance and sustainability of the system before proposing a suitable location for the central powerhouse.

3.2. Evaluation of Load Demand of all the Existing Buildings

The ratings of generators and load demand measurement of all the existing buildings serviced by respective standalone generators are presented in Tables 1 and 2. Also, the calculated percentage loading (using Equation 1) of the respective standalone generators is presented in Table 1.

Table 1. Peak load readings of buildings on 20th of October 2023, Time: 2.05 pm

S/N	Phase/ Location	Red (A)	Yellow (A)	Blue (A)	I_{ib} (%)	Remark
1	Administrative Building	26	10	31	94.10	Imbalance
2	Polytechnic Library	98.75	54.5	102	23.18	Imbalance
3	School of Engineering building	25.4	15.4	17.4	51.54	Imbalance
4	School of Business and Management Building	46	13	29	58.02	Imbalance
5	ICT/CBT Complex	9.8	6.8	4.8	70.42	Imbalance
6	School of Agricultural building	14.5	11.5	5.8	82.07	Imbalance
7	Polytechnic Health center	10.5	5.3	6.9	68.4	Imbalance

Table 2. Load demand of existing buildings

S/N	Buildings	Load demand (kW)	Generator rating (kVA)	Generator Percentage Loading
1	Engineering Workshop	49.58	Nil	
2	Administrative Block	158.75	350	45.36
3	School Workshop Building	33.77	Nil	
4	SOIAS Building	50.6	Nil	
5	Polytechnic Library Complex	93.11	350	26.60
6	Twin auditorium	150.92	Nil	
7	School of Engineering Building	122.14	350	34.90
8	Students Lavatory	5.55	Nil	
9	School of Agricultural Technology Complex	98.28	150	65.52
10	School of Business and Management Building	101.69	150	67.80
11	ICT /CBT complex	175.56	350	50.16
12	Polytechnic Health center	107.37	150	71.58

3.3. Modelling of the Proposed Synchronizable Generators

The different scenarios considered for the modelling of the synchronization of the available generators for the alternative electrical supply at FEDPOLEL. The results and analysis of the different scenarios are itemized in the following sub-headings.

3.3.1. Synchronization of the Seven Generators with their Respective Connected Buildings

The results of the ETAP model and the corresponding load flow results of all the stand-alone generators and their connected respective loads as simulated are shown in Figure 1. From the load flow results, the percentage voltage magnitude plot of the modelled network of all seven synchronized generators with their respective dedicated loads is presented in Figure 2, with the highest voltage drop of 2.32%. It shows that the voltages of the modelled network fall within the permissible voltage of ±5% of the nominal voltage.

From the load flow and the results analysis, the total loading on the combined generators synchronized together with only their respective loads connected was 46.3%, which showed that the generators, when synchronized together to supply only the dedicated buildings, did not run at maximum efficiency. The total active and reactive losses were 19.9 kW and 0.8 kVAR, respectively. The 46.3% loading of the generators also indicated that the synchronized model can still accommodate more loads.

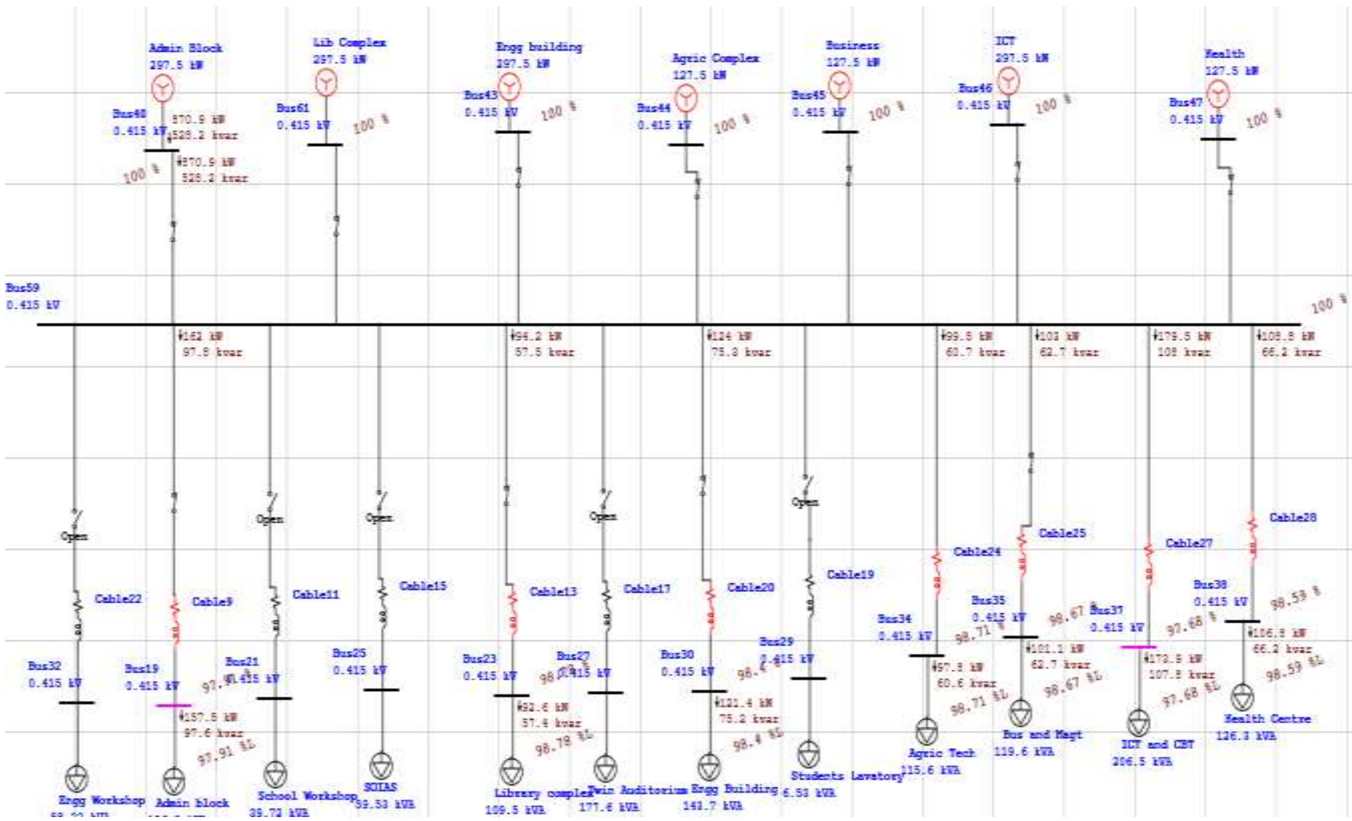

Fig. 1 Modeled network of synchronized generators with their respective dedicated loads

3.3.2. Synchronization of the Seven Generators with all the Buildings Connected to the Synchronized System

The results of the ETAP model and the corresponding load flow results of all seven standalone generators and all the loads of the buildings at FEDPOLEL connected to the synchronizing panel were simulated, as shown in Figure 3.

From the load flow and the results analysis, the total loading on the combined generators synchronized with all the loads of FEPOLEL connected was 62%, which showed that the generators, when synchronized together to supply all the buildings, can supply more loads for maximum efficiency. The total active and reactive losses were 25.1 kW and 1.0 kVAR, respectively.

The increase in the losses within the network was a result of additional distances of the new connected loads. The percentage voltage magnitude plot of the modelled network of all the seven synchronized generators supplying all the loads at FEDPOLEL is presented in Figure 4, with the highest voltage drop of 2.32%.

This shows that the voltages of the modelled network fall within the permissible voltage of ±5% of the nominal voltage.

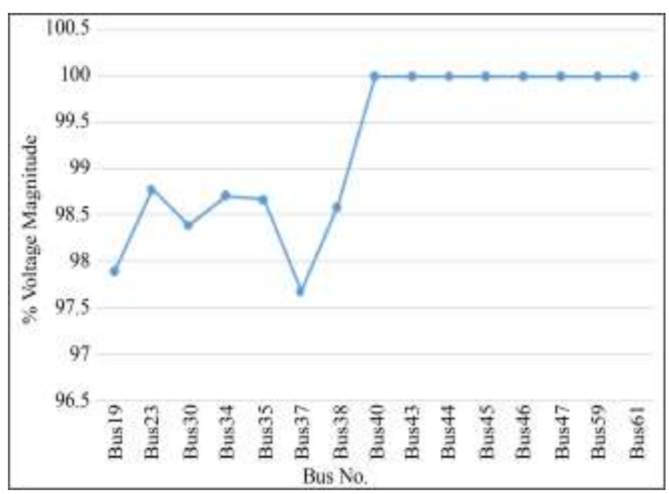

Fig. 2 Percentage voltage magnitude of the modelled network of synchronized generators with their respective dedicated loads

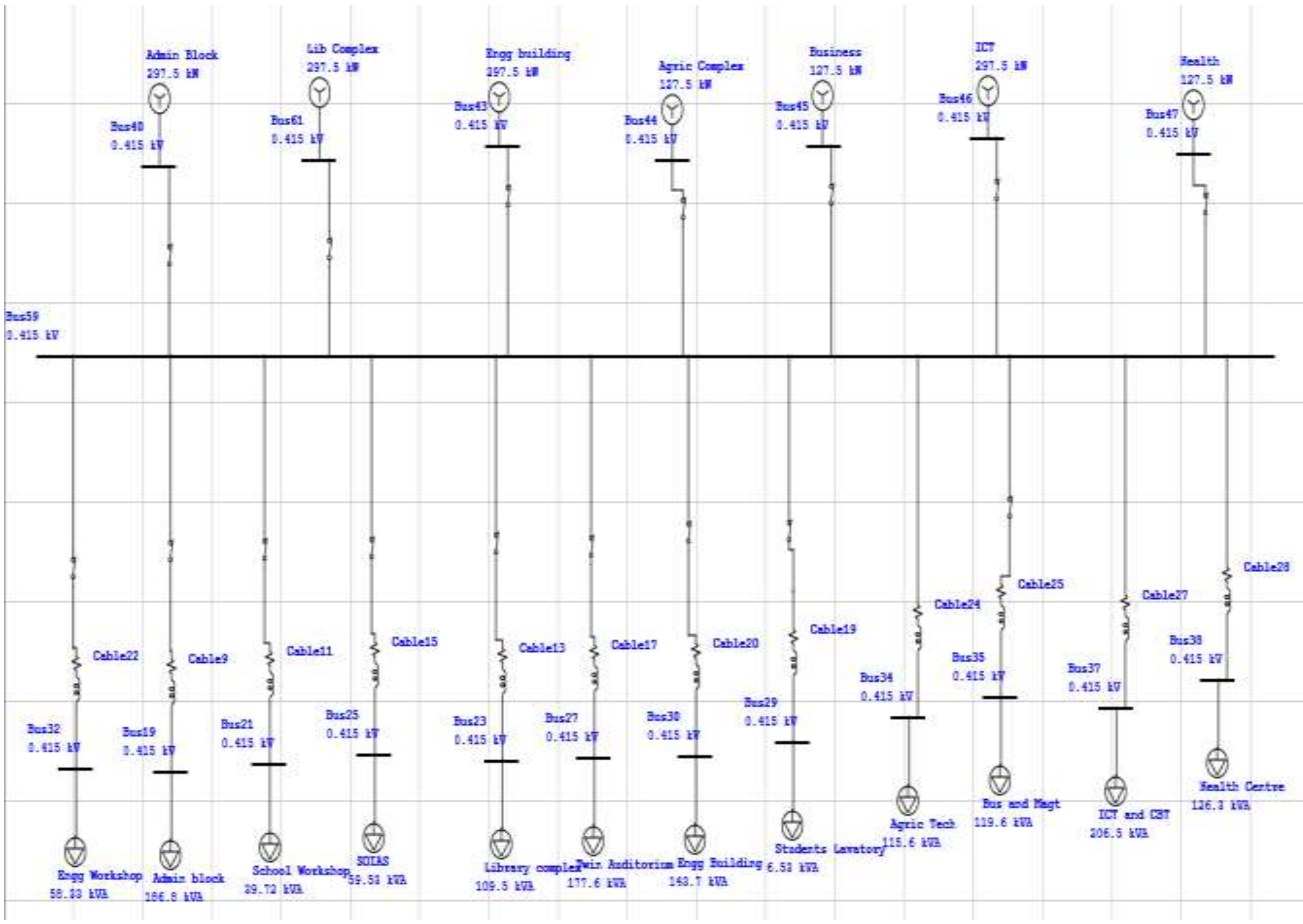

Fig. 3 Modelled network of the seven generators synchronized with all the buildings connected to the synchronized system

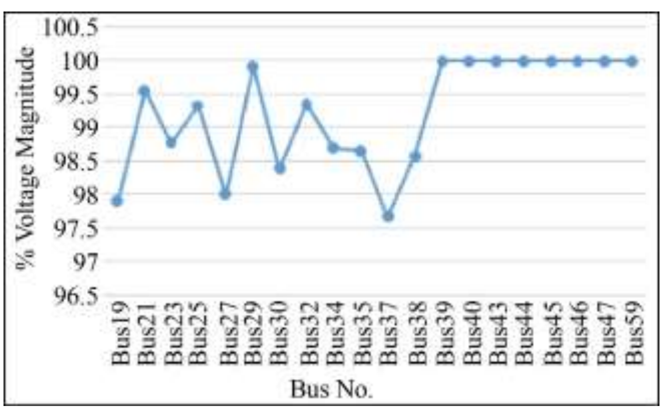

Fig. 4 Modelled network of the seven generators synchronized with all the buildings connected to the synchronized system

3.3.3. Synchronization of the Possible Minimum Number of Generators Required to be Synchronized that will be Capable of Supplying all the Loads of the Buildings

For better efficiency, maintainability, and reliability of the entire system, possible combinations of generators to be synchronized that are capable of supplying the entire buildings of FEDPOLEL and running at maximum efficiency were considered. The modelled network is shown in Figure 5. Four generators -administrative building, Polytechnic Library, and School of Engineering building ICT/CBT complex with each having a rated capacity of 350 kVA were considered the best combination to supply the total connected loads of FEDPOLEL.

The simulated results of the load flow presented in Figure 5 shows that the four synchronized generators are capable of conveniently supplying the entire load with the voltages within the permissible voltage of ±5% of the nominal voltage.

The percentage voltage magnitude graph of the load flow result is plotted in Figure 6, which shows that the maximum voltage drop for the scenario is 2.32%. The total active and reactive losses on the synchronized network are 25.1 kW and 1.0 kVAR, respectively.

From the load flow and the analysis of the results, the total loading on the four generators synchronized with all the loads of FEPOLEL connected was 82%, which showed that the generators, when synchronized together, will supply all the buildings with maximum efficiency.

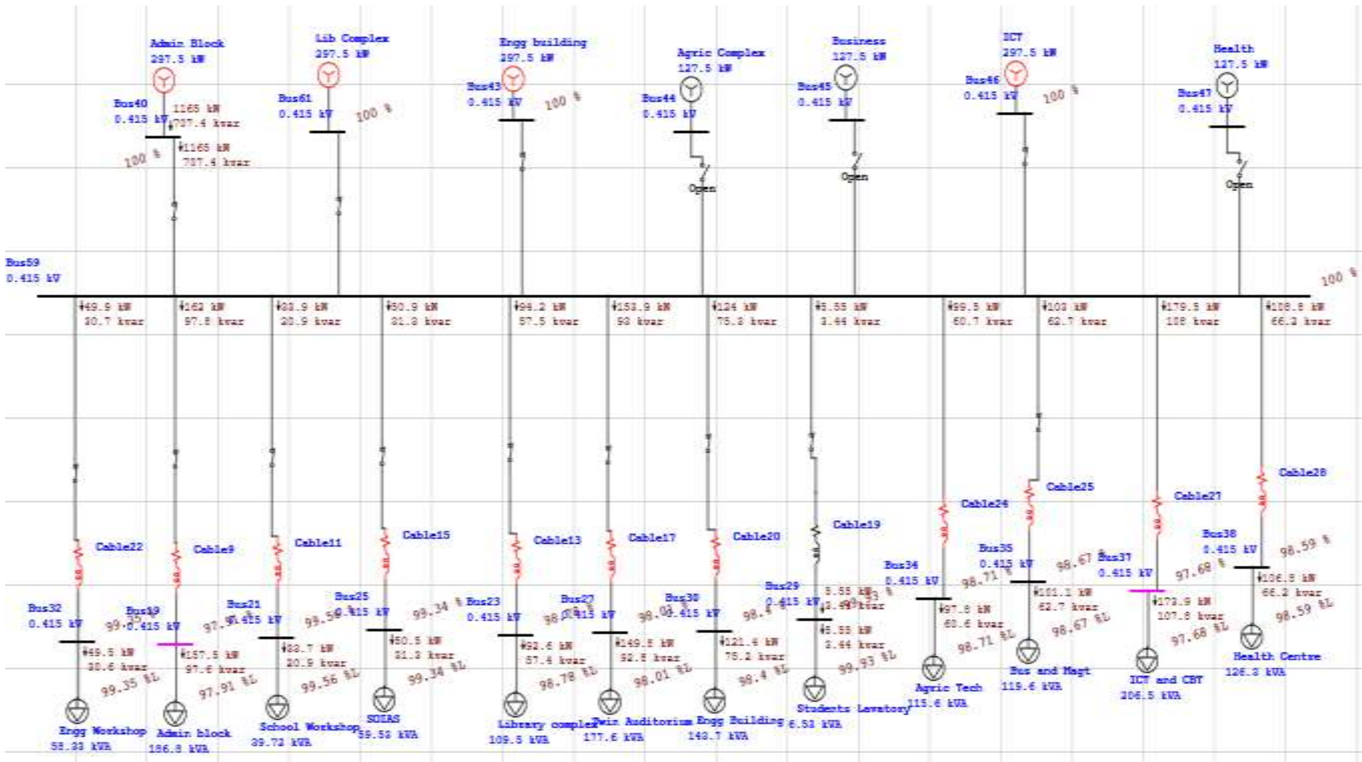

Fig. 5 Modeled network of possible four synchronized generators capable of supplying all the loads at FEDPOLEL

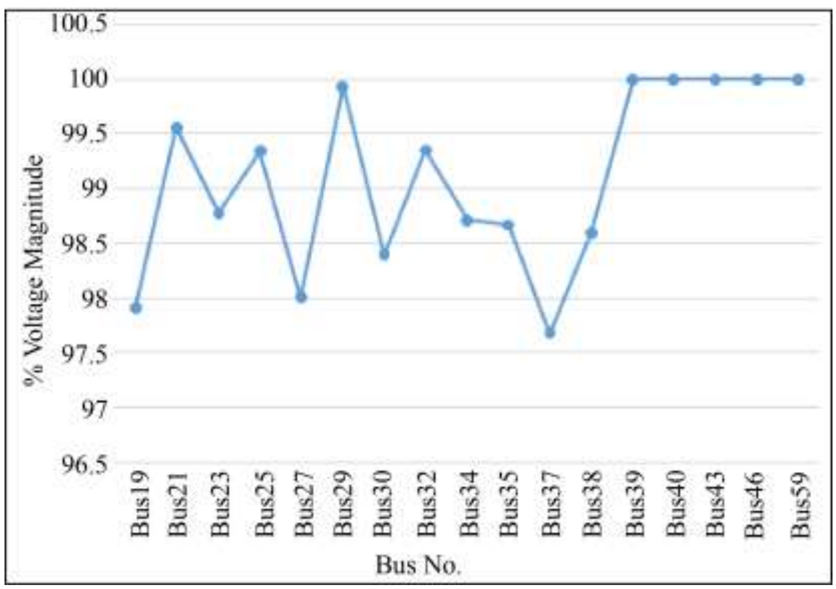

Fig. 6 Percentage voltage drop of the modelled network of possible four synchronized generators capable of supplying all the loads at FEDPOLEL

3.4. Validating the Impact of the Proposed Model

The results of the load flow recorded in the previous session showed that the modelled network has provided improved reliability, maintainability and reduced running cost since four out of seven generators can conveniently supply the entire loads of FEDPOLEL. The diesel cost, fuel consumption, and average running hours of the respective generators are presented in Table 3.

3.4.1. Cost Benefits of the Proposed Synchronized Model

The cost benefits of the proposed synchronized model are as follows:

Capital Investment

The capital investment of the proposed synchronized model was calculated using Equations 24 to 3.27. As tabulated in Table 4, the capital investment of the proposed model is ₦39, 304,644.90**.**

Table 3. Diesel cost and fuel consumption of generators

S/N	Location of generator	Rating (kVA)	Fuel consumption litre/hour	Average running hours/month	Diesel drawn/ month (litre)	Cost of Diesel at (₦1200/ltr)/month
1	Administrative Building	350	55	70-80	4125	4,950,000
2	Polytechnic Library	350	47	70-80	3525	4,230,000
3	School of Engineering Building	350	49	60-70	3185	3,822,000
4	School of Business and Management Building	150	21	60-70	1365	1,638,000
5	ICT/CBT Complex	350	50	60-70	3250	3,900,000
6	School of Agricultural Complex	150	35	60-70	2275	2,730,000
7	Polytechnic Health Center	150	26	70-80	1950	2,340,000

Table 4. Capital investment of the proposed model

SN	Description of materials	Quantity	Unit	Rate	Amount
1	Synchronization panels with Synchroscope	1	Number	4,680,000.00	4,680,000.00
2	300mm^2 SWA Cables of gauge	25	Meters	55,000.00	1,375,000.00
3	16mm^2 SWA Cables of gauge	30	Meters	1,800.00	54,000.00
4	Stay Assembly complete	2	Number	30,000.00	60,000.00
5	70mm^2 SWA Cables of gauge	40	Number	45,000.00	1,800,000.00
6	Bimetallic Line	4	Number	10,000.00	40,000.00
7	Cable termination accessories	1	Set	50,000.00	50,000.00
8	Civil Works	1	lump sum	27,000,000.00	27,000,000.00
Total Material costs (M_c) and civil works		35,059,000.00			
Installation costs		350,590.00			
Engineering costs		3,540,959.00			
Commissioning cost		354,095.90			
Grand Total (₦)		39,304,644.90			

Annual Cost of Fuel Savings

The total annual cost of fuel savings of the proposed model was calculated using Equation 28. The cost of diesel per litre amounted to ₦1300. The Annual Cost of fuel savings of the proposed model is ₦87, 204,000.

3.4.2. Payback Period with 5% Discount Rate per Annum

The payback period was computed using Equation 29 on a 5% discount rate. The Present Value (PV), Cumulative Present Value (CPV), payback period and net profit are presented in Table 5 and Figure 7. A total profit of ₦41, 191,355, which is more than the capital investment, would be realized at the end of the first year, 2024. After the completion of the installation of the proposed model, the net profit made up to ten years will amount to ₦653,822,234, as presented in Table 5 and Figure 7. It is evident from the graph that the payback period is less than six months and at the end of the first year after implementation, a profit more than the Capital Investment would be realized. The exponential (rising) curve of Cumulative Annual Net Profit (CANP) indicates that the proposed synchronized model for FEDPOLEL is feasible or profitable.

Table 5. Cumulative annual profit and payback period

Year	PV (₦)	CI (₦)	CPV (₦)	CANP (₦)
2024	87204000	39304645	80496000	41191355.1
2025	82843800	39304645	163339800	124035155.1
2026	78701610	39304645	242041410	202736765.1
2027	74766530	39304645	316807940	277503294.6
2028	71028203	39304645	387836143	348531497.6
2029	67476793	39304645	455312935	416008290.5
2030	64102953	39304645	519415889	480111243.7
2031	60897806	39304645	580313694	541009049.3
2032	57852915	39304645	638166609	598861964.6
2033	54960270	39304645	693126879	653822234.1

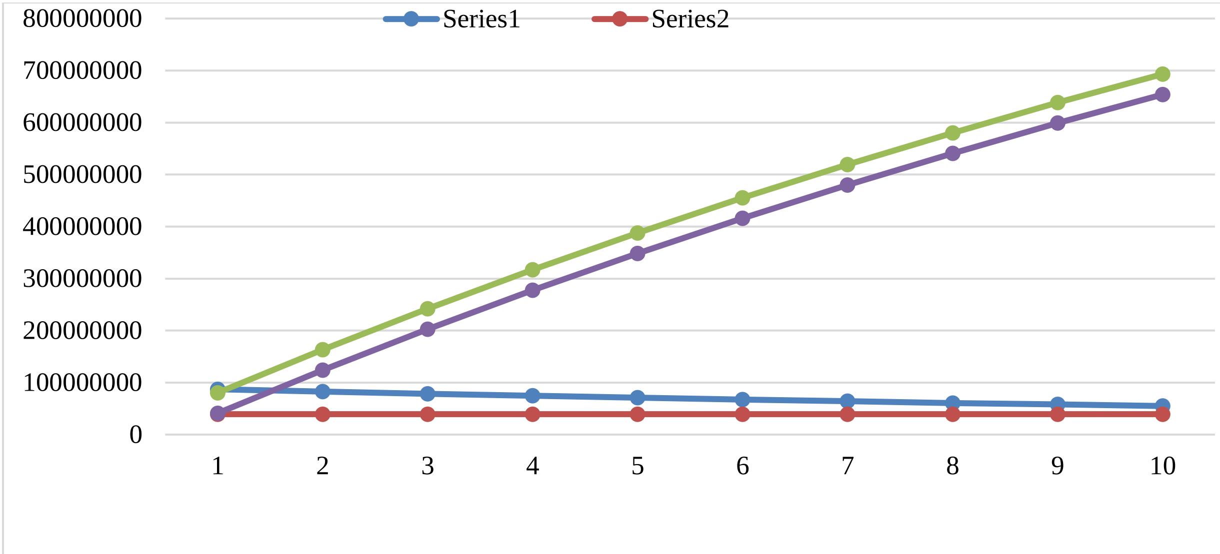

Fig. 7 Present value of annual fuel savings and payback period

4. Conclusion

This research confirms the feasibility and profitability of establishing a central powerhouse with synchronized generators to serve the entire Federal Polytechnic of Ile-Oluji (FEDPOLEL). Synchronizing the existing generators significantly improves power efficiency and optimization. Analysis showed that synchronizing all seven generators resulted in a maximum voltage drop of only 2.32%, which is within the permissible voltage of ±5% of the nominal voltage. Furthermore, this configuration allows the system to handle additional loads.

For optimal efficiency, the study identified a combination of four 350 kVA generators that can effectively power the entire FEDPOLEL, while the other three generators will be redundant for backup; this arrangement shows a generator loading of 82%.

The economic benefits are compelling. The synchronized model boasts a payback period of less than a year due to substantial annual fuel cost savings ₦87,204,000 compared to the capital investment ₦39,304,644.90. This translates to a projected profit of ₦41,191,355.1 within the first year after implementation.

Thus, implementing a synchronized generator system at FEDPOLEL offers a cost-effective solution for reliable and efficient power delivery across the entire campus.

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