TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: 073/MSPS/717

Analysis of Distribution Transformer Overload Management Using Battery Energy Storage System

By

Umesh Kumar Das

A THESIS

SUBMITTED TO THE DEPARTMENT OF ELECTRICAL ENGINEERING

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN POWER SYSTEM ENGINEERING

DEPARTMENT OF ELECTRICAL ENGINEERING

LALITPUR, NEPAL

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DEPARTMENT OF ELECTRICAL ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Analysis of Distribution Transformer Overload Management using Battery Energy Storage System"** submitted by **Umesh Kumar Das,** in partial fulfillment of the requirements for the degree of Master of Science in Power System Engineering.

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ABSTRACT

Peak load power plants, certain types of renewable energy sources, are designed to provide electricity during periods of high demand when there is a significant increase in power consumption. These power plants typically have higher operational costs due to the need for quick start-up times and increased fuel consumption. To mitigate the reliance on expensive peak load power plants, suppliers often implement various techniques to reduce peak load and shift the demand to off-peak hours. Pumped storage hydro power plants work by using excess electricity during low demand period, such as at night or during weekends when power consumption is relatively low. The excess electricity is used to pump water from a lower reservoir to an upper reservoir. Then, during periods of high demand or peak load, the stored water is released to flow downhill through turbines, generating electricity and supplying it back to the grid. This process allows energy to be stored when the demand is low and released when the demand is high. It is found that using a battery bank, the energy can be stored and supplied to the Load to reduce the peak load of the respective Distributon Transformer. The installation of BESS at the point of existence of DT has been modelled and the simulation results obtained. The installation of BESS helps to reduce the peak loading of the DT including overloading and helps prevent the outage of the transformer. Based on the simulation results, a BESS of maximum 100kW, 2000Ah installed at the point of connection of DT of 200kVA results in number of overloading reduced from 264 kW to 180 kW. The simulation shows that the number of transformer outage is expected to decrease from 20.83% before the installation of BESS to 3% after the installation. Further, there will be a reduction in power and energy losses in the system as during the peak load condition, part of the load can be shared by the BESS which results in power loss reduction maximum of 84 kW and annual energy loss of 76.650 MWh at 50 percent annual peaking with daily hours. The voltage profile improvement is another front with voltage improving from 0.93 pu to 1.00 pu during peak load condition. Considering the fact that voltage plays crucial role in satisfactory operations of various household, commercial and industrial appliances, this has to be taken into account when deciding on techno-economical analysis of the proposed scheme. Under the assumptions for this research, the proposed scheme is potentially beneficial not only from technical aspects but also economical aspect as well. The investment cost of the BESS and inverter considered in the study at present value is NPR 530,000.00 whereas the monetaroy value of the energy saved annually has been found to be NPR 267062.00

for 90% overloading and peak time electricity cost of NPR 15.00 per kWh. Even for lower overloading percentage of 20 to 40 % of the rating of the DTs, the proposed scheme may be economically viable.

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I would like to express my sincere gratitude to the respected Supervisor Prof. Dr. Nava Raj Karki and Associate Prof. Dr. Basant Gautam for their continuous guidance and kind support for this thesis work. Their valuable suggestions, feedbacks, effort and constant motivation have been crucial for this thesis work.

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ABBREBRIATIONS

AC	Alternating current
BESS	Battery Energy Storage System
CIGRE	International Council on Large Electric Systems
DC	Direct current
DCS	Distribution and Customer Service Center
DG	Distributed Generation
DS	Distribution System
ESS	Energy Storage System
GA	Genetic Algorithm
HV	High Voltage
IEEE	Institute of Electrical and Electronics Engineer
kV	Kilo Watt
kVA	Kilo Volt Ampere
kVAR	Kilo Volt Ampere Reactive
kW	Kilo Watt
LV	Low voltage
MATLAB	MATrix LABoratory
NPC	Neutral Point Clamped
DT	Distrbution Transormer
OLTC	On – Load Tap Changer
PVGS	Photo – voltaic Generation System
RES	Renewable Energy Sources
HIL	Hardware in Loop
VDI	Voltage Deviation Factor
SOC	State of Charge
SOH	State of Healt
DOD	Depth of Discharge
BMS	Battery Management System
PCC	Point of Common Coupling

CHAPTER 1:INTRODUCTION

1.1. Background

In an electrical power delivery system, electric power distribution system consists of final level that delivers power to individual consumer. The bulk power is transported by transmission system at high voltage, then distribution system is responsible to deliver power to individual consumers in required amount, in safe voltage level and also complying various consumer standards that may vary country to country. Implementing energy storage systems at the distribution transformer level can indeed be an effective approach to manage peak loads and improve the overall efficiency of the electrical grid. Battery banks, such as lithium-ion batteries, are commonly used for this purpose due to their high energy density, efficiency, and rapid response capabilities. The pumped storage hydro power plant at the distribution transformer level to help reduce peak loads. This system would involve using a battery bank to store energy during off-peak times and supply it back to the load during periods of high demand [1].

The study of the proposed system will find the capacity of storage Battery Bank system for the designed peak value and operating time. With integrating the battery bank system, it can reduce the peak load at the Distributon Transformer. By reduced the peak load of the Distributon Transformer from the system, it is proposed to reduce the investment and consequent effect of peak load power.

The transformers (DTs) are indeed costlier and critical assets within an electric distribution system. They play a crucial role for the efficient electricity delivery to consumers. They enable efficient power delivery, voltage transformation, load balancing, fault isolation, and voltage regulation. Proper management and maintenance of DTs are crucial to ensure reliable electricity supply to consumers and minimize system downtime. The overloading, non-linear load connection and operation, irregular and underprivileged maintenance are the factors affecting the life of transformer. The transformer failure percentage in Nepal is 30 to 35% and it is due to overload in urban areas because of the higher population than rural areas. Deploying the battery energy storage systems (BESS) at distribution downstream level can help prevent overloading of distribution transformers (DTs). However, overloading typically occurs only during the certain periods, and the load varies depending on the consumer type. The load for industrial users tends to have high variation compared to the domestic end users. This difference is primarily due to the operation of machinery and equipment in industrial settings. Industrial processes often require peak power demand during specific periods of time, such as when production is at its highest or during scheduled maintenance activities. This results in sharp spikes or fluctuations in the load pattern. On the other hand, the load demand for domestic consumers is generally more predictable and can be forecasted with relatively better accuracy. Domestic electricity consumption is influenced by daily routines and lifestyle patterns of households, which typically follow more consistent and predictable usage patterns. While there may be some fluctuations based on specific events or seasonal variations (e.g., increased cooling load during summer), overall, the load demand for domestic consumers tends to be more stable compared to industrial consumers. Utility companies and grid operators consider these variations in load patterns to ensure the reliable supply of electricity [1-2].

The increased stress on the distribution network during peak load periods can pose challenges to maintaining a reliable and stable power flow. Traditional approaches such as asset upgrade and network augmentation can be costly and time-consuming. Therefore, exploring alternative solutions becomes crucial in managing peak load demand without significant infrastructure investments. Here are a few approaches that can be considered: demand response, energy efficiency adaptaions, distributed generation and energy storage systems. By combining these alternative approaches and implementing advanced technologies, it is possible to mitigate the need for costly asset upgrades and network augmentation to meet peak load demand. These solutions provide more flexibility and efficiency in managing electricity demand while maintaining the reliability and stability of the distribution network.

Battery energy storage systems (BESS) can provide a reliable solution to the problem of overloading and offer numerous benefits when integrated with the downstream distribution network. BESS can be used in a variety of applications within the power system, including peak saving, voltage regulation improvement, load and frequency balancing, integration with distributed energy resources, and uninterrupted power supply. While BESS offers these benefits, it is crucial to consider the cost implications. The upfront capital cost of installing and maintaining a BESS can be significant, depending on the system's capacity and technology. However, it's worth noting that the cost of battery storage has been steadily declining in recent years, making it more economically viable in many applications. Accordingly, the authors are suggesting a break – even points for inverstment of BESS system (e.g. lead acid batteries, NaS, Li-Ion, Vanadium redox, and ZnBr) for pre-determined charge – discharge cycle considering efficiency, life – cycle, and Depth – of – Discharge (DoD) and the financial investment. An optimal saving level for DT can be defined to effectively utilize the BESS. Historical load data can provide valuable insights into load patterns and help in defining suggested variable optimum shave levels. By incorporating real-time control strategies and adaptive algorithms, the BESS can respond to changing load conditions and optimize its operation dynamically. This approach allows for better utilization of the energy storage system, regardless of whether the load matches the pre-defined load pattern or deviates from it [4-5].

BESS uses bi – directional converter cum inverter and is connected at a common coupling (CC) point with a variable load for the system and can be strategies aim to optimize the performance, efficiency, and safety of the BESS in various operating conditions. Current control loop method uses voltage at PCC to obtain current reference, active power and reactive power reference. The control pulse for bi – directional converter is calculated based on the differential error between the current of BESS and reference current. Voltage control method suggests to maintain a constant DC-link voltage discsarging the operation of charging or discharging. Battery management system control logic has been determined based on the variation of DC link voltage. The rate of charge / discharge depends only upon the variation of DC link voltage. Battery power and state of charge only determines the battery conditions. A fast-charging method is proposed where charging rate is calculated based upon maximum charging voltage, and charging voltage is calculated by state of the charge of battery. Closed loop current control method has been suggested to generate PWM signals for battery charger [5].

1.2. Objective of Thesis

The main objective of the thesis work is using a battery bank to store and supply the stored energy to the load to reduce the peak load of the respective Distributon Transformer. A distribution transformer is the important part of a utility whose failure causes interruption of power supply, considerable financial loss and lower reliability of utility. Overloading of transformer is one of the major causes for failure of the distribution transformers**.** An introduction of Battery Energy Storage System **(**BESS**)** in the distribution system can considerably reduce the load stress on a transformer by providing power during peak demand time**.** Proposing a novel method for battery charging and discharging based on real-time net power flow measurements from the Distribution Transformer (DT) and the load-side is which can provide more accurate and dynamic control of battery operations. BESS will be charged during off peak hours when the energy rate is lower and discharged during peak hours when energy rates are higher**.** The proposed BESS can have bi – directional converter that is connected at the DC**-**link. The battery charging **/** discharging cycle can be controlled in such a way that the power flow from distribution transformer shall not exceed the load of transformer more than 90% of its rated capacity**.** The charging is performed under two modes of operation**.** Current control mode which prefers till the battery SoC is 80%, and voltage control mode of charging is preferred up to 95% SoC level**.**

1.3. Scope of The Thesis

This thesis has scope of formulation for method for using a battery bank by which, the energy can be supplied during peak hours and stored during off – peak hours to the load to reduce the overloading of the respective distributon transformer.

1.4. Organization of the Report

This thesis has been organized into five chapters as below:

Chapter 1: It discusses about the background introduction of the topic, states the problem statement, objective and scope of the thesis.

Chapter 2: Literature review about distributed generation and energy storage system is discussed. Also, several related works by prominent authors are explained.

Chapter 3: This chapter explains the methodology used for Battery Energy Storage System, operational control for distribution transformer, and overload management.

Chapter 4: This chapter includes the results obtained after the use of the methodology in different cases and the results are analyzed and discussed.

Chapter 5: This chapter concludes the result of the thesis. And the suggestions for possible future works are mentioned in the chapter.

CHAPTER 2:LITERATURE REVIEW

2.1. Overview

During the coincidence of light load condition and high generation in distribution system, the intermittent distributed generators such as Inverter causes rising of bus voltage during light load condition in the system. Also, as distribution system itself have problem of voltage drop problem during the peak load duration. Hence, distribution system suffers from poor voltage regulation, low voltage and significant power losses issue.

To address this problem of voltage rise in the distribution network due to high injection traditional voltage regulating devices are not suitable due to high number of switching operations and fast response required. So, various techniques have been proposed-restriction of size of DG, active power curtailment, coordinated dispatch control, etc. to address the issue. These leads to spill of prospective clean energy.

Hence, to exploit the spilled clean energy of the distributed generators, battery energy storage system (BESS) coupled with inverter can be used. Likewise, with appropriate control strategy of the system, it can also help to improve voltage regulation, reliability and system loss reduction in the distribution system. Moreover, BESS can be used to achieve financial benefit exploiting difference of tariff system during on peak and off-peak hours. the deployment of Battery Energy Storage Systems (BESS) at the distribution downstream level can help prevent overloading of distribution transformers (DTs) and offer a reliable solution to this issue. By integrating BESS in the distribution network, several benefits and applications can be realized: load balancing, peak shaving, frequency control, voltage regulation, uninterrupted power supply and integration with distributed energy resources. Indeed, the cost of BESS is an important consideration when evaluating its deployment in a distribution network. Different battery technologies, like as lead-acid, Lithium-ion (Li-ion), Sodium-Sulfur (NaS), Zinc-Bromine (ZnBr), and Vanadium redox, have varying costs, efficiencies, cycle life, and depth of discharge (DoD). A break-even point analysis can help determine the economic viability of each technology based on these factors. To effectively utilize the BESS for peak shaving and load balancing at the distribution transformer (DT) level, an optimum shave level should be defined. This shave level determines the amount of load that can be shifted to the BESS during peak demand periods. The optimum shave level can be determined based on historical load pattern, which serves as one of the major inputs for control logic. However, it's important to note that this methodology is not applicable where real-time control is required and the load pattern deviates from the pre-defined pattern. The Battery Management System (BMS) plays a crucial role in the operation of the BESS. It estimates the state of charge (SOC) and state of health (SOH) of each battery cell in the pack, allowing for effective monitoring and control. The BMS also applies active charge equalization to the balance charge for all cells in the pack, which helps maintain the overall health and performance of the battery system [7-10].

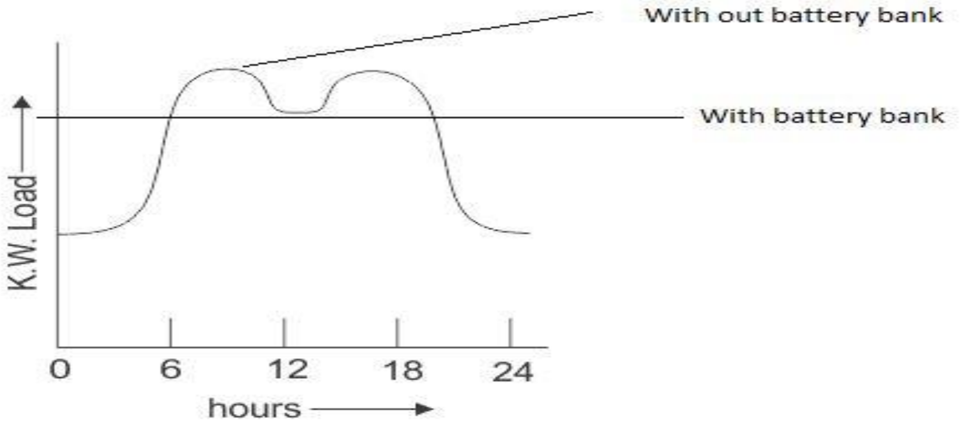


Figure 2.1: Typical daily load curve of distribution transformer

2.2. Energy Storage system

The electric energy can be stored by into other form of energy and then retrieve it when necessary. There are several types of energy storage systems available. Major of them includes following:

2.2.1. Superconducting magnetic energy storage

This storage system stores the energy by creating magnetic field in a large superconducting coil which has to be cooled cryogenically to temperature lower than its superconducting critical point. Here, there is heat dissipation loss when current is passed in the coil due to resistance of the wire. This loss is almost negligible while the coil is made from superconducting material under its superconducting state in which its resistance is almost zero. To charge and discharge the coil, a power conditioning coil is used. It has high efficiency, high power density, rapid response and very quick full discharge time but is highly expensive [8].

2.2.2. Pumped Hydroelectric Storage System

Pumped hydroelectric storage operation is a simple energy storage system which consists of two water reservoirs at different height. When there is low load demand but high generation, the excess power will be used to pump water from lower reservoir to the higher reservoir. And likewise, when electrical power is necessary to serve peak load, the water is flown to the lower reservoir through turbine to generate electrical power. Its efficiency is approximately 70-80%.

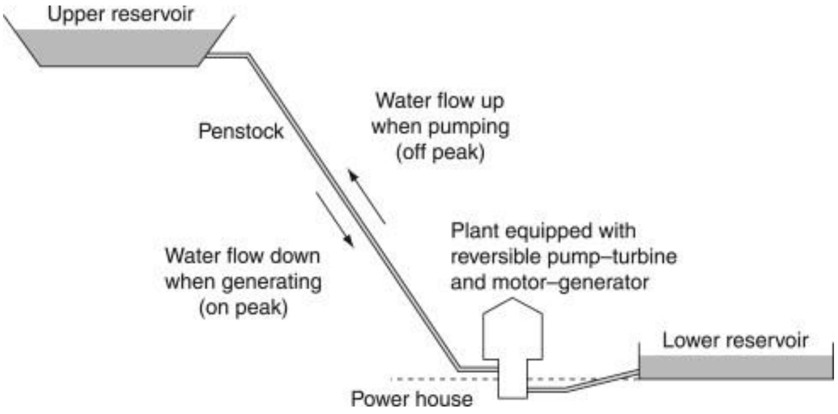


Figure 2.2: Simple model of pumped hydroelectric strorage plant

Its viability is completely dependent on the geographical location and have significant ecological impact. It also requires significant construction time to be fully functional. It had an installed capacity of around 120GW worldwide and represented 99% of global storage capacity in 2012 [6].

2.2.3. Compressed Air Energy Storage

In this storage system, a motor/generator is coupled with chain of air compressors and turbines. During charging mode, electricity is used to compress air in a tank at high pressure with the help of compressor and the electric machine that works as motor in this case. And during discharging mode, the compressed air is released through turbine and the coupled electric machine works as generator which will generate electricity. The capacity will be dependent on the air storage tank capacity. The low cycle efficiency is the main disadvantage of this system [10].

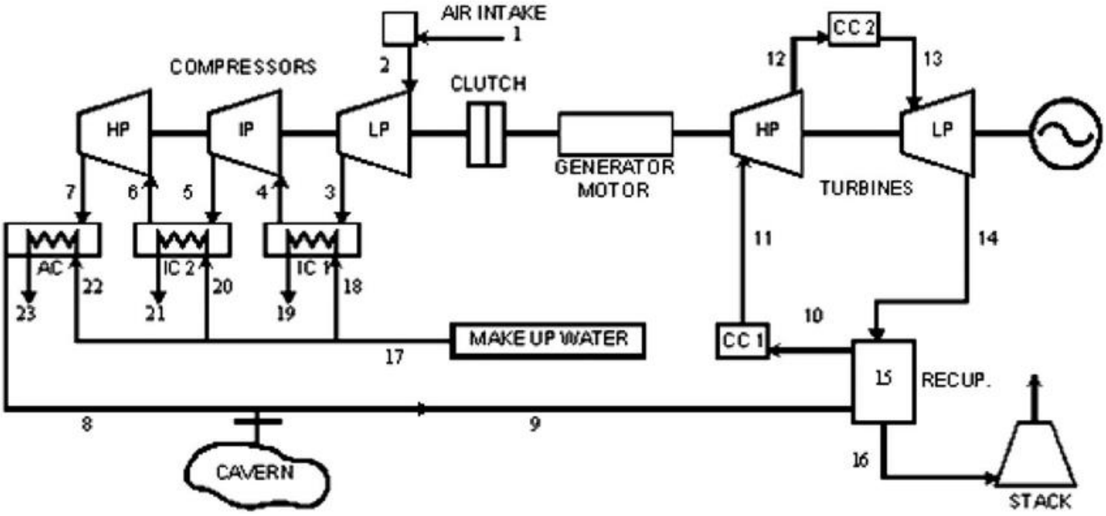


Figure 2.3: Schematic diagram of compressed air energy storage system

2.2.4. Flywheel energy storage

This system stores the energy by accelerating a rotor at very high speed. The rotor is accelerated by electric machine to store energy in the system and retains the energy in the form of inertia at the high speed. The same rotational energy of the rotor is later utilized to generate electricity while necessary. The amount of energy stored in the system is given by:

$$E = \frac{1}{2} I w^2 \tag{2.1}$$

Where, I is the moment of Inertia of the rotor, w is the angular velocity of the rotor flywheel. So, the size of moment of inertia determines the energy capacity of the system. Figure 2.3 show the general model of FES system.

For realization of the system, a flywheel is connected to an electrical machine. This machine acts as motor while accelerating the flywheel and acts as generator while recovering the power from the system. This system has good use for fast response frequency regulation in generator and distribution system for short term only as the idling loss in the system makes it unsuitable for providing standalone power backup system [11].

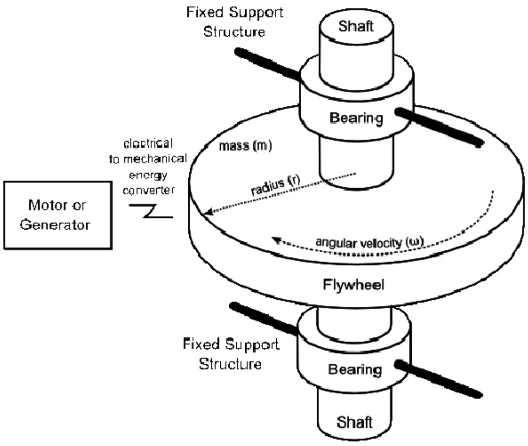


Figure 2.4: Flywheel energy storage system

2.2.5. Super Capacitor

In general, capacitor stores electric energy in the form of electric field in between parallel charged plates. The energy storing capacity can be increased either by increasing the voltage between the plates or increasing the capacitance of the system. In case of super capacitor, larger surface area is achieved by use of porous electrolyte, thereby increasing the capacitance by many times. Thereby the energy density will be very high than general capacitor. It has high efficiency and suitable for high charge discharge frequency without degradation. But due to high capital cost and high daily self-discharge rate, this system is appropriate only for smoothing of momentary voltage sags and interruptions only [11-12].

2.2.6. Battery Energy Storage System

Rechargeable battery is one of the most widely used battery technologies in daily use as well as in industrial use. Battery energy storage system stores electrical energy by converting it into electrochemical form. A BES is generally composed of numbers of electrochemical cells connected in parallel and/or series according to voltage requirement. As shown in Figure 2.5, each cell is composed of two electrodes and electrolyte in between them. Here, while charging, electrochemical reaction takes place and electrical energy is converted into chemical energy. Likewise, during discharging, reverse reaction takes place and the same stored in the form of chemical energy and is converted into electric energy [13]. Various types of BES are Lithium ion (Li-ion), lead acid, Nickel-Cadmium (NiCd), flow batteries (zinc bromine, vanadium redox, fuel cell).

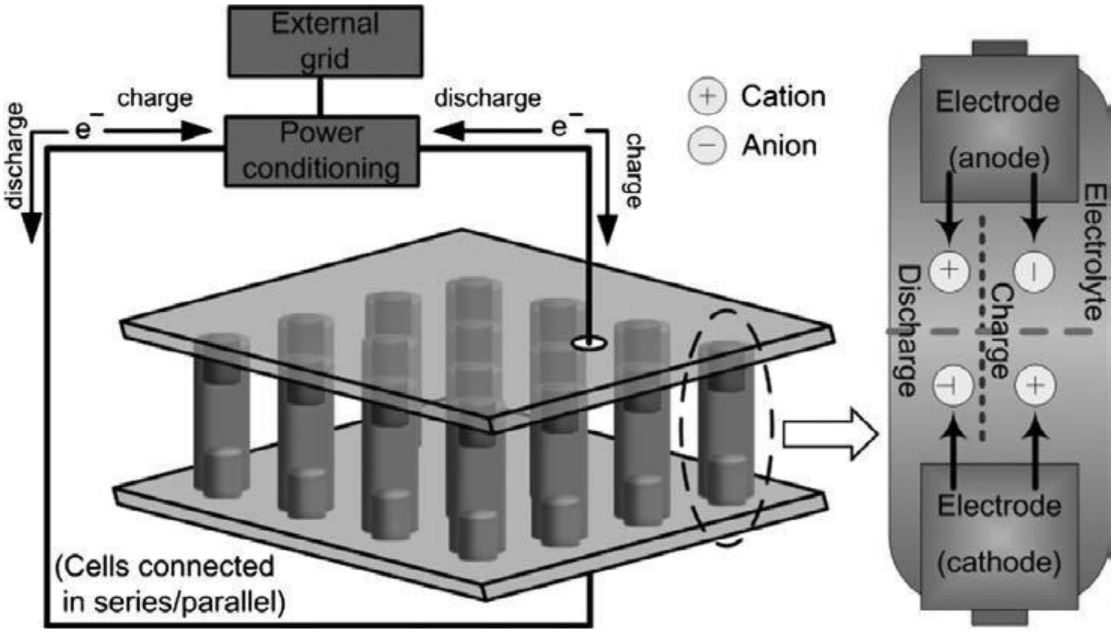


Figure 2.5: Schematic diagram of battery energy storage system

Lead-acid batteries are suitable for cheap option for bulk energy storage but has poor energy density and short life cycle of around up to 1800 cycles while Li-ion, NaS and NiCd BESS has high power density & long-life cycle but are comparatively expensive. Also flow batteries are costly but have advantage of long duration storage with non-self-discharge capability. Li-ion batteries can have life cycle of upto 20,000 cycles with cycle efficiency of up to 97%. NiCd and NaS batteries has comparatively low cycle efficiency and life cycle in comparison to Li-ion Batteries [13-14].

A flow battery consists of external two liquid electrolyte tanks and the energy is stored into two soluble liquid redox couples stored in each tank. And there is provision to pump these electrolytes to cell stack which consists of two electrolyte compartments separated by ion selective membranes where the chemical reaction takes place as shown in figure 2.6. Zinc Bromine (ZnBr), Vanadium Redox (VRB), Poly – Sulfide Bromine (PSB) are the type of flow batteries. Flow batteries have low self – discharge and high cycle life but have lower cycle efficiency [14-16].

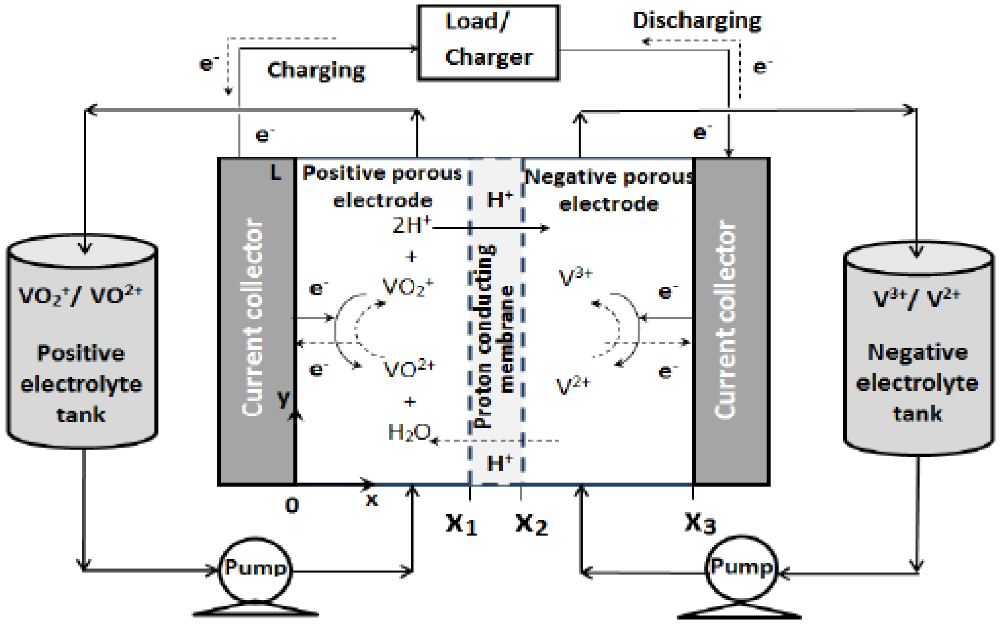


Figure 2.6: Schematic diagram of vanadium redox flow battery system

The use of BESS had been financially difficult due to its high initial investment cost. However, with advancement of battery technologies especially in Li-ion batteries and competition in electric vehicle market, the cost of battery has been reducing. Forbes reports that the price of Li-ion battery pack was more than \$1,100/kWh in 2010 while \$137/kWh in 2020 and also \$105/kWh has been already reported in China. It also claims that average price of the battery will be \$100/kWh in 2023 and will be \$58/kWh by 2030. A Li-ion battery can deliver more than 10000 cycles with excellent preservation of its capability [17]. Also, the battery voltage for the battery is almost flat in the region between 0% to 90% discharge capacity and after 90% discharge capacity, the voltage drops rapidly [18]. This is why, it is recommended to operation Li-ion batteries under 90% discharge capacity. If we have battery storage system scheduling then, the battery daily cycles and life in years can be evaluated as

$$Cycles=\frac{1}{2}\frac{\sum_{t=1}^{T}|E_b(t)-E_b(t-1)|}{DOD\ \times Batterysize} \tag{2.2}$$

$$q(years)=CycleLife/(Cycle.D) \tag{2.3}$$

$$Battery\ size\ (kWh)=\frac{|E_{max}-E_{min}|}{DOD} \tag{2.4}$$

Where, E_b(t) is energy stored in battery at any time t, DOD is considered battery depth of discharge, E_{max} & E_{min} are maximum and minimum energy in the battery. Cycle.D is number of battery cycle operated per day. Also, for battery charging and discharging, following equations can be used

$$\Delta E_b(T) = E_b(t) - E_b(t-1) \tag{2.4}$$

$$P_b(t) = \begin{cases} \dfrac{\Delta E_b(t)}{\Delta t \times \eta_c}, & if\ P_b(t) > 0 \\ \dfrac{\Delta E_b(t) \times \eta_d}{\Delta t}, & if\ P_b(t) < 0 \end{cases} \tag{2.5}$$

Where, P_b, Δt, η_c & η_d are the battery power, sampling interval, charging efficiency and discharging efficiency respectively and $\eta_c = \eta_d = \text{sqrt}(\eta_{bat})$, η_{bat} is battery round trip cycling efficiency.

While discussing about major research work relating to this work, *R. Mahat et. al*. pointed out the scenario of incidence of over-voltage problem in distribution system due to high PV injection. The author mentions that traditional voltage regulating devices, such as line switched capacitor banks, voltage regulators, and on – load tap changing transformers can be used to limit voltage but they are not useful in short time interval and the high numbers of switching operation would shorten their operational life. Also, the author mentions that independent PV inverter overvoltage control for active power curtailment, shutdown of DG, coordinated dispatch control, etc. are hence popular for limiting voltage at same limit [19-21].

J.H. Teng et.al. [22] has presented calculation of charging / discharging scheduling of the battery energy storage system for distribution system interconnected with variable solar PV generation system in their work. Also, there is no mechanism considered for the sizing and placement of BESS in the work and used predetermined sized BESS. The author has applied the approach to a test feeder in Taiwan Power Company with consideration of predefined PV and BESS location in the system.

Yasser Moustafa Atwa et.al. [6] Proposed the use of BESS for the distribution system with high penetration of wind energy to exploit spilled wind power generator energy due to system constraint. Proposed sizing of BESS to accommodate all the amounts of spilled wind power & energy and then loss minimization with that energy is evaluated. Here, the author has fixed size of BESS to maximum curtailment power and total curtailed energy and its cost factor is not considered.

Nadeeshani, Jayasekara [9] proposes for the optimal operation of Distributed energy storage systems in the distribution system to improve distribution network load and generation hosting capability with consideration of PV and wind DG in the system. The author considered two wind-based DGs and seven PV DGs allocated particular buses and represented BESS schedule in terms of Fourier series. MATLAB interior-point algorithm for the calculation of the optimum BESS operating profiles and then likewise calculated the battery size. And then the improvement of the system performance was studied in the research work.

C.J. Bennett et.al. [23] has proposed development of three phase battery energy storage scheduling for low voltage distribution networks to function for peak shaving and valley filling and phase load balancing based on the load profile of a distribution system in theresearch work. Here, using the load profile, the charging and discharging target are defined based on which battery scheduling is developed. This work mainly focusses on decreasing the peak load while other factor like power loss minimization and battery cost are not taken in to consideration.

Regarding the other application of BESS, *Adhikari, S et.al.* [24-25] discusses the use of hybrid energy storage system of battery/supercapacitor with appropriate control system for minimization of low frequency as well as high frequency power fluctuations in DC grid. It also has proposed decentralized control mechanism for PV and battery storage in two DC microgrids interconnected with tie-line. These works verify the use of BESS for power system management in the microgrids.

The optimum calculation of BESS size and schedule with consideration of minimizing distributed generation curtailment, system loss and battery cost is presented. In this research, the allocation of solar PV and battery is also considered. The artificaial intelligence techniques for optimization of size and location is used in this case. The search for the optimum in 24 hours of time, charging and discharging power value of BESS is determined using metaheuristic optimization algorithm, Genetic algorithm (GA) approach and the optimum size is also obtained. Also, results in different candidate bus locations are presented and compared. The optimal location and size of the battery bank and distributed generation is concluded based on the minimum power loss. [26-27].

2.2.7. Battery Energy Storage System

Lead acid battery (**LA**):

Lead-acid batteries have indeed been in commercial use since the late 19th century and are the most widely used battery type worldwide. They find applications in both mobile and stationary power systems. Their typical applications are emergency power supply systems, starter batteries in vehicles, stand-alone PV systems, battery systems in wind power. In past, early in the "electrification age", many lead acid batteries were used for the storage in grids. Stationary lead-acid batteries have different requirements and higher quality standards in comparison to starter batteries. They are designed for long-term use in stationary applications and offer a longer service life compared to starter batteries. Typically, the service life of stationary lead-acid batteries ranges from 6 to 15 years, depending on factors such as operating conditions and maintenance practices. These batteries can withstand a larger number of cycles, typically around 1500 cycles at 80% depth of discharge (DoD). The cycle efficiency levels of lead-acid batteries typically range from 80% to 90%. Lead-acid batteries, both vented and sealed versions (VRLA), are available for stationary applications. VRLA batteries, such as absorbed glass mat (AGM) and gel batteries, provide the advantage of being maintenance-free, as they do not require electrolyte topping up. While lead-acid batteries offer a mature and well-researched technology, their costs for stationary applications are generally higher than starter batteries. This is primarily because the design and construction of stationary batteries require additional features, such as thicker plates and robust construction to withstand deep cycling and long service life requirements. However, with advancements in manufacturing processes and increasing demand for stationary lead-acid batteries, mass production can potentially lead to price reductions. The cost of stationary lead-acid batteries may decrease, making them even more attractive for various applications that prioritize a balance between cost-effectiveness and reliable performance. It's worth noting that while lead-acid batteries continue to be a viable and cost-effective option for many stationary applications, there is ongoing research and development in battery technologies, including lithium-ion and flow batteries, which offer different characteristics and performance metrics for specific use cases [8-12].

One disadvantage of lead-acid batteries is that their usable capacity decreases when high power is discharged. As the discharge rate increases, the effective capacity of the battery decreases. For example, if a battery is discharged in one hour, only about 50 %

to 70 % of the rated capacity is available. Other drawbacks are lower energy density and the use of lead which is environmental hazards. The adavantages of lead acid batteries are a favourable cost per performance ratio, easy recyclable and a simple charging technology.

Nickel cadmium and nickel metal hydride battery (**NiCd, NiMH**):

Lithium-ion batteries have gained widespread popularity and have largely replaced NiCd and NiMH batteries in many applications due to their higher energy density, lower self-discharge, and absence of memory effect. However, nickel-based batteries still find use in specific applications where their characteristics are advantageous or where there are specific safety or regulatory requirements [11].

From a technical perspective, it is true that Nickel-Cadmium (NiCd) batteries have certain advantages, including their ability to perform well at low temperatures ranging from -20 °C to -40 °C. They have been widely used in various applications, including stationary power systems and portable devices. NiCd batteries are known for their high discharge rates, which makes them suitable for applications that require a rapid release of energy. They also have a longer cycle life compared to other rechargeable battery technologies, such as lead-acid batteries. This means they can be charged and discharged many times before their performance significantly degrades. Despite the limitations imposed on their use, NiCd batteries continue to be used in certain stationary applications, particularly in large battery systems where their performance characteristics, such as the ability to operate in a wide temperature range, are advantageous. However, alternative battery technologies, such as nickel-metal hydride (NiMH) and lithium-ion (Li-ion) batteries, have gained wider acceptance and are now more commonly used in various consumer applications due to their higher energy density and reduced environmental impact compared to NiCd batteries.

Nickel metal hydride (NiMH) batteries were developed as an improvement over nickel-cadmium (NiCd) batteries, aiming to address some of the limitations of NiCd batteries. NiMH batteries have found extensive use in portable and mobile applications, such as consumer electronics and early hybrid vehicles. However, in recent years, lithium-ion batteries have become the preferred choice in portable and mobile applications due to their even higher energy density, lower self-discharge, and longer cycle life. Nonetheless, NiMH batteries are still widely used in hybrid vehicles available on the market today. Their robustness and safety profile make them a suitable choice for automotive applications, where the batteries need to withstand high discharge rates and offer reliable performance. In terms of cost, NiMH batteries currently cost about the same as lithium-ion batteries. The pricing of battery technologies can vary based on factors such as production scale, demand, and advancements in manufacturing processes [1, 12].

Lithium-ion battery (Li-ion):

Lithium-ion batteries are the most important storage technology in the areas of portable and mobile applications since 2000 AD. The lesser cells in series can be used to achieve the applicable voltage because its each cell voltage is upto 3.7V. The lithium-ion (Li-ion) batteries offer significant advantages, including high gravimetric energy density and the potential for cost reductions through mass production. They have become the dominant battery technology in the small portable device market, thanks to their high energy density and long cycle life. However, when it comes to developing larger-scale Li-ion batteries for applications such as electric vehicles (EVs) and grid energy storage, there are indeed some challenges to address. One of the main obstacles is the high cost associated with large-scale Li-ion battery production.

Lithium-ion batteries do offer a very high efficiency, typically in the range of 95% - 98%. Li-ion batteries also provide flexibility in terms of discharge time, making them suitable for a wide range of applications. They can be designed to deliver power for durations ranging from seconds to weeks, depending on the specific requirements of the application. Regarding cycle life, standard Li-ion cells available on the market can often provide around 5000 full charge-discharge cycles. However, it's important to note that the cycle life can vary depending on factors such as the battery chemistry, operating conditions, and how well the battery is managed. As the demand for Li-ion batteries increases and production scales up, it is expected that economies of scale and technological advancements will contribute to cost reductions, making Li-ion batteries more cost-competitive across a wider range of applications.

Safety is major concern in Lithium-ion batteries because metal oxide electrodes are thermally unstable and it can be decomposed at elevated temperatures, thus releasing the oxygen which can lead to a thermal runaway. The lithium-ion batteries are equipped with a monitoring unit usually an electronics circuit to avoid over-charging and over discharging. Lithium-ion battery technology is still in development phase, and there is considerable potential progress [2, 8].

Metal air battery (Me-air):

The metal-air battery operates with utilization of the oxygen of atmosphere as the reactant for the reduction reaction and this feature makes metal-air batteries lightweight and capable of having a high energy density. Metal-air batteries have gained attention due to their potential for high energy storage capacity, making them suitable for applications such as electric vehicles and portable electronics. They are also attractive because of the oxygen required for the electrochemical reaction is abundantly available in the air. Lithium-air (Li-air) batteries have attracted significant attention due to their high theoretical specific energy, which is considerably higher than other battery types, including lithium-ion batteries. Li-air batteries have a theoretical specific energy of approximately 11.14 kWh/kg, which is comparable to the energy content of gasoline. However, there are challenges associated with the practical implementation of Li-air batteries. One significant challenge is the high reactivity of lithium with air and humidity. When lithium reacts with air or moisture, it can result in the formation of lithium hydroxide and lithium peroxide, accompanied by the release of heat and the potential for fire hazards. Managing the reactivity and ensuring the safety of Li-air batteries are critical considerations for their development [4, 22].

Currently, Zinc – air (Zn-air) batteries are technically feasible. Zinc-air batteries have been widely used in certain applications, such as hearing aids and some portable devices, due to their high energy density. However, they have limitations in terms of rechargeability and relatively shorter cycle life compared to other rechargeable battery technologies like lithium-ion batteries. An electrically rechargeable metal air system potentially offers the low materials cost and high specific energy, but none has reached marketability yet.

Sodium nickel chloride battery (NaNiCl):

The sodium nickel chloride (NaNiCl) battery has been commercially available since 1995. NaNiCl batteries typically operate at relatively high temperature around 270 °C, and it uses Nickel Chloride (NiCl) instead of Sulphur for the anode. NaNiCl batteries have limited tolerance for overcharging and overdischarging. This means that care must be taken to prevent exceeding the specified charging and discharging limits to avoid damaging the battery. NaNiCl batteries tend to develop low resistance when faults occur. This characteristic is beneficial when the batteries are connected in series. In such a configuration, if a fault occurs in one cell, it only results in the loss of voltage from that particular cell, rather than causing premature failure of entire battery system. Furthermore, the ongoing research and development efforts to improve the ZEBRA battery by increasing its power density for hybrid electric vehicles and creating high-energy versions for storing renewable energy demonstrate the versatility and potential of this technology. These advancements would not only benefit the automotive industry but also have significant implications for load-leveling in renewable energy systems and industrial applications. By continuously refining and enhancing the ZEBRA battery, researchers are paving the way for a more sustainable and efficient future. The ability to store renewable energy effectively and power hybrid vehicles with higher power densities would contribute to reducing our carbon footprint and transitioning towards a cleaner energy landscape [1, 2].

Flow batteries:

Flow batteries are a type of rechargeable battery that store energy in electroactive species dissolved in liquid electrolytes. Unlike conventional secondary batteries, where the energy is stored in the active masses of the electrodes, flow batteries store the energy in external tanks as electrolyte solutions. The flow battery system consists of two separate electrolyte tanks, each containing a different electroactive species. These tanks are connected to the electrochemical cell through which the electrolytes flow during charge and discharge cycles. When charging, the electroactive species from the tanks are pumped into the cell, where they undergo oxidation and reduction reactions to store electrical energy. During discharge, the process is reversed, and the electroactive species release the stored energy as electricity [1].

Redox flow battery (**RFB**):

In redox flow batteries (RFBs), the electrochemical cell consists of two liquid electrolyte solutions that contain dissolved metal ions as active materials. These electrolytes, known as anolyte and catholyte, are pumped to opposite sides of the cell. Redox flow batteries offer advantages such as scalability, long cycle life, and the ability to separate power and energy capacity. They are commonly used for large-scale energy storage applications, including grid-level storage, renewable energy integration, and load leveling. The continuous flow of electrolytes allows for flexible energy storage capacity and the ability to decouple power and energy ratings, making them suitable for various applications [3].

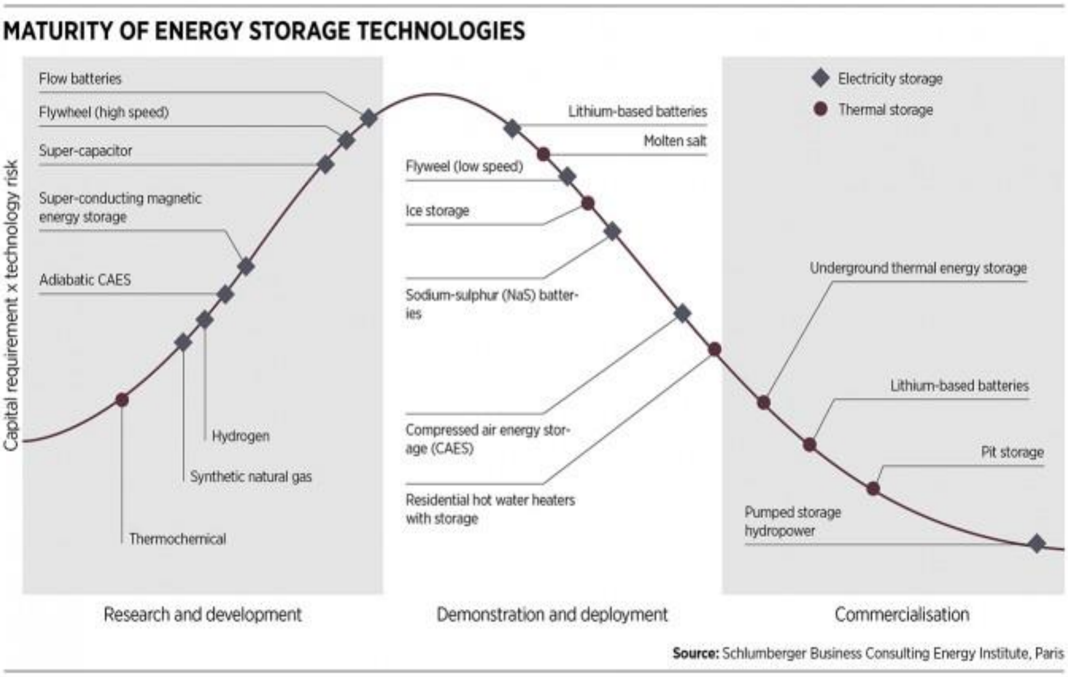
Hybrid flow battery (HFB):

In a hybrid flow battery (HFB), one active mass is internally stored within the electrochemical cell, while the other active mass remains in liquid form and is stored externally in a tank. This configuration combines features of both solid-state and flow battery systems. Therefore, hybrid flow cells combine the features of the conventional secondary batteries and redox flow batteries: the capacity of the battery depends on the size of the electrochemical cell. Typical examples of the HFB are the Zn-Br and Zn-Ce systems. In both of the cases, the anode of electrolyte consists of an acid of Zn_2+ ions. During charging Zinc is deposited at the electrode and at discharging Zn_2+ undergoes soluble. Most of the electrodes are as carbon-plastic composites because a membrane of microporous polyolefin material used. Various companies involved in commercial production of the Zn-Br battery that was developed in the 1970s by Exxon. In the United States of America, hybrid battery energy and premium power sell trailer – transportable Zn-Br systems with unit capacities of upto 1 MW for utility-scale applications and 5kW systems for community energy storage are in development [5, 6].

2.2.8. Energy Storage Technologies

The techno – researches maturity of the energy storage technology (EES) systems is presented in Figure 2.7. Altogether, five levels of maturity si considered: research and development, demonstration, mature, deployment. Most of the ESS fall into the deployment category and that they have already passed the demonstration phase but need more research and testting to reach a maturity level. The pump storage and the compressed air system could be considered mature only in natural and also, they are oldest system in generation system applications.

The high capital cost of energy storage system pushes the user to utilize multiple applications and functions across different energy chain. An aggregation of complementary benefits known as “stacking”. This concept is pictured in Figure 2.8 for many of the energy storage functions served by the key applications. In Figure 2.9, the characteristics of various ESS is presented in terms of system power rating alongside the discharge duration at rated power [27-29].



Source: Schlumberger Business Consulting Energy Institute, Paris

Figure 2.7: Energy storage technology maturity curve

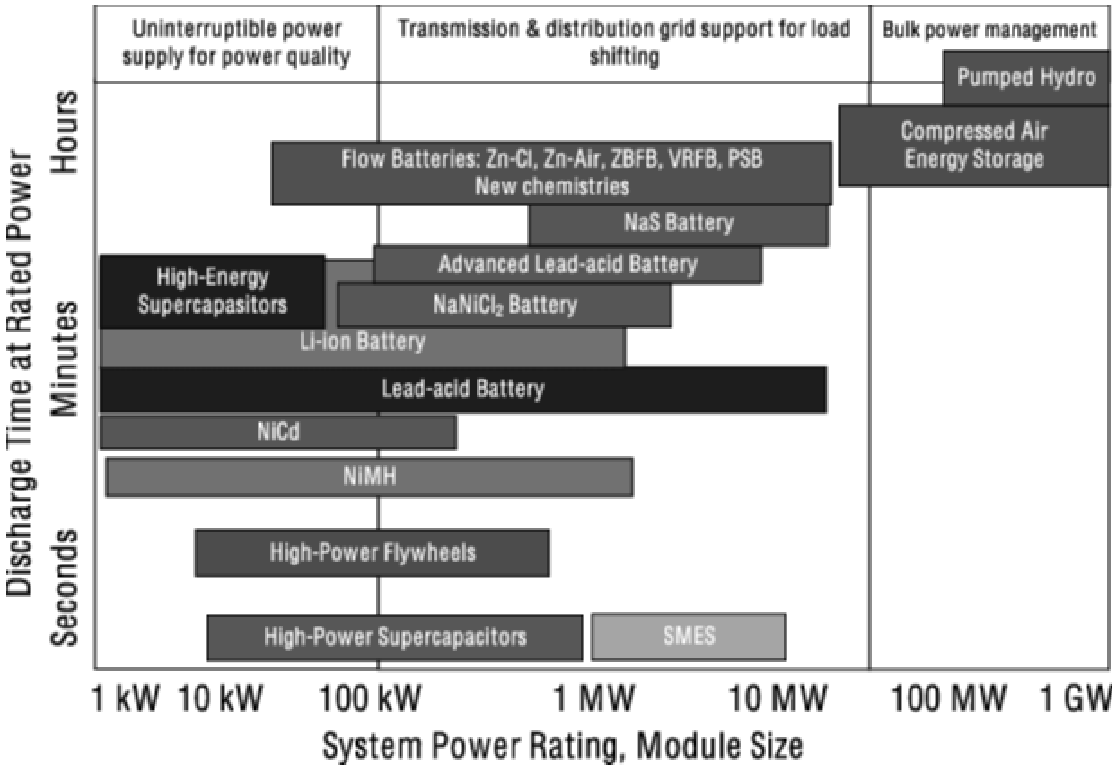


Figure 2.8: Sizing the different energy storage technologies

2.2.9. Economics of Energy Storage

Energy storage systems have the potential to bring several benefits to the electricity grid and various stakeholders. Storage systems can facilitate the renewable energy resources integration into the grid. They can store excess energy generated from renewable sources during periods of low demand or high production and release it during peak demand times, ensuring a more balanced and reliable power supply. This reduces the need for additional conventional generation capacity and helps reduce emissions from electricity generation. Energy storage systems can help optimize the operation of the electricity grid. They can provide grid services like frequency regulation, voltage control, and peak shaving, which improve the stability and reliability of the grid. By smoothing out fluctuations in electricity supply and demand, storage systems can reduce the need for expensive upgrades to the transmission and distribution infrastructure. Energy storage systems can enhance grid resilience by providing backup power during outages or emergencies. By storing energy, they can ensure a reliable power supply for critical infrastructure, such as hospitals, communication networks, and emergency services. Overall, energy storage systems have the potential to bring numerous benefits, including increased renewable energy integration, grid optimization, cost savings, and support for DER initiatives [18, 19]. As technology advances and costs continue to decline, storage systems are becoming increasingly important in the transition to a more sustainable and resilient energy future.

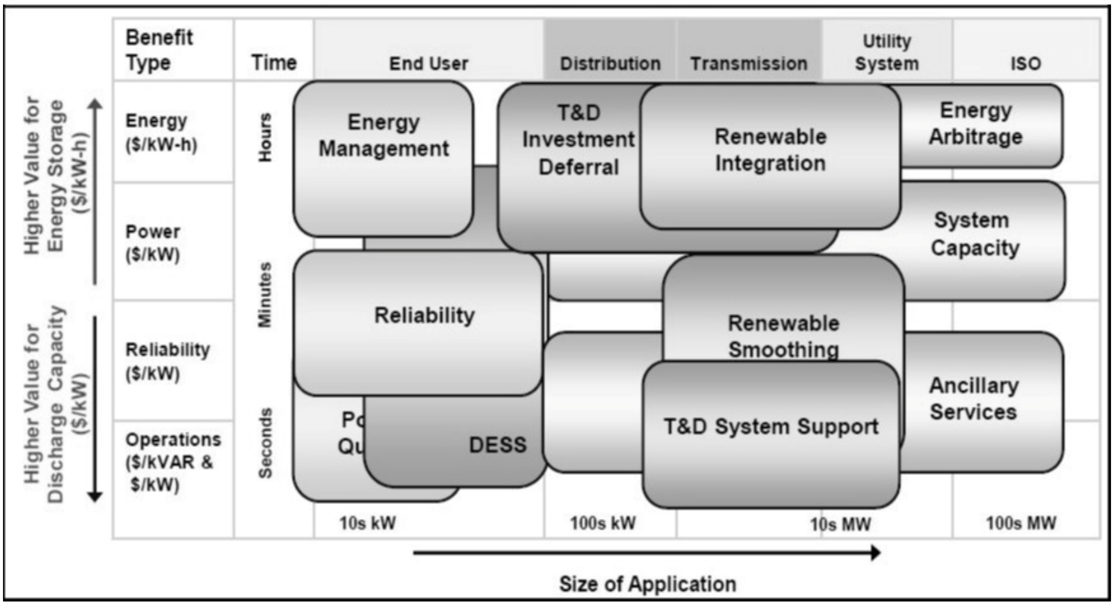


Figure 2.9: Operational benefits monetizing the value of energy storage

2.2.10. Supply security

Storage technologies are play vital role because they enhance the energy security by optimising energy supply and demand. It reduces the need of import electricity, and also reduced adjustment in generation unit output. In addition to that, BESS can provide a secured supply system by providing the peak demand facility. The storage systems are popular because they can enable the integration of more renewable energy.

CHAPTER 3:METHODOLOGY

In general, control logic for BESS operation, the overload management on a distribution transformer is proposed in order to reduce the overload stress on transformer in peak demand period. The power flows through the grid, load power, and the battery state of charge is continuously monitored. The proposed method operates on two modes of operation for charging and discharing: current control mode, and voltage control mode.

The typical block diagram of the DT overload management system is shown in Figure 3.1. The battery is connected to DC conveter and follows the inverter. The AC signal generated from inverter is filtered through LCL filter and then connected to point of common coupling where load and the transformer are connected. The bi-directional current flows through inverter and dc converter. The battery storage system only capable for providing the load during peak time and no any power flow into the grid from battery.

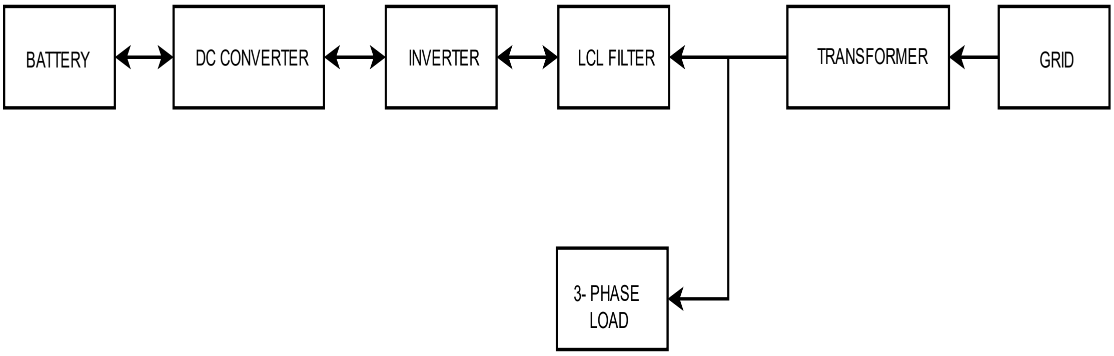


Figure 3.1: Simulation Scheme of DT with BESS

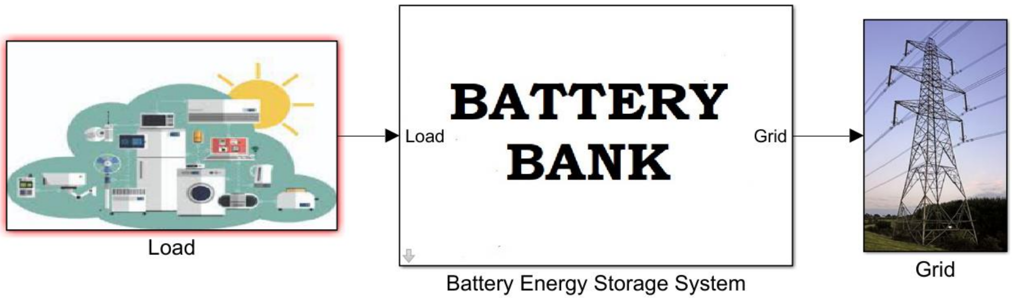


Figure 3.2: Components of the DT overload management

3.1. Grid-tied inverter control

A grid connected inverter (three-phase three-level converter) is proposed for the study in which bi-directional power flow is assumed. Inverters offer several advantages over traditional two-level inverters, including a wide operating range of DC voltage and lower harmonic distortion. A sinusoidal filter has been used to remove harmonics which are generated from the inverter. The converter converts the DC voltage to three – phase AC voltage with implementation of sinusoidal pulse width modulation (SPWM). For operation of the inverter in linear region, voltage at point of common coupling is described [27, 28].

$$V_{LL}(PCC) = \frac{\sqrt{3}}{2\sqrt{2}} m_a V_{Dc} \qquad 3.1$$

Here, ma is modulation index (≤1) , V_{LL} *(pcc)* is line voltage , and V_{DC} - converter DC Voltage.

The grid voltage is continuously monitored and phase locking technology using phase locked loop is used for synchronization the set the variable frequency of 3-phase sinusoid signal.

3.2. BESS Control Methodology

The Battery Energy Storage System (BESS) controller technique is designed to regulate the charging or discharging cycle of the battery based upon the power flow measurements from the distribution transformer (DT). The BESS is used to ensure that the loading on the transformer would not exceed the 90% of its capacity. To prevent the overloading, the shave level is defined at 180 kVA for the DT, which is 90% of the DT's rated capacity. A bi – directional converter is used for the power flow between the grid, the battery, and the load. This converter allows the power flows to both directions, enabling charging from the grid to the battery and discharging from the battery to the load. The control logic ensures that the net power flow from the grid and the load remains within the specified limits to prevent overloading of the DT. By monitoring and controlling the power flow between the grid, battery, and load, the BESS control logic helps optimize the operation of the battery storage system and ensures the distribution transformer operates within its safe operating limits.

BESS discharges when transformer loading exceeds the 90% of its capacity. The power flow from the battery for peak saving is calculated as shown in equation (3.2). Boost mode operation will be used for charging and the discharge current reference is measured in accordance with net power flow as expressed in equation (3.3).

$$P_{net} = P_L - P_{shave} \tag{3.2}$$

$$I_{Discharge} = \frac{P_L - P_{shave}}{V_b} * 1000 \tag{3.3}$$

$$P_{shave} = 90\%\ of\ 200\ kVA = 180kVA \tag{3.4}$$

Here, $I_{\text{Discharge}}$ is current supply of battery in, P_L is the load, Pshave is shaving level of transformer and Vb is the voltage of battery.

The conditions for discharge of battery is described as in equation (3.5)

$$P_{net} \geq 0\ \&\ SoC \geq 20\% \tag{3.5}$$

SoC is expressed as in equation (3.6)

$$\%SoC = \left(1 - \frac{\int I(t) * dt}{Q}\right) * 100 \tag{3.6}$$

The battery remains in idle state if it does not energy to discharge when SoC level is less than 20% even if the transformer is overloaded. The discharge rate is considered to be 0.5C in this evaluation.

Battery charging cycle is performed when the load of transformer is lower than the specificed limit and until SoC of the battery reaches 95%. There are two charging modes: boost mode also called current control mode in which charging of the bettery is upto 80% of SoC, and float mode also called voltage control mode which is suggested for the SoC above 80%. Charging period and rate of battery for boost mode of charging is described as in equation (3.7) and it should not to be exceed more than 0.3C. rate of charging for boost mode is greater than the charging of float mode.

$$I_{Discharge} = \frac{P_{shave} - P_L}{V_b} * 1000 \tag{3.7}$$

Charging current reference evaluated from equation (3.7) is compared with actual charging current in boost mode and difference is given to the PI controller. In both control modes, the PI controller plays a critical role in adjusting the inverter's duty cycle to regulate the output current or voltage. By continuously monitoring and adjusting the duty cycle, the PI controller helps maintain the desired output and compensates for any deviations between the measured and reference values. It's important to note that the specific control strategy and implementation may vary depending on the application and inverter design. The control methods mentioned here provide a general understanding of the control principles involved in voltage and current regulation in power electronic systems. The flowchart for charge and discharge is described in Figure. 3.4.

3.3. Simulation Diagram

The simulation diagram consists of charge controller, power conversion system and battery model.

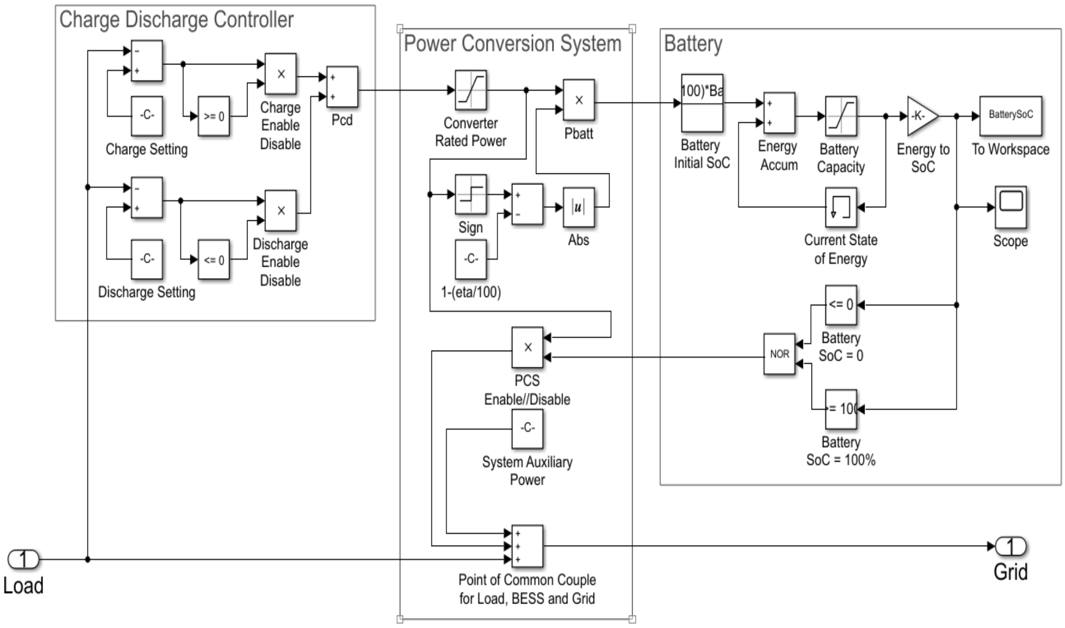


Figure 3.3: Simulation Diagram

3.4. BESS Scheduling Problem

Hence, the optimum operation power point for BESS will also be different for each hour. So, we will have 24 variables for the optimization problem which will represent charging/discharging power for each hour of the day. Then, minimization of equation. Under the constraints explained in section shall result in optimum values for the 24 variables and these will represent the optimum charging/discharging schedule for the day.

3.5. BESS Size and Location

Here, after completion of the optimization process to calculate optimum schedule, the maximum power in the scheduling will determine the inverter power and the energy storage capacity shall be decided by the energy storage requirement by the schedule. Also, here the optimum size, schedule and saving shall be calculated for preselected candidate locations and best location is selected among them for BESS.

3.6. Panel for BESS Container

When designing a panel for a Battery Energy Storage System (BESS) container, there are several factors to consider. Safety Use appropriate materials that are fire-resistant and provide adequate insulation. The panel should accommodate all the necessary electrical components required for the BESS system. This includes circuit breakers, disconnect switches, fuses, contactors, monitoring devices, and any other control or protection equipment. The panel should provide sufficient space and organization for proper wiring and cable management. Consider the size and number of cables that need to be accommodated, and plan for cable trays, ducts, or conduits as necessary to route and secure the wiring neatly. Depending on the BESS system's power and heat dissipation requirements, consider incorporating appropriate cooling and ventilation mechanisms. This may include fans, vents, or even a dedicated HVAC system to maintain optimal operating temperatures within the container. Clearly label all components, cables, and connections within the panel to ensure easy identification and maintenance.

Figure 3.5 Panel for Bess Storage

3.7. Flow Chart

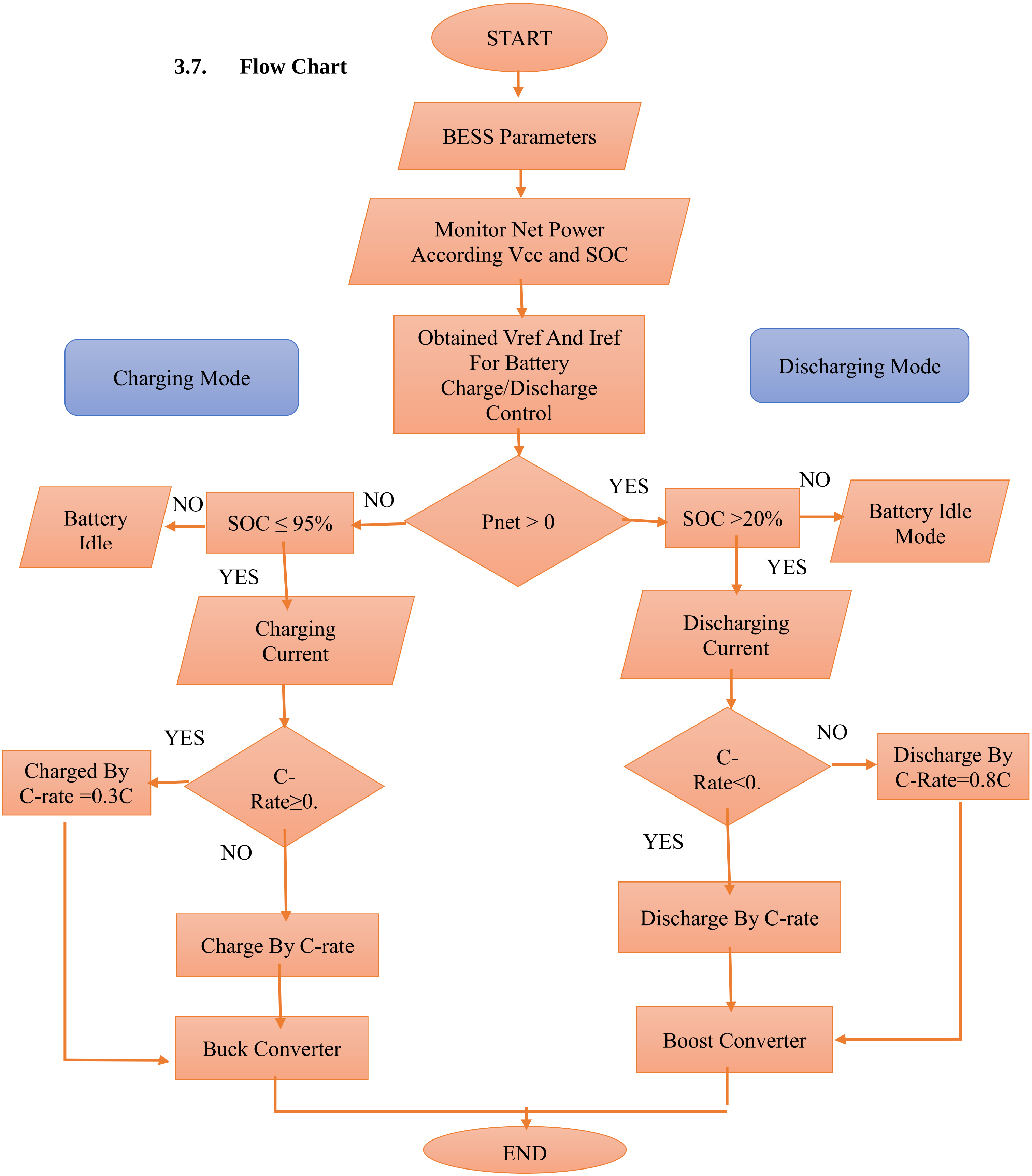


Figure 3.4 flowchart for battery charge/Discharge Control

CHAPTER 4:RESULTS AND DISCUSSIONS

4.1. Analysis of the system Under Consideration

The installation of BESS on the low voltage side of the DT is expected to reduce the overloading of the DT. For this purpose, a 200kVA, 11/0.4kV DT is considered. Dfferent overloading conditons are considered: 110%, 120%, 140% and 160% of rated capacity. These cases are dscussed in to subsequent chapteNPR

4.1.1. System Under Consideration

a) The voltage at the Transformer is considered to be at always 1pu.
b) Scenario for application of single BESS is considered.
c) The BESS charge and discharge cycle efficiency shall be considered as 90% and the battery life cycle is considered to be 8000 cycles.
d) Also, the inverter cost is considered to be NPR 1,50,000.00 for 100kW and battery cost to be NPR 190 / Ahr with 2000Ah. And the flat electricity cost is considered to be NPR 7.15 / kWhr from (23:00-05:00), NPR 8.20 (06:00-17:00) for charging of BESS and NPR 10.0 / kWhr, NPR 13.5 / kWhr and NPR 15.0 / kWhr for peak time (17:00-23:00).

4.1.2. BESS Switching ON/OFF for Load Sharing (charging during off-load and Discharging during Peak Load Condition)

The BESS is rated power of 100kW, and the battery storage capacity of 2000Ah is used with SoC of 65% charge, considering converter of 90% efficient, and the discharge power is set to such that DT is to be 180 kVA which is the intended save power level.

In Figure 4.1, it is seen that load consumption is lower than 180 kVA during nomal hour and off – peak hour. Therefore, the converter charges the battery during off – peak and normal hours. In charging period, the converter also ensures that the charging current does not exceed in such that the transformer loading becomes greater than 180 kVA. The BESS begins to discharge the current from the battery when the load consumption is above 180 kVA from (05:00-08:00) and from (15:00-23:00) maintain at shaved power level of 180 kVA till 11 hours.

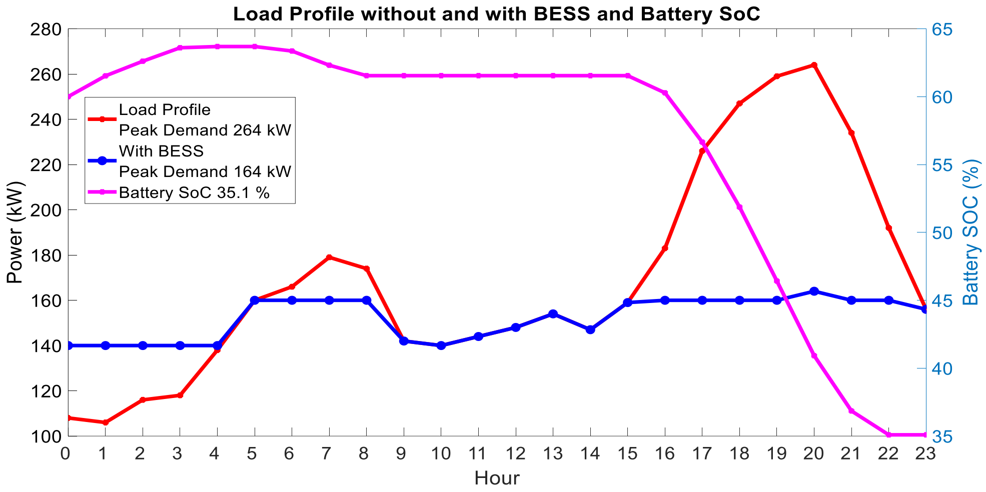


Figure 4.1: Load Profile with and without BESS at SOC 65% and DT upto 160% overloading

The battery SoC reaches to 35.1%, then the BESS starts to charge the battery again from 23:00 onwards and. This indicates that there is enough stored energy for the next day and the cycle shall sustain daily. It demonstrates that the BESS is capable of saving the peak power from 264kVA down to 180 kVA with a surplus energy of 517 kWh of from battery.

Load shifting and utilizing Battery Energy Storage Systems (BESS) to take advantage of off-peak tariff incentives. The power rating of the BESS is set to 100 kW. The battery capacity is set to 2000 Ah (Ampere-hours). This value represents the total amount of charge the battery can store. Load shifting using a BESS involves charging the battery during off-peak hours when the electricity tariff rates are lower and then discharging it during peak hours to reduce demand and avoid higher tariff rates. The specific charging and discharging strategies would depend on factors such as the availability of grid requirements that the load of transformer must be lesser or equal to 180kVA.

The BESS performance is shown in Figure 4.2. It can be clearly seen that during off-peak hours from 22:00 to 17:00 hour, the battery charges upto 55% at 19 hours, it begins to discharge and reduce the load level of 240 kVA to180 kVA. From 17:00 to 22:00 hours, battery SoC reaches 45% and begins to charge the battery again until end of 23:59. With that, the BESS can effectively shift the load of transformer from peak hours to the off-peak hours with the additional 191 kWh of energy. BESS is capable to shift the load from peak hour to off-peak hour with 45% of charge in the battery at the end of the day at 23 hours. The SoC indicates that there is stored of energy in battery and can be utilized..

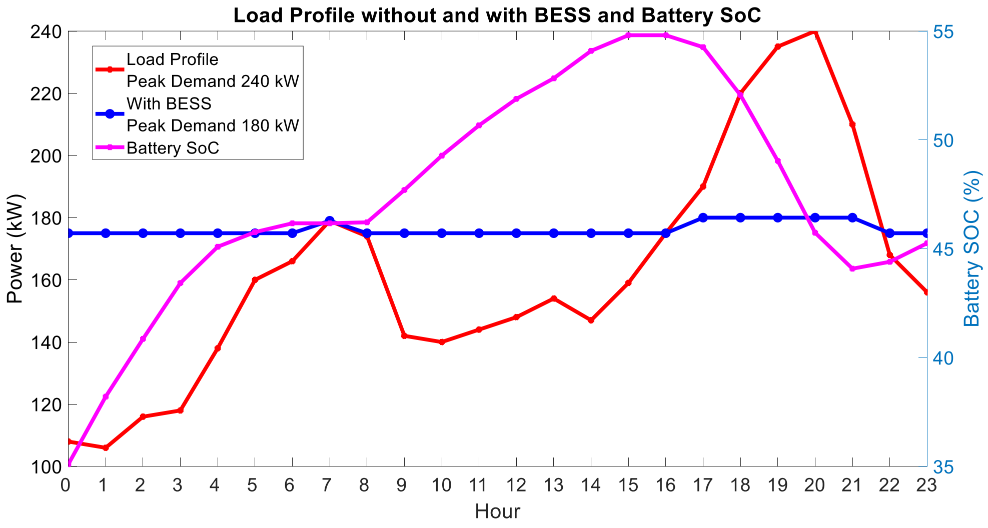


Figure 4.2: Load Profile with and without BESS at SOC 35% and DT upto 140% overloading

In Figure 4.3, the load curve without BESS and with BESS is shown and it can be clearly seen that during off-peak hours from 22:00 to 17:00 hour the The BESS charge the battery up to 65% at 18 hours battery is started to discharge and load of transformer becomes180 kVA and peak load is of 220 kVA. At the end, battery discharges and SoC levele maintained at 56% and at 22:00 hours, the SoC is increasing.

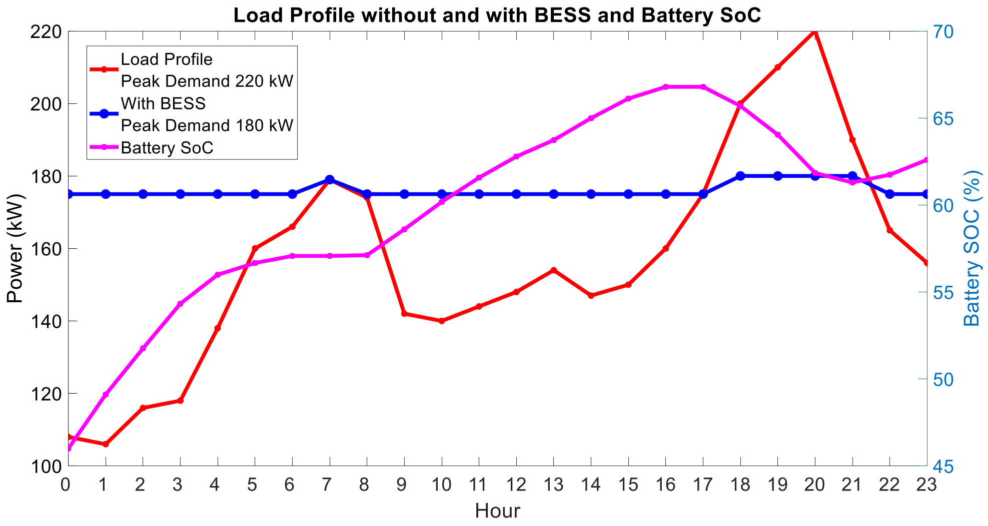


Figure 4.3: Load Profile with and without BESS at SOC 45% and DT upto 120% overloading

it seems that the BESS is effectively shifting the load from peak hours to off-peak hours by adding 95 kWh of energy on top of the load profile during peak duration. This load shifting strategy takes advantage of the lower electricity tariff rates during off-peak hours. If the BESS is able to add 95 kWh of energy during off-peak hours and utilize it during peak hours, it indicates that there is enough stored energy to meet the demand for the next day. This suggests that the BESS cycle is sustainable on a daily basis.

In Figure 4.4, during off-peak hours from 00:00 to 04:00 hour, the batteries cahrges up to 69% at 4 hours, it begins to discharge the and power fed to load level of 210 kVA to180 kVA from 05:00 to 09:00 and 17:00 to 22:00 of 10 hours with battery SoC reaches 59% and begin to charge the battery again till the end of the day. With that, the BESS effectively lowered the load of transoformer with 179 kWh of energy on top of the load profile at peak duration.

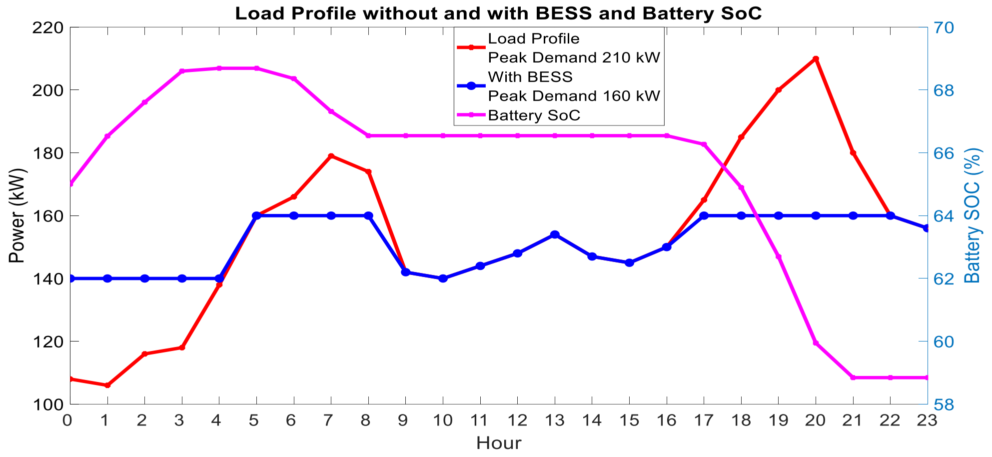


Figure 4.4: Load Profile with and without BESS at SOC 65% and DT upto 110% overloading

4.1.3. Load Input Consideration.

Table 4.1: Different loading condition data

Time Slots	160% Loading	140% Loading	120% Loading	110% Loading
0	108	108	108	108
1	106	106	106	106
2	116	116	116	116
3	118	118	118	118
4	138	138	138	138
5	160	160	160	160
6	166	166	166	166

7	179	179	179	179
8	174	174	174	174
9	142	142	142	142
10	140	140	140	140
11	144	144	144	144
12	148	148	148	148
13	154	154	154	154
14	147	147	147	147
15	159	159	150	145
16	183	175	160	150
17	226	190	175	165
18	247	220	200	185
19	259	235	210	200
20	264	240	220	210
21	234	210	190	180
22	192	168	165	160
23	156	156	156	156

4.2. Finacial Analysis

In consideration for financial analysis, the three energy rates are NPR 10 / kWh, NPR 13.5 / kWh, and NPR 15 / kWh. The total investment cost is calculated from inverter and battery cost. The total 2000Ah battery is used and NPR 190 / Ah is used as battery cost and NPR 150,000.00 is used for inverter cost. The operation and maintenance cost are considered 5% per annum of total investement cost.

Table 4.2: Financial parameter assumptions

Battery Cost	NPR 380000
Inverter Cost	NPR 150000
Total Investment	NPR 530000
O&M Cost	5% of Total investment
Interest rate	12% per annum

Table 4.3: Case 1 - 160% Loading conditions results

	Case1: 160% loading						
Time	**Load Without BESS**	**Load with BESS**	**SOC**	**Energy without BESS**	**Energy with BESS**	**Energy Diff.**	
0	108	140	60	107	140	-33	Charging
1	106	140	61.53	111	140	-29	Charging
2	116	140	62.61	117	140	-23	Charging
3	118	140	63.6	128	140	-12	Charging
4	138	140	63.69	149	150	-1	Charging

5	160	160	63.69	163	160	3	Discharging
6	166	160	63.36	172.5	160	12.5	Discharging
7	179	160	62.315	176.5	160	16.5	Discharging
8	174	160	61.545	158	151	7	Discharging
9	142	142	61.545	141	141	0	Idle
10	140	140	61.545	142	142	0	Idle
11	144	144	61.545	146	146	0	Idle
12	148	148	61.545	151	151	0	Idle
13	154	154	61.545	150.5	150.5	0	Idle
14	147	147	61.545	153	153	0	Idle
15	159	159	61.545	171	159.5	11.5	Discharging
16	183	160	60.28	204.5	160	44.5	Discharging
17	226	160	56.65	236.5	160	76.5	Discharging
18	247	160	51.865	253	160	93	Discharging
19	259	160	46.42	261.5	162	99.5	Discharging
20	264	164	40.92	249	162	87	Discharging
21	234	160	36.85	213	160	53	Discharging
22	192	160	35.09	174	158	16	Discharging
23	156	156	35.09				

Table 4.4: Case 2 - 140% Loading conditions results

	Case2: 140% loading						
Time	**Load Without BESS**	**Load with BESS**	**SOC**	**Energy without BESS**	**Energy with BESS**	**Energy Diff.**	
0	108	175	35	107	175	-68	Charging
1	106	175	38	111	175	-64	Charging
2	116	175	41	117	175	-58	Charging
3	118	175	43	128	175	-47	Charging
4	138	175	45	149	175	-26	Charging
5	160	175	46	163	175	-12	Charging
6	166	175	46	173	177	-5	Charging
7	179	179	46	177	177	-1	Charging
8	174	175	46	158	175	-17	Charging
9	142	175	48	141	175	-34	Charging
10	140	175	49	142	175	-33	Charging
11	144	175	51	146	175	-29	Charging
12	148	175	52	151	175	-24	Charging
13	154	175	53	151	175	-25	Charging
14	147	175	54	153	175	-22	Charging
15	159	175	55	167	175	-8	Charging
16	175	175	55	183	178	5	Discharging
17	190	180	54	205	180	25	Discharging
18	220	180	52	228	180	48	Discharging
19	235	180	49	238	180	58	Discharging
20	240	180	46	225	180	45	Discharging

21	210	180	44	189	178	12	Discharging
22	168	175	44	162	175	-13	Discharging
23	156	175	45				

Table 4.5: Case 2 - 120% Loading conditions results

	Case3: 120% loading						
Time	**Load Without BESS**	**Load with BESS**	**SOC**	**Energy without BESS**	**Energy with BESS**	**Energy Diff.**	
0	108	175	46	107	175	-68	Charging
1	106	175	49	111	175	-64	Charging
2	116	175	52	117	175	-58	Charging
3	118	175	54	128	175	-47	Charging
4	138	175	56	149	175	-26	Charging
5	160	175	57	163	175	-12	Charging
6	166	175	57	173	177	-5	Charging
7	179	179	57	177	177	-1	Charging
8	174	175	57	158	175	-17	Charging
9	142	175	59	141	175	-34	Charging
10	140	175	60	142	175	-33	Charging
11	144	175	62	146	175	-29	Charging
12	148	175	63	151	175	-24	Charging
13	154	175	64	151	175	-25	Charging
14	147	175	65	149	175	-27	Charging
15	150	175	66	155	175	-20	Charging
16	160	175	67	168	175	-8	Charging
17	175	175	67	188	178	10	Discharging
18	200	180	66	205	180	25	Discharging
19	210	180	64	215	180	35	Discharging
20	220	180	62	205	180	25	Discharging
21	190	180	61	178	178	0	Idle
22	165	175	62	161	175	-15	Charging
23	156	175	63				

Table 4.6: Case 4 - 110% Loading conditions results

	Case4: 110% loading						
Time	**Load Without BESS**	**Load with BESS**	**SOC**	**Energy without BESS**	**Energy with BESS**	**Energy Diff.**	
0	108	140	65	107	140	-33	Charging
1	106	140	66.53	111	140	-29	Charging
2	116	140	67.61	117	140	-23	Charging
3	118	140	68.6	128	140	-12	Charging
4	138	140	68.69	149	150	-1	Charging
5	160	160	68.69	163	160	3	Discharging

6	166	160	68.36	173	160	13	Discharging
7	179	160	67.315	177	160	17	Discharging
8	174	160	66.545	158	151	7	Discharging
9	142	142	66.545	141	141	0	Idle
10	140	140	66.545	142	142	0	Idle
11	144	144	66.545	146	146	0	Idle
12	148	148	66.545	151	151	0	Idle
13	154	154	66.545	151	151	0	Idle
14	147	147	66.545	146	146	0	Idle
15	145	145	66.545	148	148	0	Idle
16	150	150	66.545	158	155	3	Discharging
17	165	160	66.27	175	160	15	Discharging
18	185	160	64.895	193	160	33	Discharging
19	200	160	62.695	205	160	45	Discharging
20	210	160	59.945	195	160	35	Discharging
21	180	160	58.845	170	160	10	Discharging
22	160	160	58.845	158	158	0	Idle
23	156	156	58.845				

It is considered that each loading case distributed equally throught the year with 50% peaks, 75% peaks and 90% peaks. The peak energy rates are NPR 10 / kWh, NPR 13.5 / kWh, and NPR 15 / kWh. The life of battery is considered 15 years with intertest rate of 12%.

Table 4.7: Energy Rates and Revenue Results

Peaks / Energy Rate	50% Peak	75% Peak	90% Peak
NPR 10.0 / kWh	NPR 75148.94	NPR 112723.41	NPR 135268.09
NPR 13.5 / kWh	NPR 143016.13	NPR 214524.19	NPR 257429.03
NPR 15.0 / kWh	NPR 172102.06	NPR 258153.09	NPR 309783.71

The financial plots for the energy rates NPR 10.0 / kWh are presented as in Figure 4.5 to Figure 4.9. The cash flow presented show that when the peak load considered in maximum days then the revenue is also higher. The internal rate of return is zero for 50% peaks with interest rate of 4.2% and for 90% peaks with interest rate of 19%. It shows that the scheme of battery energy storage system is viable.

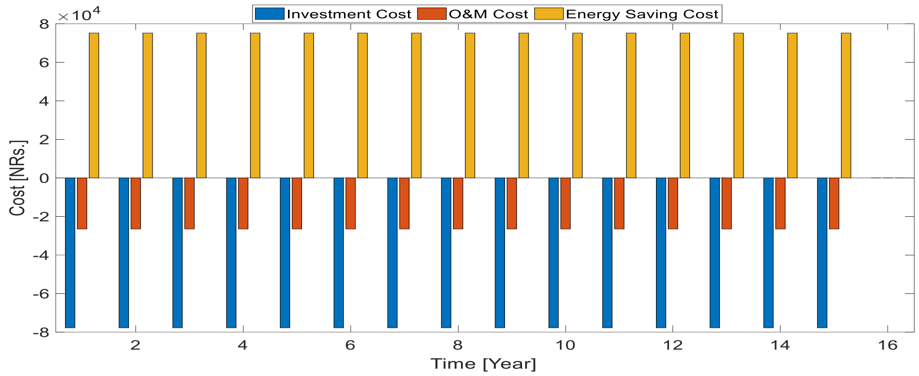


Figure 4.5: Cashflow diagram for 50% loading condtion for rates NPR 10.0 / kWh

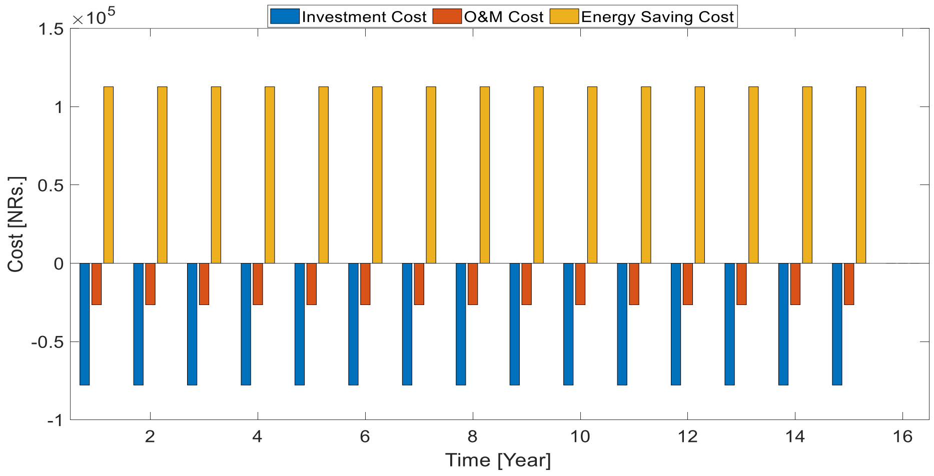


Figure 4.6: Cashflow diagram for 75% loading condtion for rates NPR 10.0 / kWh

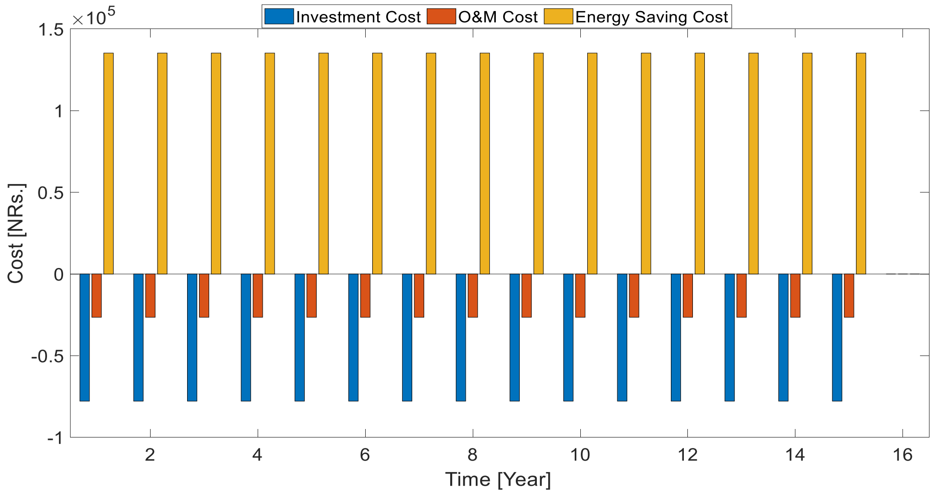


Figure 4.7: Cashflow diagram for 90% loading condtion for rates NPR 10.0 / kWh

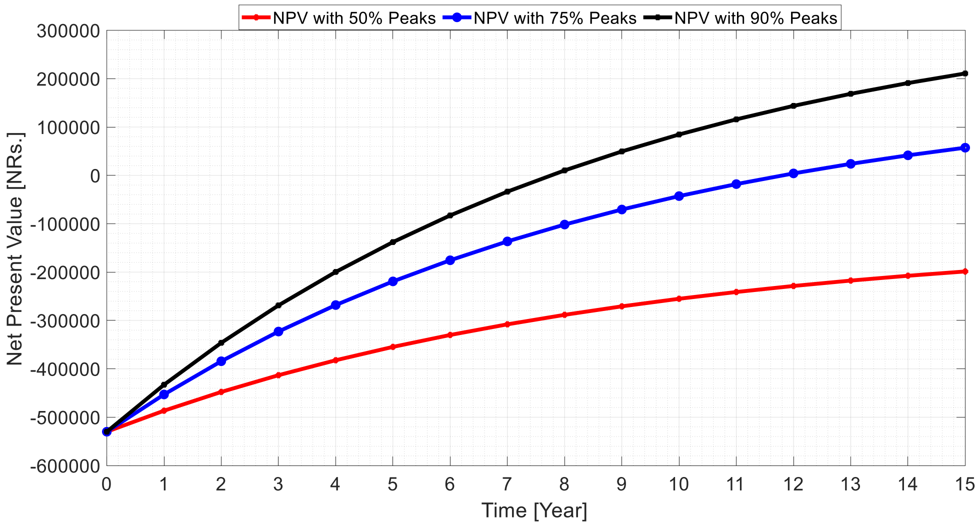


Figure 4.8: Net present values curves

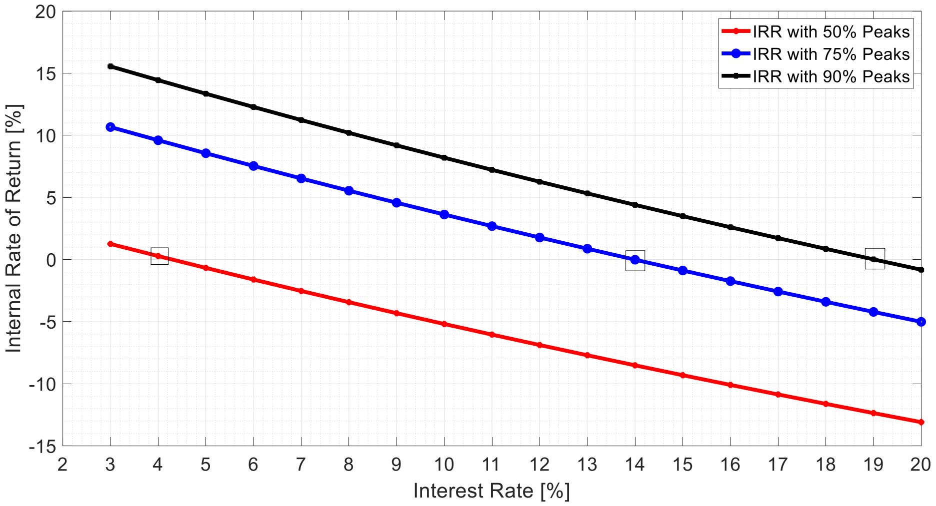


Figure 4.9: Internal rate of Return for rates NPR 10.0 / kWh

The financial plots for the energy rates NPR 13.5 / kWh are presented as in Figure 4.10 to Figure 4.14. The cash flow presented show that when the peak load considered in maximum days then the revenue is also higher. The net present value is positive for 50% peaks is after 7 years and for 90% peaks is after 3 years. It shows that the scheme of battery energy storage system is viable. With this energy rate, the higher revenue can be generated and, therefore, the reduction of payback period.

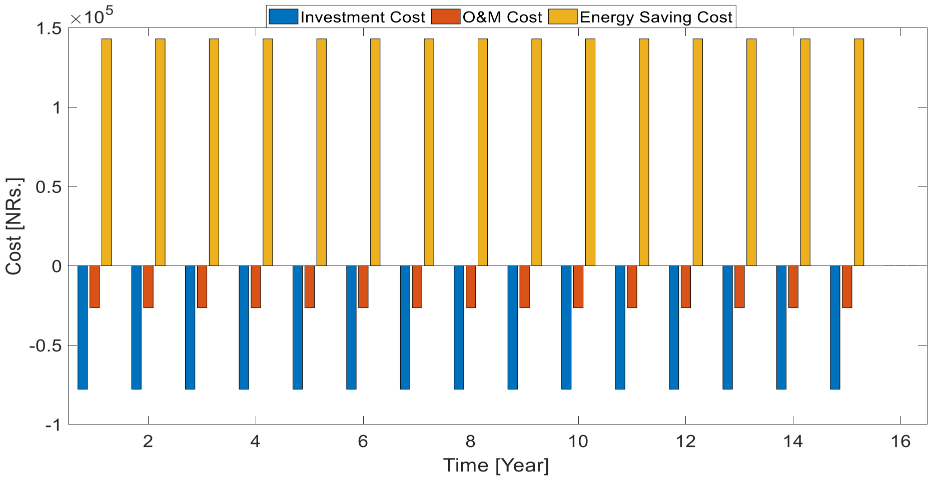


Figure 4.10: Cashflow diagram for 50% loading condtion for rates NPR 13.5 / kWh

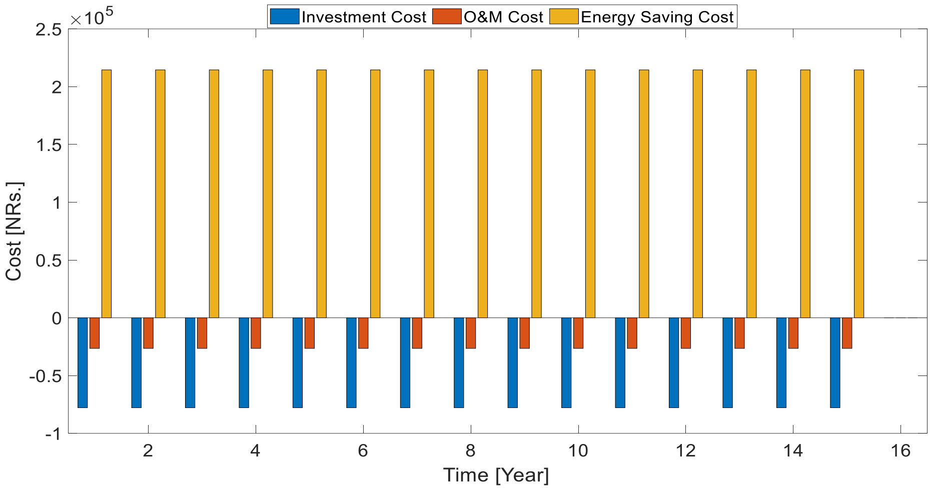


Figure 4.11: Cashflow diagram for 70% loading condtion for rates NPR 13.5 / kWh

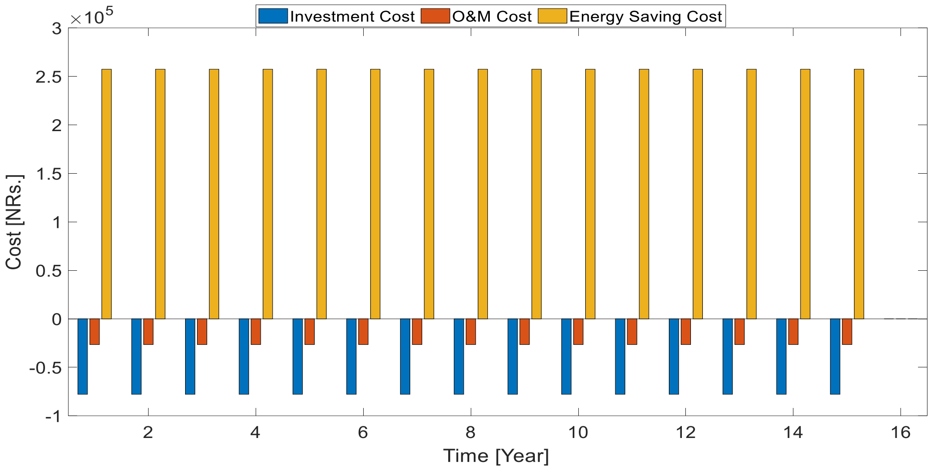


Figure 4.12: Cashflow diagram for 90% loading condtion for rates NPR 13.5 / kWh

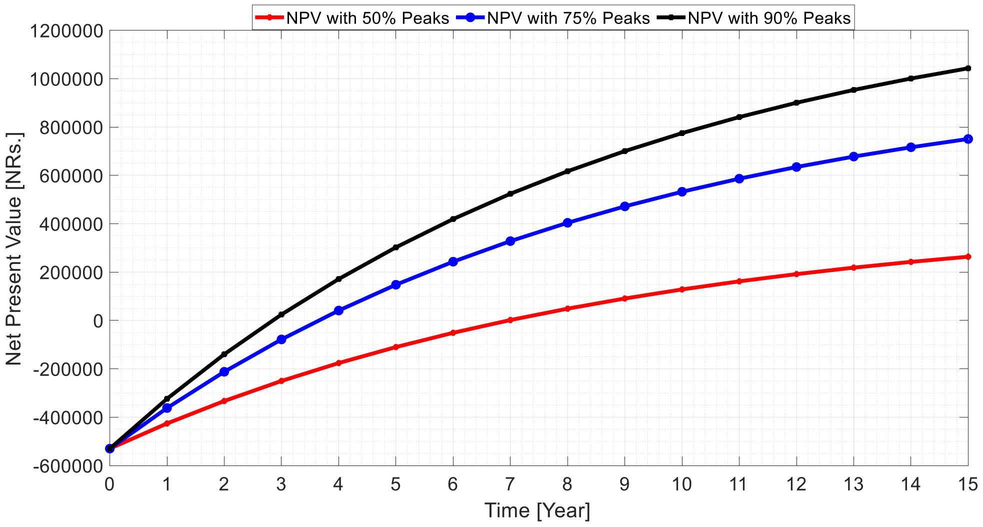


Figure 4.13: Net present values curves

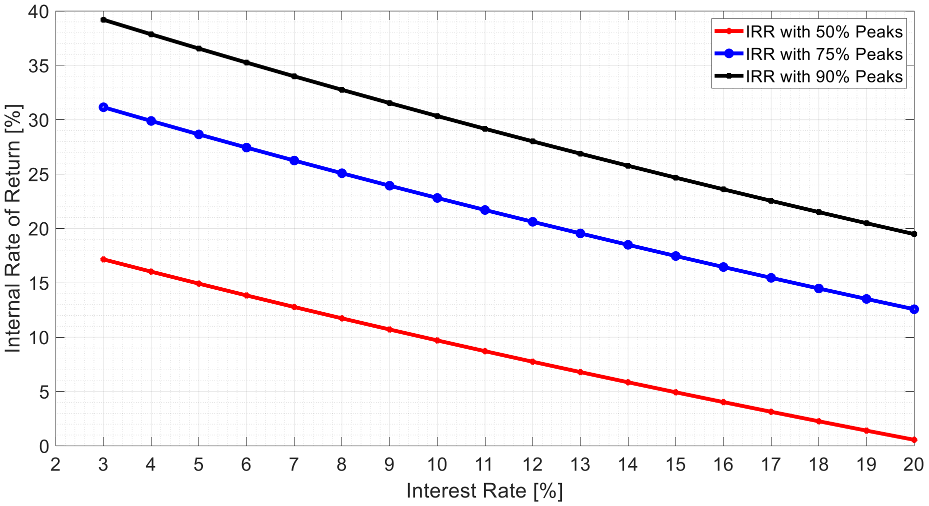


Figure 4.14: Internal Rate of Return for rates NPR 13.5 / kWh

The financial plots for the energy rates NPR 15.0 / kWh are presented as in figure.

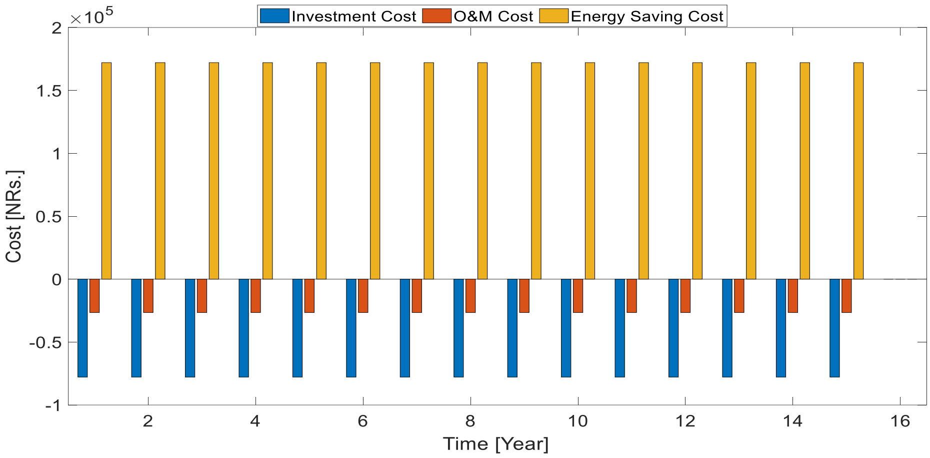


Figure 4.15: Cashflow diagram for 50% loading condtion for rates NPR 15.0 / kWh

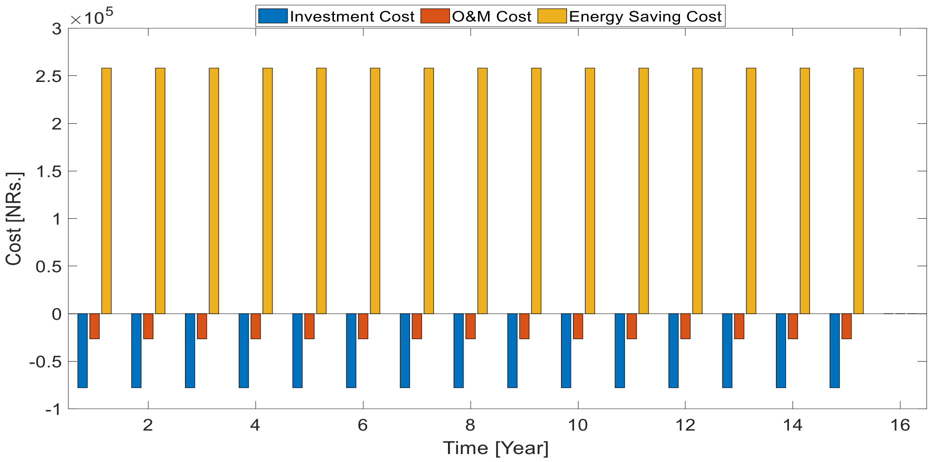


Figure 4.16: Cashflow diagram for 75% loading condtion for rates NPR 15.0 / kWh

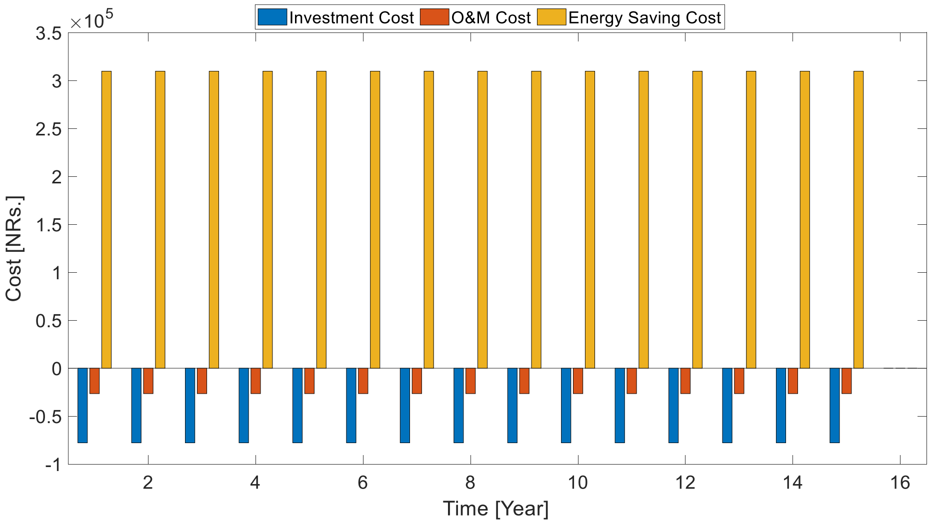


Figure 4.17: Cashflow diagram for 90% loading condtion for rates NPR 15.0 / kWh

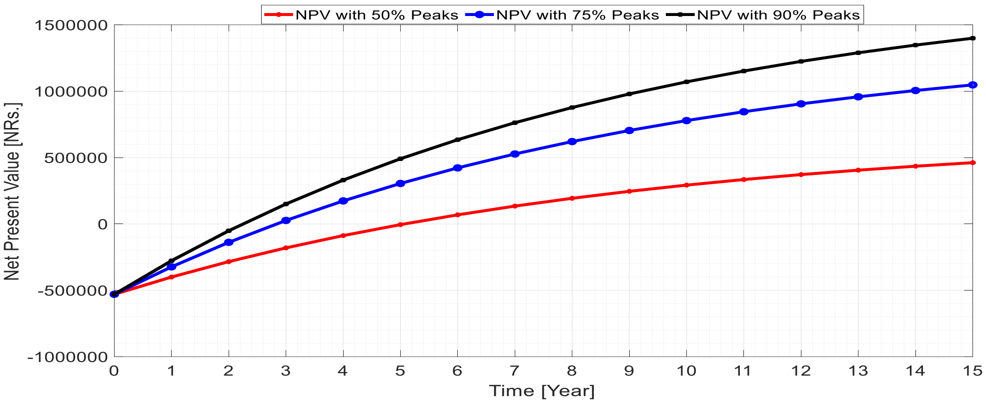


Figure 4.18: Net present value curves

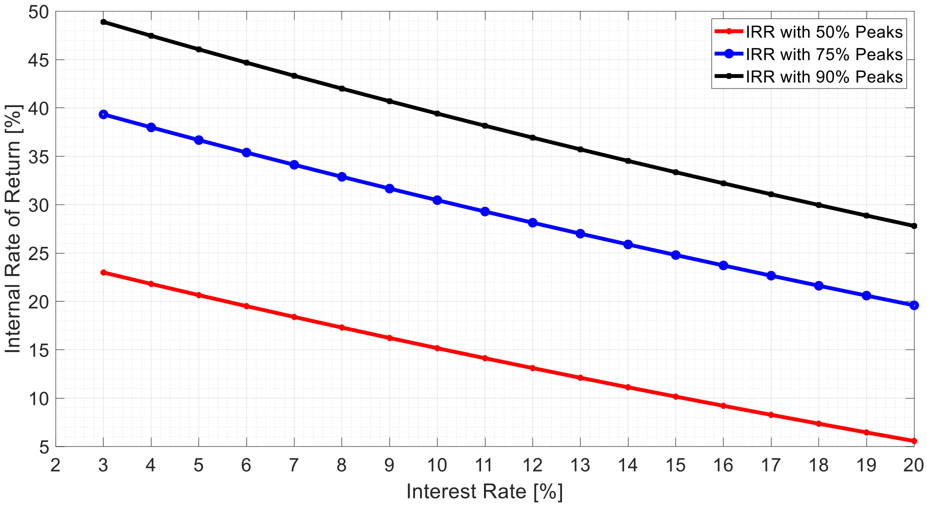


Figure 4.19: Internal Rate of Return for rates NPR 15.0 / kWh

4.3. Technical Advantage/Disadvantage.

4.3.1. Advantages: -

- It is observed that the power utilization of DT is improved with use of BESS. Also, the system loss is also reduced and system voltage regulation is also improved with the use of BESS.
- Reduction in load curtailment (Improvement in Reliability).
- From the analysis, it was found that optimum advantage of BESS is achieved by appropriate scheduling of BESS power throughout the time rather than just charging and discharging at fixed power.
- Dynamic operating benefits for the generator.
- Reduced air emissions from generation.

4.3.2. Disadvantages: -

- Introduction of Harmonics
- Disposal problem of battery after expire of its life time.

4.4. Economical Advantages and Disadvantages

4.4.1. Advantages

- Shaving from Reduction power and Enrgy Losses.
- Reduction in outage costs because of Improve Reliabilites.
- Benefits to customer because of voltage profile enhancement.
- Reduced perceived transmission and distribution investment risk.

4.4.2. Disadvantages

- Cost of BESS may be high.
- Cost of BESS control system also may be appreciable.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATONS

5.1. Conclusion

The issue of overloading of DTs in NEA distribution system is a persistent problem that needs to be dealt with realistic approach. With increasing reach of grid supplied electricity in the country that covers not only the urban and semi-urban areas but also the remote and isolated rural areas, the number of residential customers and the distribition transformers to serve these customers are increasing continuously.

In the context of large number of DTs failing due to overloading and failure to take timely measures to address the issue, this study suggests a very simple remedial measure to tackle the issue. The number of DT failures reported by NEA Bigunj distribution systems stood at 51 in F/Y 2078/079. Even the partial reduction in failure due to overloading of these DTs may save millions of rupees for the utility and help to supply electricity at more affordable prices.

Implementation of the BESS installation to alleviate overloading of DTs and, consequently, prolong their lives will serve multiple purposes such as reducing the cost of electricity supply services and cost of electricity to the customers, improve the reliability of electricity supply resulting in reduced societal cost and increased global welfare function. The study has shown the technical and economical viability of the BESS installation for conditions even at 20-30 percent overloading and assuming cost of electricity to be NPR 15 per kWh for the system peak time which falls in the evening. The annual savings from reduced outages and system loss reduction resulting from BESS installation at the lower voltage side of the DT shows great promises for the utility to solve the DT overloading and failing issue. These schemes seem to be successfully clearing the techno-economical criteria even for lower rate of electricity supplied during peak times and off-peak times which represent the most challenging segment for the operation of the DTs.

5.2. Recommendations

The following recommendations are provided in this thesis:

a) It is recommended to anaylse the data on real time basis to get more accurate effect of BESS.

b) When BESS is connected to the distribution system then there is a injection of harmonics in the grid. Harmonics and the distortion effect in the distribution can be further analysed.

c) In this thesis, only one transformer is and a day load pattern is considered for the analysis. There are various transformers is connected in a feeder. It is recommended to analyse with the various transformer and yearly load pattern.

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APPENDIX

Simulation Coding

```
clear all, close all;
comment_blocks(sys);
%set up filter for the RoCoF
s=tf('s');
Gf=eye(10)*(s/(.2/3*s+1));
sys.formin.filt=ss(Gf);
%set up filter for the active power injection by VI
Gf=eye(15)*(1/(0.03*s+1));
sys.formin.pfilt=ss(Gf);
tmp=sys.formin;
tmp.GenPU=diag(G_data(gentestcase,2));
sys.formin=tmp;
%time tripping and reconnecting a generator
dist.tgen=[200 201];
%time tripping
dist.tsplit=[200 201];
%disturbance inputs and time
dist.inp(6)=-150e6;
dist.time=15;
sys.tend=dist.time+15;
load optimgains.mat
disp('simulating nonlinear system')
tic
SimOut = sim('BESS_load','StopTime',int2str(sys.tend));
tc=toc;
```

Table A.5.1 Energy Calculattion at 160% of transformer loading from Graph.

	Case1					
Time	**Load Without BESS**	**Load with BESS**	**SOC**	**Energy without BESS**	**Energy with BESS**	**Differencce**
0	108	140	60	107	140	-33
1	106	140	61.53	111	140	-29
2	116	140	62.61	117	140	-23
3	118	140	63.6	128	140	-12
4	138	140	63.69	149	150	-1
5	160	160	63.69	163	160	3
6	166	160	63.36	172.5	160	12.5
7	179	160	62.315	176.5	160	16.5
8	174	160	61.545	158	151	7
9	142	142	61.545	141	141	0
10	140	140	61.545	142	142	0
11	144	144	61.545	146	146	0
12	148	148	61.545	151	151	0
13	154	154	61.545	150.5	150.5	0
14	147	147	61.545	153	153	0
15	159	159	61.545	171	159.5	11.5
16	183	160	60.28	204.5	160	44.5
17	226	160	56.65	236.5	160	76.5
18	247	160	51.865	253	160	93
19	259	160	46.42	261.5	162	99.5
20	264	164	40.92	249	162	87
21	234	160	36.85	213	160	53
22	192	160	35.09	174	158	16
23	156	156	35.09	0	0	0

Table A.5.2 Energy Calculattion at 140% of transformer loading from Graph.

	Case 2					
Time	**Load Without BESS**	**Load with BESS**	**SOC**	**Energy without BESS**	**Energy with BESS**	**Differencce**
0	108	175	35	107	175	-68
1	106	175	38	111	175	-64
2	116	175	41	117	175	-58
3	118	175	43	128	175	-47
4	138	175	45	149	175	-26
5	160	175	46	163	175	-12
6	166	175	46	173	177	-5
7	179	179	46	177	177	-1
8	174	175	46	158	175	-17
9	142	175	48	141	175	-34
10	140	175	49	142	175	-33
11	144	175	51	146	175	-29
12	148	175	52	151	175	-24

13	154	175	53	151	175	-25
14	147	175	54	153	175	-22
15	159	175	55	167	175	-8
16	175	175	55	183	178	5
17	190	180	54	205	180	25
18	220	180	52	228	180	48
19	235	180	49	238	180	58
20	240	180	46	225	180	45
21	210	180	44	189	178	12
22	168	175	44	162	175	-13
23	156	175	45	0	0	0

Table A.5.3 Energy Calculattion at 120% of transformer loading from Graph.

	Case 3					
Time	**Load Without BESS**	**Load with BESS**	**SOC**	**Energy without BESS**	**Energy with BESS**	**Differencce**
0	108	175	46	107	175	-68
1	106	175	49	111	175	-64
2	116	175	52	117	175	-58
3	118	175	54	128	175	-47
4	138	175	56	149	175	-26
5	160	175	57	163	175	-12
6	166	175	57	173	177	-5
7	179	179	57	177	177	-1
8	174	175	57	158	175	-17
9	142	175	59	141	175	-34
10	140	175	60	142	175	-33
11	144	175	62	146	175	-29
12	148	175	63	151	175	-24
13	154	175	64	151	175	-25
14	147	175	65	149	175	-27
15	150	175	66	155	175	-20
16	160	175	67	168	175	-8
17	175	175	67	188	178	10
18	200	180	66	205	180	25
19	210	180	64	215	180	35
20	220	180	62	205	180	25
21	190	180	61	178	178	0
22	165	175	62	161	175	-15
23	156	175	63			

Table A.5.4 Energy Calculattion at 110% of transformer loading from Graph.

	Case 4					
Time	**Load Without BESS**	**Load with BESS**	**SOC**	**Energy without BESS**	**Energy with BESS**	**Differencce**
0	108	140	65	107	140	-33
1	106	140	66.53	111	140	-29
2	116	140	67.61	117	140	-23
3	118	140	68.6	128	140	-12
4	138	140	68.69	149	150	-1
5	160	160	68.69	163	160	3
6	166	160	68.36	173	160	13
7	179	160	67.315	177	160	17
8	174	160	66.545	158	151	7
9	142	142	66.545	141	141	0
10	140	140	66.545	142	142	0
11	144	144	66.545	146	146	0
12	148	148	66.545	151	151	0
13	154	154	66.545	151	151	0
14	147	147	66.545	146	146	0
15	145	145	66.545	148	148	0
16	150	150	66.545	158	155	3
17	165	160	66.27	175	160	15
18	185	160	64.895	193	160	33
19	200	160	62.695	205	160	45
20	210	160	59.945	195	160	35
21	180	160	58.845	170	160	10
22	160	160	58.845	158	158	0
23	156	156	58.845	0	0	0

Table A.5.5 Revenue Collection of energy at peak Energy Rate NPR 10/kWh

Time	**Rate**	**Case 1**		**Case 2**		**Case 3**		**Case 4**	
	Rs/kWh	**Energy Difference (kWh)**	**Amount (NPR)**	**Energy Difference (kWh)**	**Amount (NPR)**	**Energy Difference (kWh)**	**Amount (NPR)**	**Energy Difference (kWh)**	**Amount (NPR)**
0	4.65	-33	-153.45	-68	-316.20	-68	-316.20	-33	-153.45
1	4.65	-29	-134.85	-64	-297.60	-64	-297.60	-29	-134.85
2	4.65	-23	-106.95	-58	-269.70	-58	-269.70	-23	-106.95
3	4.65	-12	-55.80	-47	-218.55	-47	-218.55	-12	-55.80
4	4.65	-1	-4.65	-26	-120.90	-26	-120.90	-1	-4.65
5	4.65	3	13.95	-12	-55.80	-12	-55.80	3	13.95
6	8.20	12.5	102.50	-4.5	-20.93	-4.5	-20.93	12.5	58.13
7	8.20	16.5	135.30	-0.5	-2.33	-0.5	-2.33	16.5	76.73
8	8.20	7	57.40	-17	-79.05	-17	-79.05	7	32.55
9	8.20	0	0.00	-34	-158.10	-34	-158.10	0	0.00
10	8.20	0	0.00	-33	-153.45	-33	-153.45	0	0.00
11	8.20	0	0.00	-29	-134.85	-29	-134.85	0	0.00
12	8.20	0	0.00	-24	-111.60	-24	-111.60	0	0.00
13	8.20	0	0.00	-24.5	-113.93	-24.5	-113.93	0	0.00
14	8.20	0	0.00	-22	-102.30	-26.5	-123.23	0	0.00
15	8.20	11.5	94.30	-8	-37.20	-20	-93.00	0	0.00
16	8.20	44.5	364.90	5	23.25	-7.5	-34.88	2.5	11.63
17	8.20	76.5	627.30	25	116.25	10	46.50	15	69.75
18	15.00	93	1395.00	47.5	220.88	25	116.25	32.5	151.13
19	15.00	99.5	1492.50	57.5	267.38	35	162.75	45	209.25
20	15.00	87	1305.00	45	209.25	25	116.25	35	162.75
21	15.00	53	795.00	11.5	53.48	0	0.00	10	46.50
22	15.00	16	240.00	-13	-60.45	-14.5	-67.43	0	0.00
23	4.65	0	0.00	0	0.00	0	0.00	0	0.00
Sum		422	6167.45	-293	-1362.45	-415	-1929.75	81	376.65

Table A.5.6 Revenue Collection of energy at peak Energy Rate NPR 15/kWh

Time	**Rate**	**Case 1**		**Case 2**		**Case 3**		**Case 4**	
	Rs/kWh	**Energy Difference (kWh)**	**Amount (NPR)**	**Energy Difference (kWh)**	**Amount (NPR)**	**Energy Difference (kWh)**	**Amount (NPR)**	**Energy Difference (kWh)**	**Amount (NPR)**
0	4.65	-33	-153.45	-68	-316.20	-68	-316.20	-33	-153.45
1	4.65	-29	-134.85	-64	-297.60	-64	-297.60	-29	-134.85
2	4.65	-23	-106.95	-58	-269.70	-58	-269.70	-23	-106.95
3	4.65	-12	-55.80	-47	-218.55	-47	-218.55	-12	-55.80
4	4.65	-1	-4.65	-26	-120.90	-26	-120.90	-1	-4.65
5	4.65	3	13.95	-12	-55.80	-12	-55.80	3	13.95
6	8.20	12.5	102.50	-4.5	-20.93	-4.5	-20.93	12.5	58.13
7	8.20	16.5	135.30	-0.5	-2.33	-0.5	-2.33	16.5	76.73
8	8.20	7	57.40	-17	-79.05	-17	-79.05	7	32.55
9	8.20	0	0.00	-34	-158.10	-34	-158.10	0	0.00
10	8.20	0	0.00	-33	-153.45	-33	-153.45	0	0.00
11	8.20	0	0.00	-29	-134.85	-29	-134.85	0	0.00
12	8.20	0	0.00	-24	-111.60	-24	-111.60	0	0.00
13	8.20	0	0.00	-24.5	-113.93	-24.5	-113.93	0	0.00
14	8.20	0	0.00	-22	-102.30	-26.5	-123.23	0	0.00
15	8.20	11.5	94.30	-8	-37.20	-20	-93.00	0	0.00
16	8.20	44.5	364.90	5	23.25	-7.5	-34.88	2.5	11.63
17	8.20	76.5	627.30	25	116.25	10	46.50	15	69.75
18	10.00	93	930.00	47.5	220.88	25	116.25	32.5	151.13
19	10.00	99.5	995.00	57.5	267.38	35	162.75	45	209.25
20	10.00	87	870.00	45	209.25	25	116.25	35	162.75
21	10.00	53	530.00	11.5	53.48	0	0.00	10	46.50
22	10.00	16	160.00	-13	-60.45	-14.5	-67.43	0	0.00
23	4.65	0	0.00	0	0.00	0	0.00	0	0.00
Sum		422C	4424.95	-293	-1362.45	-415	-1929.75	81	376.65

CASH FLOW

Peaking Consisting 50% of the year above input load with peak rate NPR10 /kWh

Year	Cash Flow	Discounted Cash Flow	Cummulative Cash Flow
0	(530,000.00)	(530,000.00)	(530,000.00)
1	48648.94	43,436.55	(486,563.45)
2	48648.94	38,782.64	(447,780.81)
3	48648.94	34,627.35	(413,153.45)
4	48648.94	30,917.28	(382,236.17)
5	48648.94	27,604.72	(354,631.46)
6	48648.94	24,647.07	(329,984.39)
7	48648.94	22,006.31	(307,978.08)
8	48648.94	19,648.49	(288,329.59)
9	48648.94	17,543.30	(270,786.30)
10	48648.94	15,663.66	(255,122.64)
11	48648.94	13,985.41	(241,137.23)
12	48648.94	12,486.97	(228,650.26)
13	48648.94	11,149.08	(217,501.18)
14	48648.94	9,954.54	(207,546.64)
15	48648.94	8,887.98	(198,658.66)

Peaking Consisting 75% of the year above input load with peak rate NPR10 /kWh

Year	Cash Flow	Discounted Cash Flow	Cummulative Cash Flow
0	(530,000.00)	(530,000.00)	(530,000.00)
1	86223.41	76,985.19	(453,014.81)
2	86223.41	68,736.77	(384,278.04)
3	86223.41	61,372.12	(322,905.92)
4	86223.41	54,796.54	(268,109.38)
5	86223.41	48,925.48	(219,183.90)
6	86223.41	43,683.46	(175,500.44)
7	86223.41	39,003.09	(136,497.35)
8	86223.41	34,824.19	(101,673.16)
9	86223.41	31,093.03	(70,580.13)
10	86223.41	27,761.63	(42,818.50)
11	86223.41	24,787.17	(18,031.33)
12	86223.41	22,131.40	4,100.07
13	86223.41	19,760.18	23,860.25
14	86223.41	17,643.02	41,503.27
15	86223.41	15,752.69	57,255.96

Peaking Consisting 90% of the year above input load with peak rate NPR10 /kWh

Year	Cash Flow	Discounted Cash Flow	Cummulative Cash Flow
0	(530,000.00)	(530,000.00)	(530,000.00)
1	108768.09	97,114.37	(432,885.63)
2	108768.09	86,709.26	(346,176.38)
3	108768.09	77,418.98	(268,757.40)
4	108768.09	69,124.09	(199,633.31)

5	108768.09	61,717.94	(137,915.38)
6	108768.09	55,105.30	(82,810.08)
7	108768.09	49,201.16	(33,608.92)
8	108768.09	43,929.61	10,320.69
9	108768.09	39,222.86	49,543.55
10	108768.09	35,020.41	84,563.97
11	108768.09	31,268.23	115,832.19
12	108768.09	27,918.06	143,750.25
13	108768.09	24,926.84	168,677.09
14	108768.09	22,256.11	190,933.20
15	108768.09	19,871.52	210,804.72

Peaking Consisting 50% of the year above input load with peak rate NPR13.5 /kWh

Year	Cash Flow	Discounted Cash Flow	Cummulative Cash Flow
0	(530,000.00)	(530,000.00)	(530,000.00)
1	116516.13	104,032.26	(425,967.74)
2	116516.13	92,885.95	(333,081.80)
3	116516.13	82,933.88	(250,147.92)
4	116516.13	74,048.11	(176,099.81)
5	116516.13	66,114.38	(109,985.43)
6	116516.13	59,030.70	(50,954.73)
7	116516.13	52,705.98	1,751.25
8	116516.13	47,058.91	48,810.16
9	116516.13	42,016.88	90,827.05
10	116516.13	37,515.08	128,342.12
11	116516.13	33,495.60	161,837.72
12	116516.13	29,906.79	191,744.51
13	116516.13	26,702.49	218,447.00
14	116516.13	23,841.51	242,288.51
15	116516.13	21,287.06	263,575.57

Peaking Consisting 75% of the year above input load with peak rate NPR13.5 /kWh

Year	Cash Flow	Discounted Cash Flow	Cummulative Cash Flow
0	(530,000.00)	(530,000.00)	(530,000.00)
1	188024.19	167,878.74	(362,121.26)
2	188024.19	149,891.73	(212,229.53)
3	188024.19	133,831.90	(78,397.62)
4	188024.19	119,492.77	41,095.15
5	188024.19	106,689.97	147,785.13
6	188024.19	95,258.91	243,044.03
7	188024.19	85,052.59	328,096.63
8	188024.19	75,939.82	404,036.44
9	188024.19	67,803.41	471,839.85
10	188024.19	60,538.76	532,378.61
11	188024.19	54,052.46	586,431.07
12	188024.19	48,261.13	634,692.20
13	188024.19	43,090.29	677,782.49
14	188024.19	38,473.47	716,255.96
15	188024.19	34,351.32	750,607.28

Peaking Consisting 90% of the year above input load with peak rate NPR13.5 /kWh

Year	Cash Flow	Discounted Cash Flow	Cummulative Cash Flow
0	(530,000.00)	(530,000.00)	(530,000.00)
1	230929.03	206,186.63	(323,813.37)
2	230929.03	184,095.21	(139,718.16)
3	230929.03	164,370.72	24,652.56
4	230929.03	146,759.57	171,412.14
5	230929.03	131,035.33	302,447.47
6	230929.03	116,995.83	419,443.31
7	230929.03	104,460.57	523,903.87
8	230929.03	93,268.36	617,172.23
9	230929.03	83,275.32	700,447.56
10	230929.03	74,352.97	774,800.52
11	230929.03	66,386.58	841,187.10
12	230929.03	59,273.73	900,460.83
13	230929.03	52,922.97	953,383.80
14	230929.03	47,252.65	1,000,636.46
15	230929.03	42,189.87	1,042,826.33

Peaking Consisting 50% of the year above input load with peak rate NPR15.0 /kWh

Year	Cash Flow	Discounted Cash Flow	Cummulative Cash Flow
0	(530,000.00)	(530,000.00)	(530,000.00)
1	145602.06	130,001.84	(399,998.16)
2	145602.06	116,073.07	(283,925.09)
3	145602.06	103,636.67	(180,288.42)
4	145602.06	92,532.74	(87,755.68)
5	145602.06	82,618.52	(5,137.16)
6	145602.06	73,766.53	68,629.38
7	145602.06	65,862.98	134,492.35
8	145602.06	58,806.23	193,298.58
9	145602.06	52,505.56	245,804.15
10	145602.06	46,879.97	292,684.11
11	145602.06	41,857.11	334,541.23
12	145602.06	37,372.42	371,913.65
13	145602.06	33,368.23	405,281.88
14	145602.06	29,793.07	435,074.95
15	145602.06	26,600.95	461,675.90

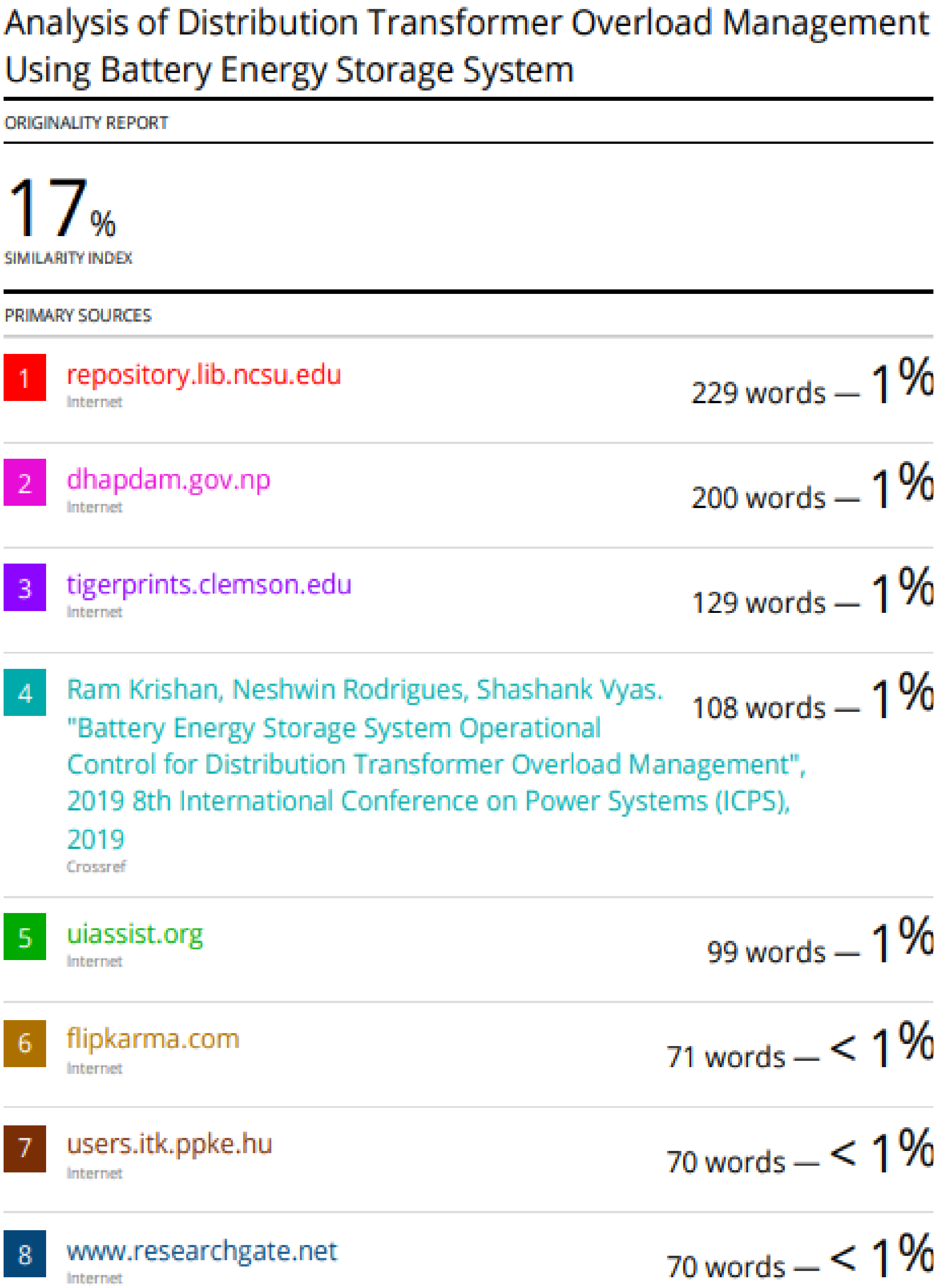
Peaking Consisting 75% of the year above input load with peak rate NPR15.0 /kWh

Year	Cash Flow	Discounted Cash Flow	Cummulative Cash Flow
0	(530,000.00)	(530,000.00)	(530,000.00)
1	231653.09	206,833.12	(323,166.88)
2	231653.09	184,672.43	(138,494.46)
3	231653.09	164,886.09	26,391.63
4	231653.09	147,219.73	173,611.36
5	231653.09	131,446.18	305,057.55
6	231653.09	117,362.66	422,420.21

7	231653.09	104,788.09	527,208.30
8	231653.09	93,560.80	620,769.10
9	231653.09	83,536.43	704,305.53
10	231653.09	74,586.10	778,891.62
11	231653.09	66,594.73	845,486.35
12	231653.09	59,459.58	904,945.93
13	231653.09	53,088.91	958,034.84
14	231653.09	47,400.81	1,005,435.65
15	231653.09	42,322.15	1,047,757.80

Peaking Consisting 90% of the year above input load with peak rate NPR15.0 /kWh

Year	**Cash Flow**	**Discounted Cash Flow**	**Cummulative Cash Flow**
0	(530,000.00)	(530,000.00)	(530,000.00)
1	283283.71	252,931.88	(277,068.12)
2	283283.71	225,832.04	(51,236.08)
3	283283.71	201,635.75	150,399.67
4	283283.71	180,031.92	330,431.59
5	283283.71	160,742.78	491,174.38
6	283283.71	143,520.34	634,694.72
7	283283.71	128,143.16	762,837.88
8	283283.71	114,413.54	877,251.42
9	283283.71	102,154.95	979,406.37
10	283283.71	91,209.77	1,070,616.14
11	283283.71	81,437.30	1,152,053.44
12	283283.71	72,711.87	1,224,765.31
13	283283.71	64,921.31	1,289,686.63
14	283283.71	57,965.46	1,347,652.09
15	283283.71	51,754.87	1,399,406.96



Analysis of Distribution Transformer Overload Management Using Battery Energy Storage System

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