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Analysis of Battery Energy Storage System for power system load factor improvement – a case of Kenya's power system.

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Analysis of Battery Energy Storage System for Power System Load Factor Improvement – A Case of Kenya's Power System

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Declaration and Approval

Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the dissertation itself.

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Sign: ________________________ Date: 22/05/2025________________

Approval

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Abstract

The Load Factor is a key measure of an electrical power system's efficiency. Load Factor is the ratio of average electrical demand over a period to the peak demand in that period. Kenya's current load factor stands at approximately 73% as of March 2025, but there is room for improvement, mainly by adjusting electricity consumption patterns among domestic electricity consumers. Kenya's power usage peaks between 6–7 AM and 6–10 PM, with off-peak periods, particularly between 11PM – 4AM, experiencing demand drops of up to 50%. To meet peak demand, significant investments in grid infrastructure are required, yet these assets remain underutilized during off-peak hours, creating economic inefficiencies and increased technical losses. This research explores using Battery Energy Storage Systems (BESS) to bridge the gap between peak and off-peak demand. By charging BESS units during low-demand periods and discharging them during peak hours, the study aimed to homogenise energy usage and create a more balanced consumption pattern. An action research design was employed to simulate the technical and economic viability of BESS. Results showed that through peak shaving, a properly sized BESS unit could reduce peak demand on a pilot distribution feeder from approximately 6000kW to 4000kW, aligning it with its normal average loading. This improved the feeder load factor from 51% to 77%. Although the BESS deployment involved a high initial cost, the return on investment achieved through improved efficiency justified its adoption. The study presents a viable and scalable model to enhance Kenya's grid load factor, optimize infrastructure use, and reduce reliance on costly thermal power sources, which are mainly dispatched during peak demand periods.

Keywords: Load Factor, Electrical Power System Efficiency, Demand, Battery Energy Storage Systems (BESS), Peak Shaving, Distribution Feeder, Load Balancing

Table of Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
EPRA	Energy and Petroleum Regulatory Authority
GWH	Gigawatt Hour
KVA	Kilovolt Ampere
LCOS	Levelised Cost of Storage
O&M	Operations and Maintenance
SCADA	Supervisory Control and Data Acquisition
SLD	Single Line Diagram
SWOT	Strengths Weaknesses Opportunities and Threats

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Dedication

This dissertation is dedicated to the unwavering support and love of my family, whose sacrifices and encouragement has been the driving force behind my academic journey. Their belief in my abilities and relentless support has been my pillars of strength. This accomplishment is as much theirs as it is mine.

To my friends and mentors who have offered guidance, shared insights, and stood by me throughout this endeavour, I extend my heartfelt appreciation. Your contributions have been instrumental in shaping the outcome of this dissertation.

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1. Introduction

1.1. Background of the Study

Efficiency in the electrical energy value chain is a pivotal concept in the energy sustainability discussion. As a result, researchers, engineers and sector player are continually in a quest to discover new means of improving efficiency in energy generation, transmission and distribution process. Energy losses however, are a common occurrence not only in power utilization or distribution, but also mainly in the generation and transmission process. To date, the average net efficiency of power generation worldwide is around 34% with almost two thirds of calorific content of primary fuel input into electricity generators lost as waste heat (Khatib, 2012, p. 334).

Efficiency in power generation is mainly dependent on the technology used in the generation process. Hydroelectric power generation is mainly the most efficient power generation method, enjoying a generation efficiency of up to 90%. Given this efficiency, coupled with the mode and consistency of supply of the input energy, i.e. water, it is mainly suitable for base load power supply (Killingtveit, 2020). Other suitable base load power supplies may include coal, combined cycle gas plants, nuclear and geothermal.

Gas, solar and wind power plants enjoy relatively lower power generation efficiency of less than 40%. They are however, ideal for supply of peak load given the ease and simplicity involved in the generation process. They have a short and simple start up process and can be on boarded with ease and speed onto the grid to cater for spikes in power demand (Ding et al., 2019). Solar and wind however pose a major drawback due to their intermittency and at time may not be reliably available when required for peak load supply.

The above factors reliably indicates that the usage pattern by consumers has a bearing on the efficiency of the power generation process. Electricity grid utilities generally have strict power supply obligations to its users, requiring them to supply quality and reasonable priced electricity under all circumstances and demand patterns. Generally, in terms of generating capacity, it means that supply should always follow demand. Unfortunately, the timing of peak demand rarely coincides with the availability of the most convenient peak supply. The power generator therefore must anticipate the demand pattern and cater for peak demands with the unavoidable consequence of power under-utilisation during the daily and seasonal periods of low power demand. This inefficient use of capital and infrastructure has a major bearing in the cost of energy. Power generation firms therefore, have to employ different mitigation strategies to minimise the effect of power underutilisation during low demand periods (*Electricity Demand*, 2016).

Some of the means employed by utilities in enhancing grid efficiencies due to different usage patterns with differing peak demand periods include:

Grid interconnection - A local or regional interconnected grid enables cross-border or regional power exchange, allowing areas with surplus capacity to export excess power to regions facing deficits. This flexibility helps balance supply and demand, smoothing the power demand curve for more efficient, continuous energy utilization and optimal use of power infrastructure. Additionally, variations in peak and off-peak load periods—due to time zone differences and usage patterns—further enhance the utilization factor of power generation plants (Rafique et al., 2018).

Spinning reserves - These are power plants that provide generating capacity that can be brought on stream at a very short notice. They can be viewed as the extra power generating capacity of the generator that is already synchronised onto the power grid. These reserves are needed to satisfy power peak demands, which cannot be met by the base load power generators (Khoshjahan et al., 2019).

Peak shaving - This is a strategy for avoiding peak demand on the electrical grid, at the user end by reducing power consumption at intervals of high demand. This can be achieved by switching off equipment with high-energy draw during peak periods, or incorporating of onsite power storage options, such as battery packs that can be used to power equipment during peak durations, and the batteries charged during off peak periods (Smith, 2023).

Load levelling - Closely related to peak shaving, involves scheduled loading by consumers, by moving their demand or maximum consumption away from peak periods to off peak periods, thus flattening the demand curve (Telaretti & Dusonchet, 2016a).

Load shedding - As a last resort, it may be necessary to disconnect some loads periodically when the demand exceeds the supply. Oftentimes, heavy industries with a high degree of power consumption provide shed-able loads that can be automatically shed off the grid to ensure grid stability during excess demand (Smith, 2023).

A key tool used in measuring and determining the efficiency of power generation station is the Load factor. The load factor can be defined as the ratio of the actual amount of electrical energy delivered to the power system in a designated period of time to the total possible electrical energy that could be delivered to the system in a designated period of time (*Part 2 Introduction to Power Systems.Pdf*, Orenge S. 2023). The load factor is represented by the below equations 1 and 2;

$$\text{Load Factor} = {Average\ Load}\Big/{Maximum\ Load\ in\ a\ given\ time\ period} \qquad (1)$$

$$\text{Load Factor} = \begin{matrix} Energy\ consumed\ or \\ generated\ in\ time\ T\ hrs \end{matrix}\Big/ {Max.demand\ x\ T\ hrs} \qquad (2)$$

This research therefore aims to find ways of improving load factor especially at the power generation and distribution level, and consequently improve on Kenya's grid power efficiency. It may be noted that a number of the above mentioned mitigation strategies employed for efficiency improvement have a relation to energy storage. Through technologies such as BESS, peak shaving, load levelling and even load shedding can be made possible through transitioning to off grid power utilization during peak durations while scheduling for charging of the BESS units during off peak durations.

1.2. Problem Statement

The efficiency of Kenya's power generation and distribution system is significantly impacted by fluctuations in electricity demand, particularly the pronounced evening peak between 1800 hrs and 2200 hrs, followed by a sharp decline in demand from 2300 hrs to 0400 hrs. This variability results in a reduced electrical load factor at the generation, transmission and distribution levels, leading to inefficiencies in power system utilization. The steep variation between peak and off-peak demand poses operational and economic challenges, including increased generation costs and underutilization of infrastructure during off-peak hours. To address this issue, this study explores the integration of Battery Energy Storage Systems (BESS) at the distribution level as a strategy for energy storage. By implementing peak shaving and load shifting techniques, BESS can help optimize load distribution, enhance grid stability, and improve the overall load factor of Kenya's power generation, transmission and distribution network.

1.3. Research Objective

The research is aimed at determining the requirements and approach for efficient adoption of BESS to improve Kenya's power system load factor. This is to be established by focusing on the below specific objectives:

i) Assess the currently used methods for load factor stabilization in Kenya.

ii) Analyse the electricity supply and demand curve in Kenya.
iii) Simulate the technical viability for BESS adoption at the electricity distribution level.
iv) Develop and validate a model for integration of BESS to stabilise electricity load factor in Kenya.

1.4. Research Questions

The research questions to be answered by this study are:

i) What are the current methods used in Kenya for load factor improvement and stabilisation?
ii) What are the current electricity supply and demand patterns across domestic electricity users in Kenya?
iii) How can BESS technology be best tailored for domestic electricity usage?
iv) How can BESS be modelled to simulate its load factor improvement capability on the grid?

1.5. Justification

As previously highlighted, Kenya experiences a significant surge in electricity usage during the evening peak hours, typically from 1800 hrs to 2200 hrs, followed by a decrease in demand as the night progresses into early morning, around 2300 hrs to 0400 hrs the next day. This fluctuation is also noted to be largely driven by domestic consumers who currently account for about 30% of the nation's total demand. This study aims to illustrate that by integrating BESS for domestic/residential users, Kenya can achieve a more balanced distribution of electricity demand, leading to an enhancement in the country's power system load factor.

1.6. Scope

This study aims to enhance Kenya's power system efficiency and grid load factor, currently at 73%, by mitigating inefficiencies arising from significant fluctuations between peak and off-peak energy demand. The research focuses on developing a practical model for utilizing BESS to optimize electricity consumption patterns, specifically targeting domestic electricity users. The study adopts an action research design to ensure practical applicability and relevance, targeting improvements in both technical and economic aspects of Kenya’s power system.

1.7. Limitation

The duration and resources allocated for the research is limited. Never the less, it is my belief that the limited scope establishes a trend that will resemble the findings as would have been for an extended research project.

The high initial costs associated with BESS makes this research model capital intensive and financial viability is only realised in the long term.

1.8. Report Organisation

This dissertation is organized into five main chapters, each contributing to a comprehensive understanding of the research problem and its context.

Chapter one introduces the study by presenting the background, including an overview of Kenya's power sector and its electrical energy dispatch profile. It outlines the research problem, objectives, and key questions that guide the study. Additionally, the chapter provides the justification for the research, defines its scope, and discusses any limitations encountered.

Chapter two presents a review of relevant literature, exploring key concepts such as energy efficiency, the significance of load factor improvement, and the management of load factor in Kenya. It examines various battery energy storage system (BESS) technologies, including lithium-ion, lead-acid, and solid-state batteries, with a focus on their application in enhancing power system performance. The chapter concludes with the identification of research gaps and the development of a conceptual framework.

Chapter three outlines the research methodology. It describes the research design, unit of analysis, and data collection methods employed in the study. The chapter also details the research model, data analysis techniques, and ethical considerations taken into account throughout the research process.

Chapter four presents the results and discussion. It begins with a description of the data sources and preparation techniques, followed by a detailed analysis of the findings. The chapter includes the modeling and sizing of a utility-scale BESS solution for load factor correction on the Kibra feeder, a summary of the charge and discharge impact on load profile parameters, and a cost-benefit analysis. It also compares the study's findings with similar projects and research for validation purposes.

Chapter five concludes the dissertation by summarizing the key findings and offering recommendations based on the research outcomes. It also outlines potential areas for further research to build upon the work presented in this study.

Additional sections such as the list of figures, tables, abbreviations, and comprehensive appendices are included to support the main text and enhance the reader's understanding.

2. Literature Review

2.1. Introduction

This chapter delves into the importance of enhancing the load factor and its influence on the overall efficiency of power systems. In line with research question one in section 1.4, it examines different methods utilized to improve the load factor in power systems in general, as well as those specific to the Kenyan power system. The research aims to construct a conceptual framework integrating BESS into a case study of Kenya's utility provider, with the objective of achieving efficient and effective load factor enhancement in Kenya. This endeavour seeks to address existing research gaps identified in other relevant studies.

2.2. Energy Efficiency

Energy Transition is a rapidly emerging concept in the energy space and it mainly entails migration from current energy sources and trends which carry with them a set of undesired consequences, to a more desired and sustainable model of power generation, distribution and consumption. With this campaign, has emerged key points of concern for all players towards a smooth energy transition. These mainly entail sustainability and energy efficiency.

Sustainability in the energy space is the state that ensures the production, distribution and consumption of electrical energy in a way that ensures availability over a long period of time without affecting the social, environmental and economic variables that support energy production value chain (Musonye, 2023).

Energy efficiency is adoption of various measures aimed at reducing and/or optimizing power and energy demands from the electrical power system without affecting the normal activities entailed in electrical energy consumption. This may be achieved through supporting the sustainability of the power system and the environment by (1) minimising greenhouse gas emissions by reducing or optimizing the energy demand, (2) enhancing the technical management of the grid installation by avoiding downtimes and unplanned outages and (3) reduction in running and operating cost of the installation ("Electrical Energy Efficiency," 2022).

Energy efficiency is vital in a power system as it ensures that avoidable energy losses during generation, transmission and distribution of electricity are kept at a minimal. Through this, one is able to realise, reliable, sustainable and affordable power. One of the measures of ensuring energy efficiency in a power system is efficient Load Factor management.

2.3. Load Factor Significance and Improvement on the Grid

Noting that the load factor is an indicator of power generation, distribution and consumption efficiency, the higher the load factor, the higher the efficiency. It is therefore desirable for a power plant and/or power generation station to experience a load factor as close as possible to unity. Improving the load factor of an electrical grid is primarily about controlling the peak demand. Lowering the peak demand will automatically enhance the load factor percentage.

Lowering the peak demand can be achieved by bulk shifting of loads away from peak demand periods to off peak durations as shown in figure 2.1 below. This can be achieved by efficient scheduling of appliances usage to off peak periods. This conscious load scheduling homogenously distributes electricity consumption in the energy demand profile across the day. This process is known as load balancing or peak shaving and it has the below impact on a typical load curve (*Load Factor*, 2020);

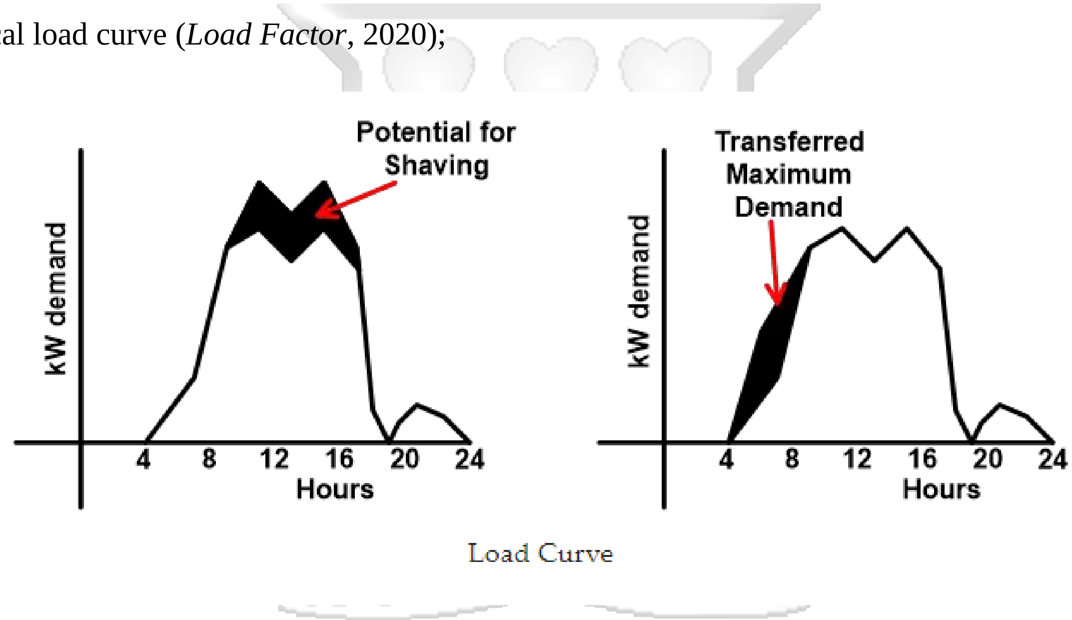

Figure 2.1: Load curve indicating peak shaving and load transfer

A low load factor, on the other hand means a high maximum demand and a low utilization rate of electrical energy. This essentially means that the capacity of electrical energy remains inactive for an extended period of time reducing on the efficiency of the electrical grid, increasing the per-unit cost of electrical energy to the consumer.

In general, a high load factor positively contributes to the efficiency of a power system through (1) Generation efficiency, given that the average load is closer to the maximum load, power generators operate more consistently. They also operate near their rated capacities enhancing efficiency as generators are designed to operate at maximum efficiency at or near their rated capacity. (2) Transmission and Distribution efficiency, as it allows for optimal utilization of grid infrastructure and minimises losses associated with energy transmission over long distances. (3) Economic Efficiency, which is achieved by maximizing the return on investment on power generation and distribution infrastructure. Power plants are capital-intensive investments and their economic viability is closely tied to how much they are utilised (Hao, 2023).

Various strategies for enhancing the load factor are employed in power systems. They include:

Demand Side Management (DSM) - DSM involves efforts to alter consumer behaviour regarding electricity consumption patterns. This entails utilizing various incentives like time-of-use pricing and behavioural change campaigns, which aim to educate consumers about their electricity usage habits and foster adjustments to curtail overall consumption and peak demand. In critical situations, DSM may involve load shedding measures to prevent infrastructure overload (Strbac, 2020).

Load Factor Tariffs - Implementing tariffs that incentivize customers to maintain a consistent level of demand over time encourages more stable usage patterns and increases the load factor (Soliman et al., 2019).

Energy Storage Systems - Deploying grid scale energy storage systems, such as batteries, pumped hydro, or compressed air energy storage, enables storing excess energy during periods of low demand and releasing it during peak demand, thereby improving the load factor (Cerna et al., 2023). This is currently in its conceptualisation and feasibility stage in Kenya.

Smart Grid Technologies - Advanced grid technologies, including real-time monitoring, control systems, and predictive analytics, enable better management of electricity distribution, leading to improved load factor by optimizing resource allocation and reducing downtime (Cerna et al., 2023).

Load Forecasting - Accurate forecasting of electricity demand helps utilities plan and optimize their resources effectively, avoiding underutilization or overloading of infrastructure, thus improving the load factor (Cerna et al., 2023).

Combining these techniques in an integrated approach tailored to the specific characteristics of the power system can significantly enhance the load factor and overall efficiency of the electricity grid.

2.4. An Overview of Kenya's Power Sector

Kenya is a rapidly growing economy not only in East Africa but also across the continent of Africa recording an average annual growth of 5.9% in the last 10 years. With the steady growth in the economy, so has there been a steady growth in its electrical energy demand. Electricity demand in Kenya amounted to 10 gigawatt hours in 2022, increasing steadily from 8.4 gigawatt demand in 2017. (*Kenya*, 2023b). As of 2022, Kenya recorded an installed generation capacity of 3.3 gigawatts of electricity with geothermal being the highest contributor of the installed capacity, followed by hydro and thermal power sources. (*Kenya*, 2023a).

A typical daily demand profile for Kenya, for a week duration, is shown in the below load curve in figure 2.2. The load profile shows a fairly consistent demand profile throughout the week with a morning peak between 09h00 to 10h00 and a more significant evening peak typically occurring at 20h00. The load curve also shows a reduced demand from 02h00 to 04h00. Kenya has a recorded load factor of approximately 73% as of March, 2025 (NCC, 2025).

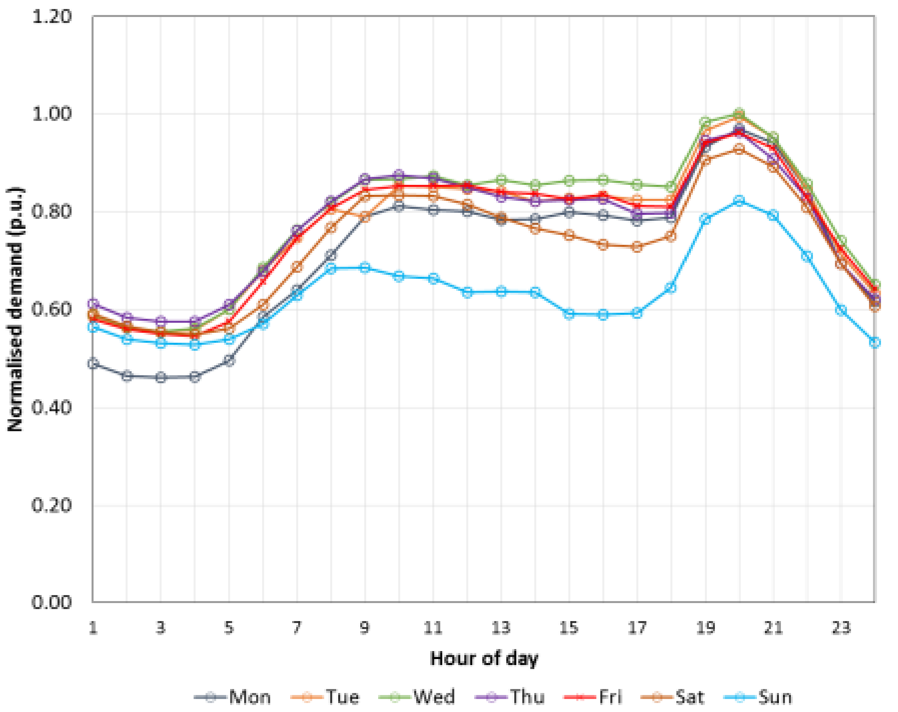

Figure 2.2: Daily demand load profile for Kenya

Source: (Hart & Jarrad Wright, 2016a)

Figure 2.3 below shows a further look at the demand profile within the different sectors, residential, commercial and Industrial. From the representation, it is evident that commercial and industrial customers have a relatively similar demand profile of increased energy demand from 06h00 to 21h00 with a peak demand at approximately 12h00.

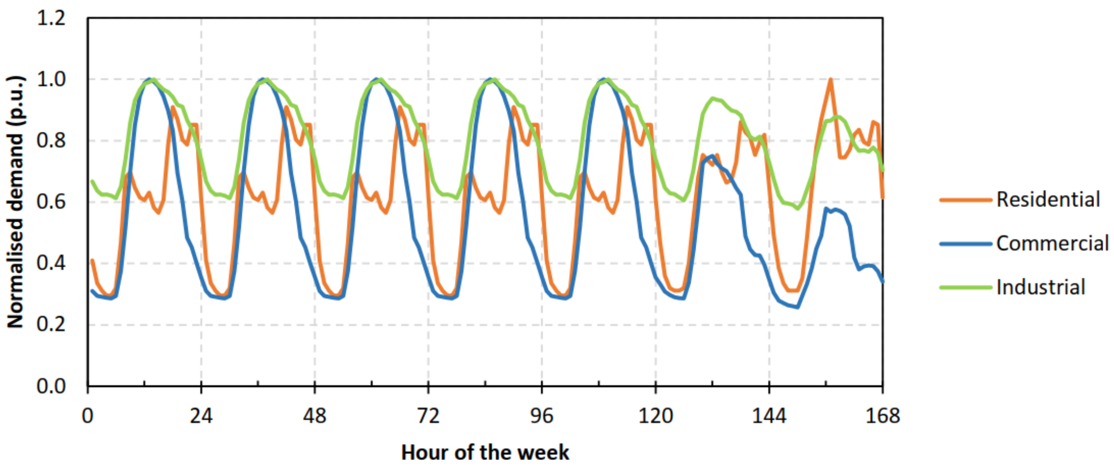

Figure 2.3: Weekly demand profile for residential, commercial and industrial type loads

Source: (Hart & Jarrad Wright, 2016b)

The residential demand profile on the other hand is lower throughout the day but experiences a significant spike in the energy demand from approximately 18h00 to 23h00. It may therefore be deduced that the significant evening peak demand experienced at the national grid level at 20h00 may mainly be attributed mainly to domestic/residential loads.

Due to the increased efforts towards attaining the Universal Electricity Access by 2030, through enhanced projects such as the Last Mile Connectivity, Kenya has experienced a steady growth in energy demand across all its consumer categories. In the financial year 2024/2025, Kenya has experienced an increased energy demand of up to 7,222.37 GWh marking a 6.13% increase (417.09 GWh) from the 6,805.28 GWh recorded in the previous financial year (EPRA Statistics Committee, 2025).

Analysing this energy growth per consumer category, figure 2.4 below shows an accelerated growth in industrial and residential energy demand from the year 2010. Electricity consumption by the industrial sector in Kenya reached approximately 12000 terajoules (3,333 GWh) in 2010. On the other hand, residential consumers demanded nearly 6000 terajoules (1,666 GWh) in the same year. Fast forward a decade later, it is noted that the industrial sector demanded 16000 terajoules (4,444 GWh) in 2020, while the residential consumers nearly doubled their demand within that decade, reaching a consumption marker of almost 12000 terajoules (3,333 GWh) in the same year.

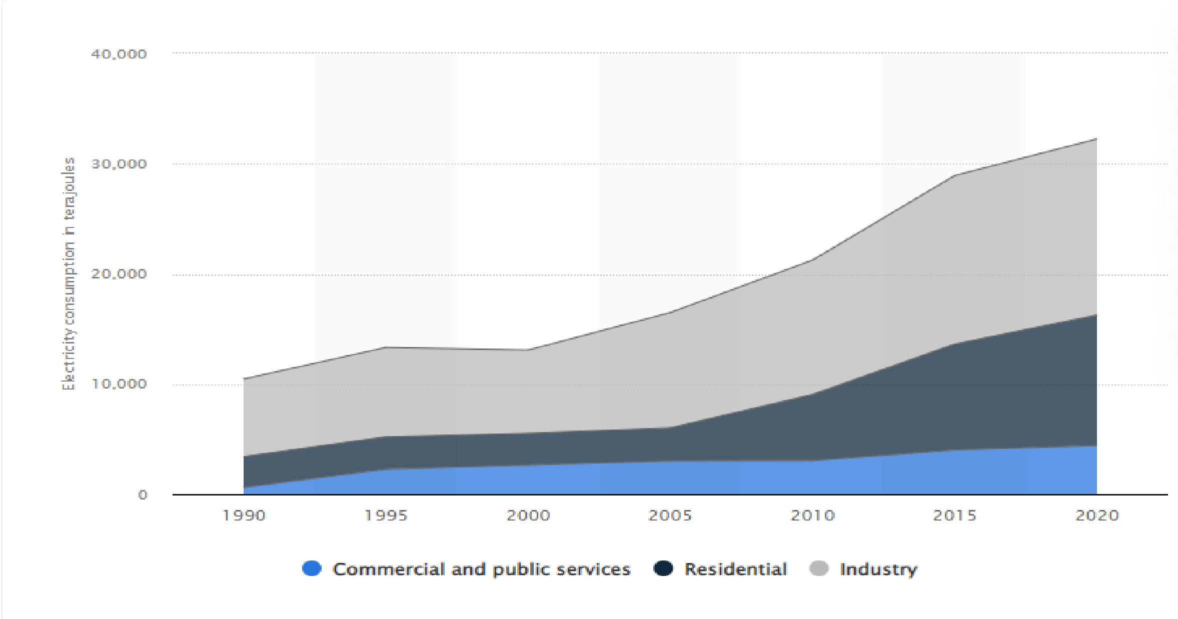

Figure 2.4: Electricity consumption in Kenya from 1990 to 2020, by sector

Source: (Cowling, 2023)

This, as mentioned above may be attributed to efforts by the government and other key players in achieving the universal electricity access, a campaign mainly targeting the residential/domestic electricity users.

A summary of electricity sales among various consumer categories is a shown in figure 2.5 below:

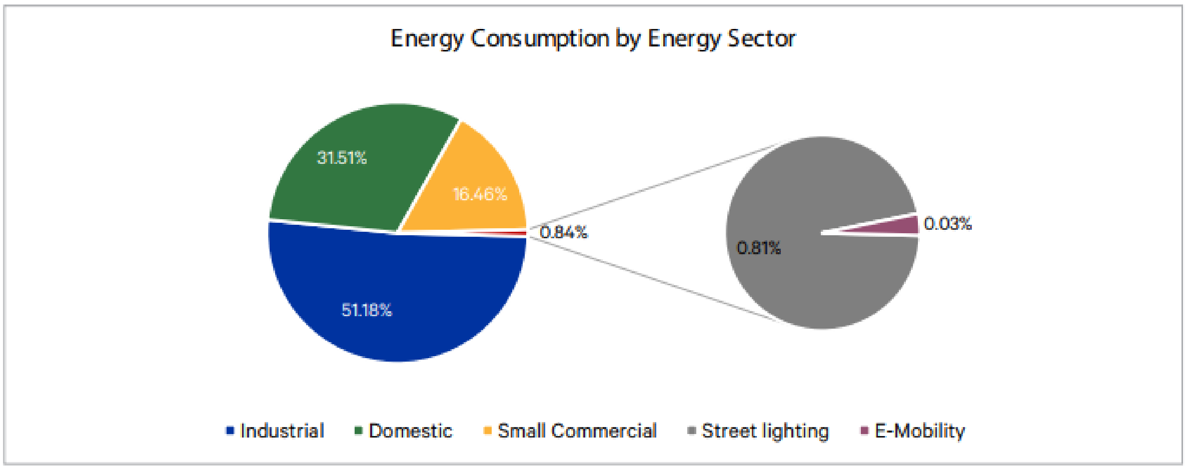

Figure 2.5: Electricity Consumption by Sector (EPRA Statistics Committee, 2025)

With the government actively promoting enhanced connectivity across the nation, particularly focusing on domestic and small commercial consumers who currently represent approximately 48% of the energy demand, Kenya's existing load factor of 73% is likely to decrease. The is mainly because the prevalent electricity usage pattern in this demography, as evidenced in figure 2.3, further catalyses the heightened peak energy demand currently experienced at around 20h00 and further increases the disparity between peak and off peak demand. It is therefore imperative for government and stakeholders to employ such strategies as will be discussed in this study towards adoption of a fairly constant and distributed electrical energy usage pattern, which in turn results in a more homogenous electrical energy demand profile.

2.5. Electrical Energy Dispatch Profile in Kenya

The energy dispatch process in Kenya primarily relies on merit order, a prioritization document for power generation created by the country's energy regulator, EPRA, in coordination with relevant stakeholders. The merit order mainly refers to the order in which dispatch-able power generation plants are utilised to meet the energy demand in Kenya. It is mainly informed by the energy production cost, availability of renewable energy sources as well as the various negotiated power purchase agreements (PPAs). Figure 2.6 below indicates a typical energy dispatch profile in Kenya (*SatMgtBrief 2024-04-13.Xlsx*, 2024).

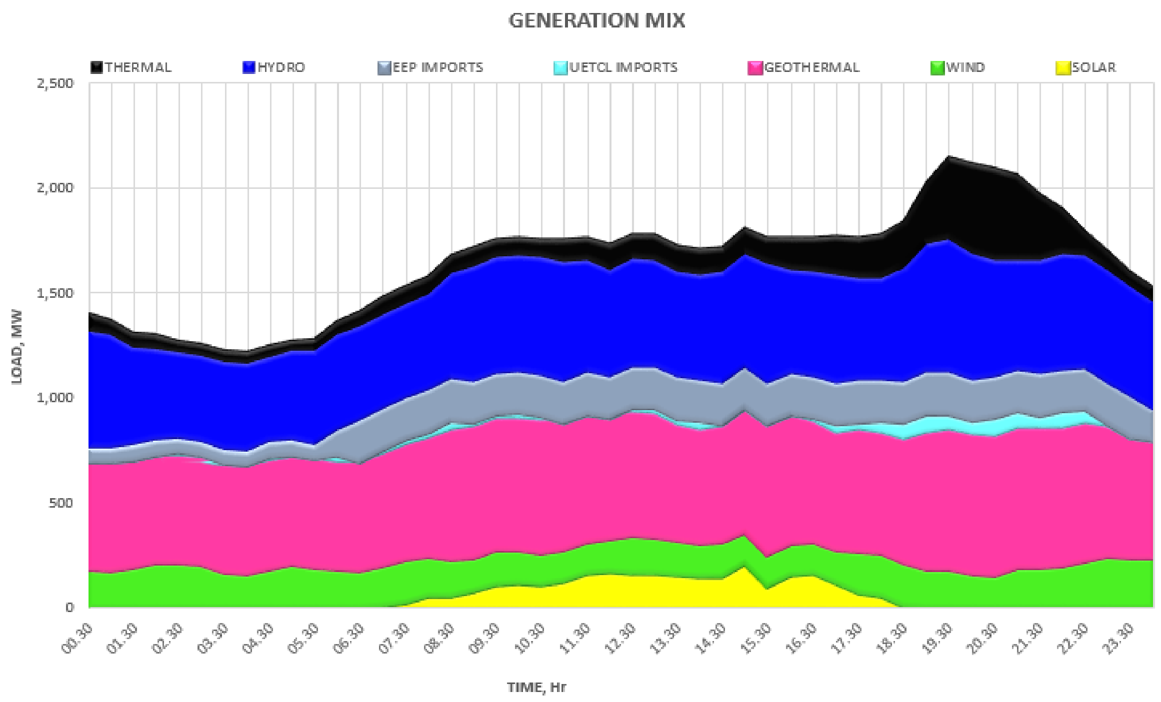

Figure 2.6: Typical Daily Dispatch profile in Kenya

As can be noted from figure 2.6, geothermal and hydro generators are mainly deployed to supply the base load due to their cheaper cost, availability and eco-friendly nature and as such are constantly dispatched throughout a 24 hour day cycle. Imports in Kenya are mainly from Ethiopia (Ethiopian Electric Power, EEP) and Uganda (Uganda Electricity Transmission Company Limited, UETCL) and are mainly renewable based and as such, are used to supply daytime loads as per their respective PPAs. Renewables i.e. wind and solar, are self-dispatched resources, based on their availability while thermal sources act as a peak supply resource only due to their high cost and increased carbon footprint.

2.6. Load Factor Management in Kenya

Kenya currently employs some of the strategies highlighted in section 2.3 for its load factor improvement. These include:

(1) Load factor tariff. This is a pricing system where electricity costs are adjusted based on a customer's load factor, computed as the ratio of their average power usage to their peak power usage over a specific period, essentially rewarding customers who have a more consistent electricity draw throughout the billing cycle (KPLC, 2024a).

(2) Demand Side Management. Through incentives like time-of-use (TOU) pricing and behavioural change campaigns, Kenya Power has embarked on shifting electricity demand away from conventional peak demand periods. Introduced in 2018 by the Kenyan government to encourage productive electricity use, Kenya Power implemented the TOU electricity pricing system. Under this system, large commercial and industrial consumers benefit from significantly reduced rates for electricity consumed during off-peak hours, typically between 10:00 PM and 6:00 AM on weekdays. These off-peak rates offer discounts of up to 50% compared to peak-hour rates, aiming to increase power utilization during periods of low demand while stimulating manufacturing and industrial activity (KPLC, 2024b).

(3) Load forecasting and power planning. Through programmes such as the Least Cost Power Development Plan (LCPDP), the government of Kenya has developed power plans and projections from 2022 to 2041. The plan contains four main outputs from the studies carried out, i.e. the electricity demand forecast, the recommended generation expansion plan, a tariff evolution trend for the medium term period of the plan and the recommended transmission expansion plan. All of which is geared towards developing a capacity expansion plan to meet the projected demand at minimal cost and highest efficiency (MOE&P, 2022).

It is important to note that most load factor improvement strategies, such as load factor-based incentives and TOU tariffs, are primarily targeted at commercial and industrial electricity consumers in Kenya. This focus on commercial and industrial electricity consumers and excluding domestic users has created a gap, highlighting the need for strategies as the one proposed in this study, which aims to address load factor improvement among domestic electricity users, a significant contributor to power system inefficiencies.

This research focuses on energy storage systems, in particular BESS, and its application towards load factor improvement.

2.7. Battery Energy Storage Systems (BESS) Technology

Battery energy storage system is a rapidly emerging technology, which mainly consists of rechargeable batteries, which are used to store electrical energy from different sources, and discharge it when needed. This simple yet transformative technology is gaining significance with the increased drive for sustainable energy transitions.

There are several battery technologies utilised in BESS, the most popular as shown below:

2.7.1. Lithium Ion Batteries

This is a type of rechargeable battery, which uses the reversible intercalations on Li + ions into electronically conducting solids to store energy ("Lithium-Ion Battery," 2023). Lithium ion are the most popular and commercially utilised type of battery for energy storage systems. This is because of their favourable characteristics such as a high energy density, ability to charge and discharge more efficiently, low self-discharge rate and a longer lifespan with little maintenance requirements. Lithium ion technology is mature and well understood, making it a less risky choice that newer, less proven technologies (Smith, 2023).

However, Lithium ion batteries do have some drawbacks, such as requirement of a sophisticated battery management system to prevent overheating and maintain optimal battery health.

2.7.2. Lead Acid Batteries

This rechargeable battery type utilises lead and sulphuric acid to function. This is a more mature technology that has been around since 1859 and are often applicable where the battery isn't cycled frequently and periodic high surge currents are required such as in starting motor vehicles or emergency back-up power ("Lead–Acid Battery," 2023). They are reliable, inexpensive and readily available making them widely used as well.

They however suffer drawbacks such as lower energy density compared to Lithium ion batteries, and a shorter lifespan particularly under deep cycle use. They require significance maintenance for optimal uphold its performance and life cycle and have a potential for environmental harm if not properly recycled or disposed (Smith, 2023).

2.7.3. Solid State Batteries

Solid state is an emerging battery technology that utilises solid electrodes and electrolytes instead of the liquid based electrolyte found in other batteries. This technology has a potential for higher energy density, enhance safety due to its incorporation of a non-flammable solid electrolyte, and a longer lifespan with minimal maintenance.

However, the technology is still at an early stage of development and yet to be commercially available in large scale. The manufacturing process is also costly and complex (Smith, 2023).

2.8. Use of BESS to Improve on Power System Load factor

Lithium-ion batteries are preferred in BESS application due to their high energy density, long lifespan, efficiency, and fast charging/discharging capabilities. These advantages make them well-suited for grid balancing, renewable energy integration, and backup power applications (Del Valle et al., 2018). Studies around load factor improvements by use of BESS technology, are mainly centred on three key concepts, i.e. Peak Shaving, Load shifting and Energy Arbitrage.

Peak shaving – This is essentially storing electrical energy during low demand periods and releasing it during high-energy demand periods. This in turn reduces energy demand from the grid during peak periods (Smith, 2023).

Load shifting – which entails scheduling of charging of BESS away from peak periods to more favourable durations i.e. during off peak timings and when the energy tariff may be lowered. This shifts the demand on the grid away from peak to off peak periods, levelling out the demand curve on the utility distributor.

The above two concepts as shown in figure 2.7 below, may be summarised as peak shaving and valley filling. Several studies have emerged on these concepts most of which are geared towards enhancement of the power system efficiency.

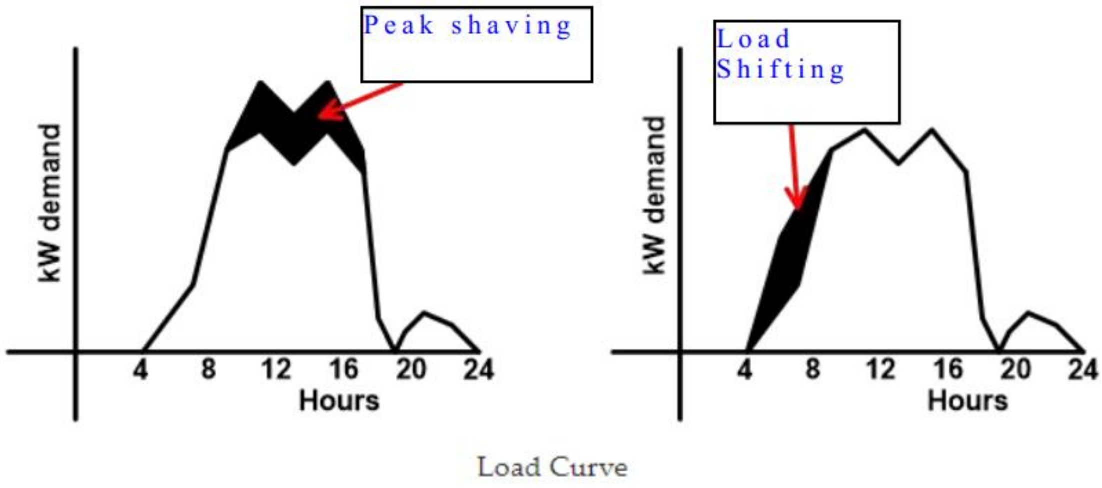

Figure 2.7: Load curve indicating peak shaving and load shifting

Energy Arbitrage – This is a technique employed to improve energy economics by purchasing power during off peak periods, when the unit cost is cheapest, and storing for usage during peak periods, when the unit cost of electricity is most expensive. This concept is made possible by use of the BESS.

The research paper by Telaretti & Dusonchet, (2016a) presents a study concerning the implementation of a peak load reduction approach by altering the power diagram. The research focuses on analysing a case study conducted in an office environment, where notable peak loads were observed on weekdays. To mitigate these peaks, BESS was utilized, storing surplus energy during off-peak periods and supplying it during peak periods. The simulated results display a modified power diagram reflecting this strategy. However, the study's scope is restricted, as it does not determine the optimal operation and size of the BESS.

Earlier studies also conducted a parametric examination to explore how various factors influence the economic viability of BESS for peak load reduction. This assessment, conducted by Telaretti & Dusonchet, (2016b) scrutinized three specific parameters: the variance between high and low electricity prices, peak demand charges, and the initial investment cost for BESS. The findings regarding economic feasibility indicate that, given the existing BESS prices, large-scale battery energy storage technologies are not economically viable without incentives.

In their paper, Chen & Sen, (2016) address an isolated optimization challenge aimed at maximizing revenue through energy arbitrage. A company investor installs a BESS with defined specifications, including capacity (measured in MW) and maximum operating hours, followed by an economic assessment involving investment leverage analysis and net present value computation. Ultimately, the conclusion drawn is that BESS presents a notably costly remedy for contemporary grid challenges. Despite the strategy of charging during periods of low energy prices and discharging during peak prices, the generated revenue remains considerably modest when contrasted with the prevailing capital expenses associated with lithium-ion batteries.

2.9. Cost of BESS

Battery costs are expected to keep decreasing over the medium to long term, although the pace of this decline will differ significantly depending on the type of battery technology. Similarly, the various components of BESS are likely to experience different rates of cost reduction, influenced by factors such as standardization levels, economies of scale, and industry learning (Frankel et al., 2018).

The costs of BESS are generally expressed in one of two ways: (1) cost per kW (or MW), which is the total installed cost of the system divided by its instantaneous power output (typically listed as $/kW), or (2) cost per kWh (or MWh), which is the total system cost divided by its expected energy output (typically listed as $/kWh). Additionally, for any specific BESS, this cost metric can be presented in the following ways:

Installed cost: This represents the total cost of a battery energy storage system, encompassing all essential components and associated services. It includes the battery equipment itself, such as the battery management system, cells, and modules, as well as the balance of system (BOS) components. Typical BOS elements include containers, climate control systems, power management systems, fire suppression systems, and other supporting infrastructure. Additionally, the installed cost accounts for engineering, procurement, and construction (EPC) services. It may also incorporate soft costs such as customer acquisition and project development, grid interconnection, overhead, taxes, and applicable duties (Frankel et al., 2018). These itemised costs are broken down as shown in figure 2.8 below;

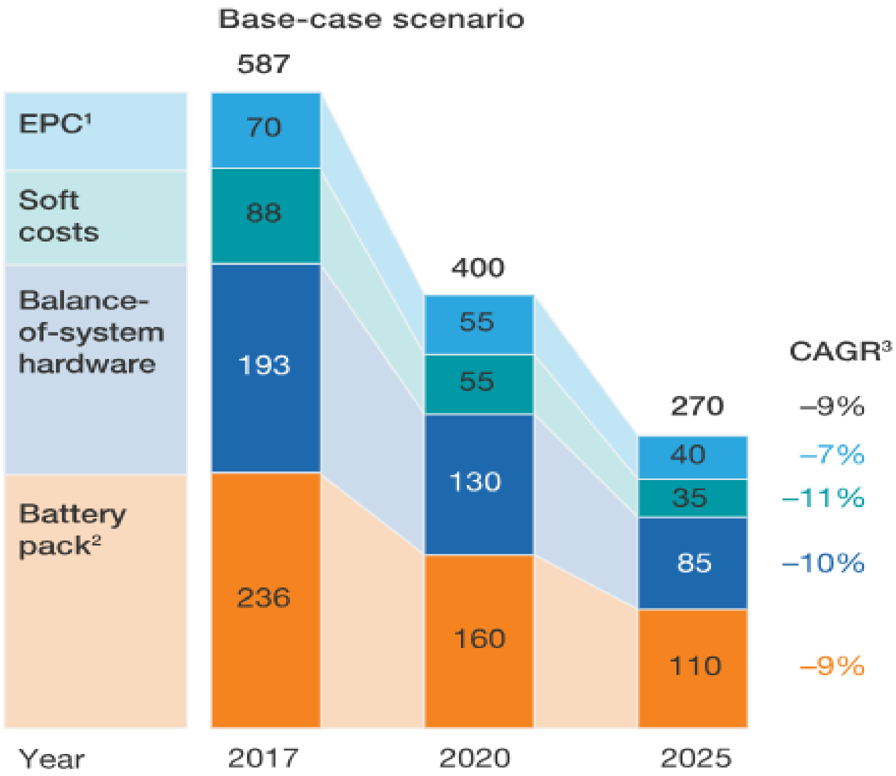

Figure 2.8: BESS Base-case Scenario Global Cost Estimates

Source: McKinsey & Company, GTM Research

Levelized Cost of Storage (LCOS): This represents the comprehensive cost of designing, building, and operating the BESS over its entire useful lifespan. This includes maintenance costs and the impact of battery degradation (Ahlen et al., 2020). The LCOS for battery technologies varies significantly depending on the specific application, commonly referred to as the "use case." Lithium-ion BESS can be deployed in both Front-of-the-Meter (FTM) and Behind-the-Meter (BTM) configurations. BTM applications are typically associated with commercial and industrial (C&I) facilities or residential settings, with or without integrated solar photovoltaic (PV) systems. In contrast, FTM applications generally involve large-scale deployments such as peaking capacity participation in wholesale electricity markets, transmission and distribution (T&D) support, and utility-scale solar PV combined with BESS.

As illustrated in the global cost estimates in Figure 2.9, lithium-ion batteries used in FTM applications had a projected 2021 LCOS ranging from $108/MWh to $471/MWh, depending on the specific use case. When integrated with solar photovoltaic (PV) power generation, lithium-ion BESS achieve the lowest LCOS, estimated between $108/MWh and $140/MWh. However, the LCOS increases for other FTM applications, with the highest range from

$263/MWh to $471/MWh observed in T&D use cases. In contrast, BTM applications exhibit significantly higher LCOS values, ranging from $829/MWh to $1,152/MWh. This is largely due to smaller system capacities and the associated loss of economies of scale (Jülch, 2022).

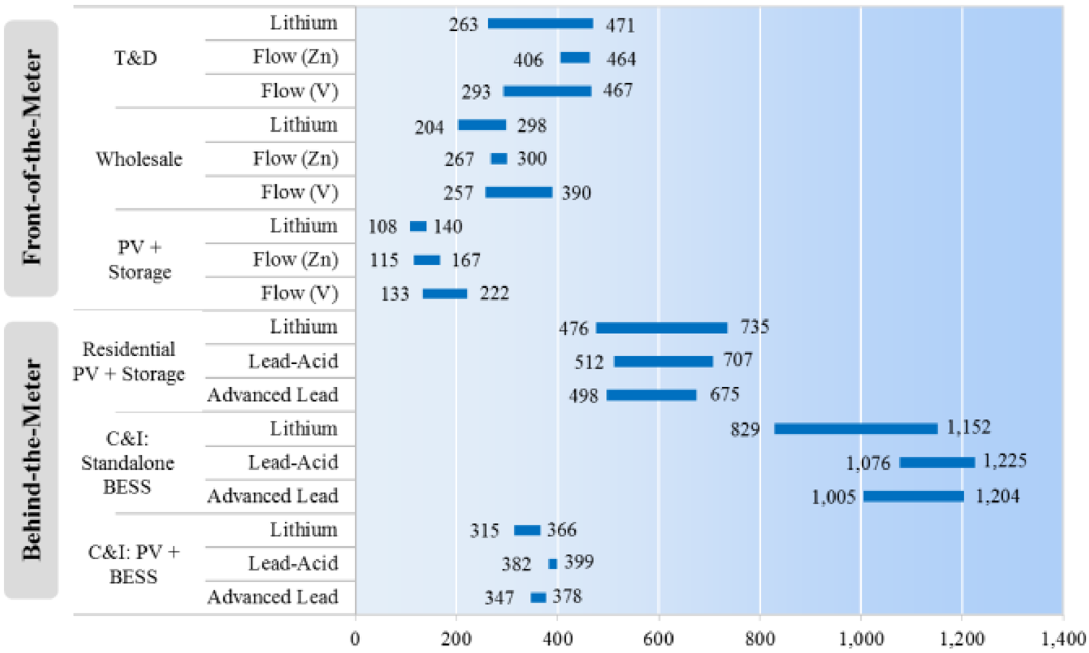

Figure 2.9 LCOS Comparison for various use cases ($/MWh)

2.10. Summary of Research Gaps

Generally, large-scale BESS grid installations, in addition to peak shaving services, can offer various ancillary services vital for maintaining grid stability and reliability. These services include voltage regulation and support, reactive power support, frequency control, spinning reserve, and emergency power provision during outages.

However, several challenges accompany such installations. These challenges encompass scheduling BESS for optimal operation, determining the appropriate size of BESS as installing them at an unsuitable or non-optimal size can lead to increased costs, system losses, and unnecessary BESS capacity. The high capital costs associated with BESS also presents a practical obstacle to implementing peak shaving methods. While using BESS for grid peak load shaving is more effective, it poses challenges due to the complexities of large-scale installations. As such, the operation and maintenance of large-scale BESS are notably more challenging, requiring highly skilled manpower (Uddin et al., 2018).

Hence, this study aims to tackle these hurdles, and bridge the research gap by relocating BESS installations from large-scale grid setups to smaller distribution level installations for domestic electricity users. This approach presents a simpler and more cost-effective solution. The study will aim to illustrate that, through a strategic and focused implementation of this solution, the cumulative impact of numerous small-scale BESS installations can yield comparable benefits for the grid without the earlier mentioned challenged associated with large-scale BESS deployment.

2.11. Conceptual Framework

The fundamental idea underpinning this study is illustrated in Figure 2.10.

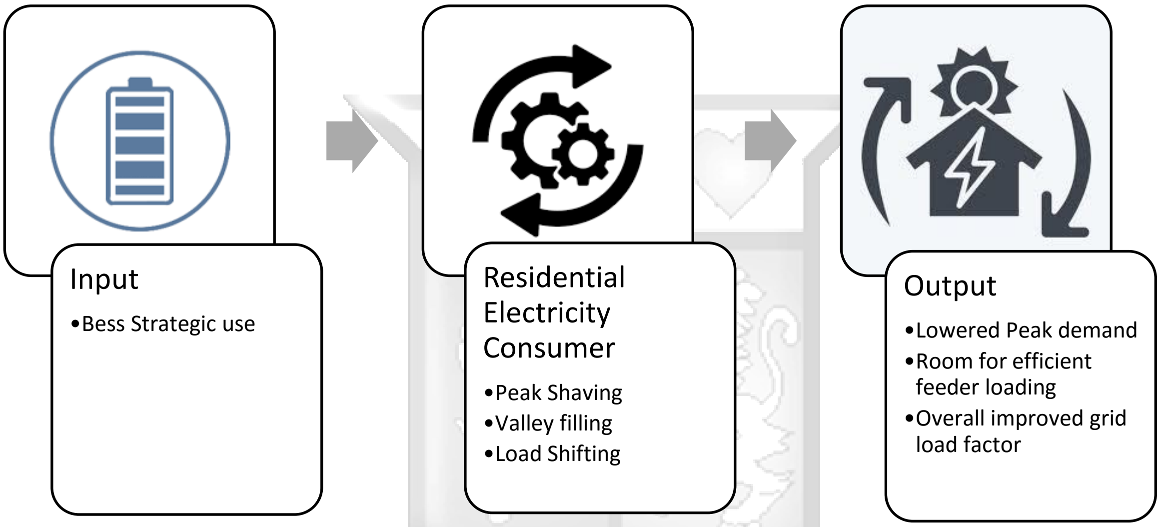

Figure 2.10: BESS Study conceptual framework

It is anticipate that by integrating BESS technology into residential electricity usage, the efficiency of the electrical grid may be enhanced. As discussed previously in this document, the morning and evening peaks in electricity demand experienced on the power grid is largely attributable to residential/domestic users. Therefore, strategic deployment of BESS technology at the domestic distribution level has the potential to achieve peak shaving, valley filling, and load shifting, as elaborated earlier in this chapter. This can be effectively accomplished by scheduling the BESS unit's charging cycle between 0000hrs and 0300hrs and its discharge cycle (transitioning loads off the grid) between 1800hrs and 2200hrs.

In the long term, this practice is expected to enhance power system efficiency by reducing peak demands. It also facilitates the achievement of a more uniform feeder load curve, which allows for efficient and optimal feeder loading. Overall, this practice leads to improvements in grid load factor and utilization factor. Additionally, it enables the utilization of cheaper energy sources typically available during off-peak periods, such as wind power, thus minimizing reliance on traditional fossil fuel sources like thermal power, which are usually dispatched to meet peak demands in Kenya.

3. Methodology

3.1. Introduction

This section outlines the systemic approach used in this research study to meet its objectives. The section includes components such as the type of research design employed, units of analysis, data collection method, model development indicating justification on the choice of simulation software used, and data analysis technique and ethical considerations.

3.2. Research Design

This study adopts an action research design. According to *Research Design*, (2023) this types of research design involves initial exploratory analysis and the development of an action strategy. It is focused on finding a solution to the modern day problem of cost of power, and mitigation of energy losses and inefficiencies. The study design follows the four key stages of action research design, i.e. (1) Planning - identification of different electricity usage patterns and identifying where deployment of BESS will elicit the best results towards achieving the research objectives. (2) Action – This is carried out through simulation of proposed strategies towards achievement of research objectives. (3) Observing and (4) Reflecting – Through analysis of the simulated results the research conducts analysis and derive appropriate conclusions on the impact of BESS on power system efficiency.

This makes the study practical in addressing the challenge of power system efficiency, while at the same time is relevant for many other related research topics.

3.3. Unit of Analysis

The unit of analysis as defined by Trochim, (2020) represents the major entity that will be of analysis in the study. The first component the study looks at is the BESS technology and solution currently available in the market. The study does not seek to re-invent the wheel, but rather explore how existing solutions in the BESS industry can be explored as a tool in load factor improvement of the grid level.

The next unit analysed is the most suitable and practical loading model for integration with the BESS solution. The study examines customer load profiles across different socio-economic groups, i.e. low-income, middle-income, and high-income households. Its goal is to determine which group contributes most significantly to the currently observed low load factor. This information will help identify where the BESS enhancement strategy would be most effective in improving the country's general load factor. The analysis focuses on data from domestic electricity users within Nairobi city since Nairobi, as a metropolitan area, according to (EPRA Statistics Committee, 2024) constitutes 43.7% of Kenya's electricity demand and represents a broad spectrum of socio-economic classes. The resulting model is considered reliable for nationwide application.

The final key area of analysis involved developing a representative model of the solution to evaluate its technical, social, and economic feasibility. This included estimating the costs of the proposed model, performing a cost-benefit analysis, calculating the return on investment, and assessing the expected benefits for key stakeholders, such as the distribution licensee (Kenya Power) and electricity consumers.

3.4. Data Collection Method

The study employed secondary data from the Kenya National Bureau of Statistics (KNBS) on classification on low income, middle income and high income household areas. KNBS, (2023) in their 2022 economic survey classified Nairobi low income households as those spending sh. 46,355 or less in a month, Nairobi middle income households as those spending between sh. 46,356 - 184,394 per month and high income Nairobi households as spending above sh. 184,394 per month.

The KNBS data was further coupled with secondary data from KPLC on electricity distribution feeder data, serving the established household areas of low middle and high income. This was aimed at establishing pilot feeders for the study, which aided in establishing the electricity demand pattern for the three income category residential areas in Nairobi.

3.5. Research Model

The research model is demonstrated in the flow chart in figure 3.1 below. Secondary data from KNBS was obtained to establish low, middle and high income areas in the Nairobi Metropolitan area. Corresponding secondary data was obtained from KPLC on the respective distribution feeder demand data serving these designated low, middle and high income areas. The load factor to the various feeder demand profile was obtained, analysed and compared to one another in order to determine, in which of the three socio-economic electricity user profiles, poor load factor was prevalent.

An appropriately sized and designed BESS solution was deployed and simulated to enhance the feeder with the poorest load factor. The enhancement with respect to load shifting from peak demand durations to off peak durations was effected in order to lower the peak demand and raise the off-peak demand.

The enhanced feeder load factor was obtained and analysed to establish whether there was any significant improvement post BESS enhancement.

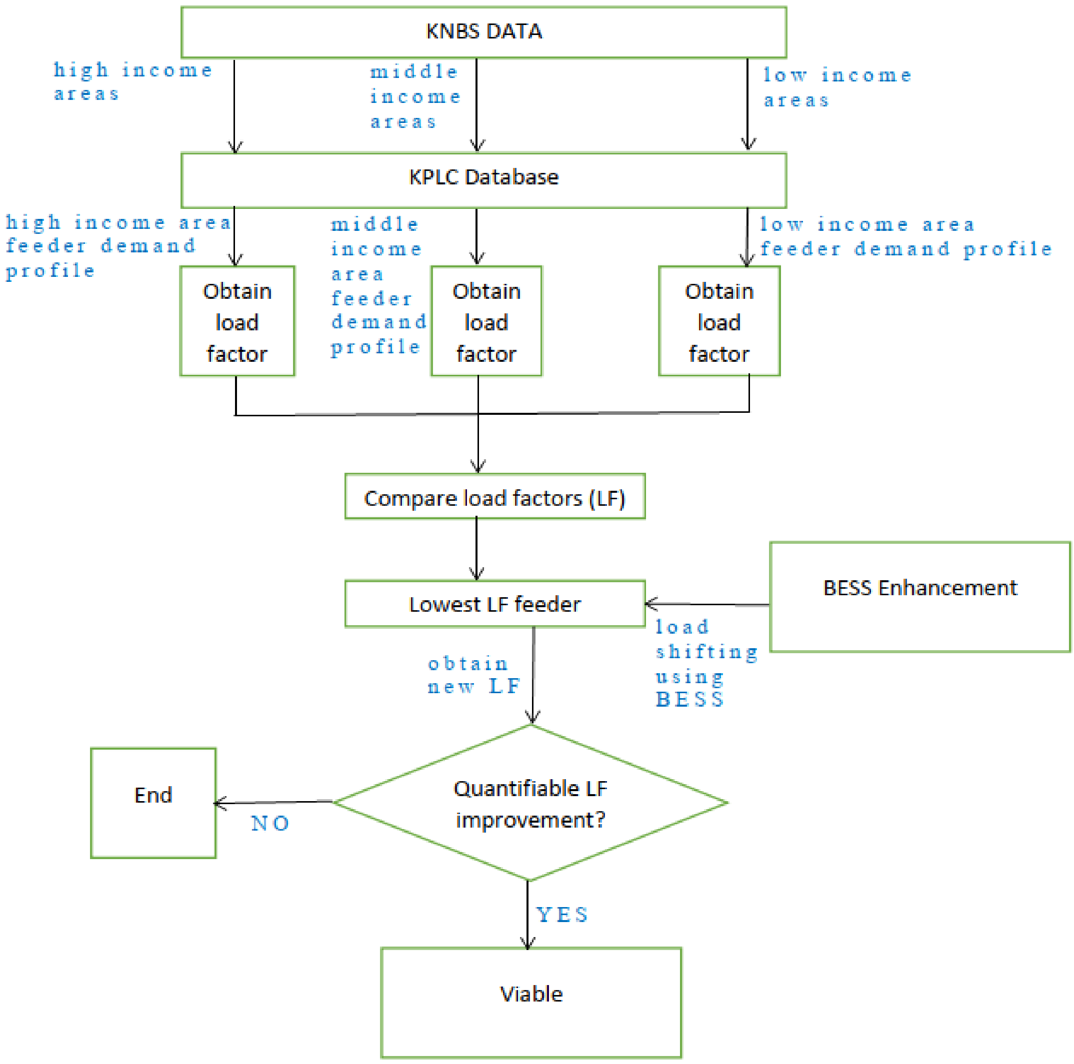

Figure 3.1: Flow chart of research model

The above model may be simulated by use of relevant simulation software. Available simulation software include R, PSCAD, PSS®E, MATLAB and DIgSILENT PowerFactory. DIgSILENT PowerFactory was the more preferred simulation software for the above model as it offers the following advantages over its counterparts in this research application:

Compared to alternatives like ETAP, PSCAD, PSS®E, or MATLAB/Simulink, DIgSILENT PowerFactory stands out for its combination of versatility, precision, and industry-focused features, particularly in transmission and distribution network studies. It integrates power system analysis, simulation, and optimization into a single platform, eliminating the need for multiple software solutions.

The software supports a wide range of analyses, including load flow, fault analysis, transient stability, electromagnetic transients (EMT), and harmonic analysis. Its robust numerical algorithms deliver highly accurate simulations, making it a trusted tool among industry professionals, utilities, and researchers globally.

PowerFactory is designed to handle projects ranging from small-scale systems to large, complex networks without requiring additional modules. It adheres to international standards (e.g., IEC, IEEE), enabling its application across diverse regions and projects. The software features detailed models for generators, transformers, renewable energy sources, and advanced protection devices. Additionally, it provides specialized tools for renewable energy integration, microgrids, and hybrid systems.

In Kenya, DIgSILENT PowerFactory is widely utilized by key utility companies, including Kenya Power and KETRACO, demonstrating its reliability and acceptance as an industry-standard tool for power system modelling in the local market.

3.6. Data Analysis Technique

Secondary data was collected on electricity demand from distribution feeders over a six-month period. The data was consolidated into a typical day profile by averaging the hourly demand for each day across the three-month period. This approach aimed to enhance accuracy and provide a true representation of the typical daily demand profile for the respective feeders.

Each feeder's profile was analysed individually to determine key parameters, such as peak demand, daily distributed energy, and load factors. Additionally, these parameters were examined and compared across different socio-economic classes of electricity end users, allowing for appropriate conclusions to be drawn.

BESS enhancement was applied to the feeder with the lowest load factor, based on the assumption that achieving success on this feeder would ensure success on other feeders with relatively better load factors. Following the implementation of BESS enhancements on the distribution feeder with the lowest load factor, the enhanced grid simulation output was compared against the original demand curve data obtained from KPLC. Load factor before and after the BESS enhancement was calculated and analysed. The primary success indicator was where the feeder load factor showed significant improvement, achieving or exceeding 0.75 (75%).

This threshold aligns with the Kenya Grid Code, 2024 (EPRA, 2024), which specifies a minimum load factor of 75% as essential for efficient operation and optimal utilization of power system infrastructure. Meeting this benchmark ensures effective use of generation, transmission, and distribution systems while minimizing inefficiencies like underutilized capacity.

The study's final results were presented in a clear, simple and precise manner, addressing all research objectives comprehensively.

3.7. Ethical Consideration

This research study adheres to the highest ethical standards and principles in accordance with The Strathmore University Institutional Scientific Ethics Review Committee (SU-ISERC), an independent recognized entity accredited by NACOSTI. The following ethical considerations will be carefully addressed and implemented throughout the research process:

Informed Consent: All participants and facilitator involved in this study were fully informed about the purpose, procedures, risks, and benefits of their participation. They were provided voluntary and informed consent before participating in any research activities.

Confidentiality and Anonymity: Confidentiality of participants' personal information and data was strictly maintained throughout the study. All collected data was anonymized and stored securely to prevent unauthorized access. Only authorized members of the research team were allowed access to identifiable information, and data was reported in aggregate form to preserve anonymity.

Respect for Autonomy and Dignity: Participants' autonomy, dignity, and rights were respected at all times. They were accorded the freedom to withdraw from the study at any point without consequences, and their decisions will be honoured without question.

Beneficence and Justice: The research aims to generate knowledge that benefits society and contributes to the advancement of science, while also ensuring that the distribution of benefits and burdens is fair and just. Efforts were made to ensure that the research process was inclusive, respectful, and equitable for all involved parties.

By upholding these ethical considerations, the study affirmed its commitment to conducting responsible and ethical research that upholds the rights, dignity, and welfare of all participants and stakeholders involved.

4. Results and Discussion

4.1. Introduction

This chapter addresses the second research question outlined in Section 1.4. It examines the current electricity supply and demand patterns among domestic electricity users in Nairobi, Kenya, categorized by their socio-economic groups. Additionally, it analyses the load factors across these consumer categories, highlighting how they compare to one another.

The chapter further discusses on the findings on the socio-economic group of domestic electricity users identified as the primary contributors to poor load factors on the grid infrastructure. The discussion forms the basis for developing a BESS model designed to address this issue, thereby answering research questions 3 and 4 outlined in Section 1.4. To this end, this chapter contains a proposed design model tailored to domestic electricity usage and simulates how the model can be implemented with the aim of load factor improvement on the feeder demand profile. The model is further validated using similar projects and research that have been implemented across different electricity distribution grids worldwide.

4.2. Data Collected and Sources

The data used in this study was sourced from the KNBS Consumer Price Index Rebasing Report of March 2020. This report categorizes areas in Nairobi, Kenya, by socio-economic status into low, middle, and high-income household areas. These categorizations helped identify the specific areas for which secondary data on domestic electricity demand trends was obtained.

Additional secondary data was sourced from SCADA reports and logs within Kenya Power's Facilities Database (FDB), providing real-time electricity demand information for the relevant distribution infrastructure corresponding to the household areas identified in the KNBS data. Data collection covered a six-month period to account for variations in demand patterns influenced by factors such as seasonal weather changes and school calendars.

Further data from reports and publications was used to summarize the methods currently employed in Kenya for load factor stabilization.

4.3. Data Preparation Techniques

The SCADA reports and logs collected over the six-month period were substantial and required thorough cleaning to ensure accuracy. Manual analysis was conducted to identify and address instances where SCADA monitoring was offline, resulting in non-real-time data transmission.

For offline periods lasting less than two hours, demand was extrapolated based on the last recorded real-time data and manually inputted. However, for offline periods exceeding two hours, the affected data was discarded. In such cases, readings were sourced from an additional day when the logging was fully online and real-time.

The cleaned data was then condensed into a typical day profile by averaging the hourly logged data for each day over the six-month period. The resulting data was well labelled and organized into an hourly log for a typical day. This profile was visualized as a line graph, plotting electricity demand against the time of day, to clearly illustrate daily demand patterns.

4.4. Results and Data Analysis

KNBS in their report, (KNBS, 2020), reported that Nairobi's low expenditure group constituted 70.89 per cent of all households in Nairobi and was represented by the areas of Githurai, Kawangware, Eastleigh, Kangemi, Dandora, Kariobangi, Kibera and Kayole in Nairobi Metropolis. Nairobi's middle expenditure group constituted 25.58 per cent of all of Nairobi's households and was represented by the areas of South C, Nairobi CBD and Buruburu. Finally, Nairobi's upper expenditure group constituting 3.53 per cent of Nairobi's households was represented by the areas of Westlands, Kilimani, Hurlingham, Langata and Karen.

Based on the above representation, the corresponding KPLC distribution feeder lines supplying power to these areas were analysed to showcase the energy demand pattern of the different household categories in Nairobi. The feeder names for the respective residential areas in Nairobi are as tabulated in table 4.1 below:

Table 4-1: 11kV Feeders supplying High, Middle and Low Income areas in Nairobi

#	**11kV Feeder Name**	**Originating Primary Substation**	**Area serving**	
1	Hurlingham	Kileleshwa 66/11kV s/s	Hurlingham	High Income
2	Elgeyo Marakwet Rd	Kileleshwa 66/11kV s/s	Kilimani	
3	Nairobi Hospital	Ngong rd 66/11kV s/s	Kilimani	
4	Buruburu	Kimathi 66/11kV s/s	Buruburu	Middle Income
5	Harambee	Kimathi 66/11kV s/s	Buruburu	
6	5 Star	Nairobi West 66/11kV s/s	South C	
7	Kamunde	Huruma 66/11kV s/s	Kariobangi	Low Income
8	K.South	Huruma 66/11kV s/s	Kariobangi	
9	Infill	Komarock 66/11kV s/s	Kayole	

10	Kibra	Ngong rd 66/11kV s/s	Kibera	

The energy demand from these feeder distribution lines for a 6 month period were analysed and average daily demand curves for the respective feeders were plotted for a typical 24 hour day cycle as shown below in figures 4.2 – 4.11 . The load factors for the respective feeders were also obtained using the below equations 3 and 4;

Load factor = $^{Daily\ average\ demand\ in\ T\ hrs}/_{Peak\ demand\ X\ 24hr\ day\ cycle}$ (3)

Load factor = $^{Area\ under\ the\ load\ curve}/_{Peak\ demand\ X\ 24hr\ day\ cycle}$ (4)

Where: the area under the load curve was obtained using Trapezoidal rule demonstrated in figure 4.1 below. The rule states that the area under the curve may be calculated by dividing the curve into small trapezoids and the summation of the areas of the small trapezoids will give the area under the curve (Cuemath, 2023), i.e.;

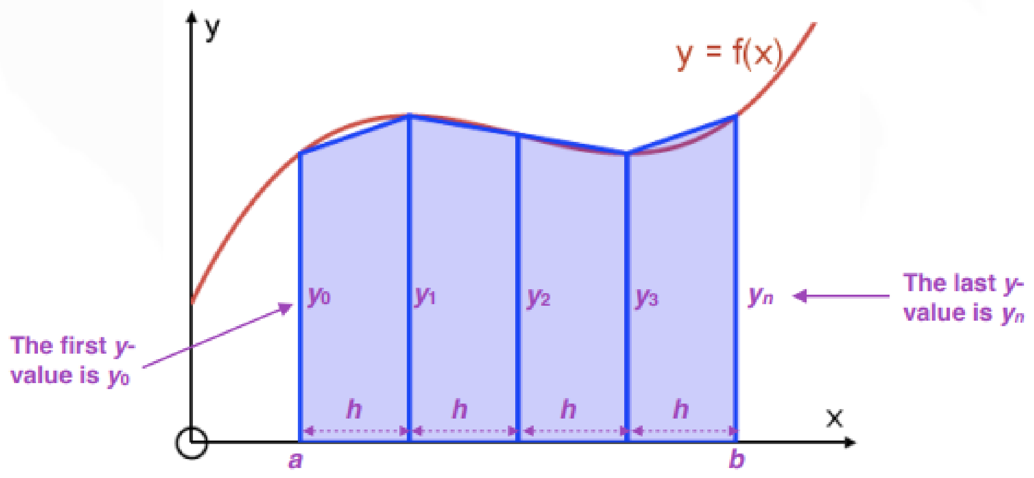

Figure 4.1: Trapezoidal Rule Calculation

Area = $\frac{h}{2}(y_0 + 2(y_1 + y_2 + y_3 + \ldots + y_{n-1}) + y_n)$ (5)

where h (trapezium width) = $^{(b-a)}/_{n}$

The respective feeder demand characteristics were summarised in tables 4.2 - 4.11 below:

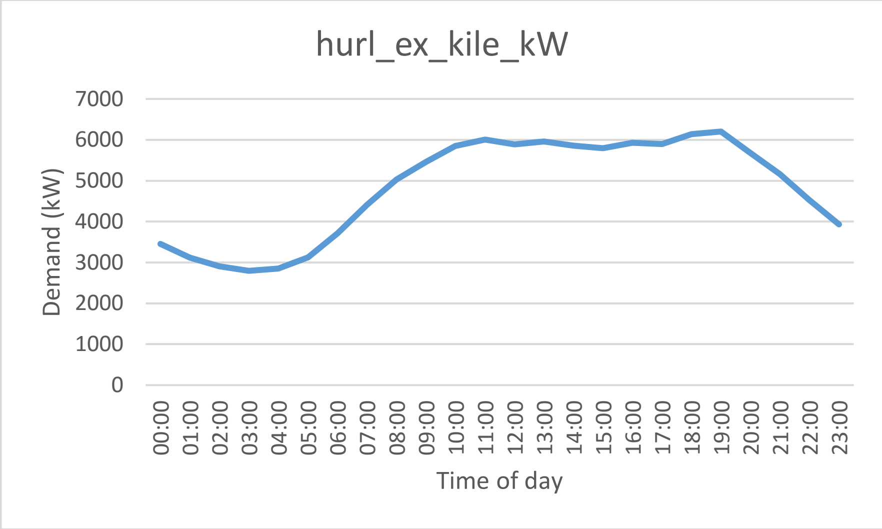

Figure 4.2: Hurlingham feeder demand curve

Table 4-2: Hurlingham feeder demand characteristics

Name	**Hurlingham (high income)**
Primary substation	Kileleshwa 66/11kV s/s
Daily average demand	111,986.76 kWh
Peak demand	6202.85 kW at 1900hrs
Load Factor	0.75

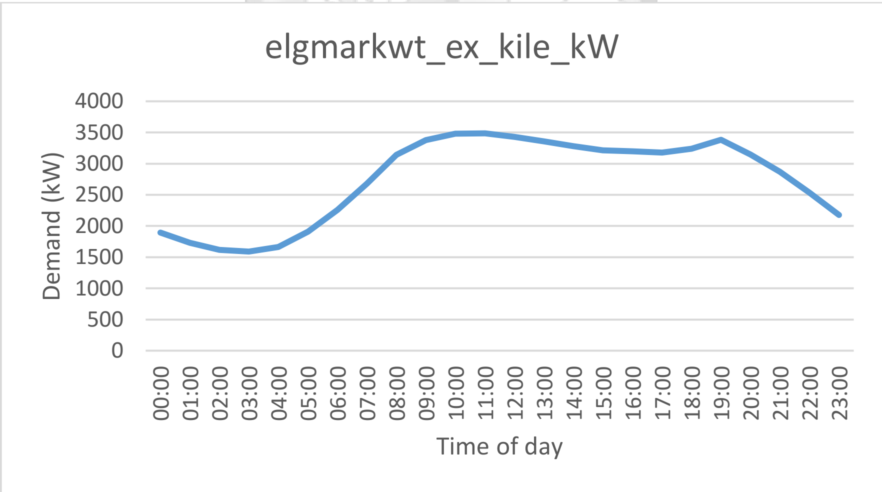

Figure 4.3: Elgeyo-Marakwet feeder demand curve

Table 4-3: Elgeyo-Marakwet feeder demand characteristics

Name	**Elgeyo Marakwet rd (high income)**
Primary substation	Kileleshwa 66/11kV s/s
Daily average demand	63,805.5 kWh
Peak demand	3486.16 kW at 1900hrs
Load Factor	0.76

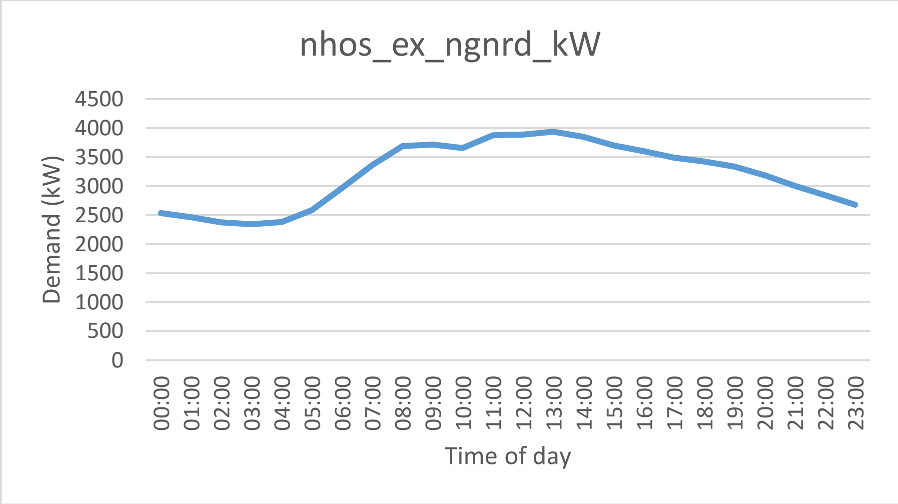

Figure 4.4: Nairobi Hospital feeder demand curve

Table 4-4: Nairobi Hospital feeder demand characteristics

Name	**Nairobi Hospital (high income)**
Primary substation	Ngong rd 66/11kV s/s
Daily average demand	74,277.51 kWh
Peak demand	3937.6 kW at 1300hrs
Load Factor	0.79

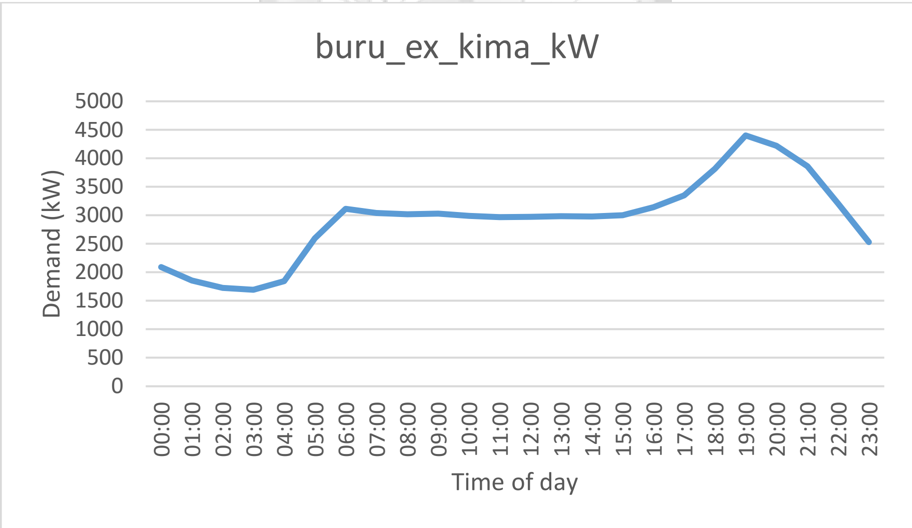

Figure 4.5: Buruburu feeder demand curve

Table 4-5: Buruburu feeder demand characteristics

Name	**Buruburu (middle income)**
Primary substation	Kimathi 66/11kV s/s
Daily average demand	68,129.05 kWh
Peak demand	4,401.17 kW at 1900hrs
Load Factor	0.64

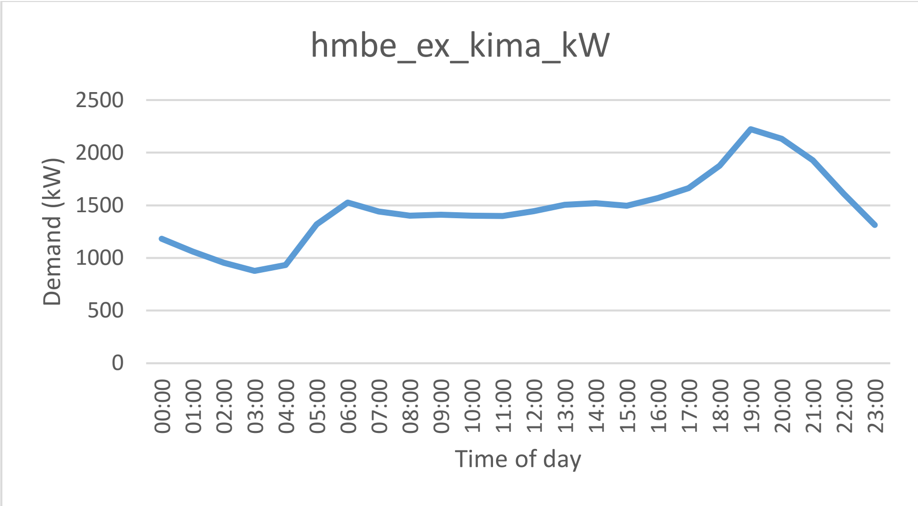

Figure 4.6: Harambee feeder demand curve

Table 4-6: Harambee feeder demand characteristics

Name	Harambee (middle income)
Primary substation	Kimathi 66/11kV s/s
Daily average demand	33,937.96 kWh
Peak demand	2,223.14 kW at 1900hrs
Load Factor	0.64

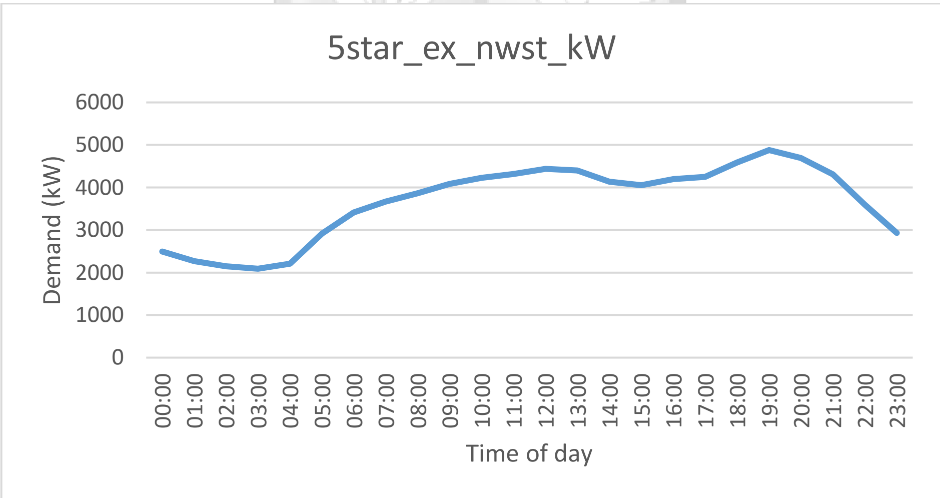

Figure 4.7: 5-Star feeder demand curve

Table 4-7: 5-Star feeder demand characteristics

Name	5 star (middle income)
Primary substation	N/west 66/11kV s/s
Daily average demand	85,444.65 kWh
Peak demand	4,879.13 kW at 1900hrs
Load Factor	0.73

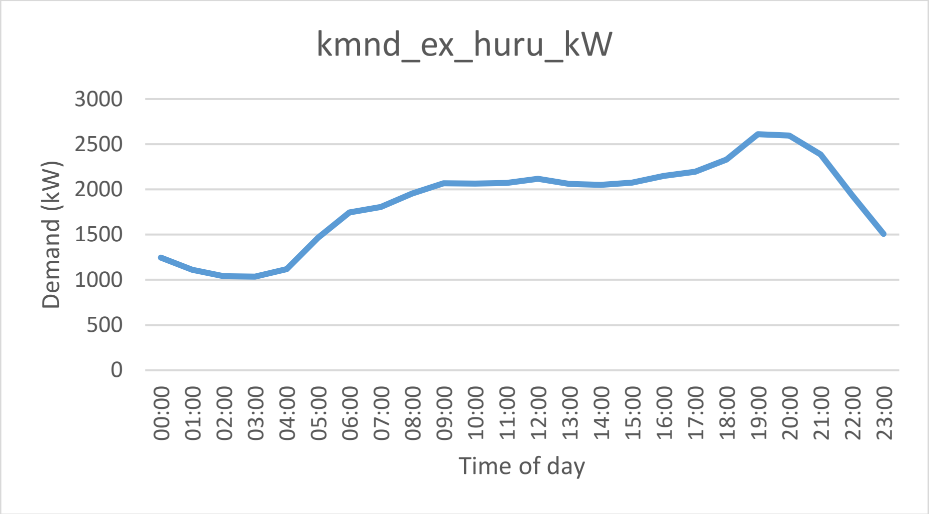

Figure 4.8: Kamunde feeder demand curve

Table 4-8: Kamunde feeder demand characteristics

Name	**Kamunde (low income)**
Primary substation	Huruma 66/11kV s/s
Daily average demand	43,368.03 kWh
Peak demand	2,611.17 kW at 1900hrs
Load Factor	0.69

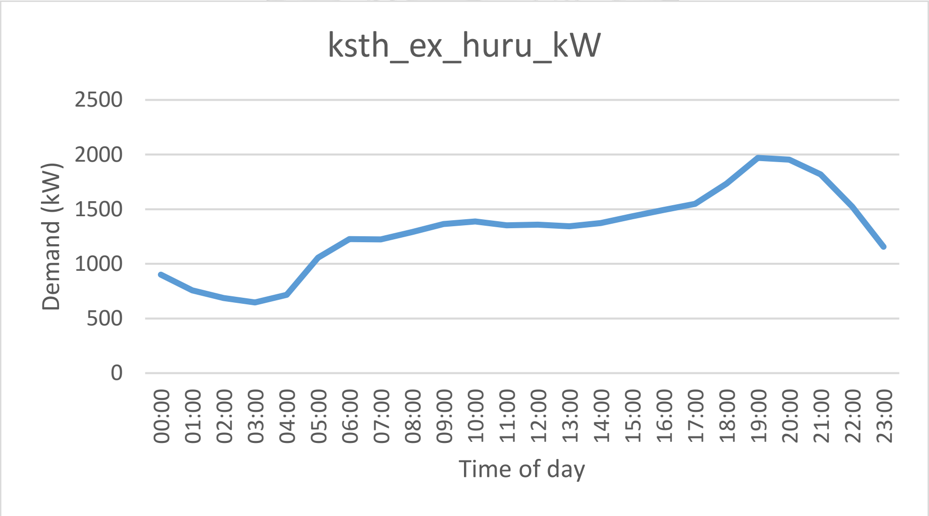

Figure 4.9: K-South feeder demand curve

Table 4-9: K-South feeder demand characteristics

Name	**KSouth (low income)**
Primary substation	Huruma 66/11kV s/s
Daily average demand	30,283.22 kWh
Peak demand	1,969.66 kW at 1900hrs
Load Factor	0.64

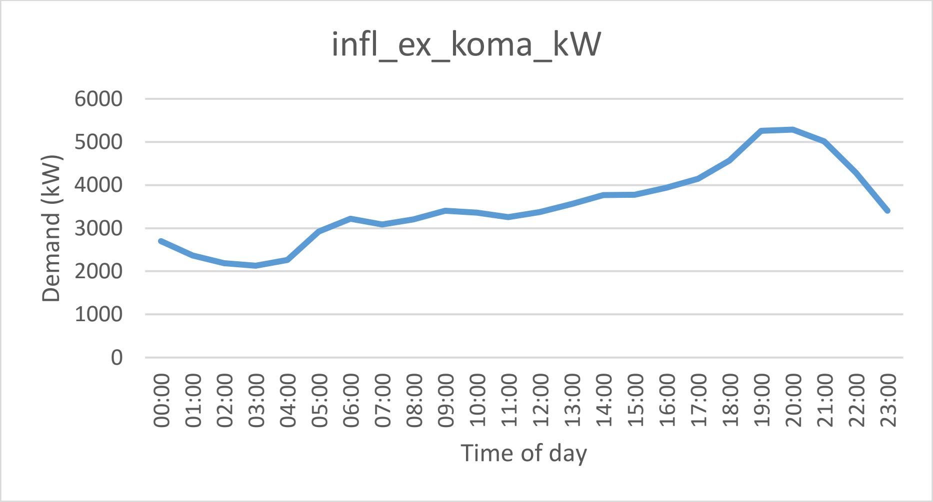

Figure 4.10: Infill feeder demand curve

Table 4-10: Infill feeder demand characteristics

Name	**Infill (low income)**
Primary substation	Komarock 66/11kV s/s
Daily average demand	81,457.51 kWh
Peak demand	5286.8 kW at 2000hrs
Load Factor	0.64

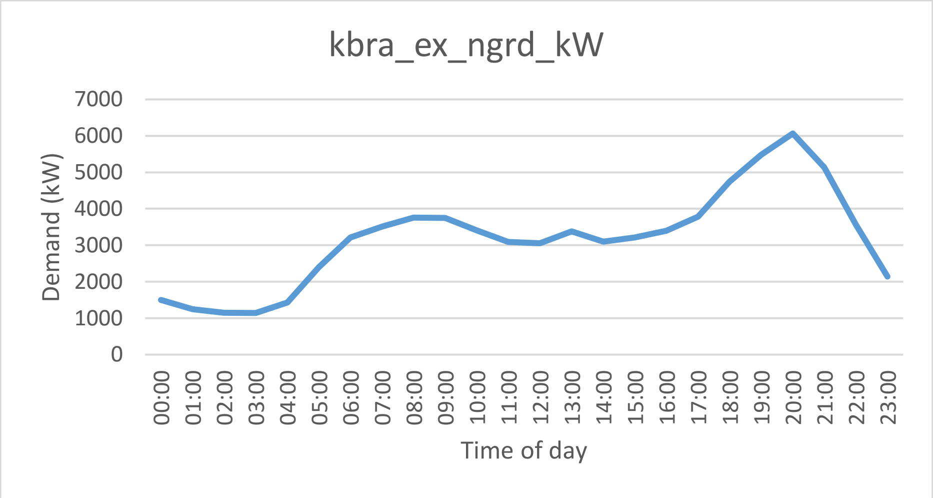

Figure 4.11: Kibra feeder demand curve

Table 4-11: Kibra feeder demand characteristics

Name	**Kibra (low income)**
Primary substation	Ngong rd 66/11kV s/s
Daily average demand	74,811.29 kWh
Peak demand	6065.77 kW at 2000hrs
Load Factor	0.51

4.5. Summary of Findings

Table 4-12 Feeder Load Factor Summary

#	11kV Feeder Name	Originating Primary Substation	Area serving	Load Factor (LF)	
1	Hurlingham	Kileleshwa 66/11kV s/s	Hurlingham	0.75	High Income (Ave LF=0.77)
2	Elgeyo Marakwet Rd	Kileleshwa 66/11kV s/s	Kilimani	0.76	
3	Nairobi Hospital	Ngong rd 66/11kV s/s	Kilimani	0.79	
4	Buruburu	Kimathi 66/11kV s/s	Buruburu	0.64	Middle Income (Ave LF=0.67)
5	Harambee	Kimathi 66/11kV s/s	Buruburu	0.64	
6	5 Star	Nairobi West 66/11kV s/s	South C	0.73	
7	Kamunde	Huruma 66/11kV s/s	Kariobangi	0.69	Low Income (Ave LF=0.62)
8	K.South	Huruma 66/11kV s/s	Kariobangi	0.64	
9	Infill	Komarock 66/11kV s/s	Kayole	0.64	
10	Kibra	Ngong rd 66/11kV s/s	Kibera	0.51	

As summarised in table 4-12, the average load factor for feeders in low-income areas was 0.62, compared to 0.67 for middle-income areas and 0.77 for high-income areas. It is therefore apparent from the sampled feeders, that domestic customers of low income status are the bigger contributors of the low load factor recorded for domestic supply in Nairobi and subsequently in Kenya. This discrepancy may likely be attributed to the significantly lower electricity demand observed in and around low-income households during the day, in contrast to middle- and high-income households. Several factors may contribute to this, including: (1) middle- and high-income households typically having a greater number of domestic appliances, which increases electricity consumption during the day, and (2) a higher concentration of electricity-dependent businesses, such as restaurants, spas, gyms, and auto repair shops, tending to be located near middle- and high-income residential areas.

The validity of the above assumptions could be ascertained through a comprehensive survey on the acquisition of household appliances across high, middle, and low-income households, along with an assessment of businesses established in these areas. However, conducting such a validation is beyond the scope of this study.

It is therefore apparent that electrical load factor correction is essential, especially among low-income households.

4.6. Utility Scale Load Factor Correction using BESS

This research aimed at exploring the strategy of using BESS for peak shaving and valley filling at the utility level. Specifically, it proposed implementing this solution at the 11kV feeder level by installing a BESS unit at the load centre, which would discharge during peak demand hours and charge during off-peak periods. Installation at the 11kV distribution network was considered due to the following reasons:

(1) The 11kV distribution feeders provided a decentralized and targeted approach, effectively isolating and focusing the solution on the intended low-income households.
(2) At the same time, the feeder distribution network, unlike service lines to individual homes, offered a centralized location for BESS installation, enhancing equipment safety while simplifying maintenance, monitoring and control.
(3) Implementing the solution at the utility level shielded low-income households from the high initial costs of BESS acquisition, making the solution accessible to this socio-economic group of electricity users.

The design configuration for the various 11kV feeders originating from 66/11kV substations may be represented as shown in the single line diagram (SLD) in figure 4.12 below. The substations surveyed are all supplied from 66kV supply lines. This incomer is stepped down to 11kV supplies, which are distributed to the load centres via 11kV overhead feeder lines. Various general loads are distributed along the feeder length to depict the supply network to various customers.

The proposed BESS deployment, as illustrated in the SLD in Figure 4.13, is strategically positioned downstream, away from the feeder source and closer to the load centre. This placement ensures that, once dispatched, the BESS unit effectively offsets power drawn from the feeder supply, thus optimizing on power flow.

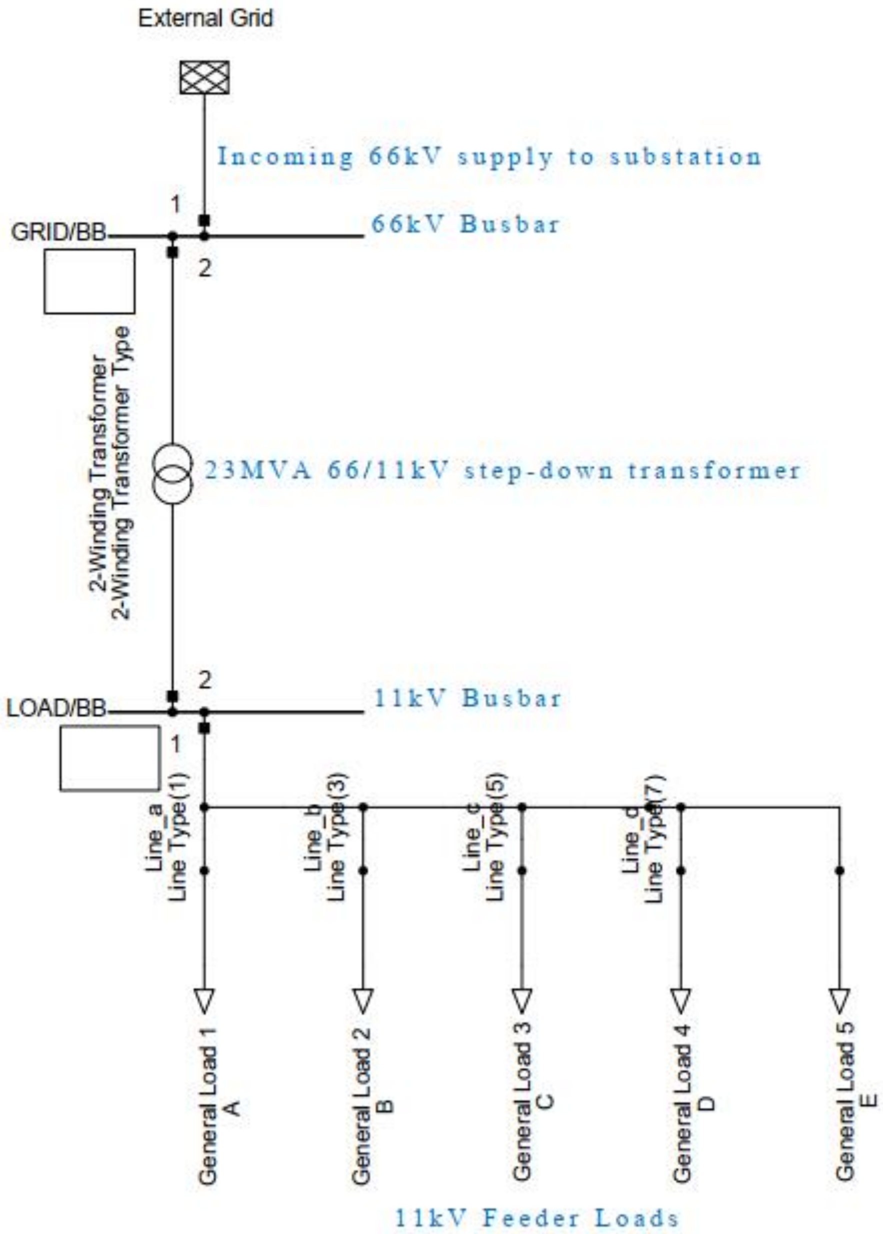

Figure 4.12: Distribution Feeder Configuration

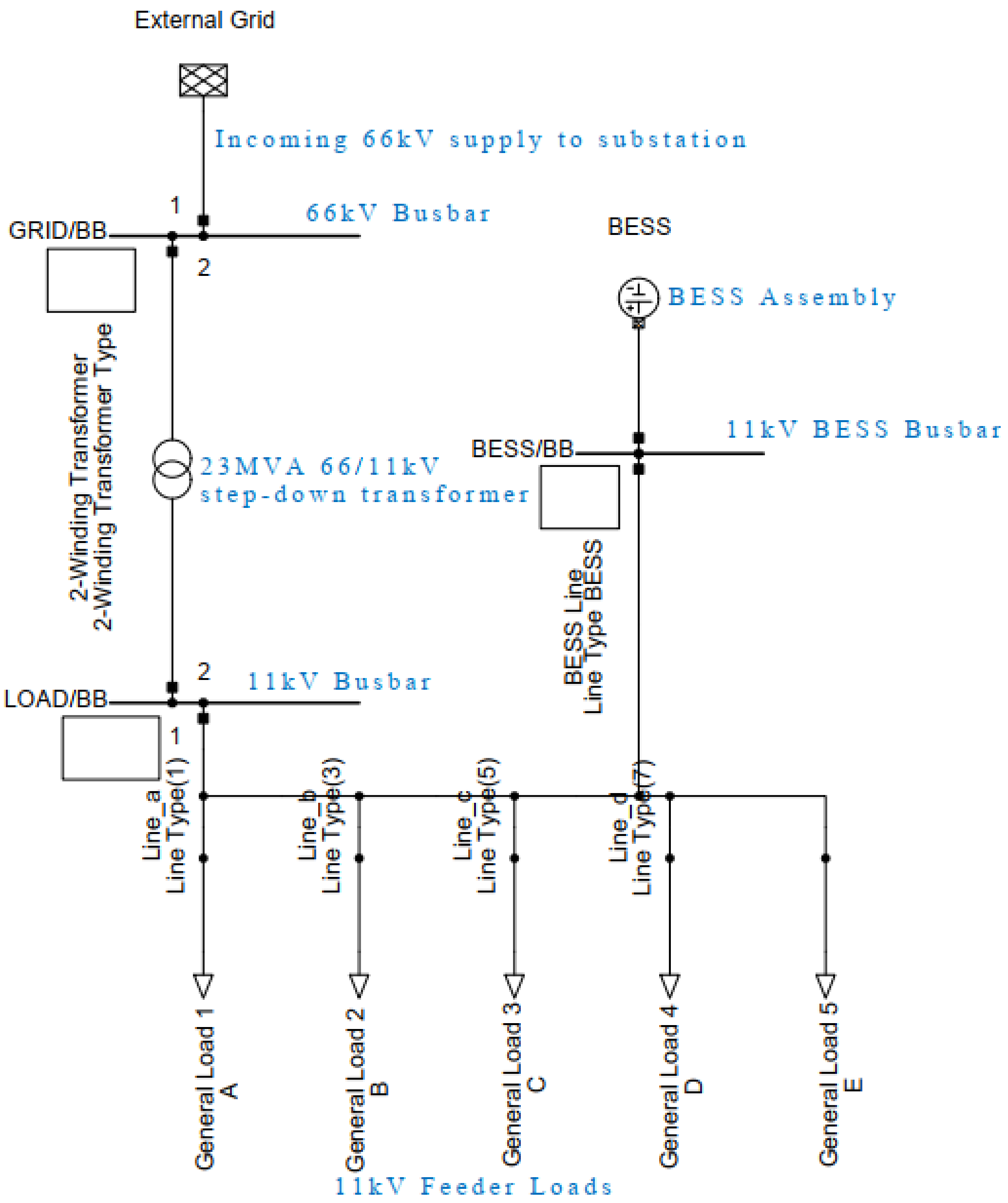

Figure 4.13: SLD for BESS - Feeder Connection

4.6.1. Sizing of Utility Scale BESS

Kibra feeder from Ngong road 66/11kV substation had the lowest load factor of 0.51 and therefore was used as a case study, based on the assumption that achieving success on this feeder would ensure success on other feeders with relatively better load factors. Using the demand profile of Kibra feeder, the goal is to reduce the peak demand exceeding the normal average, i.e. above 4000kW that occurs between 1800hrs and 2200hrs by drawing power from a BESS. To achieve this, the battery unit must be capable of supplying the energy required to meet the demand represented by the shaded area in figure 4.14 below.

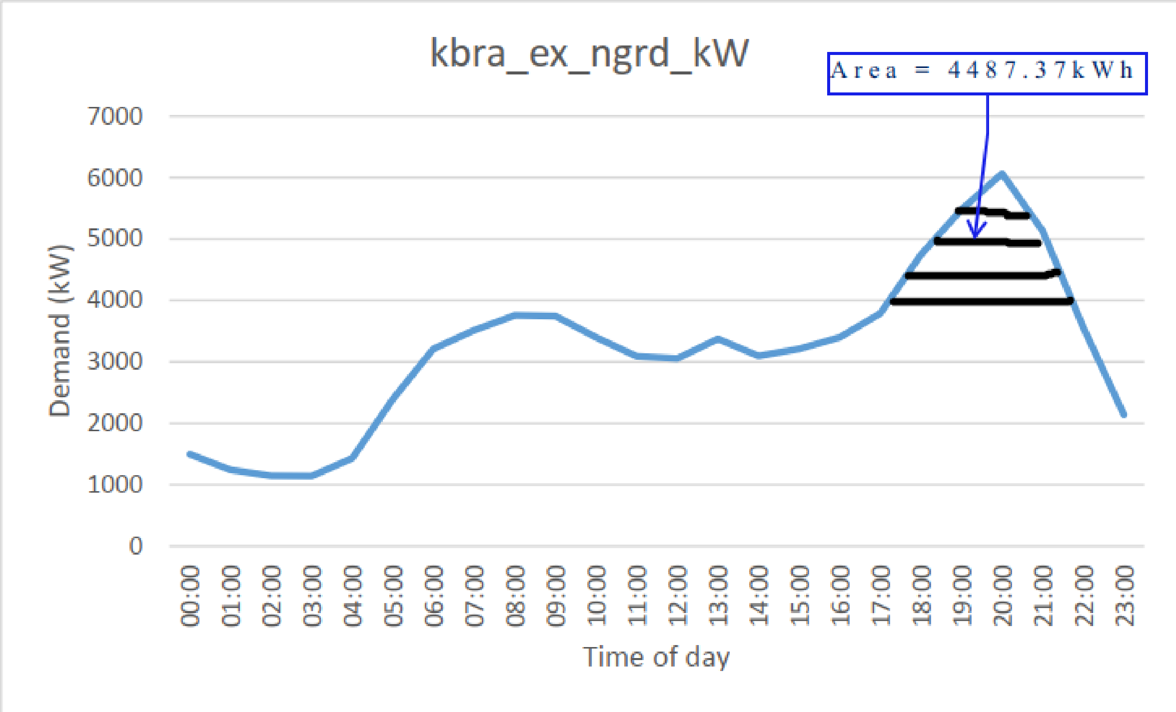

Figure 4.14: Sizing of BESS unit

By obtaining the area under the curve that is shaded between 1800hrs and 2200 hrs using trapezoidal rule, we realise an energy demand of 4487.37 kWh as shown in table 4.14 below.

Table 4-13: Sizing of BESS Unit

	A	**B**	**A - B**	
time _of_day (hr)	**original demand (kW)**	**peak shaved demand (kW)**	**BESS compensated demand (kW)**	**Area of BESS compensated demand (Trapezoidal rule) (kWh)**
1800	4746.40	4000	746.40	1113.92
1900	5481.45	4000	1481.45	1773.61
2000	6065.77	4000	2065.77	1599.84
2100	5133.91	4000	1133.91	
			Sum	**4487.37**

The assuming battery parameters are as shown in table 4.15 below:

Table 4-14: Assumed BESS Parameters

Parameter	**Description**	**Specs.**
Depth of Discharge (DoD)		80%
Required energy demand (kWh)	To supply the peak shaved energy	4487.37
Total battery energy size (kWh)	(Required demand X 100%)/DoD (80%)	Approx. Size = 5500kWh
Battery power requirement (kW)	To enable supply up to the highest BESS compensated demand of 2065.77kW at 2000hrs @ 80% loading	Size = (2065kW x 100%)/80% = 2500kW
Charge current @ 11kV	80A	80A
Charge power requirement @ 11kV	P=sqrt 3 X 11kV x charge current (80A)	approx. 1500kW
Charge time (T)	T = battery size (5500kWh)/ charge power (1500kW)	T = 3.6 hrs
Service Life		10 years

4.7. Summary of BESS Charge and Discharge Impact on Kibra Feeder Load Profile Parameters

The BESS charge and discharge cycles therefore impact Kibra feeder demand profile as simulated in appendix E, figures 0.1 – 0.16 and are summarised in table 4-16 below, assuming a BESS charging time of between 0000hrs to 0300hrs and discharge time of 1800hrs to 2100hrs.

Table 4-15: Summary of BESS Charge and Discharge Impact on Kibra Feeder Profile Parameters

		A		**B**		**A - B**		**C**		**A + C**		
	time _of_day (hr)	**original demand on Load BB (Busbar) (kW)**		**peak shaved demand on Load BB (Busbar) (kW)**		**BESS compensated demand on BESS BB (Busbar) (kW)**		**BESS charge demand on BESS BB (Busbar) (kW)**		**Valley filled demand on Load BB (Busbar) (kW)**		**Resulting feeder demand (kW)**
Discharge cycle	18:00:00	Fig 0.1	4746.4	Fig 0.2	4000	Fig 5.5	746.4					4000
	19:00:00	Fig 0.3	5481.45	Fig 0.4	4000	Fig 5.7	1481.45					4000
	20:00:00	Fig 0.5	6065.77	Fig 0.6	4000	Fig 5.9	2065.77					4000
	21:00:00	Fig 0.7	5133.91	Fig 0.8	4000	Fig 5.11	1133.91					4000
Charge cycle	00:00:00	Fig 0.9	1498.3					Fig 0.10	1500	Fig 0.10	2998.3	2998.3
	01:00:00	Fig 0.11	1242.82					Fig 0.12	1500	Fig 0.12	2742.82	2742.82
	02:00:00	Fig 0.13	1146.44					Fig 0.14	1500	Fig 0.14	2646.44	2646.44
	03:00:00	Fig 0.15	1141.11					Fig 0.16	1000	Fig 0.16	2141.12	2141.12

The resulting demand curve in comparison with the original demand curve is as shown in figure 4.15 below.

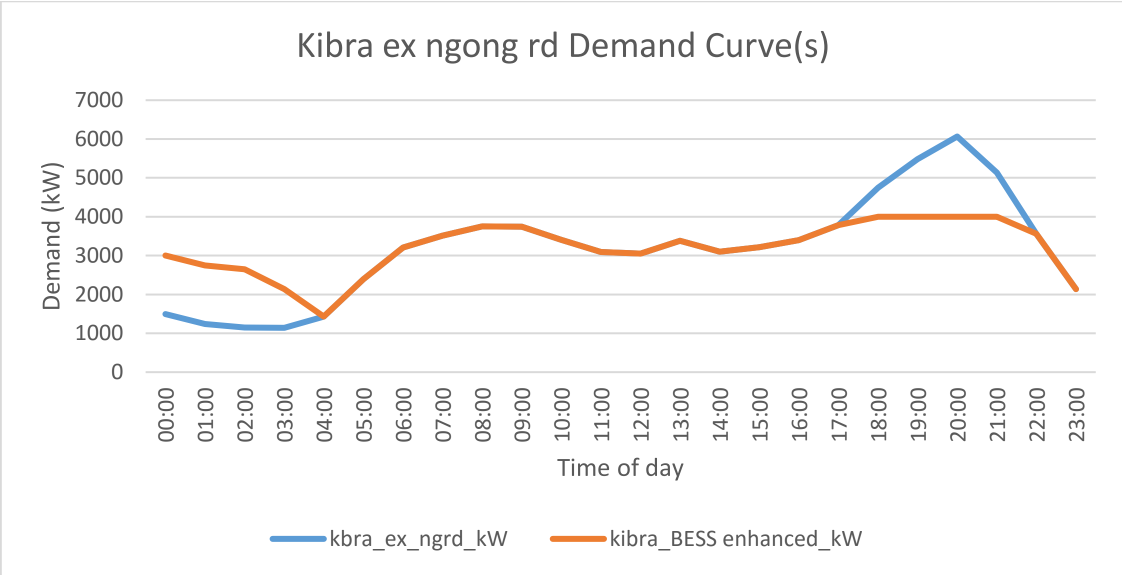

Figure 4.15: Original vs BESS-enhanced Demand Curve

A comparison of the demand curve before and after BESS enhancement on Kibra feeder shows a significant improvement in the load factor from 0.51 to 0.77. This is as shown in table 4-17 below:

Table 4-16: Feeder Demand Characteristics Comparison

	Original	BESS enhanced
Name	Kibra	
Primary substation	Ngong rd 66/11kV s/s	
Daily average demand	74,811.29 kWh	74133.76 kWh
Peak demand	6065.77 kW at 2000hrs	4000kW at 1800-2100hrs
Load Factor	$= \frac{74{,}811.29kWh}{6065.77kW\ x\ 24hrs}$ = 0.51	$= \frac{74{,}133.76kWh}{4000kW\ x\ 24hrs}$ = 0.77

4.8. Cost Benefit Analysis of Utility Scale BESS

4.8.1. Cost of Sized BESS Solution

As highlighted in section 2.7, the cost of BESS continues to decline thanks to continued advances in manufacturing scale and technology as well as improvements in storage-system engineering and design. Mckinsey and Company in their research article (Frankel et al., 2018) for global estimates of BESS technology, estimates BESS costs in a base case scenario at $270/kWh in the year 2025 as shown in figure 2.3.

In addition to the above costs, the cost of power transformation (step-up and step down) requires consideration. This is necessitated by the proposed design concept of integrating BESS at the 11kV feeder voltage level. The peak charge and discharge cycles operate at a power requirement of between 1900kV – 2065kV. The optimal transformer size for this power transformation would be a 2500kVA auto-transformer allowing for up to a maximum of 80% loading during either charging of discharging cycle. The current cost for such power transformation as per KPLC infrastructure design and costing database (DCS) may be approximated at KES, 10,000,000 ($ 77,000 at 1USD = KES 130).

The total cost of storage plus power transformation therefore may be estimated as below:

Cost of 5.5MWh (5500KWh) storage = Cost per KWh x Battery size (KWh) (6)

= $270 x 5500 = $ 1,485,000

Cost of storage and power transformation = $ 1,485,000 + $ 77,000

= $ 1,562,000

For better analysis of the cost effectiveness and viability of BESS deployment, the Levelised Cost of Storage (LCOS) is sought since it gives an all in approach as it includes all of the aforementioned installed costs and incorporates the projected operational expenditures, such as maintenance costs and battery degradation over time. LCOS is given by equation 7 as below:

$$LCOS = \frac{Capital + \sum_{t=0}^{n} \left(\frac{O\&M + Fuel}{(1+r)^t}\right)}{\sum_{t=0}^{n} \left(\frac{MWh}{(1+r)^t}\right)} \quad (7)$$

Where: Capital = total capital cost

O&M = typically, operation and maintenance cost over time t is allocated at $10/kW – yr for Li-Ion batteries (Rowland & Vazquez, 2020), therefore, for the above 2500kW, O&M = $10/kW x 2500kW = 25,000 annually

Fuel = charging cost in time t (which we may consider net zero since the cost incurred at charge cycle is recovered at discharge cycle)

MWh = The amount of electricity delivered by the BESS over time (t), i.e. (80% DoD x 5500kWh x 365 days)/1000 = 1606MWh annually

r = discount rate (%) assumed at 12% due to Kenyan-specific factors such as inflation rate, cost of capital, and country risk premium

n = battery useful life considered at 10 years

Table 4-17: LCOS Computation for 5.5MWh BESS unit

CAPEX			1562000			
Discount rate, r (%)			12%			
Year (t)	O&M (O)	Fuel (F)	Total (O+F)	Discounted (O+F)/(1+r)^t	Annual MWh delivered (DoD@80%) x 5500 KWh x 365 days)/1000	Discounted (MWh)/(1+r)^t
1	25000	0	25000	22321.42857	1606	1433.928571
2	25000	0	25000	19929.84694	1606	1280.293367
3	25000	0	25000	17794.5062	1606	1143.119078
4	25000	0	25000	15887.95196	1606	1020.642034
5	25000	0	25000	14185.67139	1606	911.2875303
6	25000	0	25000	12665.77803	1606	813.6495806
7	25000	0	25000	11308.73038	1606	726.4728398
8	25000	0	25000	10097.0807	1606	648.6364641
9	25000	0	25000	9015.250625	1606	579.1397001
10	25000	0	25000	8049.330915	1606	517.089018
			Sum 1	**141255.5757**	**Sum 2**	**9074.258184**

LCOS $/MWh	(Capex + Sum 1)/Sum 2
LCOS $/MWh	**187.7019081**

The LCOS for lithium-ion technology in this specific Front-of-the-Meter (FTM), Transmission and Distribution (T&D) application is estimated at $187/MWh. This value is comparable, though lower than the global LCOS estimates, which range from $263/MWh to $471/MWh, as shown in figure 2.4. The reduced cost in this case study is primarily attributed to the absence of fuel costs, the cost of electricity used to charge the BESS unit. Since the model is implemented at the electricity utility level, the cost of charging is effectively offset by revenues generated during discharge, rendering the net charging cost close to zero.

4.8.2. Economic Gains from Feeder Load Factor Improvement

Using the Kibra Feeder as a case study and maintaining the same user trend, the feeder's loading can be scaled up to utilize up to 80% of its equipment rating while adhering to the set overcurrent protection limit, which is designed at 400A according to KPLC standards. This corresponds to a power rating calculated as follows:

P=Sqrt 3 X Voltage X Current X 0.8 (80% feeder loading) (8)

P =Sqrt 3 X 11kV x 400A x 0.8 = 6096.8 kW

In the original feeder demand curve, Kibra feeder had a peak demand of 6065kW at 2000hrs against an equipment and overcurrent rating of 6096.8kW. If consideration is made to scale up loading on Kibra feeder, the scaling factor would be 1, given by the equation 9 below:

Scaling factor = ${Equipment\ rating}/{Peak\ demand}$ (9)

Scaling factor = ${6096.8kW}/{6065kW}$ = 1

This indicates that the feeder is currently loaded to the maximum allowable capacity and has no room for scaling up demand. Any additional load growth within the same vicinity would necessitate load transfer to a new feeder infrastructure.

The BESS enhanced feeder on the other hand allows for scalability of the feeder loading given that the peak demand will be lowered by the BESS assembly. Given that the designed BESS can supply a peak power demand of 2000kW (2500kW BESS power rating at 80% loading), the current peak demand on Kibra feeder of 6065.77kW achieved at 2000hrs can be scaled to 6065.77kW + 2000kW (BESS supplied) = 8085.77kW. This translated to a new scaling factor achieved by the equation 10 below:

Scaling factor = ${BESS\ scaled\ peak\ demand}/{Original\ Peak\ demand}$ (10)

Scaling factor = ${8085.77kW}/{6065.77kW}$ = 1.33

Increased loading on the BESS enhanced feeder by a factor of 1.33 throughout a typical day, assuming similar electricity usage trends and comparing it to the original demand curve is as indicated in figure 4.16 below;

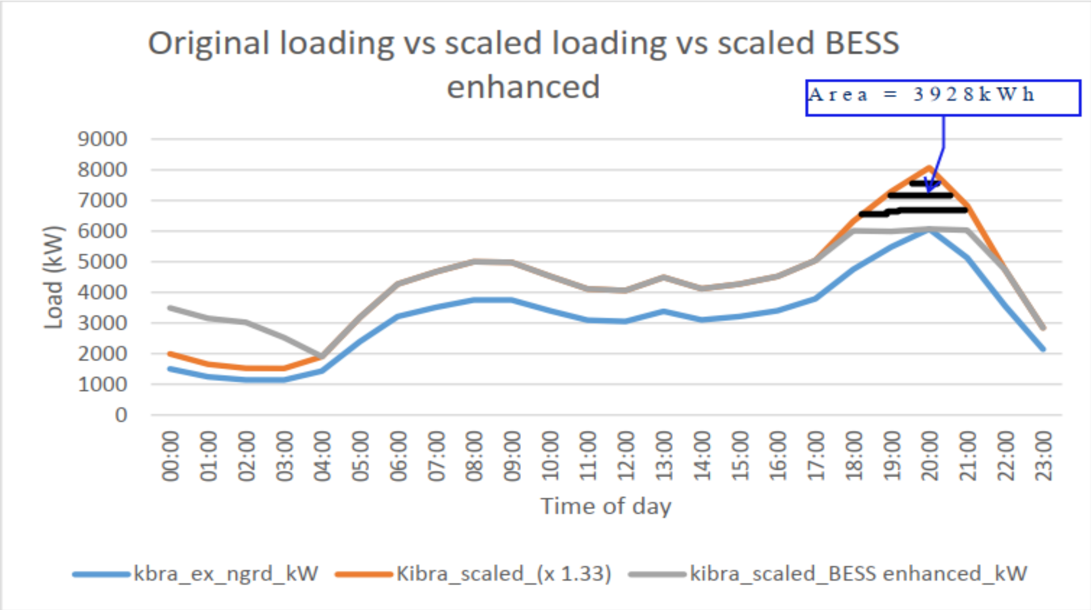

Figure 4.16: Original vs Scaled Demand Curve

In-order to observe the feeder capacity rating of approx. 6000kW, the deployed 5,500kWh BESS assembly would supply energy output of 3,928kWh represented by the shaded area between the scaled demand curve and BESS enhanced scaled demand curve. This is as tabulated in table 4.19 below:

Table 4-18: Scaled demand loading

	A	**A x 1.33**	**B**	**(Ax1.33) - B**	
time _of_day (hr)	**original demand (kW)**	**Scaled demand (kW)**	**peak shaved demand (kW)**	**BESS compensated demand (kW)**	**Area of BESS compensated demand (Trapezoidal rule) (kWh)**
18:00	4746.4	6312.712	6000	312.712	801.5203
19:00	5481.45	7290.329	6000	1290.3285	1678.901
20:00	6065.77	8067.474	6000	2067.4741	1447.787
21:00	5133.91	6828.1	6000	828.1003	
				Sum	**3928.209**

Obtaining the energy supplied by the above scenarios, the original loading of Kibra feeder supplied an energy of approximately 74,811.29 kWh on a typical day whereas the scaled up feeder after BESS enhancement and load factor improvement would supply 104,249 kWh of energy.

Therefore, additional electrical energy distributable while utilising the same infrastructure due to load factor improvement is:

104,249 kWh - 74,811.29 kWh = 29437.73 kWh daily

Translating the additional energy distributable to revenue at a electricity sales tariff of KSh 28.64/kWh according to (Shah, 2024), gives a daily additional revenue of;

KSh 28.64/kWh X 29437.73 kWh = KES 843,096.46 or USD 6,485.36 (1 USD = KSh 130)

In the audited financial results for the year ending 30th June, 2024, Kenya power realised an annual profit before tax of KES 43.67 billion against an electricity sales of KES 231.12 billion (KPLC, 2024c). From these financial results, the ratio of profit to electricity sales as realised by the utility can therefore be deduced as:

Profit: Sales ratio = $\frac{Annual\ Profit}{Annual\ Sales} = \frac{KES\ 43.67\ billion}{KES\ 231.12\ billion}$ = 19%

The scaled revenue can therefore be summarised in the table 4-20 below:

Table 4-19: Scaled Revenue Summary

(i)	Daily scalable distributed energy, kWh	29437.73
(ii)	Daily scalable revenue (KSh)	KES 843,096.46
(iii)	Daily scalable revenue (USD)	USD 6,485.36
(iv)	Annual scalable revenue, USD (365 days)	USD 2,367,155.45
(v)	Annual Profit from scaled revenue @ 19%	USD 449,759.54
(vi)	*Corrected Profit, $P_{(cr)}$ by a factor of 0.8	USD 359,807.63

*Item (vi) applies a correction factor of 0.8 to the annual profit derived from scaled revenue, accounting for a 20% reduction in realized profit. This adjustment aligns the ideal simulated values with real-world deviations caused by occurrences such as inefficiencies, equipment de-rating of the BESS unit, variability in electricity usage patterns from scaled-up demand, and the limitations of BESS in compensating for excessively heightened peaks that exceed the design parameters.

To evaluate the profitability of BESS investment against the realized scalable revenue due to BESS enhancement of the feeder, Net Present Value (NPV) financial metric was used. This metric evaluated the present value of all future cash flows generated by the investment and evaluate the same against the initial investment cost. A positive NPV will indicate that the projected earnings exceed the anticipated costs, suggesting that the investment is likely to be profitable. Conversely, a negative NPV will imply that the investment's costs outweigh the benefits, making it potentially unwise to pursue.

NPV was obtained as below:

NPV = $\sum_{t=0}^{n} R/(1+i)\ \hat{}t$ (11)

Where R = net annual cash inflow – net annual cash outflow (O&M cost)

i = discount rate (assumed at 12% due to Kenyan specific factors such as inflation rate, cost of capital and country risk premium)

t = Number of time periods (10 years to correspond with the BESS anticipated lifespan)

Cumulative Revenue, representing the net cumulative income generated from the BESS infrastructure investment will be obtained as below:

Cumulative revenue = (Initial investment) + $\sum_{t=0}^{n} NPV\ income$ (12)

The above calculations are as tabulated in table 4-21 and figure 4.17 below:

Table 4-20: Projected Revenue from Increased Electricity Sales

Year	**Annual Sales**	**Annual profit @ 19% of sales made**	**Corrected Profit (at 0.8 cr. factor)**	**Annual O&M Cost**	**Net Profit**	**NPV @ 12% discounting rate**	**Cumulative Revenue**
		P	**P(cr)**	**O**	**P(cr)-O**		-USD 1,562,000.00
1	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 298,935.38	-USD 1,263,064.62
2	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 266,906.59	-USD 996,158.03
3	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 238,309.46	-USD 757,848.57
4	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 212,776.30	-USD 545,072.27
5	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 189,978.84	-USD 355,093.43
6	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 169,623.96	-USD 185,469.46
7	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 151,449.97	-USD 34,019.50
8	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 135,223.19	USD 101,203.69
9	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 120,734.99	USD 221,938.68
10	USD 2,367,155.45	USD 449,759.54	USD 359,807.63	USD 25,000.00	USD 334,807.63	USD 107,799.10	USD 329,737.77

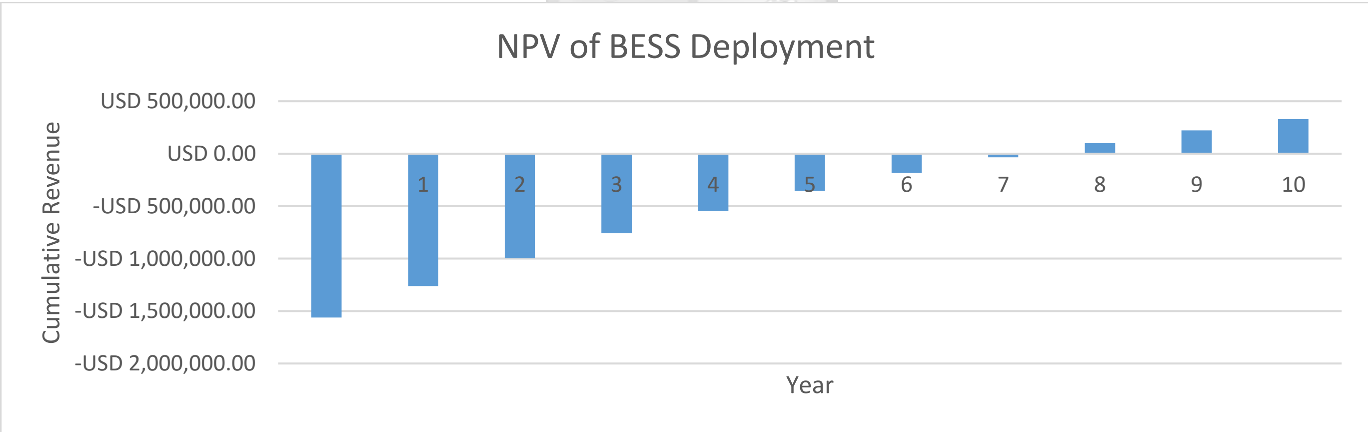

Figure 4.17: NPV of BESS Deployment

As shown in figure 4.17, the projected revenue from increased sales, achieved by utilizing the existing feeder infrastructure with BESS enhancements, is sufficient to recover the initial BESS investment by the end of year 7. From year 8 onward to the projected 10-year lifespan of the BESS unit, additional profit attributed to the BESS investment and improved load factor is realized, amounting to over $329,000 by year 10. This demonstrates that investing in BESS at the feeder level for load factor optimization, particularly in areas with potential for load scaling, is financially viable. This approach, confirming the limitation declared in section 1.7, where financial viability is realised much later into the project lifespan (from year 8 to year 10), it allows for other economic gains to the electricity distributor. This is because it significantly reduces the need for utilities like Kenya Power to invest in expensive primary substations in regions experiencing residential population growth and increasing electricity demand. The strategy maximizes the efficiency of existing infrastructure.

4.9. Research Validation Using Similar Projects and Research

The use of BESS for peak shaving, particularly in distribution networks, as demonstrated in this study, is rapidly gaining traction in power systems worldwide. BESS-driven peak shaving and load shifting have been adopted to address various challenges in distribution networks, including inefficiencies, capacity constraints, and the optimization of energy economics. Below are examples of such projects and research:

(1) BESS Solution for Distribution Network Operators – KD Energo, Czech Republic

KD Energo, a distribution network company in the Czech Republic, specializes in energy production, distribution, and sales in Králové Dvór and its surroundings. Wattstor, the BESS design and installation contractor integrated an Energy Management System (EMS) with a 528kW/648kWh battery storage system to optimize electricity demand. The system provides peak shaving by injecting power when needed, enhancing grid efficiency (Wattstor, 2025).

(2) American Electric Power BESS – Charleston, WV, USA

Since June 2006, AEP has operated a 1.2 MW, 7.2 MWh sodium–sulfur (Na–S) battery energy storage system for peak shaving. The system discharges once daily during summer peaks and twice daily in winter. After a year of operation and testing, AEP concluded that, despite its high initial costs, the system's benefits—including distributed energy storage with intelligent monitoring and grid planning capabilities—justify its implementation (C.D Parker, 2019).

(3) Energy Storage for Peak Shaving – Björnarbo, Sweden

Sala-Heby Energi Elnät supplies electricity to Sala, Heby, Morgongåva, and Björnarbo in Sweden. The region's grid faces bottlenecks and power shortages, prompting a study by Jonsson & Peterson, (2022) on the feasibility of a 500kWh BESS for peak shaving. The findings indicate that BESS can effectively reduce power peaks, alleviating capacity constraints. However, financial viability for Sala-Heby Energi Elnät is expected only in the long term.

5. Conclusion, Recommendation and Further Work

5.1. Introduction

This chapter provides a broad summary of the key research findings and aligns them with the main research objective outlined in Section 1.3. By doing so, it presents a holistic view of the research's benefits to Kenya's power system, particularly in improving the load factor. Additionally, the chapter offers recommendations and suggests areas for future research to further build upon and enhance the work conducted in this study.

5.2. Conclusion

The study aimed to determine the requirements and approach for the efficient adoption of BESS to enhance Kenya's power system load factor. The findings revealed that low load factors were more prevalent in low-income areas within Nairobi's metropolitan area. Using Kibra distribution feeder as a case study, which was identified as having the lowest load factor among the sampled distribution feeders. The study demonstrated that the strategic deployment and dispatch of BESS improved the load factor from 0.51 (51%) to 0.77 (77%), surpassing the success threshold of 0.75 (75%) recommended in the Kenyan Grid Code.

The study also demonstrated that, despite the high initial cost of BESS deployment, its ability to facilitate peak shaving and load shifting on Kibra feeder enabled a 33% increase in feeder loading capacity. This, in turn, expanded electricity distribution and sales by the same factor (0.33) while utilizing existing infrastructure. Further financial analysis using NPV metric, based on the improved sales per infrastructure, indicated a project repayment period of seven years, well within the project's lifetime. Additionally, profitability was projected to improve further by the end of the 10-year BESS lifespan.

In summary, this project illustrates that BESS can be strategically integrated into existing electricity distribution infrastructure to enhance efficiency through peak shaving, valley filling and load shifting, leading to improved load factors. Higher load factors create opportunities to scale up distribution loads, optimizing the utilization of existing infrastructure, particularly in urban areas experiencing population growth and increased clustered domestic electricity demand.

Although profitability is realised later in the project lifetime, BESS installation on electricity distribution infrastructure minimizes the need for frequent and costly investments in primary substations and new feeder lines to accommodate growing demand, offering economic reprieve to utilities. It also addresses the challenges of large-scale BESS deployment, as discussed in Section 2.7, while delivering comparable benefits by consolidating the advantages of smaller, distributed installations.

Moreover, efficiently loaded electrical infrastructure can generate returns proportional to the cost of the investment. On a national scale, this approach could cumulatively lower Kenya's current peak demand, which is predominantly met by thermal sources, thereby eliminating thermal sources from Kenya's energy mix. This strategy would also enable the country's demand curve to grow more gradually and uniformly over time, fostering a more sustainable energy landscape.

5.3. Recommendation

This research presents significant opportunities for energy arbitrage through the integration of BESS into utility distribution networks. BESS can enhance energy economics by allowing the utility off-taker purchase electricity during off-peak periods, when unit costs are lowest, and storing it for use during peak periods, when electricity prices are highest. The energy demand from BESS charging during off-peak hours could be leveraged to justify reduced power purchase tariffs for the off-taker, which may be transferable to the end user, resulting in reduced cost of electricity to end users.

This approach also optimizes on excess energy available during off peak periods that would otherwise go unused or curtailed. In the financial year 2023–2024, EPRA reported that 812.8 GWh of energy, equivalent to 5.9% of total energy generated, was curtailed (EPRA Statistics Committee, 2024). Geothermal power plants, which primarily function as baseload plants, were particularly affected. This is because geothermal curtailment has notable drawbacks, such as geothermal venting, where geothermal steam is wastefully released into the atmosphere to reduce generator rotor speeds. Additional challenges include thermal cycling and the potential collapse of geothermal wells (Dobson et al., 2020).

By increasing electricity demand during off-peak periods, this approach not only enhances energy utilization but also alleviates curtailment pressures on geothermal power plants, mitigating both environmental and operational risks associated with geothermal energy curtailment.

5.4. Further work

This study was limited to a simulated research approach due to budgetary and time constraints. With adequate funding and time allocation, future research could advance the study into a pilot project, implementing BESS on an actual feeder to further validate its practicality in real-world scenarios.

Further exploration may also be pursued on how the distributed BESS infrastructure can be consolidated to provide further ancillary services such as voltage regulation and support, reactive power support, frequency control, spinning reserve, and emergency power provision during outages.

References

Ahlen, J., Binet, T., Muhoro, P., & Seibert, B. (2020, May). *Battery Energy Storage Overview Report Update May 2020*. National Rural Electric Cooperative Association, National Rural Utilities Cooperative Finance Corporation, CoBank, and NRTC. https://www.cooperative.com/programs-services/bts/Documents/Reports/Battery-Energy-Storage-Overview-Report-Update-May-2020.pdf

C.D Parker. (2019). *American Electric Power—An overview | ScienceDirect Topics*. https://www.sciencedirect.com/topics/engineering/american-electric-power

Cerna, F. V., Coêlho, J. K., Fantesia, M. P., Naderi, E., Marzband, M., & Contreras, J. (2023). Load Factor Improvement of the Electricity Grid Considering Distributed Energy Resources Operation and Regulation of Peak Load. *Sustainable Cities and Society*, *98*, 104802. https://doi.org/10.1016/j.scs.2023.104802

Chen, A., & Sen, P. K. (2016). Deployment of battery energy storage system for energy arbitrage applications. *2016 North American Power Symposium (NAPS)*, 1–8. https://doi.org/10.1109/NAPS.2016.7747920

Cowling, N. (2023, September 22). *Kenya: Electricity consumption by source*. Statista. https://www.statista.com/statistics/1277614/electricity-consumption-in-kenya-by-source/

Cuemath. (2023). *Trapezoidal Rule—Formula | Trapezoidal Formula*. Cuemath. https://www.cuemath.com/trapezoidal-rule-formula/

Del Valle, J. A., Ansean, D., Carlos Viera, J., Antuna, J. L., Gonzalez, M., & Garcia, V. (2018). Analysis of Advanced Lithium-Ion Batteries for Battery Energy Storage Systems. *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 1–6. https://doi.org/10.1109/EEEIC.2018.8493934

Ding, Z., Hou, H., Yu, G., Hu, E., Duan, L., & Zhao, J. (2019). Performance analysis of a wind-solar hybrid power generation system. *Energy Conversion and Management*, *181*, 223–234. https://doi.org/10.1016/j.enconman.2018.11.080

Dobson, P., Dwivedi, D., Millstein, D., Krishnaswamy, N., Garcia, J., & Kiran, M. (2020). Analysis of curtailment at The Geysers geothermal Field, California. *Geothermics*, *87*, 101871. https://doi.org/10.1016/j.geothermics.2020.101871

Electrical energy efficiency. (2022). *CIRCUTOR*. https://circutor.com/en/support/training/notebooks/electrical-energy-efficiency/

Electricity Demand. (2016). https://www.mpoweruk.com/electricity_demand.htm#matching

EPRA. (2024, March). *Kenya National Distribution Grid Code KNDGC-March-2024-.pdf*. https://www.epra.go.ke/sites/default/files/Documents/Kenya1-National-Distribution-Grid-Code-KNDC-March-2024-.pdf

EPRA Statistics Committee. (2024, June 30). *EPRA Energy and Petroleum Statistics Report FY 2023-2024*. https://www.epra.go.ke/sites/default/files/2024-10/EPRA%20Energy%20and%20Petroleum%20Statistics%20Report%20FY%202023-2024_2.pdf

EPRA Statistics Committee. (2025, March). *Bi-Annual Energy & Petroleum Statistics Report 2024_2025.pdf*. https://www.epra.go.ke/sites/default/files/2025-03/Bi-Annual%20Energy%20%26%20Petroleum%20Statistics%20Report%202024_2025.pdf

Frankel, D., Kane, S., & Tryggestad, C. (2018, June 8). *The new rules of competition in energy storage | McKinsey*. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-new-rules-of-competition-in-energy-storage

Hao, T. (2023, November). *(25) Optimising Power Systems: Understanding Load Factor for Enhanced Efficiency | LinkedIn*. https://www.linkedin.com/pulse/optimising-power-systems-understanding-load-factor-enhanced-kai-hao-z4iyc/

Hart, C. & Jarrad Wright. (2016a). *Impact of novel and disruptive approaches/technologies on a distribution utility: A Kenyan case study*. https://doi.org/10.13140/RG.2.1.4234.3920

Hart, C. & Jarrad Wright. (2016b). *Impact of novel and disruptive approaches/technologies on a distribution utility: A Kenyan case study*. https://doi.org/10.13140/RG.2.1.4234.3920

Jonsson, S. O., & Peterson, C. (2022, June). *Energy Storage for Peak Shaving: Case study for the distribution grid in Björnarbo*. Uppsala Universitet. https://www.diva-portal.org/smash/get/diva2:1672417/FULLTEXT01.pdf

Jülch, V. (2022). Comparison of electricity storage options using levelized cost of storage (LCOS) method. *Applied Energy*, *183*, 1594–1606. https://doi.org/10.1016/j.apenergy.2016.08.165

Kenya: Capacity of electricity generation. (2023a). Statista. https://www.statista.com/statistics/1240951/installed-capacity-of-electricity-generation-in-kenya/

Kenya: Electricity domestic demand. (2023b). Statista. https://www.statista.com/statistics/1320880/electricity-domestic-demand-in-kenya/

Khatib, H. (2012). Energy Efficiency and Electrical Power Generation. In Z. Morvaj (Ed.), *Energy Efficiency—A Bridge to Low Carbon Economy*. InTech. https://doi.org/10.5772/38173

Khoshjahan, M., Dehghanian, P., Moeini-Aghtaie, M., & Fotuhi-Firuzabad, M. (2019). Harnessing Ramp Capability of Spinning Reserve Services for Enhanced Power Grid

Flexibility. *IEEE Transactions on Industry Applications*, *55*(6), 7103–7112. https://doi.org/10.1109/TIA.2019.2921946

Killingtveit, Å. (2020). *Hydroelectric Energy—An overview | ScienceDirect Topics*. https://www.sciencedirect.com/topics/engineering/hydroelectric-energy

KNBS. (2020, March). *Kenya-Consumer-Price-Indices-Rebasing-Report-March-2020.pdf*. https://www.knbs.or.ke/wp-content/uploads/2023/09/Kenya-Consumer-Price-Indices-Rebasing-Report-March-2020.pdf

KNBS. (2023). *Home—Kenya National Bureau of Statistics, Nairobi, Kenya*. https://www.knbs.or.ke/

KPLC. (2024a). *Electricity Bill Components*. https://kplc.co.ke/storage/01J1ATVMZTY698754FJ9RHKH8H.pdf

KPLC. (2024b). *FAQs: Tariff*. Kenya Power. https://kplc.co.ke/faq/tariff

KPLC. (2024c, October 29). *KPLC PLC Audited Financial Results for the year ended 30th June, 2024*. https://www.kplc.co.ke/annual-reports

Lead–acid battery. (2023). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Lead%E2%80%93acid_battery&oldid=1185973753

Lithium-ion battery. (2023). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Lithium-ion_battery&oldid=1187378578

Load Factor: What is it? (And How To Calculate It) | Electrical4U. (2020, October 11). Https://Www.Electrical4u.Com/. https://www.electrical4u.com/load-factor/

MOE&P. (2022, June). *Electrical Power Development | Energy*. https://www.energy.go.ke/electrical-power-development-0

Musonye, F. S. (2023). MSc. Sustainable Energy Transitions Lecture Notes. *Strathmore University, MSSET Energy Porject Development, Finance and Management*.

NCC. (2025, April 2). *NCC Management Brief 2025-04*.

Part 2 Introduction to Power Systems.pdf. (n.d.).

Rafique, S. F., Wang, Z., & Rafique, R. (2018, May 21). *Global power grid interconnection for sustainable growth: Concept, project and research direction—Rafique—2018—IET Generation, Transmission & Distribution—Wiley Online Library*. https://ietresearch.onlinelibrary.wiley.com/doi/full/10.1049/iet-gtd.2017.1536

Research Design: What It Is (Plus 20 Types) | Indeed.com. (2023). https://www.indeed.com/career-advice/career-development/research-design

Rowland, L., & Vazquez, T. (2020). *Black Hills Energy April 28, 2020*. *20*.

SatMgtBrief 2024-04-13.xlsx. (n.d.).

Shah, S. (2024, October). *Electricity cost in Kenya*. https://www.stimatracker.com/

Smith, M. (2023, August 8). *Battery Energy Storage: How it works & why it's important - EVESCO*. Power Sonic. https://www.power-sonic.com/blog/what-is-battery-energy-storage/

Soliman, S. A., Helal, I., & Youssef, A. M. (2019). Electric Load Management Using Electricity Tariff Algorithm. *International Journal of Emerging Electric Power Systems*, *8*(5). https://doi.org/10.2202/1553-779X.1185

Strbac, G. (2020). Demand side management: Benefits and challenges. *Energy Policy*, *36*(12), 4419–4426. https://doi.org/10.1016/j.enpol.2008.09.030

Telaretti, E., & Dusonchet, L. (2016a). Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram. *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)*, 1–6. https://doi.org/10.1109/EEEIC.2016.7555793

Telaretti, E., & Dusonchet, L. (2016b). Battery storage systems for peak load shaving applications: Part 2: Economic feasibility and sensitivity analysis. *2016 IEEE 16th*

International Conference on Environment and Electrical Engineering (EEEIC), 1–6. https://doi.org/10.1109/EEEIC.2016.7555795

Trochim, W. M. K. (2020). *Unit of Analysis*. https://conjointly.com/kb/unit-of-analysis/

Uddin, M., Romlie, M. F., Abdullah, M. F., Abd Halim, S., Abu Bakar, A. H., & Chia Kwang, T. (2018). A review on peak load shaving strategies. *Renewable and Sustainable Energy Reviews*, *82*, 3323–3332. https://doi.org/10.1016/j.rser.2017.10.056

Wattstor. (2025). *BESS Solutions for Distribution Network Operator*. Wattstor. https://wattstor.com/case-study/case-study-energo-kd-ems-battery-for-distribution-network/

Appendices

Appendix A: Similarity Report

ANALYSIS OF LF IMPROVEMENT BY BESS 060325.docx

ORIGINALITY REPORT

12%	10%	4%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.coursehero.com Internet Source	1 %
2	docslib.org Internet Source	1 %
3	Submitted to University of Technology Bahrain Student Paper	<1 %
4	Moslem Uddin, Mohd Fakhizan Romlie, Mohd Faris Abdullah, Syahirah Abd Halim, Ab Halim Abu Bakar, Tan Chia Kwang. "A review on peak load shaving strategies", Renewable and Sustainable Energy Reviews, 2018 Publication	<1 %
5	erepository.uonbi.ac.ke Internet Source	<1 %
6	pluginhighway.ca Internet Source	<1 %
7	www.statista.com Internet Source	<1 %
8	www.readkong.com Internet Source	<1 %
9	mts.intechopen.com Internet Source	<1 %
10	Submitted to Baker College Online Student Paper	<1 %

11	Sergio B. Sepúlveda-Mora, Steven Hegedus. "Making the case for time-of-use electric rates to boost the value of battery storage in commercial buildings with grid connected PV systems", Energy, 2021 Publication	<1 %
12	Submitted to Walter Sisulu University Student Paper	<1 %
13	core.ac.uk Internet Source	<1 %
14	www.0358idc.com Internet Source	<1 %
15	su-plus.strathmore.edu Internet Source	<1 %
16	Submitted to Iona College Student Paper	<1 %
17	Submitted to Lebanese International University Student Paper	<1 %
18	Nhi Thi Ai Nguyen, Dinh Duong Le, Van Duong Ngo, Van Kien Pham, Van Ky Huynh. "Optimal Operation of Energy Storage Systems for Peak Load Shaving Application", 2023 International Conference on System Science and Engineering (ICSSE), 2023 Publication	<1 %
19	Hökelek, İsmail Harun. "Optimum Placement and Cost-Benefit Analysis of Battery Energy Storage Systems", Middle East Technical University (Turkey), 2024 Publication	<1 %
20	www.cell.com Internet Source	

Appendix B: Ethical Clearance Confirmation

Strathmore
UNIVERSITY

11th September 2024

Mr Owino Moses,
moses.ooriare@strathmore.edu

Dear Mr Owino,

RE: Use of Battery Energy Storage System (BESS) as a Means of Improving the Electrical Power System Load Factor – A Case of Kenya's Electrical Power System

This is to inform you that SU-ISERC has reviewed and **approved** your above **SU-masters** proposal. Your application reference number is **SU-ISERC2322/24.** The approval period is from **11th September 2024 to 10th September 2025.**

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by SU-ISERC.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to SU-ISERC within 72 hours of notification.
iv. Any changes anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to SU-ISERC within 72 hours.
v. Clearance for the export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to the expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days of completion of the study to SU-ISERC.

Before commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology, and Innovation (NACOSTI) https://research-portal.nacosti.go.ke/ and obtain other clearances needed.

Yours sincerely,

Mr Ambrose Rachier,
Chairperson; SU-ISERC

Ole Sangale Rd, Madaraka Estate. PO Box 59857-00200, Nairobi, Kenya. Tel +254 (0)703 034000
Email admissions@strathmore.edu www.strathmore.edu

Appendix C: NACOSTI Research Licence

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **544551**

Date of Issue: **15/October/2024**

RESEARCH LICENSE

This is to Certify that Mr.. Moses Oriare Owino of Strathmore University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nairobi on the topic: Use of Battery Energy Storage System (BESS) to Improve the Electrical Power System Load Factor – A Case of Kenya's Electrical Power System for the period ending : 15/October/2025.

License No: **NACOSTI/P/24/41224**

544551

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix D: Feeder Demand Raw Data

	high_income			middle_income			low_income			
time_of_day	hurl_ex_kile_kW	elgmarkwt_ex_kile_kW	nhos_ex_ngnrd_kW	buru_ex_kima_kW	hmbe_ex_kima_kW	5star_ex_nwst_kW	kmnd_ex_huru_kW	ksth_ex_huru_kW	infl_ex_koma_kW	kbra_ex_ngrd_kW
00:00	3453.466859	1895.17701	2537.808067	2093.754362	1181.397143	2493.139199	1244.761946	900.5058883	2697.15333	1498.302627
01:00	3113.834771	1727.639899	2464.930532	1853.720586	1060.752651	2268.360948	1111.334805	757.6196004	2366.14754	1242.823316
02:00	2904.710016	1619.25763	2373.990953	1728.417652	953.1971092	2144.349181	1041.357791	685.6348513	2190.295698	1146.440243
03:00	2795.784268	1589.506803	2343.482563	1692.98674	877.2943587	2089.930773	1035.606689	646.7190619	2130.023332	1141.114923
04:00	2852.872048	1664.02217	2378.536528	1846.406403	933.7754255	2208.46985	1119.429651	716.490203	2265.927601	1430.791452
05:00	3128.183272	1910.567106	2584.132193	2594.053029	1319.256436	2916.591818	1464.322313	1056.246255	2924.708731	2394.489246
06:00	3715.777103	2260.526383	2966.924993	3113.438755	1525.36464	3416.188647	1746.530085	1225.873667	3218.024888	3209.754882
07:00	4410.04917	2680.258672	3363.727903	3040.770727	1441.7056	3669.981644	1804.846867	1223.079719	3086.027494	3513.868623
08:00	5031.176386	3139.492936	3687.984219	3019.798834	1402.497505	3864.825501	1953.650951	1290.719471	3203.090909	3755.047994
09:00	5461.711417	3379.932928	3714.321302	3031.644868	1410.554966	4080.187473	2069.942658	1363.778849	3404.350659	3746.861836
10:00	5853.641844	3479.446238	3655.981304	2992.243097	1401.544675	4223.197724	2065.481804	1388.352822	3361.106022	3403.163818
11:00	6005.894181	3486.162956	3876.753724	2968.45714	1399.784725	4313.376471	2073.191756	1352.481986	3258.966187	3090.398517
12:00	5890.755899	3431.221667	3888.467682	2970.93503	1445.740121	4437.759711	2117.233529	1359.67083	3376.411746	3054.319293
13:00	5956.792223	3355.92058	3937.634864	2986.468941	1504.340185	4396.964253	2060.191658	1345.035929	3561.185363	3377.709752
14:00	5854.460671	3279.474556	3848.394824	2980.164833	1519.127403	4136.550722	2049.035854	1371.944412	3768.016392	3097.942368
15:00	5795.613138	3212.142703	3700.332876	3002.482	1494.973701	4055.116939	2076.123456	1435.722876	3776.937639	3213.675491
16:00	5927.550026	3199.698692	3600.682686	3138.829817	1568.453244	4197.352363	2149.591321	1492.335801	3940.149033	3398.260709
17:00	5894.923489	3176.141917	3487.859164	3350.569271	1663.704286	4251.802961	2196.706989	1547.488215	4150.312018	3787.500382
18:00	6136.262041	3241.51536	3424.626201	3815.271792	1875.802991	4589.859221	2329.983186	1732.657556	4572.048135	4746.402924
19:00	6202.854704	3384.067812	3334.51413	4401.169581	2223.134821	4879.12871	2611.16535	1969.663792	5261.905019	5481.446805
20:00	5677.636201	3144.286243	3188.353498	4221.774942	2133.132097	4693.355141	2595.11935	1954.412002	5286.799231	6065.766255
21:00	5158.078572	2871.994434	3002.388354	3861.026758	1927.583443	4308.725746	2388.123467	1817.322257	5017.585176	5133.909737
22:00	4524.830853	2537.456862	2844.706522	3205.816798	1608.038174	3590.408404	1932.294704	1522.085217	4286.702634	3561.135879
23:00	3933.263083	2174.347454	2679.765599	2531.45406	1315.001805	2931.188767	1508.765474	1155.25903	3404.433488	2138.628085

Appendix E: Load Flow Simulation for Charge and Discharge Cycle on Kibra Feeder

a. Discharge Cycle

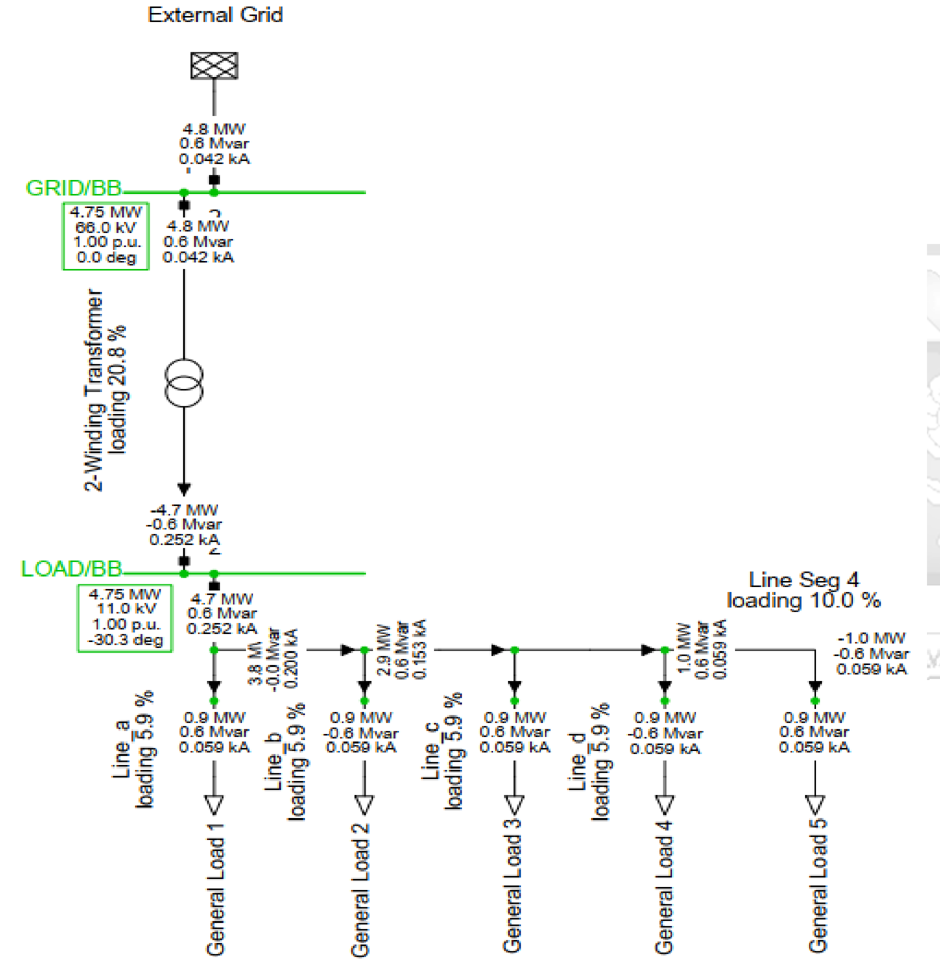

Figure 0.1: Load Flow at **1800hrs** without BESS enhancement

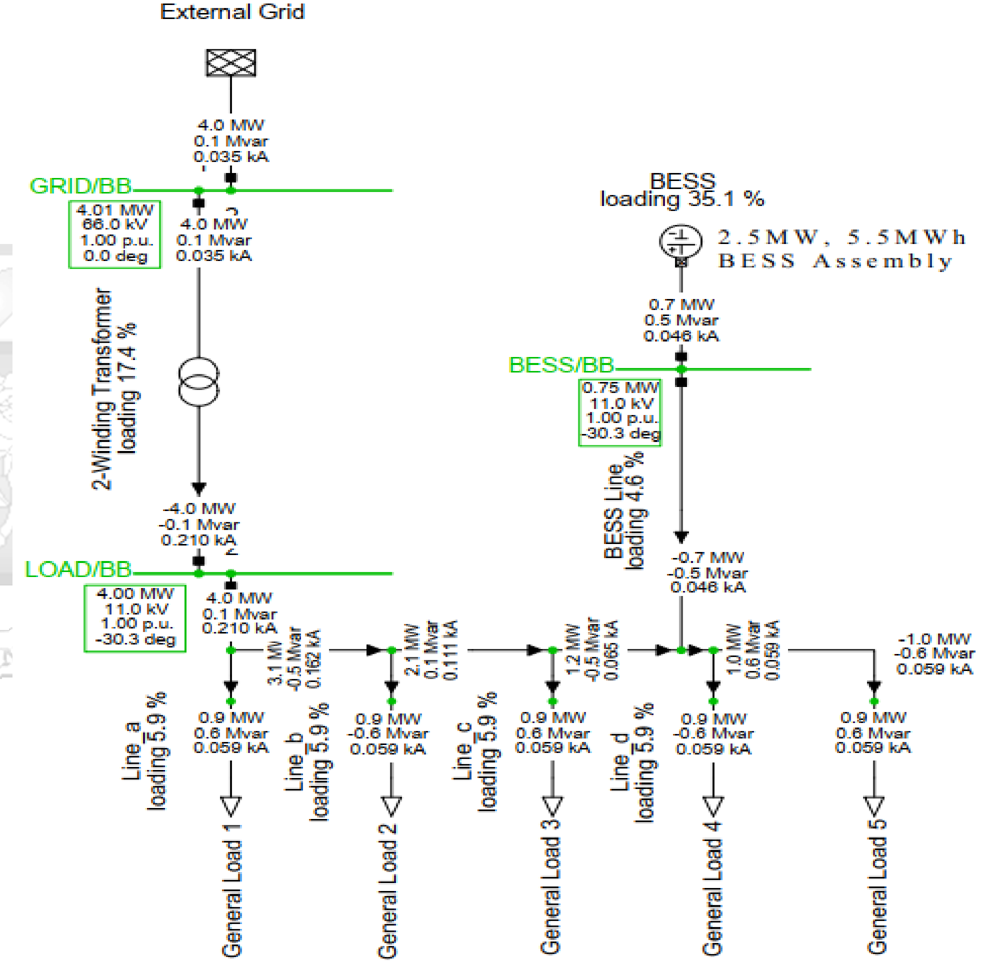

Figure 0.2: Load Flow at **1800hrs** with BESS enhancement

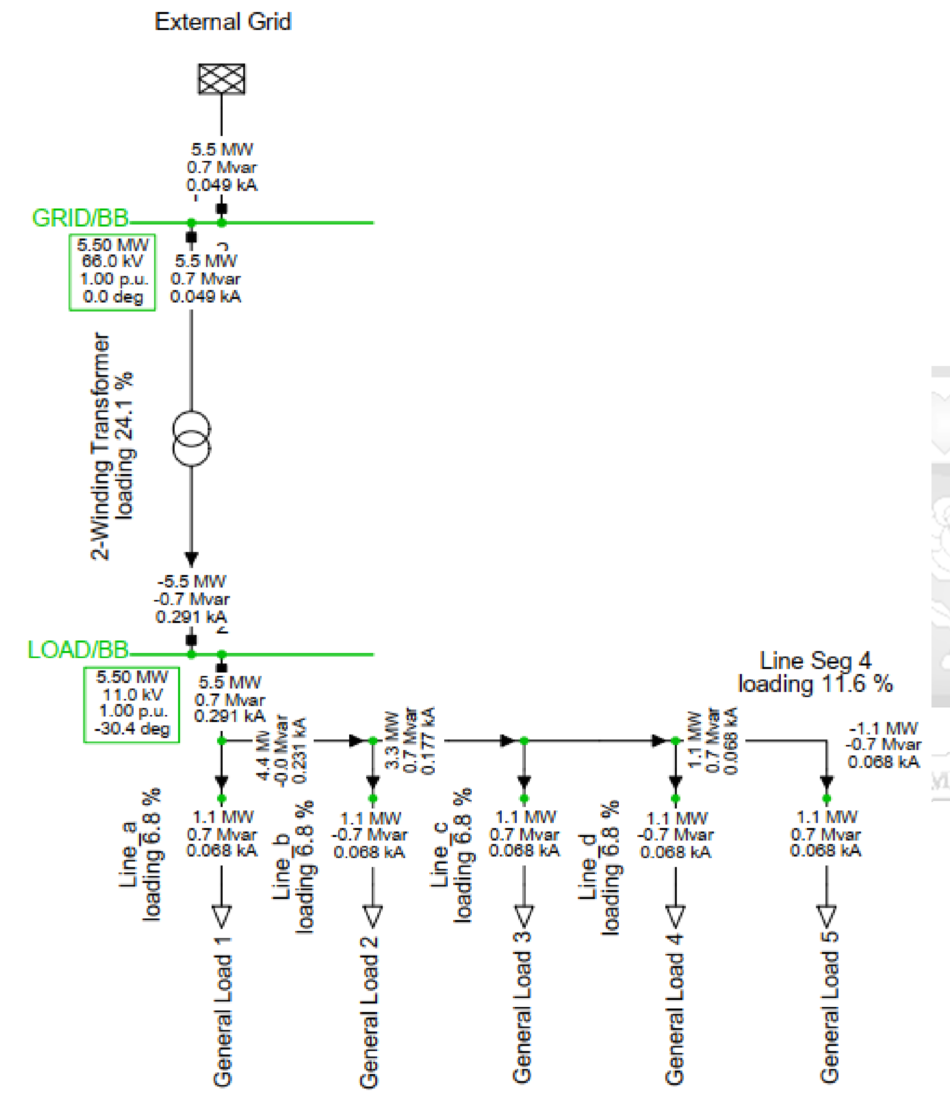

Figure 0.3: Load Flow at **1900hrs** without BESS enhancement

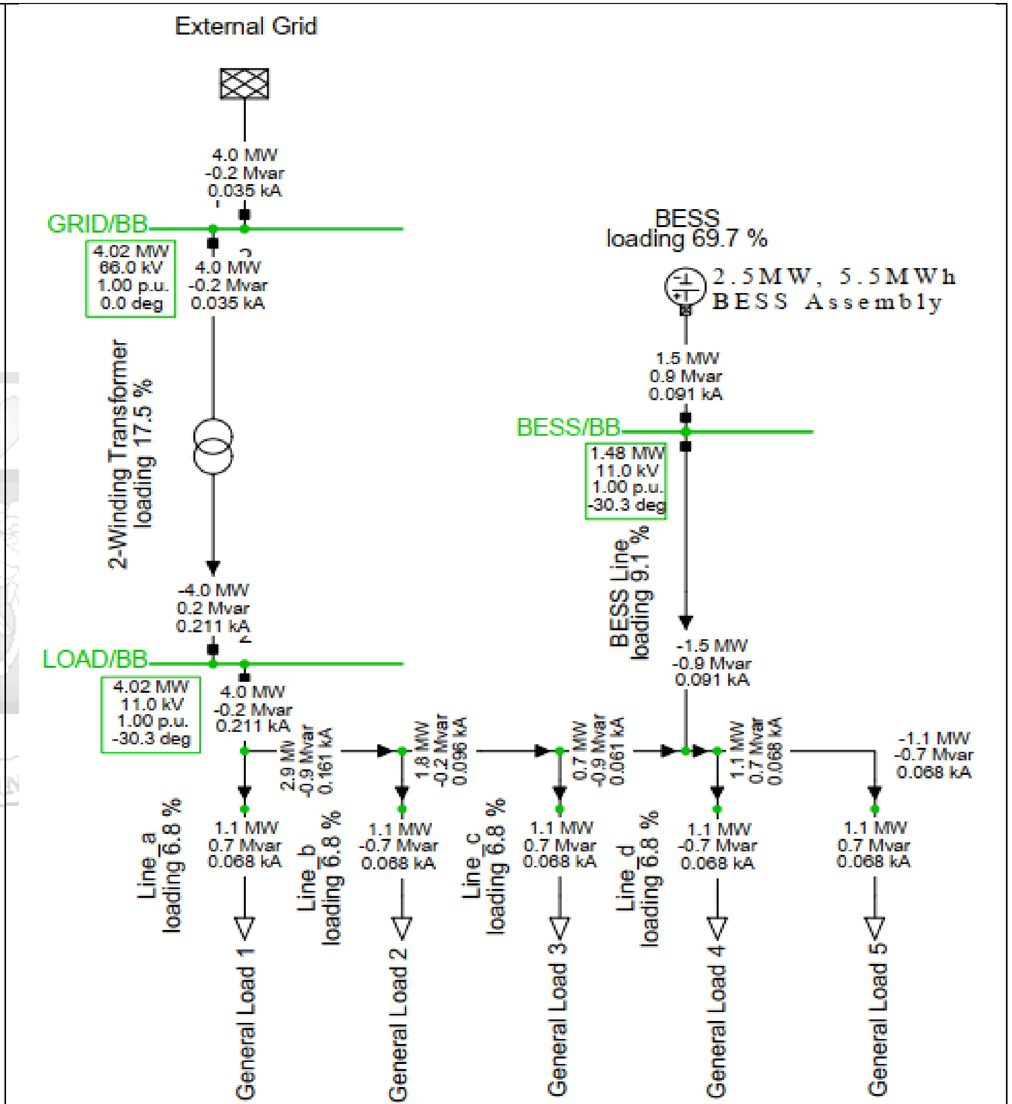

Figure 0.4: Load Flow at **1900hrs** with BESS enhancement

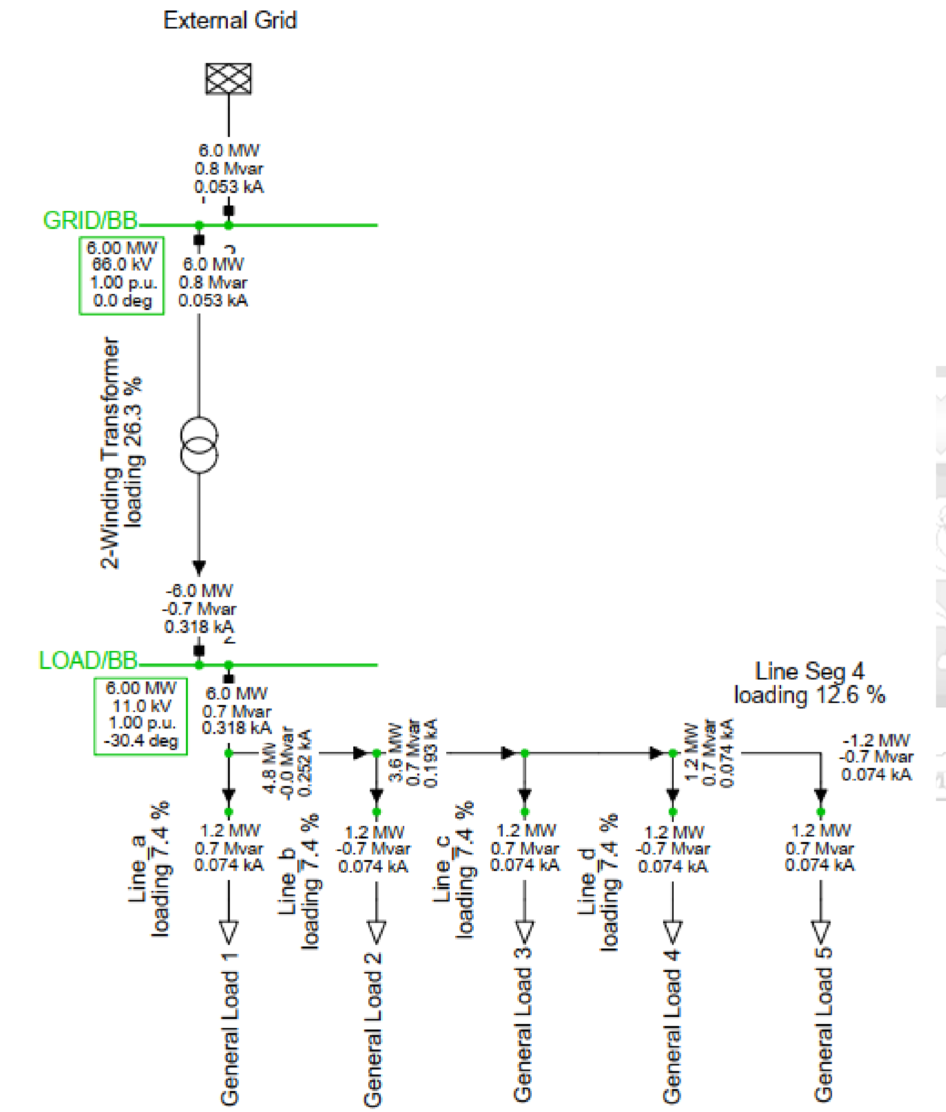

Figure 0.5: Load Flow at **2000hrs** without BESS enhancement

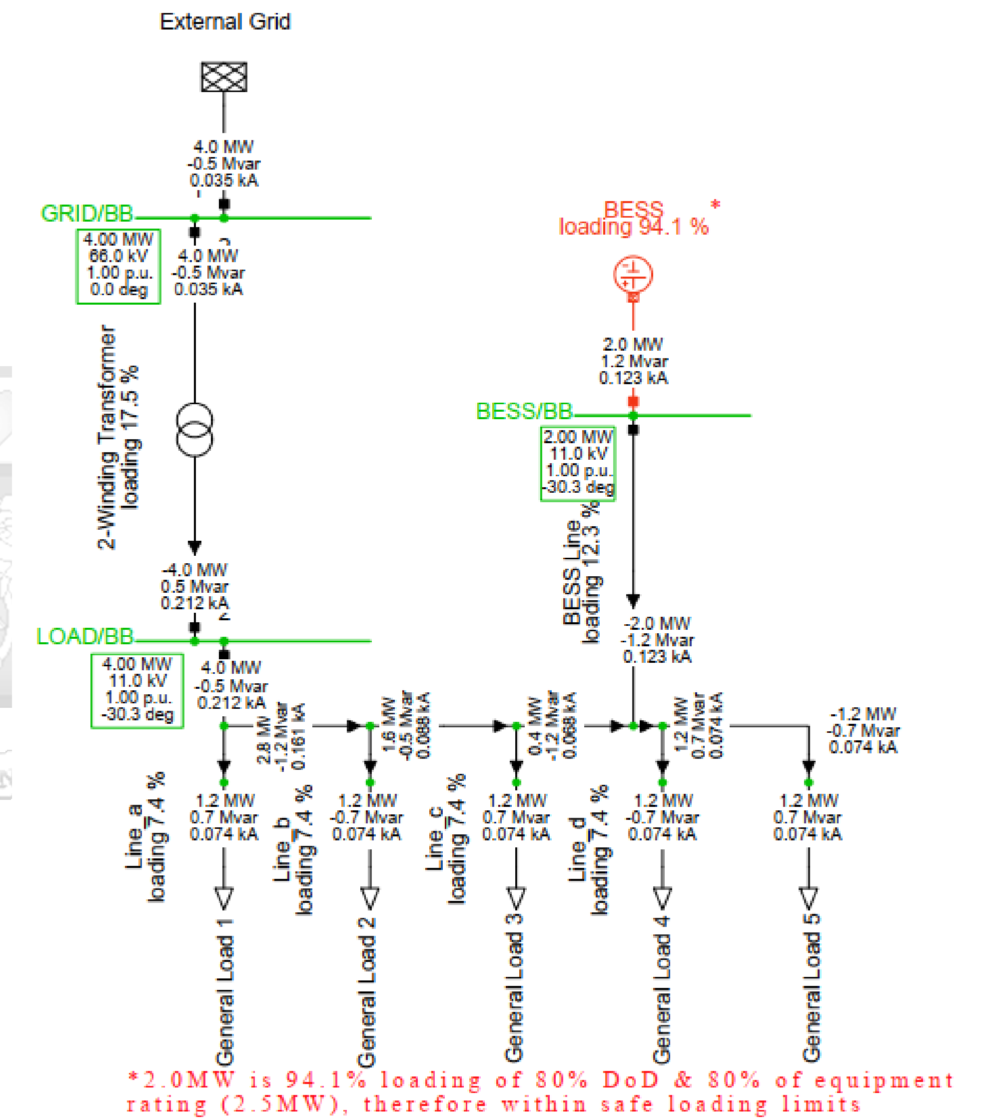

Figure 0.6: Load Flow at **2000hrs** with BESS enhancement

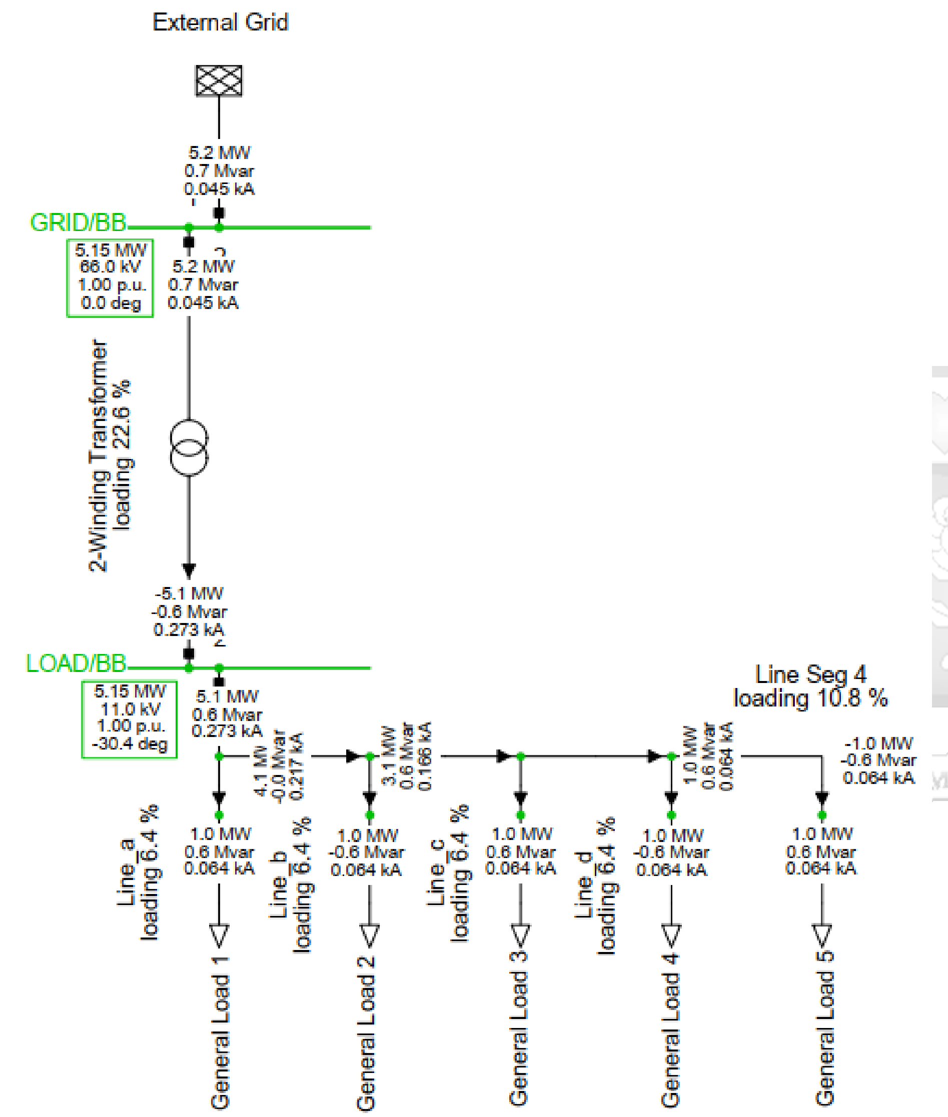

Figure 0.7: Load Flow at **2100hrs** without BESS enhancement

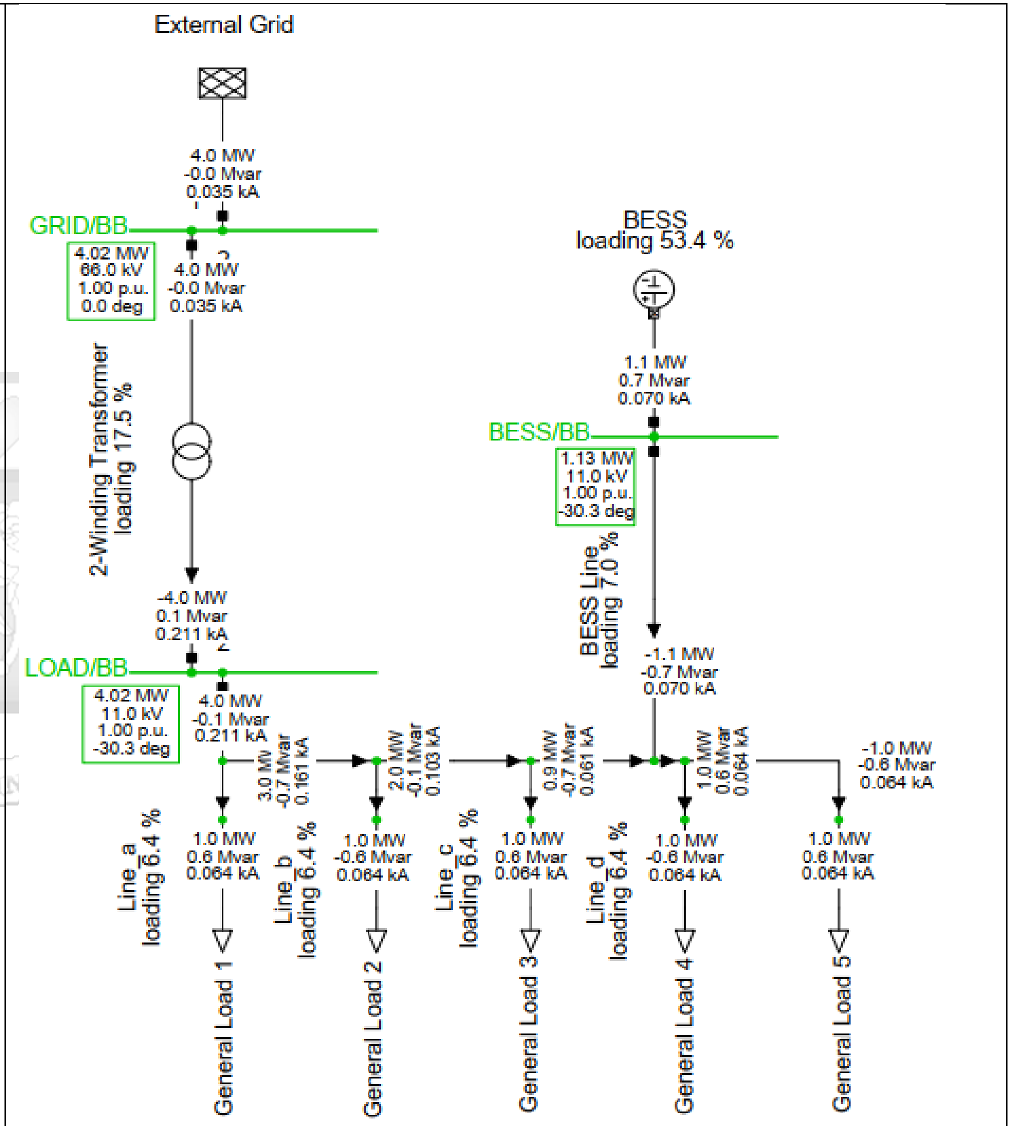

Figure 0.8: Load Flow at **2100hrs** with BESS enhancement

b. Charge Cycle

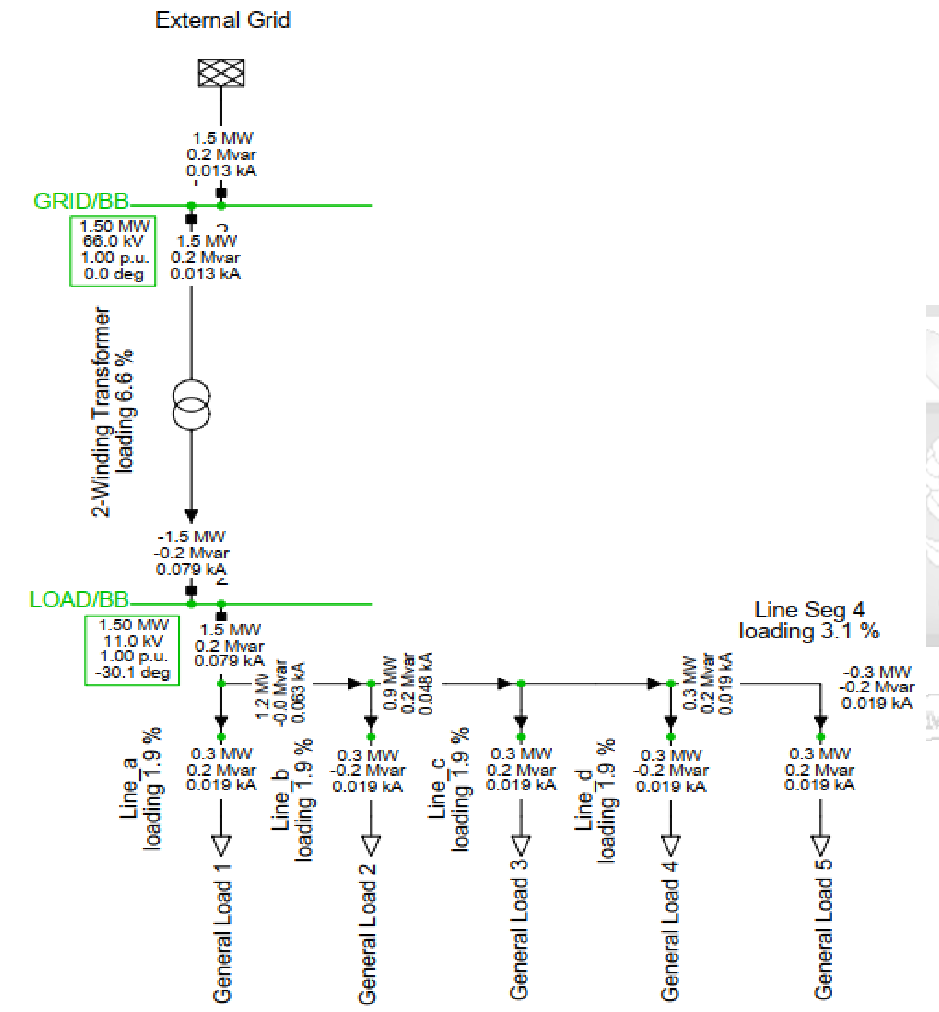

Figure 0.9: Load Flow at **0000hrs** without BESS enhancement

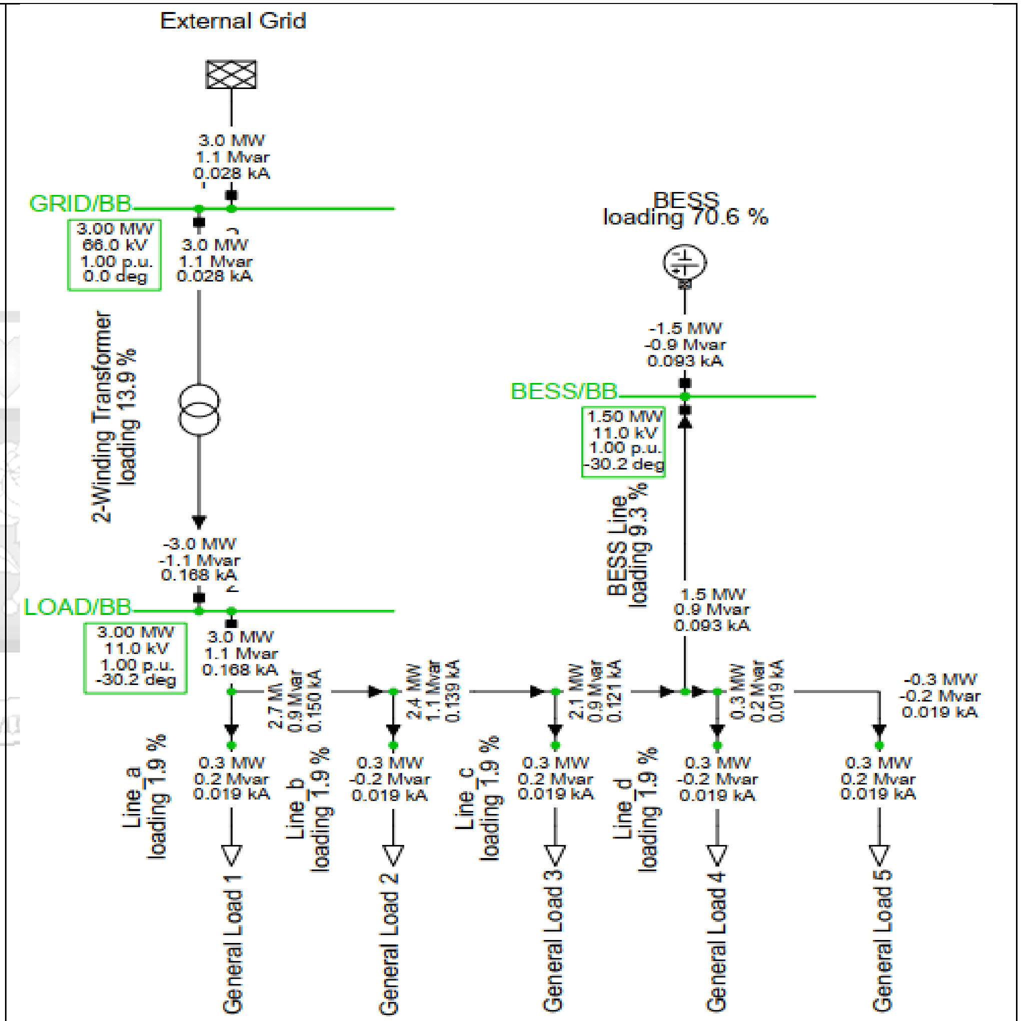

Figure 0.10: Load Flow at **0000hrs** with BESS enhancement

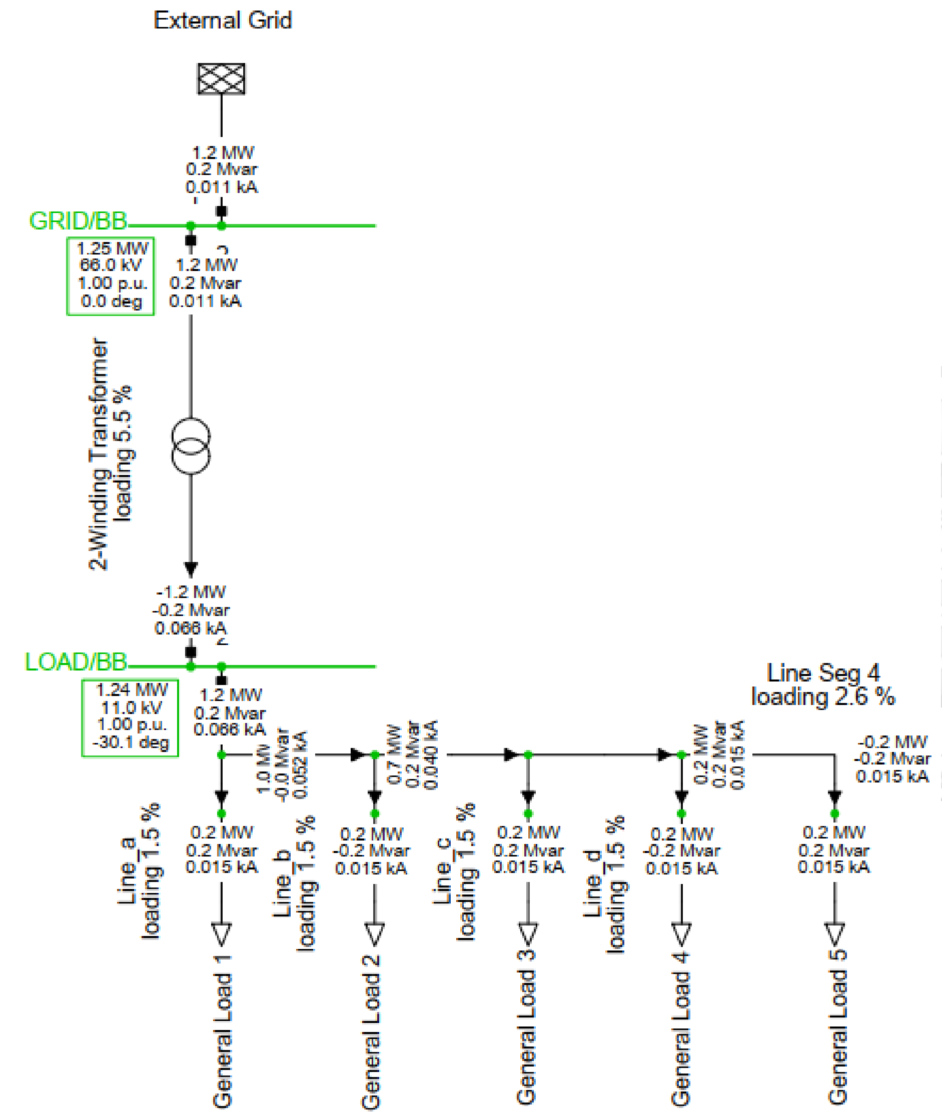

Figure 0.11: Load Flow at **0100hrs** without BESS enhancement

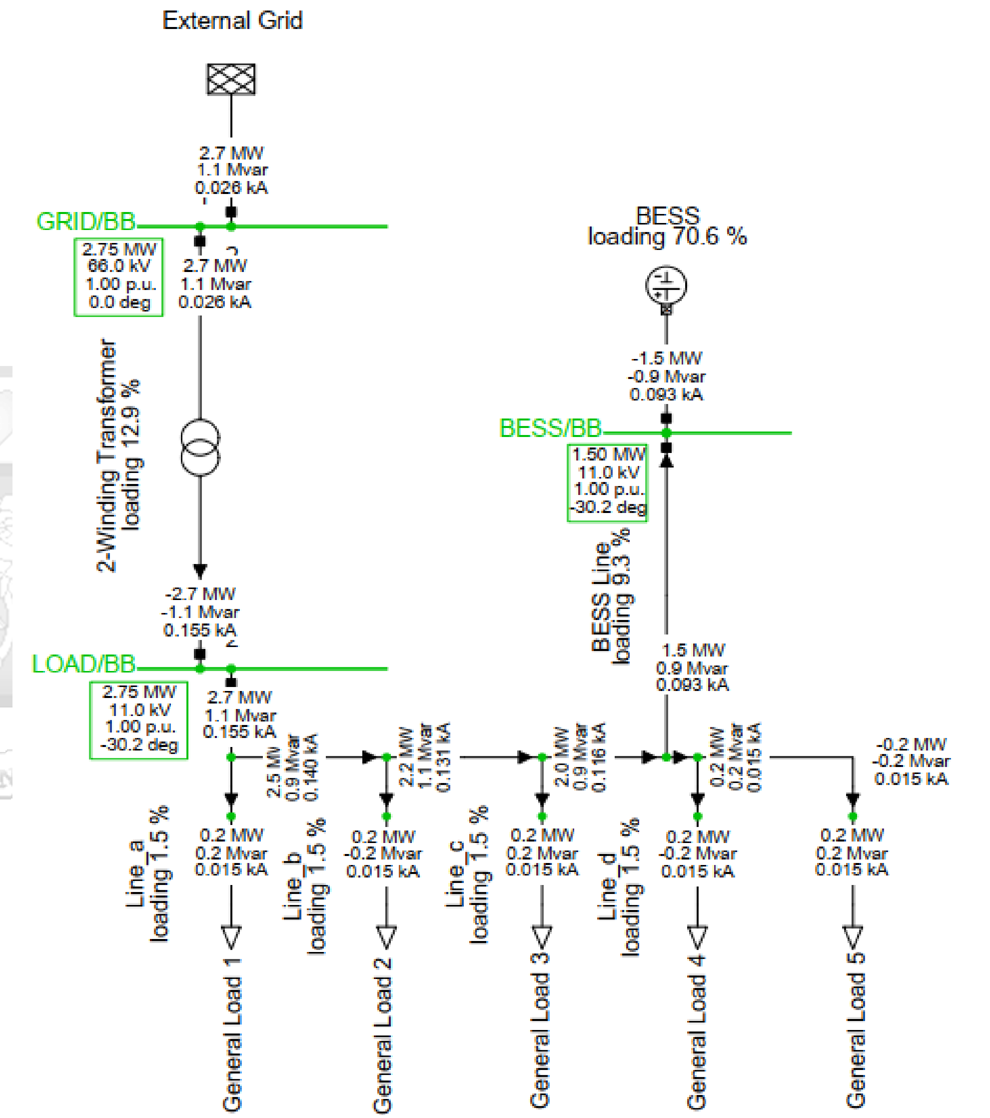

Figure 0.12: Load Flow at **0100hrs** with BESS enhancement

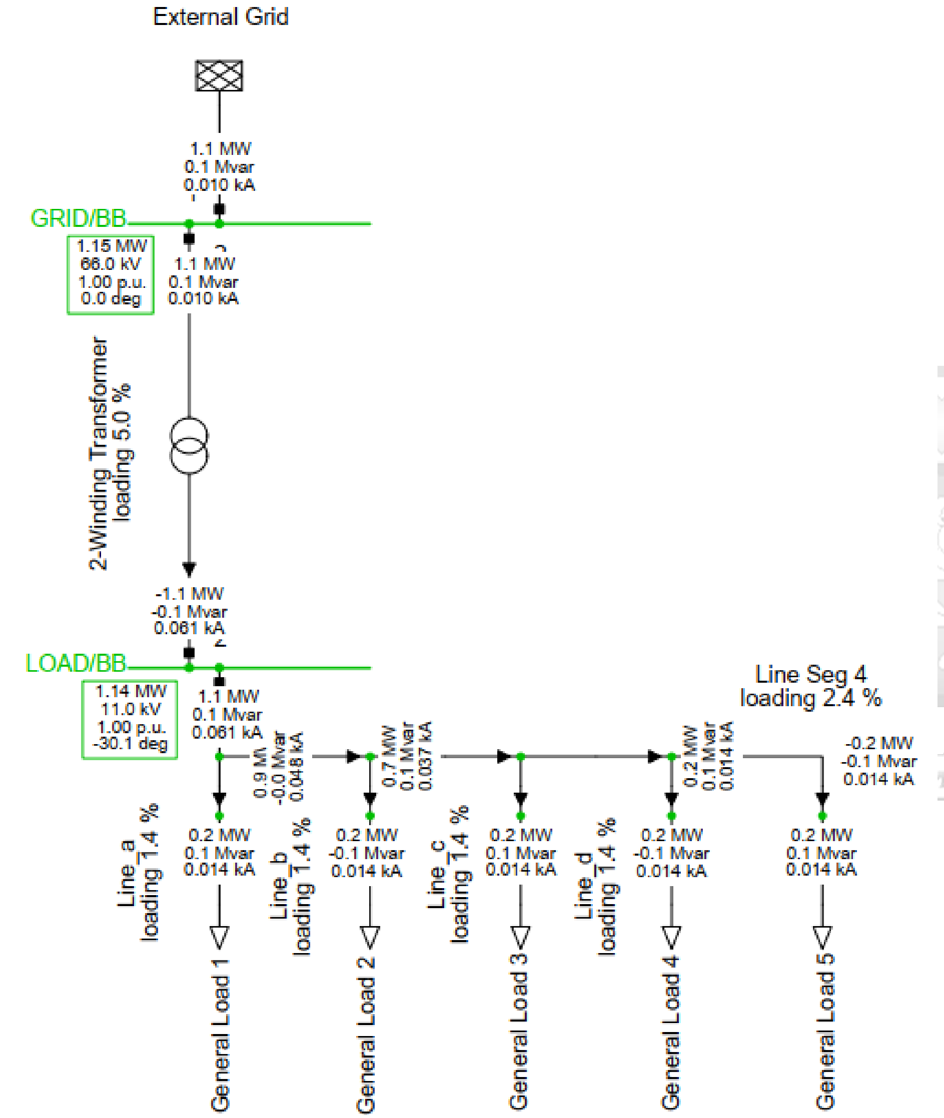

Figure 0.13: Load Flow at **0200hrs** without BESS enhancement

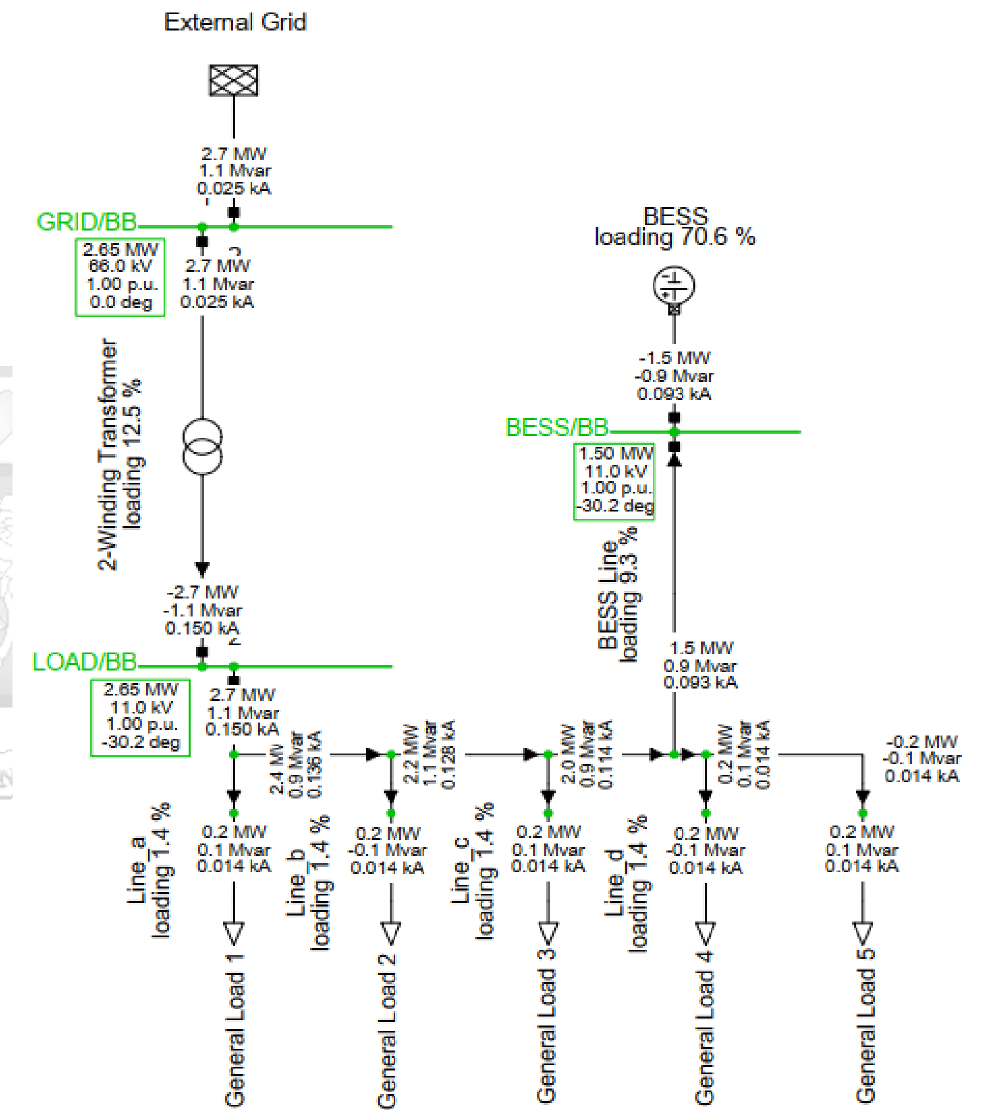

Figure 0.14: Load Flow at **0200hrs** with BESS enhancement

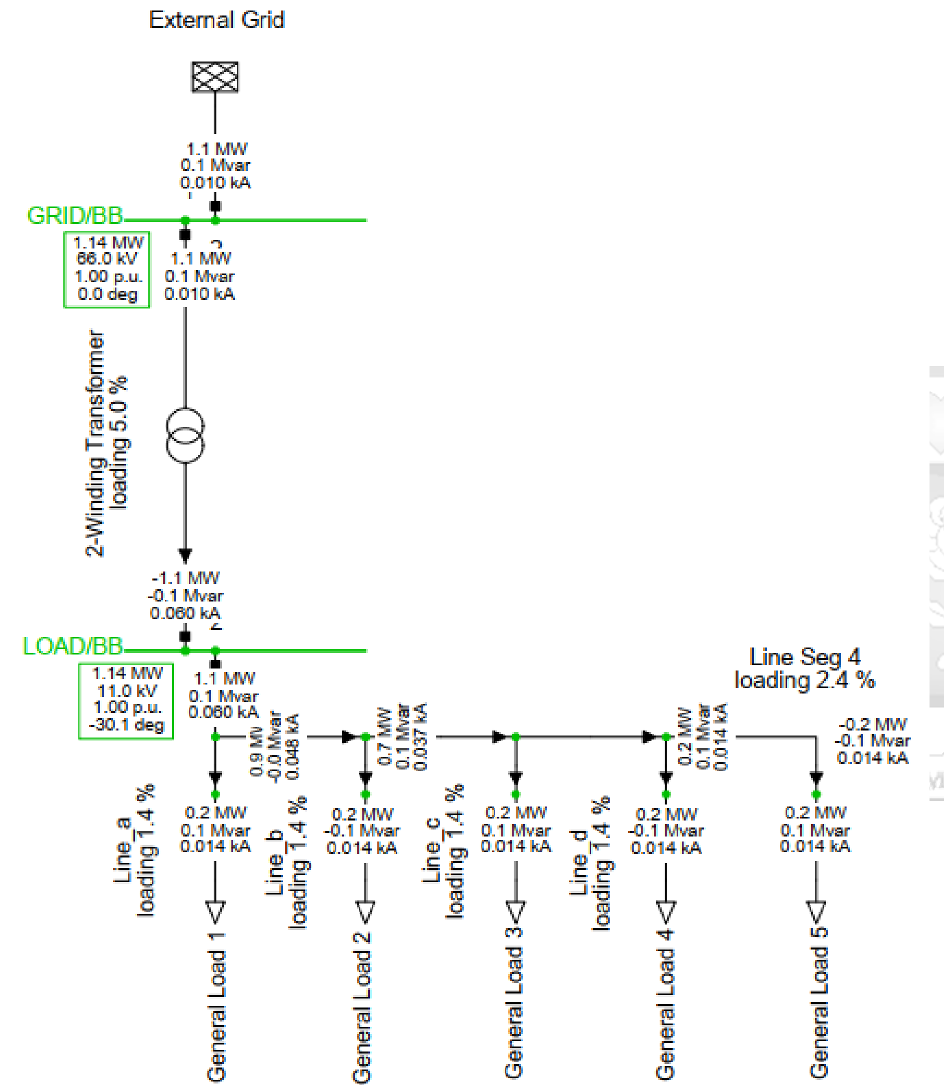

Figure 0.15: Load Flow at **0300hrs** without BESS enhancement

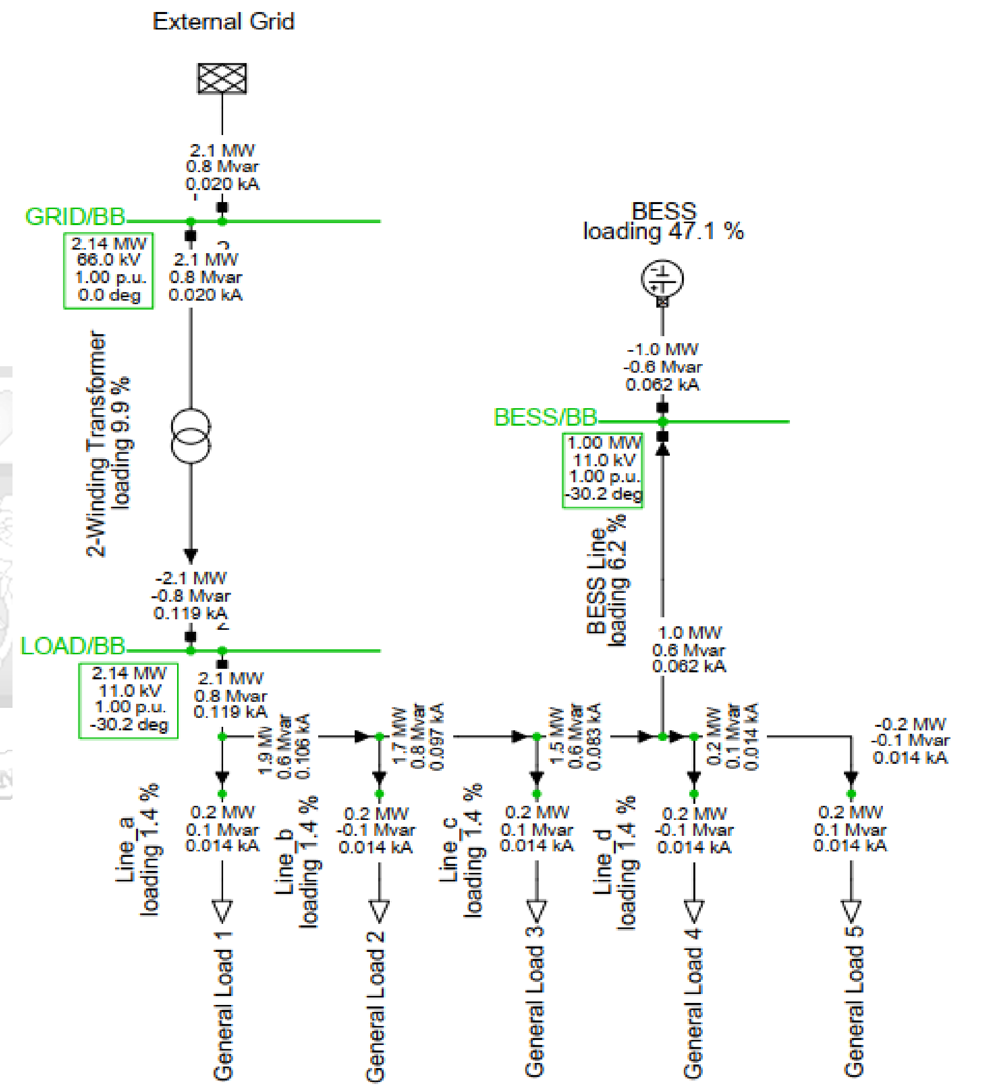

Figure 0.16: Load Flow at **0300hrs** with BESS enhancement

Appendix F: DigSILENT Licence Agreement

DIgSILENT PowerFactory Licence Contract

LC2024-04333

between

Moses Oriare Owino
No. 4 Mubea Apt.
Thindigua Highway St.
Kiambu
Kenya

hereinafter the Licensee

and

DIgSILENT GmbH
Heinrich-Hertz-Str. 9
72810 Gomaringen
Germany
Tel: +49 (0) 7072 - 9168-0
Fax: +49 (0) 7072 - 9168-88
E-mail: mail@digsilent.de

hereinafter the Licensor

Licensee:	Moses Oriare Owino, Kiambu, Kenya
Product:	DIgSILENT *PowerFactory*
Version:	*PowerFactory 2024*
Product Description:	The software with the below listed functions is delivered according to the "**PowerFactory Product Specification**" of the corresponding Version, which is available at https://www.digsilent.de/product-specification (herein after referred to as "**Product Specification**"). The Product Specification is an essential part of this license contract.
Licence Agreement:	The usage of the software must be in accordance with the "**DIgSILENT Licence Agreement**" valid by the date of this contract, which is available at https://www.digsilent.de/licence-agreement (herein after referred to as "**Licence Agreement**"). The Licence Agreement is an essential part of this license contract.
License IDs:	The licenses under this contract are listed in the appendix of this document
Contract Start Date:	**15.10.2024**
Maintenance:	(15.10.2024 - 15.10.2025) The scope of the maintenance and support services is defined in the document "**Maintenance & Support Services**" available at https://www.digsilent.de/maintenance-support
Company Credentials:	Company ID: THX Company Password: H8B5J316961 (for user registration)
Support Centre:	https://www.digsilent.de/de/support.html
Hotline:	tel. +49 (0)7072 / 9168-50 – German tel. +49 (0)7072 / 9168-51 – English

Gomaringen, 15.10.2024
DIgSILENT GmbH

This document was issued electronically and is therefore valid without signature.

Applicable appendix: List of licences