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SOLAR AND WIND HYBRID INTEGRATION USING GENERATION EXPANSION PLANNING

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SUBMITTED BY: **WAGATE PRISCILLAH WACHORO**

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SUPERVISORS: **DR. PETER MOSES MUSAU**

EXAMINERS: **1. MR. BENSON ONYANGO OJWANG**

2. DR DHARMA

PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONICS ENGINEERING OF THE UNIVERSITY OF NAIROBI

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Declaration of Originality

NAME OF STUDENT:	WAGATE PRISCILLAH WACHORO
REGISTRATION NUMBER:	F17/1626/2013
COLLEGE:	ARCHITECTURE AND ENGINEERING
FACULTY/SCHOOL/INSTITUTE:	ENGINEERING
DEPARTMENT:	ELECTRICAL AND INFORMATION ENGINEERING
COURSE TITLE:	BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING
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This Project is submitted to the Department of Electrical and Information Engineering, University of Nairobi with my approval as the Student Supervisor:

Dr. Peter Moses Musau

Signature: **Date:**

……………………………………………… …………………………………

Dedication

I dedicate this to my parents and to my sisters for their love and continuous encouragement throughout my academic journey.

I love you all.

Acknowledgement

I first and foremost thank God for the strength, health and opportunity to pursue this course.

To my family, I thank you all for the continual support and encouragement in all I endeavor to do.

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List of Abbreviations

ABC	Artificial Bee Colony
ACO	Artificial Ant Colony
BA	Bat Algorithm
CVaR	Conditional Value at Risk
DA	Dragon Fly Algorithm
DC	Direct Current
ESSs	Energy Storage Systems
FABC	Fuzzified Artificial Bee Colony
GA	Genetic Algorithm
GAMS	General Algebraic Modelling System
GENCOs	Generating Companies
GEP	Generation Expansion Planning
GSA	Gravitational Search Algorithm
HBMO	Honey Bee Mating Optimization
ISO	Independent System Operator
LP	Linear Programming
MATLAB	Matrix Laboratory
MGT	Modified Game Theory
MILP	Mixed Integer Linear Programming

PSO	Particle Swarm Optimization
PV	Photo Voltaic
RES	Renewable Energy Sources

Abstract

Wagate Priscillah Wachoro, F17/1626/2013, Solar and Wind Hybrid Integration Using Generation Expansion Planning

Generation expansion planning(GEP) focuses on obtaining a short or long term plan that is optimal for the construction of new generation plants while taking economic constraints into consideration. In the past decade, there has been an increase in the demand for electrical energy. A balance between supply and demand must be maintained while considering environmental factors. Due to environmental regulation to generation companies to consider emission as an important constraint, renewable energy sources have emerged to be a better alternative to fossil fuels. To obtain the optimal plan, a simulation was done using MATLAB. A hybrid with a capacity of 30 MW was considered. The results obtained show that the solar and wind hybrid are the best options when minimizing costs is the priority since they had a production cost of $0.08/kW compared to that of thermal which is $0.19/kWh. The model formulated provides and effective optimization solution for a long term plan thus solving the GEP problem. Further research should be carried out on distributed solar and wind generators close to the point of use to mitigate power loss and minimize costs over large solar project.

CHAPTER 1

1.1 Introduction

Definition of key terms

Generation expansion planning (GEP)

Generation expansion planning (GEP) refers to the problem of identifying the most reliable technology, expansion size and timing for the establishing of new power plants. [7]. Expansion is necessitated by the growth of demand as well as depreciation of existing plants due to aging which causes unreliability and instability [1].

Planning may be categorized as long term and short term. It is termed as short term when reliable energy returns are expected to meet loads forecasted over a short period of time (about 5 years or less) [5].and considered long term planning, when the existing power systems are to be expanded to serve forecasted load over a long period of time of about 25 years [6].

Hybrid System- Generation expansion planning (GEP) refers to the problem of identifying the most reliable technology, expansion size and timing for the establishing of new power plants. [7]. Expansion is necessitated by the growth of demand as well as depreciation of existing plants which causes unreliability and instability [1].

Solar and Wind Hybridized Integration using GEP refers to a generation expansion plan that deals with multi-type renewables, specifically Wind and Photo Voltaic (PV) and focuses on their uncertainty characteristics and fluctuations in energy production [6].

In the GEP problem the planner is required to determine the optimal plan that would encourage investors and other potential financiers to put up new generation systems [1]. In the last decade, there has been a massive increase in electricity generation with 70% of this being from fossil fuels resulting in a proportional increase in carbon emissions [2]. In a bid to curb the resulting increase in pollution and with the emergence of global warming as a major environmental issue, political measures have been put in place to decarbonize energy sectors leading to considerable growth in renewable energy technologies (RETs) which are expected to be the main source of electricity generation [3]. The advancement of time has also seen the development of renewable energy sources (RES) which is a prospective solution for sustainable future environment since it is a better alternative to fossil fuels [4].

GEP is a long-term planning problem and there is a lot of uncertainty that comes with it due to the changing technological factors such as storage [5]. The main purpose of long-term planning is to expand the power systems that already exist so they can meet future load forecast over a long period of time [6].

This project will focus on GEP to address the problem of choosing the most reliable technology, expansion size, location and when the new power plants should be constructed while ensuring that they meet expected demand growth [7]. A model shall be implemented using MATLAB software [8].

1.2 Problem Statement

In previous works, mixed integer linear programming (MILP) is used using a deterministic approach whose main objective is minimizing investment costs and maximizing social welfare [1]. In other works, the GEP problem has been solved using Meta-heuristic optimization techniques where virtual mapping procedure is applied to increase efficiency and increase the success rate [2]. Different approaches have been taken to optimize when there is uncertainty by using the deterministic generation investment model that minimizes cost and optimizes the portfolio for future generation of renewable sources [3]. A long-term model plan has also been developed using a multistage, stochastic nonlinear programming method to solve the problem of probability distribution of electricity prices [4]. Another work adopts a forward moving approach where a static block mechanism is designed where the decision for expansion and production it taken into account for any instantaneous time thus accounting for long-term planning [5]. Static Residue Load Duration Curve (S-RLDC) is proposed to deal with uncertainty by tackling probability distribution and availability of renewable output and come up with an estimator that is needed for long-term GEP in a quantifiable way [6]. Gravitational Search Algorithm (GSA) which is based on Newton's laws of gravity is used to solve the optimization problem [7]. A case study of China has been considered where external costs are used to calculate the value of energy technologies and RES in China [8].

No comprehensive research has been undertaken regarding the outcome of uncertainties that are not predetermined. Such uncertainties are drastic change in generation or demand that could be due to severe weather or breakdown. This project proposes developing an energy portfolio containing a range of options on both demand and supply.

1.3 Objectives

The overall objective is to come up with a plan that minimizes total costs by solving the problem of GEP for integrated hybrid of solar and wind system and advising investors to establish in new units that are reliable and that meet the growing demand.

The specific objectives are as follows

i. To determine the location and capacity of new generating units.
ii. Evaluate ways to improve the existing power systems.
iii. To formulate a power system model that integrates solar and wind hybrid into expansion planning.
iv. Simulate the formulated model in MATLAB to validate its effectiveness.

1.4 Research Questions

i. How can we optimize the generation capacity of a new power plant?
ii. What are the limitations of the existing power systems and how can they be addressed?
iii. How can solar and wind be integrated into GEP?

1.5 Justification for The Study

There has been a fast growth in demand in Kenya power systems in the recent years and this is expected to continue in future [9]. In order to accommodate the growing demand, there is need to consider other sources of electricity apart from the hydro and thermal power. In this study, we shall focus on solar and wind hybridization. By integrating the hybrid of solar and wind in an expansion plan, we can satisfy the population's growing demand for energy.

There have been climate targets set and similar political policies put in place aimed to decarbonize energy sectors in the nation [10]. This has led to growth of Renewable Energy Sources (RESs) in the electricity sectors. Solar and wind are considered the best alternatives because they are readily available and environmentally friendly.

1.6 Scope of Work

This project will involve research on the topics of power generation, power planning and power expansion. The project will also involve finding the optimal generation expansion plan that is cost effective and that by using a mathematical model. A mathematical formulation shall be solved using MATLAB software package.

CHAPTER 2

2.1 LITERATURE REVIEW

Sima C.A, Lazaroiu G.C, Dumbrava V, Lazaroiu G C Tirsu M and Galbura V [1] in their work **Integration of renewable Energy Sources Using Generation Expansion Planning,** presented a single-stage model whose function was to minimize operational cost and maximize social welfare. To address the Generation Expansion Problem(GEP), an independent system operator(ISO) has to solve a mathematical model by modifying the model to determine the optimal solution for other systems. This work proposed a General Algebraic Modelling System(GAMS) optimization method to introduce network data represented in tables. This work does not take into consideration the uncertainties and losses due to direct current(DC) power flow.

Generation expansion planning considering reliability of the system: A review on various optimization techniques. Ballireddy, T. R., & Modi, P. K. (2017**)** [2]. This work proposed that the GEP be solved as a two stage stochastic programming problem. Reliability analysis and expansion planning were incorporated along with dispatching problems. A model was applied to solve a problem giving tradeoffs between cost and environmental impacts. A hybrid Modified Game Theory/Particle Swarm Optimization(MGT/PSO) algorithm was proposed for GEP problem. The methods used were Particle Swarm Optimization(PSO) and Honey Bee Mating Optimization(HBMO) for solving GEP problem with the aim of minimizing investment cost. Energy Storage Systems (ESSs) has been an effective means of storing energy. This work does not look into the effects of ESSs on the environment and also the social welfare.

Kendziorski M, Setje Eilers M, and Kunz F [3] in their work **Generation Expansion Planning under Uncertainty: An application of Stochastic Methods to the German Electricity System,** analyzed the effects of different approaches of modelling to deal with uncertainties due to electricity systems with renewable generation. A comparison was made between different methodological concepts of handling uncertainties in long term generation planning models. The analysis was limited to uncertainties arising from weather dependent renewable generation. This work recommended the extension of uncertainties approach to address both long-term and short-term uncertainties. In this work, three methods were proposed; Risk measurement using Conditional Value at Risk(CVaR), Benders decomposition to solve nested optimization problems and Regret minimization for robust optimization. This work also demonstrated how robustness can be achieved by using stochastic or robust optimization approaches. However, the biggest drawback of these approaches was high system costs and the two approaches used different technologies.

Zhan Y., Zheng Q. P., Wang, J and Pinson, P. (2017) in their work **Generation Expansion Planning with Large Amounts of Wind Power via Decision-Dependent Stochastic Programming** [4] introduced a decision –dependent stochastic programming model for long term power GEP. The variables were probabilities of price outcomes. An optimization strategy was developed to maximize the total profit. In this work, a quasi-exact solution approach was used to solve the non-linear stochastic program. Through price and demand analysis, this work concluded that wind penetration and profit were related to price and demand. This work also concluded that generation expansion investment was important in determining probability distribution. The methods used were linear-formulation and quasi-exact method to solve non-linear optimization and bilinear problems. The proposed decision-dependent model provided an effective optimization solution for long-term GEP. This work did no look into short-term GEP problem.

In the paper **A Methodology for Generation Expansion Planning for Renewable Energy Economies**, **Rasouli, M., and Teneketzis D. (2016)** [5]**,** focused on GEP in an economy that used renewable energy only. In this work, the contribution is in two folds: A forward moving approach to deal with economic, political and technological uncertainties and an expansion block mechanism that allowed Generating Companies(GENCOs) to communicate and plan their investment. The method used is T-horizon static mechanism that aligned the GENCOs objective with the ISO's objective to maximize social welfare. From this work, the mechanism presented was anonymous and the outcome of the mechanism was independent on GENCOs' indexing. Also, the outcome of the mechanism was investment decisions only.

Shengyu, W., Lu, C., Xiaoqing, Y., & Bo, Y. (2015) in their work **Long-term generation expansion planning under uncertainties and fluctuations of multi-type renewables** [6] proposed a GEP planning model that provided an effective method for optimal investment in dispatchable generation source and fluctuating capacity to incorporate large amounts of wind and Photo Voltaic(PV) energy. The model was implemented in an actual district and the outcome was that renewables uncertainties could be dealt with while still maintaining computation simplicity. In this they proposed two methods: Wavelet decomposition to get information about fluctuations in quantitative way and Statistical Residue Load Duration Curve(S-RLDC) to deal with uncertainties of renewable output. This work did not consider the geographical effect that would bring a better representation of PV and wind fluctuations.

Sadeghi, H., Mohammadian, M., Abdollahi, A., Rashidinejad, M., and Mahdavi, S. M. (2014) in their work **Renewable-based generation expansion planning considering environmental issues using GSA** [7] proposed a comprehensive GEP model for evaluation of different generation technologies. This work incorporated a feed-in-mechanism to encourage GENCO to invest more on renewables. The main idea was to reduce greenhouse gases. In this work, a model was proposed. This model gave rise to a large-scale non-linear programming problem with mixed variable. Gravitational search algorithm(GSA) was used to solve the problem and the results showed that penetration of renewable energy sources (RES) in GEP satisfied the GENCO investment plan and also the reduction in greenhouse gases. The method used was net present worth method to do computation for a 6-year optimization horizon. However, the large number of logical constraints that need to be accounted for made the solution of the GEP problem difficult.

Khan, A. Z., Yingyun, S., & Ashfaq, A. (2014) in their work **Generation expansion planning considering externalities for large scale integration of renewable energy** [8] took to account the effects of integrating externalities on large-scale integration of RES in GEP problem. Two scenarios were considered to apply the mode. From the base case, the results showed that reliance on fossil fuels continued to burden the environment with greenhouse gases emissions. This work evaluated this burden and drew a conclusion that fossil fuels were more expensive than switching to low carbon technologies and RES. The method used was unit damage cost of pollutants to evaluate external cost. Dose response functions were used to quantify health damage due to carbon emissions. This work did not look into externalities of cost and availability of RES in small scale.

A summary table of the literature review is illustrated in Table 2.1.

Table 2. 1:A Summary of Literature Review on Contributions and Weaknesses

Ref No	Authors	Title	Contributions	Weaknesses
[1]	Sima C.A, Lazaroiu G.C, Dumbrava V, Lazaroiu G C,Tirsu M and Galbura V	Integration of renewable Energy Sources Using Generation Expansion Planning	• Wind power plants as new generating units. • Investment decision was taken once • A mathematical decision was applied to a 6-bus system	• A bigger grid was not considered • Investment decisions was to be taken at every step
[2]	Ballireddy, T. R., & Modi, P. K.	Generation expansion planning considering reliability of the system: A review on various optimization techniques	• A review of drastic changes in electrical power generation • Integration of energy sources to minimize greenhouse emissions.	• Considering different constraints and reliable criteria to minimize planning cost and environmental pollution simultaneously

Ref No	Authors	Title	Contributions	Weaknesses
[3]	Kendziorski M, Setje Eilers M, and Kunz F	Generation Expansion Planning under Uncertainty: An application of Stochastic Methods to the German Electricity System	• Analysis of different modelling approaches to deal with uncertainties • Focused only on particular short-term uncertainties	• Extending the uncertainty approaches in generation planning to address both long and short term uncertainties to provide a better representation of future challenges in electricity and energy systems
[4]	Zhan Y., Zheng Q. P., Wang, J and Pinson, P.	Generation Expansion Planning With Large Amounts of Wind Power via Decision-Dependent Stochastic programming	• Decision making for the stochastic programming model	• Models with endogenous uncertainties

Ref No	Authors	Title	Contributions	Weaknesses
[5]	Rasouli, M., and Teneketzis, D	A Methodology for Generation Expansion Planning for Renewable Energy Economies	• Imposing short-term procurement obligations to GENCO • Capacity markets to deal with short horizon planning	• Long term contracts were not constructed
[6]	Shengyu, W., Lu, C., Xiaoqing, Y., & Bo, Y	Long-term Generation Expansion Planning Under Uncertainties and Fluctuations of Multi-type Renewables	• Wavelet decomposition to reveal fluctuation amplitude thus account for fluctuation effects.	• Did not take geographical diversity and aggregation effects into consideration • Inclusion of candidate lines
[7]	Sadeghi, H., Mohammadian, M., Abdollahi, A., Rashidinejad, M., and Mahdavi, S. M.	Renewable-based generation expansion planning	• Use of GSA to obtain solution to GEP problem	• Effects of incorporating RES on environment and social welfare were not considered

Ref No	Authors	Title	Contributions	Weaknesses
		considering using GSA	• Employment of renewable sources to achieve greenhouse gas mitigation	
[8]	Khan, A. Z., Yingyun, S., & Ashfaq, A	Generation expansion planning considering externalities for large scale integration of renewable energy	• Large scale integration of RES in GEP problem • Consideration of environmental externalities in GEP	• Did not take into consideration the intermittent nature of RES
Proposed Project		• Develop an energy portfolio that is to be used to solve the GEP problem • Come up with a method of integrating wind and solar hybrid • Come up with a plan that encourages investor to build new generation units		

2.2. PROBLEM FORMULATION

2.2.1 Assessment of Potential Sites

Selecting an appropriate site is key to success of any renewable energy project financially and technically. Site selection plays a major role in financial returns of the project, ongoing operations and maintenance and overall safety. There are several factors to consider when selecting a site for renewable energy generation units. These factors include: viability for electricity generation, security concerns, whether the site is physically able to accommodate the facility, who has control over the site and whether the project is distributed or not [21].

2.2.1.1 Assessment of Potential Sites for Wind Farms

The assessment of potential wind farms influences the power generated from wind turbines and the impact on the power grid. This is important to the wind power integration analysis. The most important criterion to decide the location of wind farm is the promise of strong wind. The main parameters that capture wind power potential at a site are wind speed, wind power density and capacity factor [16].

Wind Power Density

The theoretical wind density of wind at an instant of time can be calculated as follows.

$$\rho = \rho_a V^3 A_1 \tag{2.1}$$

ρ_a is density of air, V is speed of wind and A_1 is area swept by turbine blade.

Arithmetic Mean of Wind Speed

The arithmetic mean of wind speed V at a site is calculated using expected value theorem in the proposed model.

$$V = \sum_{i=1}^{N_d} a_i \Gamma\left(1 + \frac{1}{b_i}\right) w_i \tag{2.2}$$

Where Γ is the gamma function while a_i and b_i are Weibul parameters.

Capacity Factor of a Wind Turbine

It is the ratio of actual power generation over a period of time to the total potential power generated if it was possible to operate at full capacity indefinitely.

$$CF = P_w/R \times T \tag{2.3}$$

Where P_w is actual energy produced in time T, R is the maximum plant rating and T is operating time.

The total actual energy can be expressed as

$$P_w = \frac{1}{2} C_p \times \rho \times A \times V^3 \tag{2.4}$$

P_w is the total energy,C_p is operating efficiency factor, ρ is density of air in kg/cm^3, A is surface area of turbine and V is speed of wind.

For maximum power, the operating efficiency is should be 1, the area swept by the turbine should be maximum, the average wind density and the velocity are maximum and CF is 0.8.

$$\left\{ \begin{matrix} For \max P_w \\ C_p \leq 1 \\ A \leq max \\ \rho \leq 1.23 \frac{kg}{m^3} \\ \frac{2m}{s} \leq V \leq \frac{25m}{s} \\ 10\% \leq CF \leq 80\% \end{matrix} \right\} \tag{2.5}$$

If the assessed site satisfies the constraints in equation (2.5), it is considered a potential site for the wind farm [21].

2.2.1.2 Assessment of Potential Sites for Solar Farms

The energy produced by a PV panel depends on surface area of the panel, solar radiation and temperature. Determining the optimal site for the solar plant is important when the objective is to obtain maximum output [12].

Temperature

The operation temperature of the solar panels can be calculated as

$$T_c = T_{air} + \frac{(50℃ - T_{ref})}{80℃} S \qquad (2.6)$$

Where S is insolation level and T_{air} is ambient air temperature.

Solar Radiation

Solar radiation is part of electromagnetic radiation emitted by the sun in large amounts. The spectral radiance depends on emitting properties of the surface and the temperature of an object. It can be calculated as

$$I = I_o \times K_t \qquad (2.7)$$

Where I_o is the calculated solar radiation and K_t is the clearness index.

Area

The total array area can be calculated as shown in equation (2.8) considering a rectangular solar panel.

$$A = N(l \times w) \qquad (2.8)$$

N is the total number of PV modules, l is the length of the solar panel and w is the width of the solar panel.

The total energy from PV panels can be formulated as

$$P_s = nAI\left[1 - \beta\left(T_c - T_{ref}\right)\right] \qquad (2.9)$$

n is conversion efficiency, A is solar array area, I is solar radiation, T_c is the outside temperature β is the temperature coefficient which is -0.47% and T_{ref} is the room temperature.

For maximum power, n =1, T_c is maximum, the solar radiation is maximum and the solar array area is maximum.

$$\left\{\begin{matrix} For \max P_s \\ n \leq 1 \\ T_{ref} \leq 25℃ \\ 15℃ \leq T_c \leq 35℃ \\ A = max \\ I = max \end{matrix}\right\} \tag{2.10}$$

If the assessed site satisfies the constraints in equation (2.10), it is considered a potential site for the solar plant to be put up.

2.2.2 Improving Existing Power Systems Using Hybrid of Solar and Wind Plus Storage

2.2.2.1 Hybrid of Solar and Wind

The combination of wind and solar energy leads to reduced storage requirements. The combination of complementary and multi-type energy storage is the hybrid system. The total energy produced by the hybrid system can be given by equation (2.11) [11].

$$P_{Hyb} = P_w + P_s \tag{2.11}$$

P_{Hyb} being the total energy generated by the hybrid unit.

2.2.2.2 Improving Existing Power Systems

Solar power generation is one of the most promising distributed generation technologies. Power intermittency and voltage swings of this resource affects the reliability of the micro-grid. Micro-grids powered by PV require battery energy storage system(BESS) to cater for power intermittency. Adding wind turbines can help supplement the energy stored in batteries since wind often blows when the sun does not shine. The hybrid system can also be supplemented by the existing traditional power plants [20].

The existing power plants include the hydro and thermal generators.

$$P_{trad} = P_{thermal} + P_{hydro} \tag{2.12}$$

The total energy of the system consists of the sum of the hybrid, thermal and hydro energy. This energy should meet the expected demand.

$$P_{demand} = P_{Hyb} + P_{trad} + P_{discharging} \tag{2.13}$$

P_{hydro} is total hydro energy, $P_{thermal}$ is the total thermal energy $P_{discharging}$ is the energy stored in batteries and P_{trad} is the total traditional energy.

2.2.3 Uncertainties

2.2.3.1 Uncertainties due to drastic change in generation

The potential of wind and solar energy is more than efficient to supply to electricity demand of industrial societies. However, these resources are only available intermittently.

In case of over generation, the surplus electricity can be stored for use in times when solar and wind are low. Over generation could be due to a fall in demand [18].

When the energy generated is much greater than the demand,

$$P_{Hyb} \gg P_D \tag{2.14}$$

$$P_{Hyb} + \sum U = P_D \tag{2.15}$$

Where P_{Hyb} is total energy from the hybrid unit, P_D is the power demand and U is the uncertainties. The uncertainty is solved by charging the batteries and exporting the rest of the energy to neighboring grids.

$$\sum U = P_{charging} + P_E \tag{2.16}$$

$$P_{Hyb} = P_D + P_{loss} + P_{charging} + P_E \tag{2.17}$$

Where $P_{charging}$ is the power stored on the batteries, P_{loss} is the power loss and P_E is the power exported to neighboring grid.

In case when the supply is low, power stored in the batteries can be used to supplement the power supply. Also, the traditional generation units can be used to supplement the power from the hybrid generating unit [18].

$$P_{Hyb} \ll P_D \tag{2.18}$$

$$P_{Hyb} + \sum U = P_D \tag{2.19}$$

$$\sum U = P_{discharging} + P_{trad} \tag{2.20}$$

$$P_{Hyb} + P_{discharging} + P_{trad} = P_D + P_{loss} \tag{2.21}$$

$$P_{total} = P_D + P_{loss} \tag{2.22}$$

Where $P_{discharging}$ is energy from the batteries, P_{trad} is energy from hydro and thermal plants

2.2.3.2 Uncertainties due to drastic change in demand

When the power demand is low, excess energy can be stored in batteries. Since the batteries cannot store all the surplus energy, the rest is exported to neighboring grids [19].

$$P_D \ll P_{Hyb} \tag{2.23}$$

$$P_{Hyb} = P_D + \sum U \tag{2.24}$$

$$\sum U = P_{charging} + P_E \tag{2.25}$$

$$P_D = P_{Hyb} - P_{charging} - P_E - P_{loss} \tag{2.26}$$

When the power demand is high, the excess energy can be compensated for by borrowing from the traditional sources or from the storage reserves.

$$P_D \gg P_{Hyb} \tag{2.27}$$

$$P_{Hyb} + \sum U = P_D \tag{2.28}$$

$$\sum U = P_{discharging} + P_{trad} \tag{2.29}$$

$$P_D = P_{Hyb} + P_{discharging} + P_{trad} - P_{loss} \tag{2.30}$$

$$P_D = P_{total} - P_{loss} \tag{2.31}$$

2.2.4 Costs

The cost parameters are considered for both existing units as well as those of units to be put up [8].

2.2.4.1 Investment cost

The levelized investment cost for putting up the new hybrid power plant can be formulated as shown in equation (2.32).

$$I_{Inv} = \sum_{t=1}^{T} \left(I_{IA} . P_{Hyb} . w_{Hyb} . CF_{Hyb} . h_{Hyb} \right) \tag{2.32}$$

Where t is index representing years of the planning horizon, I_{IA} is the annual investment cost, T is number of years in planning horizon, w_{Hyb} is number of hybrid units required in year t, CF_{Hyb} is capacitor factor of the hybrid power plant, h_{Hyb} is average utilization hours of the hybrid unit and P_{Hyb} is capacity of new hybrid power plant (MW).

2.2.4.2 Cost of Production of Hybrid Unit

Operation and maintenance cost of the hybrid plants to be put up can be shown in the following equations.

$$C_{Hyb} = \sum_{t=1}^{T} \left(O_{Hyb} . P_{Hyb} . CF_{Hyb} . h_{Hyb} \right) \tag{2.33}$$

Where C_{Hyb} is the cost of production of possible hybrid unit to be built, O_{Hyb} is the operation and maintenance cost of the hybrid system, P_{Hyb} is capacity of the new hybrid power plant (MW), CF_{Hyb} is capacitor factor of new power plants and h_{Hyb} is average utilization hours of the hybrid power plants.

2.2.4.3 Cost of Production of Thermal Unit

When renewable energy from the solar and wind power plants is not enough, backup infrastructure of dispatch-able fossil fuel power is required. The total cost of operating a thermal plant can be illustrated in the equation below.

$$C_{thermal} = \sum_{n=1}^{N} \left(C_{fuel} . P_{thermal} CF_{thermal} . h_{thermal} \right) \tag{2.34}$$

Where C_{fuel} is annual fuel cost for thermal power plants in year , $P_{thermal}$ is capacity of thermal power plant (MW), $CF_{thermal}$is capacitor factor of thermal power plants and $h_{thermal}$is average utilization hours of thermal power plants.

2.2.4.4 Cost of Production of Hydro Unit

$$C_{hydro} = \sum_{t=1}^{T} \left(O_{hydro}.P_{hydro}.CF_{hydro}.h_{hydro} \right) \quad (2.35)$$

WhereO_{hydro} is the operation cost of the hydro plant, P_{hydro} is capacity of the hydro power plant (MW), CF_{hydro} is capacitor factor of hydro power plant and h_{hydro} is the average utilization hours of the hydro plant.

2.2.4.5 Total Costs

$$C_{total} = I_{Inv} + C_{thermal} + C_{hydro} + C_{Hyb} \quad (2.36)$$

Where C_{total} is the total cost, I_{Inv} is the investment cost of the new hybrid unit, $C_{thermal}$ is the cost of production of thermal unit, C_{hydro} is cost of production of hydro unit and C_{Hyb} is the cost of production of both solar and wind unit.

The objective function of the mathematical model that minimizes the total cost and maximize social welfare can be formulated as shown [1].

$$min \sum C_{total} = min \sum_{Hyb} I_{Inv} G_{Hyb} + \sum_{so} \sigma_{so} \cdot \left[\sum_{t} C_{thermal} P_{thermal,so} + \sum_{h} C_{hydro} P_{hydro,so} + \sum_{Hyb} C_{Hyb} P_{Hyb,so} \right] \quad (2.37)$$

Where I_{Inv} is the investment cost for hybrid generation unit, G_{Hyb} is generation capacity of new hybrid unit that is possible to be built, σ_{so} is weight of operation condition, $C_{thermal}$ is cost of production of thermal unit, $P_{thermal}$ is power produced by thermal unit, C_{hydro} is the cost of production of hydro unit, P_{hydro} is power produced by hydro unit, C_{Hyb} is cost of production of possible to be built hybrid unit and P_{Hyb} is power produced by new hybrid unit that is possible to be built.

2.2.5 Constraints

Energy Constraint

Balance between energy sold in the market and that produced by all units, both existing and new must be maintained. Type and number of added unit in each stage should be selected so that demand can be met while maximizing profits [7].

$$\sum_{t\epsilon t_b} P_{thermal} + \sum_{h\epsilon h_b} P_{hydro} + \sum_{Hyb\epsilon Hyb_b} P_{Hyb} - \sum_b P_{loss} = \sum_{d\epsilon d_l} L_d \quad (2.38)$$

Where $P_{thermal}$ is power produced by thermal unit t $[MW]$,P_{hydro} is power produced by hydro unit h $[MW]$,P_{Hyb} is the power produced by new hybrid unit that is possible to be build Hyb $[MW]$,L_d is consumption of demand d $[MW]$, P_{loss} is power loss $[MW]$, b is the number of buses, d is demand, h is hydro energy generation units, t is thermal energy production units and Hyb is hybrid energy production unit possible to be build.

Power Production Constraint

The power produced by each generator for both existing and possible ones cannot be higher than their capacity [1].

$$0 \leq P_{thermal} \leq G_{thermal} \quad (2.39)$$

$$0 \leq P_{hydro} \leq G_{hydro} \quad (2.40)$$

$$0 \leq P_w \leq G_w \quad (2.41)$$

$$0 \leq P_s \leq G_s \quad (2.42)$$

Limitation of Construction

The construction time of the generating units which is proportional to their type restricts the number of units selected to build during a planning interval [7]

$$0 \leq N_{i,m}^{u} \leq N_{i,m}^{max} \tag{2.43}$$

Where upper bounds relate to the maximum number of units that can be installed for each technology type, N is the construction time, i is the number of units selected to build and m is types of generation units.

Budget Constraint

The decision making on GENCOs depend on capacity investment on it, forecasted demand market, clearing price and business strategies. This can be illustrated as shown in equation (2.44) [15].

$$Max\ \pi_i = (P - C_i)q_i \tag{2.44}$$

$$P = constant = a\left[\sum_{i=1}^{N_g} q_i\right] \tag{2.45}$$

Where P is market clearing price (MCP),π is profit of GENCO, a is demand coefficient, $constant$ is a known parameter for the market, q is power [MW] produced by GENCO, N_g is number of GENCOs and C is the cost of the GENCO.

Power Generation Constraint

This constraint is formulated to make sure that the generation capacity meets the load requirements of the system [8].

$$\sum_{i\epsilon N}(P_i^N . w_{it} . \rho_N) + \sum_{i\epsilon E}(P_i^E . \rho_E) \geq L_t \tag{2.46}$$

Where P_i^N is capacity of new power plant of type i (MW), w_{it} is number of unit type i required in year t, ρ_N is availability rate of the new generation unit at peak load, P_i^E is the capacity of existing power plant of type i (MW), ρ_E is availability rate of the existing generation unit at peak load.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

In this chapter, various optimization methods are classified in section 3.2. In section 3.3, the methods applied to the problems in section 2.1 are reviewed and their rationale and significance are shown. Their weaknesses are also stated. The strength and weaknesses of the methods are tabulated in a summary table; Table 3.1. In section 3.4, the proposed method is reviewed in details. A pseudocode is also included. Mapping of the problem to the proposed method is illustrated in section 3.5. A summary table, Table 3.2 is included. This table shows the proposed method parameter and the mapped formulated parameter for each case. In section 3.6, the simulation tool is described. In section 3.7, the validation technique is shown. The work-plan and budget are also included in this chapter.

3.2 Classification of Optimization Methods

Optimization is the selection of the best element from a set of some available alternatives. An optimization algorithm is a basic principle of nature which shows many different advantages and disadvantages using computer efficiency and global search. Given an objective function, it takes a number of parameters as its inputs whose goal is to find the combination of parameters and return the best value [22].

Optimization methods can be classified into 3 broad categories:

i. Artificial Intelligence Techniques.
ii. Hybrid Optimization Techniques.
iii. Convectional Optimization Techniques.

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Artificial Intelligence Techniques

These techniques try to simulate human behavior. These methods remember past findings and learn and adapt their performance. They can also plan their own path. They include:

Genetic Algorithm(GA)

It uses the method of natural selection and genetics for obtaining optimal solutions. In GA, multiple solutions called chromosomes are generated. Chromosomes consists of random values or different control variables whose values are to be optimized [7].

Particle Swarm Optimization (PSO)

PSO is an optimization algorithm which provides initial population based on searching algorithm where each particle changes its position according to time It is based on behavior of the flock of birds or school of fish searching for food. A number of particles are randomly generated to form a population. Unlike in GA, the particles are not discarded. The particles move in the multi-dimensional space searching for the optimal solution [24]

Ant Colony Optimization(ACO)

It is based on the foraging technique of real ant colonies. ACO is a population based search where ants search for food which is the optimal solution. ACO was firstly proposed by Marco Dorigo in 1991. ACO is the technique for finding the shortest paths between source to destination, each ant's effort to search a path or route between its nest and a food source. In real world where ants are wander randomly and able to search the shortest path or route between its nest and a food source, when the ants realized that the old path is not best way then they try to find the new shortest path and deposit a certain amount of pheromone trail, other ants follow the path where good amount of pheromone, and this path get more reinforced with more pheromone [24].

Tabu Search(TS)

TS is a kind of neighborhood search. It starts from single point or solution and moves towards the final optimal solution. Initially current solution is randomly selected from which neighbor solutions are chosen and best solution obtained based on objective function [23].

Simulated Annealing(SA)

It is inspired by the process of annealing in metal work involving heating and cooling a material to alter its physical properties. Temperature is the variable in the heating process. When the temperature is high, the algorithm will be allowed to accept solutions worse than the current one. Temperature reduction reduces chances of accepting worse solutions [29].

Differential Evolution(DE)

The Differential Evolution (DE) algorithm is one of the latest evolutionary optimization methods proposed by Storn and Price for complex continuous non-linear functions It is similar to GA except it can efficiently handle the floating point. DE generates a random initial population which then changes and improves through mutation, crossover and selection processes. The selection process and mutation scheme of DE makes it self-adaptive [26]

Hybrid Optimization Techniques

The main motivation for the hybridization of different algorithmic concept is to exploit and combine the advantages of individual strategies. They include:

Hybrid ACO-PSO

The hybrid ACO and PSO is the combination technique of ant colony optimization and particle swarm optimization. To solving enhanced problem, an original and knowledgeable technique swarm intelligence. The ACO and PSO is the two most intelligent algorithm of the swarm intelligence. We deliver a combination of algorithms ACO —PSO. Unlike the traditional ACO-PSO, the new optimization algorithm makes complete use of parameter of both algorithms. In the given algorithm, the PSO is used to enhance the attributes in the ACO, which define that the selection of parameter doesn't depends on artificial experience, but relies on the robust search on the particles in the PSO. We also used an enhance utilization of ACO, by this technique we have found the shortest path or routes of ants [24].

Artificial Bee Colony with Particle Swarm Optimization(ABC-PSO)

Artificial Bee Colony Algorithm is a newly proposed optimization algorithm. Its high probability of avoiding the local optimal make up the disadvantage of Particle Swarm Optimization Algorithm. Particle Swarm Optimization Algorithm is in easy model, which can help us to find out the optimal solution more easily. This hybrid method is better than both standard ABC and PSO.ABC is executed until the terminal criterion is achieved. The best solutions are generated and the best individual solutions are fed to PSO [25].

Dragon Fly Algorithm with Particle Swarm Optimization(DA-PSO)

First, the dragonflies in DA are initialized to explore the search space to find the area of the global solution. Then, the best position of DA is obtained. The obtained best position from DA is then substituted as the global best position in the PSO equation. DA-PSO is better than both standard DA and PSO on speed and convergence. The bench function improves the optimization convergence and overcome local optimum efficiency by introducing good individuals from DA and PSO [27]

Fuzzified Artificial Bee Colony Algorithm (FABC)

ABC is used to locate food resources in a multi-dimensional search space. With each generation cycle, the best result is chosen from the optimal set using fuzzy fitness [28].

Convectional Optimization Techniques

These methods use statistical and mathematical operations to obtain an optimal solution.

They include:

Linear Programming(LP) Method

It a method to achieve the best outcome such as maximum outcome or lowest cost in a mathematical model. It is a technique for optimizing a linear objective function that has linear inequalities [30].

Non-linear Programming(NLP) method

It is an optimization method where some constraints or the objective function are nonlinear [30]

Integer Programming(IP) Method

In this method, all variables are integers. The objective function and the constraints are linear. In the case of 0-1, the unknown constraints are binary [30].

Successive Linear Programming(SLP)

The method is based on solving a sequence of first-order approximations of a model. It is used for solving non-linear optimization problems [30].

3.3 Review of the Methods Applied to the problem

Sima C.A, Lazaroiu G.C, Dumbrava V, Tirsu M and Galbura V used General Algebraic Modeling System(GAMS) optimization is used to introduce network data because it can handle linear and non-linear equations and it has a wide variety of optimization problems. However, this it method does not allow full exploitation of power system properties. It also prohibits application in problems where the inherent inflexibility of modeling language does not allow full exploitation of power system properties [1].

T.R Ballireddy and P.K Modi used particle swarm optimization(PSO) and honey bee mating optimization(HBMO) to solve GEP problem with the aim of minimizing investment cost. PSO is easy to implement and it has easy calculations. It however suffers from partial optimization. HBMO responds better to rapidly changing environment. However, it may miss the optimum and provide a near optimum solution in a limited runtime period [2].

M kendziorski, Setje Eilers M and Kunz F used benders decomposition to solve nested optimization problems. They recalculated the dispatch costs for each scenario with optimal min-max capacity solution. They also used regret minimization technique to minimize the maximum regret of any scenario. Benders decomposition has poor feasibility [3].

Zhan Y, Zheng Q.P, Wang J and Pinson P used linear formulation and quasi-exact methods to solve non-linear optimization and bilinear problems. Linear formulation provides possible and practical solutions However, there is no guarantee to get integer valued solutions and it does not take into consideration the effects of time uncertainty. Quasi-exact method can be used to identify and address threats to validity. In this method, statistical analysis may not be meaningful due to lack of randomization [4].

Mohammad Rasouli and Demosthenis used a forward moving and planned by proceeding forward in time. They considered a time horizon *T* and designed a static expansion block mechanism for generation expansion decisions for the next *T* years. The T horizon static mechanism makes it easy to choose an investment that will bring maximum profits. It also takes into account the GENCOs' information and models the GEP problem's environment over the horizon *T* based on the information available at *t*. However, for a long horizon T, there are high uncertainties about the GEP problem's environment towards the end of the horizon [5].

Shengyu W, Cheng Lu, Y Xiaoqing and Yuan B used Statistical residue load duration curve(S-RLDC) to deal with uncertainties characteristics. The method preserves the simplicity of load duration curve(LCD) method for GEP when covering the probability distribution and confidence level of renewable output. In this method, the convolution of wind and solar power in different domain is used. This method is also used as an estimator in flexible generation capacity in long-term GEP. This method is easy to implement. However, the estimates are not reliable [6].

Sadeghi H, Mohammadian M, Abdollahi A, Rashidinejad M and Mahdavi S.M used Gravitational search algorithm(GSA) which is based on Newtonian law of gravity to solve the problem of penetration of RES. They considered a 6-year optimization horizon to expansion planning. Because of the stochastic nature of GSA, different trials were performed to obtain the best input parameters. This method is chosen because it is easy to implement. It however has slow searching speed [7].

Khan A.Z, Yingyun S and Ashfaq used Genetic Algorithm(GA) to solve GEP problem.GA works by creating a population of possible solutions known as genomes and evaluating the fitness of each genome. GA has does not need derivatives and other information for optimization. It also uses probabilistic transition rules to find the solution. This method does not guarantee optimality. Unit damage of costs was also used to evaluate external costs because it is applicable to both new and old projects. This method is however biased [8].

A summary table showing the strength and weaknesses of the method is explained in Table 3.1.

Table 3. 1: A Summary of Reviewed Methods Showing the Strength and Weaknesses

Method	**Strength**	**Weaknesses**
General Algebraic Modeling System(GAMS)	• Wide variety of optimization problems • Can handle simultaneous linear and non-linear equations systems	• Prohibits application in problems where the inherent inflexibility of modeling language does not allow full exploitation of power system properties.
Particle Swarm Optimization(PSO)	• Has no overlapping and mutation calculation • Calculation in PSO is very simple • PSO is based on intelligence	• Suffers from partial optimization • Cannot work out the problems of scattering and optimization
Honey Bee Mating Optimization(HBMO)	• Responds better to rapidly changing environment • Has high fault tolerance capabilities • Fairly simple to perform the functions	• It may miss the optimum and provide a near optimum solution in a limited runtime period
Benders decomposition	• Has better performance with tighter formulation • Useful for both mixed integer and linear programming.	• Has poor feasibility and optimal cuts • Slow convergence • In certain cases, only the local minima is found

Method	**Strength**	**Weaknesses**
Conditional Value at Risk(CVaR)	• Provides adequate picture of risk reflected in extreme tails • It has a clear engineering interpretation. • It is superior to standard deviation • It is a coherent risk measure	• Has poor out of sample performance • Accuracy of CVAR estimation is heavily affected by accuracy tail modeling
Linear Formulation	• Improves quality of decision by making it more objective than subjective • Provides possible and practical solutions	• There is no guarantee that we will get integer valued solutions • Does not take into consideration the effects of time uncertainty
Quasi-exact method	• Threats to validity can be identified and addresses • Researchers can tailor experiment while still maintaining validity of design • Reactions of test subjects are more likely to be genuine	• Statistical analysis may not be meaningful due to lack of randomization • Human error affects the validity of any project

Method	**Strength**	**Weaknesses**
T-horizon static Mechanism	• Easy to choose the investment that will bring greatest chance of success	• Termination risks can be very high
Wavelet decomposition	• There is no loss of information • There is no phase-shifting of original signal	• Computationally complex for fine analysis • Its discretization is less efficient and natural
Statistical Residue Load Duration Curves(S-RLDC)	• It is easy to understand how change occurs at the load from one hour to another • Provided for relation between load time series of different countries	• The information obtained for more years of loading does not give reliable estimates
Gravitational Search Algorithm(GSA)	• Ease of implementation • Short computation • Higher precision and more consistent result • Capability to escape from local minima	• Complex operation • Long computational time • Slow searching speed in the last iteration
Dose response functions	• Takes uncertainty and variability into account	• Available data may not allow modeling

Method	**Strength**	**Weakness**
	• Can be used to establish reference dose	• Rare effects may occur such a rare malfunction
Unit damage cost	• Applicable for both new and old projects • Encourages development of new techniques for evaluation of social benefits.	• The method of collecting data is biased • There is always a loser in the process • The government is not completely aware of the benefits of the program.

3.4 The Proposed Method

The proposed method is the Bat Algorithm(BA) which is a meta-heuristic optimization algorithm developed by Xin Sha Yang in 2010. This algorithm is inspired by echolocation behavior of bats. Echolocation works as a type of sonar. Micro-bats emit a loud and short sound pulse. After a fraction of time, the echo returns back to the bat ears. The bat receives the echo and locates the position of the prey. Bats are able to distinguish the difference between an obstacle and a prey and this allows them to hunt even in complete darkness [22].

3.4.1 Assumptions

For simulation of the foraging behavior of bats to be done, the biological mechanism of the mechanism must obey some idealized assumptions.

i. All bats use echolocation to sense some distance and they can also tell the difference between food and barrier in the background on some magical way.
ii. All bats fly with velocity V_i at position X_i with a fixed frequency f_{min} ,varying wavelength λ and loudness A_O to search for prey. They can automatically adjust the wavelength or frequency of their emitted pulses and adjust the rate of pulse emission $\gamma\epsilon(0,1)$ depending on how far the target is.
iii. Although the loudness can vary in many ways, it is assumed that it varies from a large positive A_O to a minimum constant value A_{min}.

The algorithm generates a set of solutions randomly then searches the optimal solution by cycle and strengthens the local search in the search process. The local solution near the optimal solution is obtained by random flight. This way, the BA finally finds the global optimal solution

3.4.2 Initialization of Bat Algorithm

The initial population is generated randomly for n number of bats. The foraging space of bats is the d dimension. At time $t-1$, the location and the flight velocity of the i^{th} bat are X_i^{t-1} and V_i^{t-1} respectively. While X_* is the current global optimal location [22].

3.4.3 Updating the frequency and velocity of the bat

At a time t, the velocity position of the i^{th} bird are updated using the following equations.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \tag{3.1}$$

$$V_i^t = V_i^{t-1} + (X_i^{t-1} - X_*)f_i \tag{3.2}$$

$$X_i^t = X_t^{t-1} + V_i^t \tag{3.3}$$

Where f_{min} and f_{max} are minimum and maximum frequency of the sound waves emitted by the bats, respectively. β is a random number conforming to the uniform distribution in [0 1].

When setting up initial values, the frequency of launch sound waves of each bat obeys the uniform distribution in $[f_{min}, f_{max}]$. Their frequencies are first obtained according to equation (3.1). The velocities and positions are then updated according to equations (3.2) and (3.3).

3.3.4 Local search

For the local search, each bat carries out a random walk based on the optimal solution. A new solution is produced as shown in equation (3.4).

$$X_{new} = X_{old} + \varepsilon\bar{A}(t) \tag{3.4}$$

Where ε is a random number obeying the uniform distribution in [1,1], X_{old} is a solution randomly selected from the current optimal solution and $\bar{A}(t)$ is the average loudness for all bats at the t^{th} iteration.

3.4.5 Loudness and pulse emission rate

The update rules of the loudness of pulse emission of the bat A_i and the velocity V_i are described as follows:

If a bat finds a prey, it will reduce its impulse response and increase the velocity of its pulse emission. In BA, the loudness of pulse emission of the bat A_i and velocity V_i are adjusted by the equations (3.5) and (3.6) respectively.

$$A_i^{t+1} = \alpha A_i^t \tag{3.5}$$

$$V_i^{t+1} = V_i^t[1 + e^{\gamma t}] \tag{3.6}$$

Where V_i^0 is the initial velocity and A_i^0 is the initial loudness which are randomly selected. α and γ are constants.

$$\begin{Bmatrix} 0 < \alpha < 1 \\ \gamma > 0 \end{Bmatrix} \tag{3.7}$$

3.4.6 Advantages and disadvantages of Bat Algorithm

3.4.6.1 Advantages

i. Simple, flexible and easy to implement.
ii. Efficiently solves a wide range of problems especially the non-linear problems.
iii. Takes a short time to give the best solution.
iv. Gives reliable optimal solutions.
v. Can be used to solve complicated problems.
vi. The loudness and pulse emissions rates essentially provide a mechanism for automatic control and auto-zooming into the region.

3.4.6.2 Disadvantages

i. Bat algorithm converge very quickly at an early stage and then the convergence rate slows down.
ii. It is a requirement for a large-scale application to be tested.

3.4.7 Pseudocode

i. Initiate assessment of potential sites for solar and wind.
ii. Determine solar and wind parameters that affect the power generated.
iii. Evaluate if the site gives maximum generation. If it does not, go back to step (i).
iv. Improve the existing power systems by integrating wind and solar and storage.
v. Determine the total energy generated.
vi. Determine the uncertainties due to change in supply and demand.
vii. If the demand is met, plan for the optimal power plan.
viii. Check if the optimal plan is cost effective. If it is not, repeat step (vii).
ix. If the cost is minimized, the objective function is achieved.
x. End.

3.5 Mapping of the Problem to the Proposed Method

The problem involves selecting the best site for setting up the hybrid generating unit. The hybrid unit is integrating with existing systems. The integrated system is expected to meet the load demand at minimal costs.

The parameters in the BA are: echolocation, loudness, bat population, frequency and pulse rate.

Echolocation

Echolocation represents the objective function which is to plan for an optimal site to build our hybrid unit. It also involves planning for the power so that it can meet the demand. The prey is the problem. When the bat finally catches the prey, the objective is achieved. This is when minimum costs are incurred.

Loudness

If a bat finds its prey, it will reduce the impulse response and its loudness will decrease. Loudness represents the demand to be met. The higher the power deficit is, the more the loudness. When this deficit is met, the loudness decreases. This loudness vary from A_{min} to A_O.

Bat population

This a set of random solutions. It represents the number of possible sites to choose from to get the best site. In the case of demand and supply, it represents the total number of generation units required to supply power. In our case its 5 generators which comprise of 2 solar generators,1 wind generator, 1 hydro generator and 1 thermal generator.

Frequency

When a bat finds its prey, it increases its pulse emission frequency. The minimum frequency is the minimum power generated from all the generators. The power generated by the hybrid unit is affected by the solar and wind parameters. When minimum power is produced, the profits are minimal since extra costs will be incurred when supplementing for the power deficit. When maximum power is produced, the demand is met and the return profits are maximum.

A summary table showing proposed method parameter and mapping formulated parameter is illustrated in Table 3.2.

Table 3. 2: A Summary of Proposed Method Parameters and Mapped Parameters

	Mapped Parameter				
Proposed Method Parameter	**Solar**	**Wind**	**Improving Existing Power Systems**	**Uncertainties**	**Costs**
Echolocation	Optimal site	Optimal site	Integrating solar and wind into existing power systems.	Meeting the load demand	Minimizing total costs
Loudness	Temperature	Wind velocity	Load demand	Demand	Total costs
Bat population	Possible number of sites to choose from	Possible number of sites to choose from	Total number of units in the power system.	Number of generation units	Number of generation units
f_{max}	Maximum solar radiation	Maximum capacity factor	Maximum power generated by all units	Maximum power that can be supplied	Maximum profits
f_{min}	Minimum solar radiation	Minimum capacity factor	Minimum power generated by all units	Minimum power that can be supplied	Minimum profits

FLOWCHART

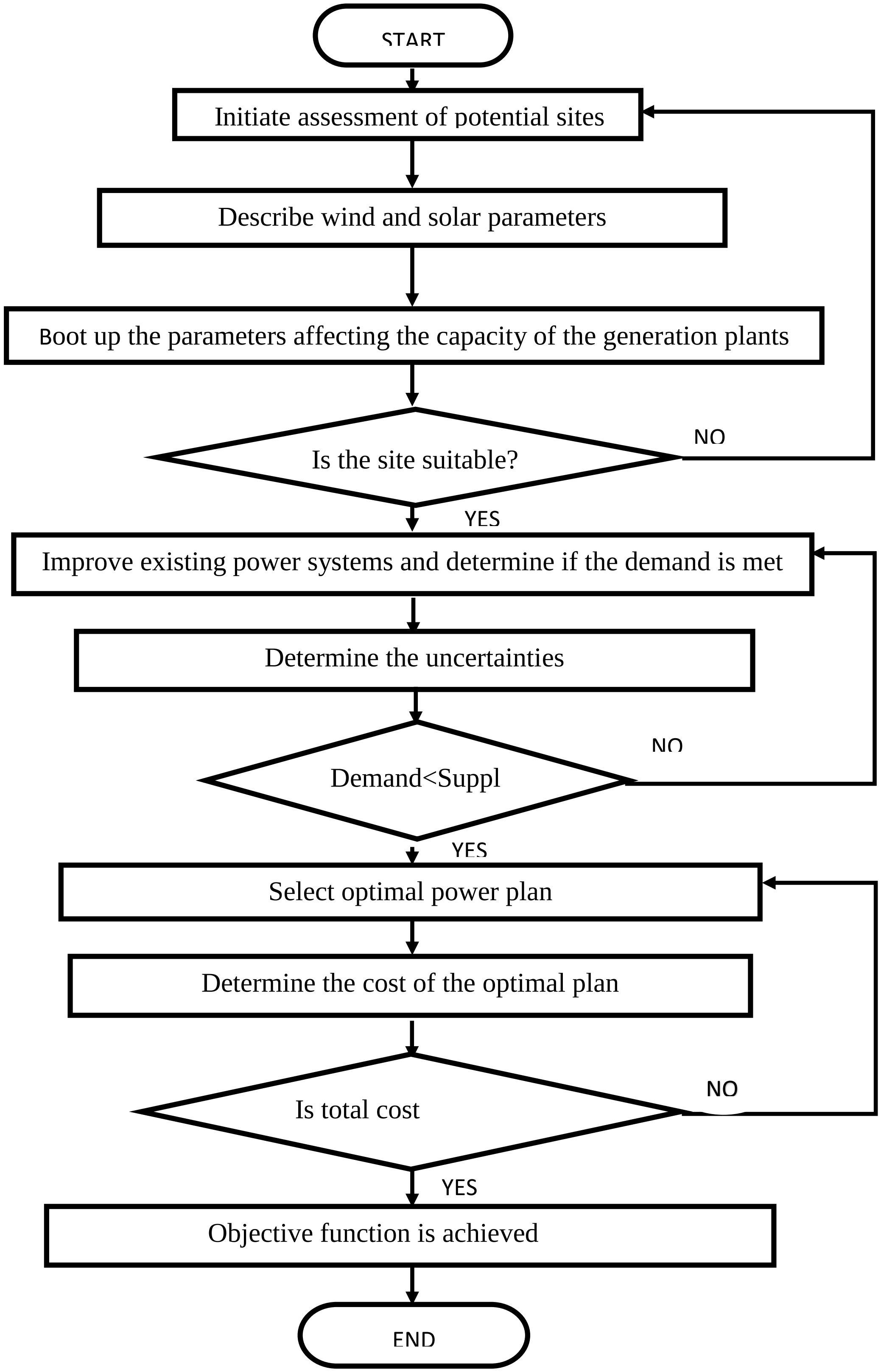


Figure 3. 1: Flowchart for the Pseudocode

3.6 Simulation Tool

MATLAB will used as the simulation tool. The relevant data will be fed to MATLAB determine the optimal plan that minimizes investment cost.

3.7 Validation Technique

The proposed bus technique for test and validation is the IEEE 14-bus consisting of 14 buses,5 generators and 11 loads.

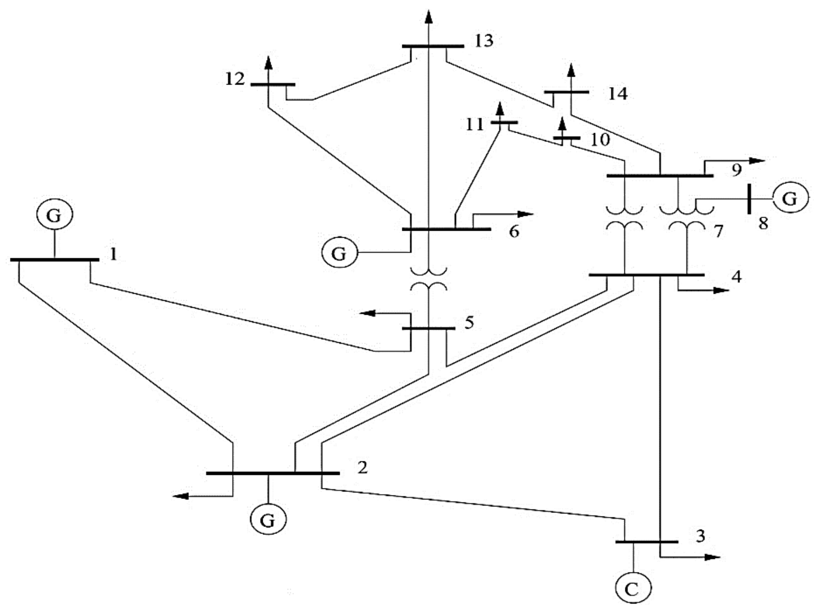
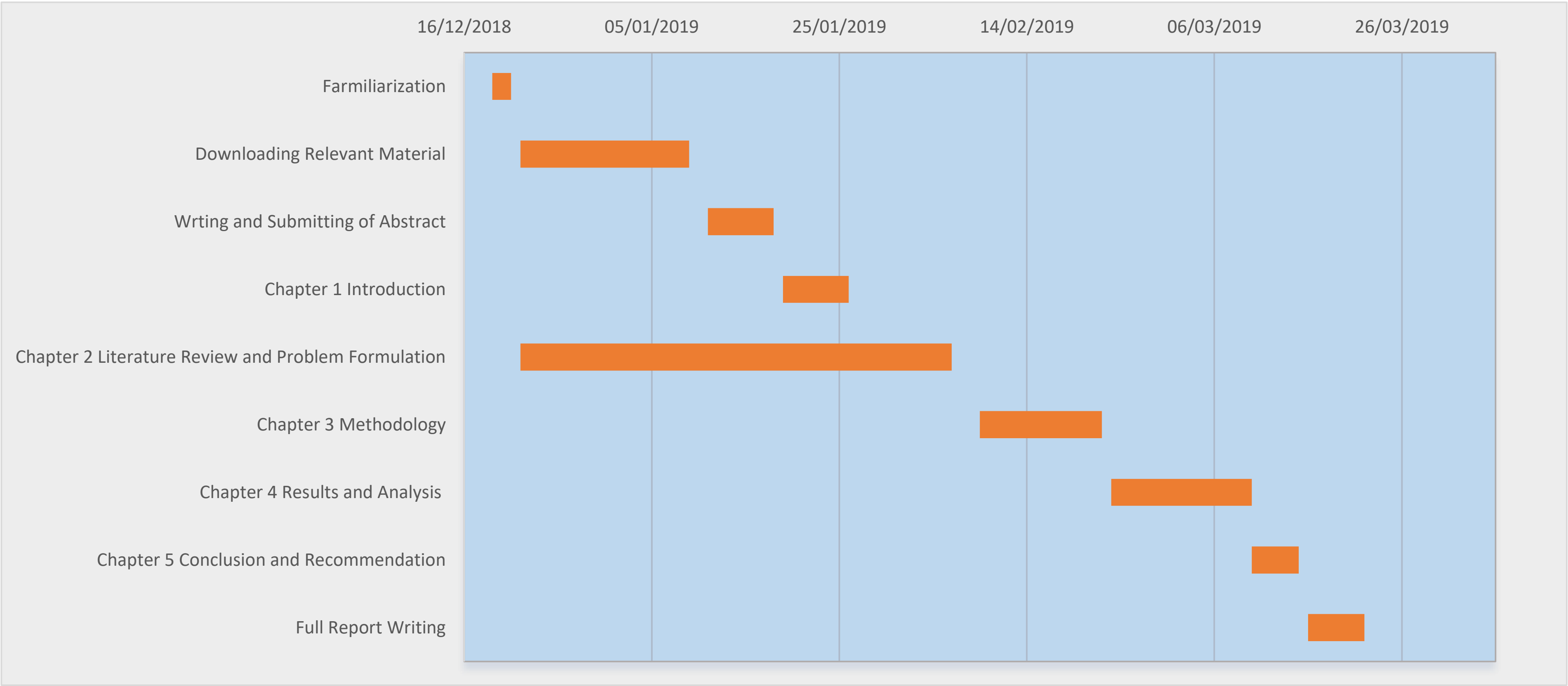


Figure 3. 2: Single line diagram for the IEEE 14-bus system

WORKPLAN

Table 3.3: Workplan



BUDGET

Table 3. 3: Workplan

Item Name	**Quantity**	**Price Per Quantity**	**Price(Ksh)**
Pencils	2	50	100
Pens	4	25	100
Document holder bag	1	200	200
Exercise books	2	75	150
Internet bundles(GB)	40	100	4000
Printing(pages)	300	5	1500
Total(Ksh)			**6050**

CHAPTER 4

4.1 RESULTS

Five generators were used in the simulation. These include 2 thermal generators, 1 hydroelectric generator, 1 solar generator and 1 wind power generator. The results for optimal generation for each generator have been simulated The total load demand ranges from 10MWh to 80 MWh.

The following cases were to be determined:

CASE 1: Assessment of potential sites.

CASE 2: Improving existing power systems using hybrid of solar and wind plus storage.

CASE 3: Uncertainties due to drastic change in generation and demand

CASE 4: The total costs of the integrated system

Bat algorithm was used to find the optimal solution. For the parameters already discussed, the results were demonstrated in the table below. The results are as listed below.

The results for all the five cases are shown in the tables 4.1 to 4.9.

4.1.1 Case 1: Assessment of potential sites

Table 4. 1: Solar Energy in MWh for Various Values of Solar Radiation

Annual Average Rad	Solar Power (MWh)
200	4.18
300	6.28
400	8.37
500	10.46
600	12.56
700	14.65
800	17.75

Table 4. 2: Wind Energy in MWh for Various Values of Wind Velocity

Wind Velocity (m/s)	Wind Power (MWh)
4	0.07
6	0.26
8	0.62
10	1.23
12	2.12
14	3.38
16	5.04
18	7.17
20	9.84
22	13.09
24	17.00

4.1.2 CASE 2: Improving existing power systems using hybrid of solar and wind plus storage.

Table 4. 3: Results for Improving Existing Power Systems

Demand (MWh)	Hybrid plus storage(MWh)	Deficit/ Excess (MWh)	Traditional (MWh)	Export to grid (MWh)
10	30	20	0	20
20	30	10	0	10
30	30	0	10	0
40	30	-10	10	0
50	30	-20	20	0
60	30	-30	30	0
70	30	-40	40	0
80	30	-50	50	0

4.1.3 CASE 3: Uncertainties due to drastic change in generation and demand

Table 4. 4: Results for Drastic Change in Demand

Time of day (hours)	Demand (MWh)	Hybrid (MWh)	Deficit/ Excess (MWh)	Battery charging (MWh)	Battery discharging (MWh)	Traditional (borrow) (MWh)	Sell to grid (MWh)
0000	10	30	20	4.8	0	0	15.2
0200	12	30	18	0	0	0	18
0400	15	30	15	0	0	0	15
0600	30	30	0	0	0	0	0
0800	40	30	-14.8	0	4.8	10	0
1000	10	30	15.2	4.8	0	0	10.4
1200	20	30	10	0	0	0	10
1400	25	30	5	0	0	0	5
1600	28	30	2	0	0	0	2
1800	35	30	-9.8	0	4.8	5	0
2000	40	30	-10	0	0	10	0
2200	15	30	10.2	4.8	0	0	5.4

Table 4. 5: Results for Drastic Change in Generation

Time of day (hours)	Hybrid (MWh)	Demand (MWh)	Deficit/ Excess (MWh)	Battery charging (MWh)	Battery discharging (MWh)	Traditional (borrow) (MWh)	Sell to grid (MWh)
0000	5	20	-15	0	4.8	10.2	0
0200	8	20	-12	0	0	12	0
0400	10	20	-10	0	0	10	0
0600	12	20	-8	0	0	8	0
0800	15	20	-5	0	0	5	0
1000	20	20	0	0	0	0	0
1200	25	20	5	4.8	0	0	0.2
1400	23	20	3	0	0	0	3
1600	18	20	-2	0	2	0	0
1800	10	20	-10	2	0	8	0
2000	5	20	-15	0	0	15	0
2200	20	20	0	0	0	0	0

4.1.4 CASE 4: The total costs of the integrated system

Table 4. 6: Results for Investment Cost for Solar and Wind Hybrid

Demand (MWh)	Solar Investment Cost ($ Millions)	Wind Investment Cost ($ Millions)
10	21.9	28.03
15	32.85	42.08
20	43.8	56.06
25	54.75	70.08
30	65.7	84.09
35	76.65	98.11
40	87.6	112..13

Table 4. 7: Results for Production Cost for Solar, Wind, Hybrid, Thermal and Hydro Units

Demand (MW)	Solar Production cost ($ Millions)	Wind Production cost ($ Millions)	Thermal Production cost ($ Millions)	Hydro Production cost ($ Millions)
10	43.8	70.08	332.88	107.31
15	65.7	105.12	499.32	160.97
20	87.6	140.16	665.76	268.27
25	109.5	175.20	832.20	268.27
30	131.4	210.24	998.64	321.93
35	153.3	245.28	1165.10	375.59
40	175.2	280.32	1331.50	429.24

Table 4. 8: Results for Total Cost for Solar, Wind, Thermal and Hydro Units

Demand (MWh)	Total cost of generation of Solar ($ Millions)	Total cost of generation of Wind ($ Millions)	Total cost of generation of Thermal($ Millions)	Total cost of generation of Hydro($ Millions)	Gross income ($ Millions)
10	67.50	98.11	332.88	107.31	438
15	98.55	147.16	499.32	160.97	657
20	131.40	196.22	665.76	268.27	876
25	164.25	245.20	832.20	268.27	1095
30	197.10	294.43	998.64	321.93	1314
35	229.95	343.39	1165.10	375.59	1533
40	262.80	392.45	1331.50	429.24	1752

Table 4. 9: Results for Total Cost for Solar, Wind, Thermal and Hydro Units

Demand (MWh)	Total Profits From Solar Unit ($ Millions)	Total Profits From Wind Unit ($ Millions)	Total Profits From Hydro Unit ($ Millions)	Total Profits From Thermal Unit ($ Millions)
10	370.50	339.89	330.69	105.12
15	558.45	509.84	496.03	157.68
20	744.60	679.84	607.73	210.24
25	930.75	849.8	826.73	262.80
30	1116.90	1020	992.07	315.36
35	1303.05	1189.61	1157.41	367.90
40	1489.20	1359.55	1322.76	420.50

4.2 ANALYSIS

From the tables in section 4.1 the following graphs were plotted.

4.2.1 Assessment of Potential Sites

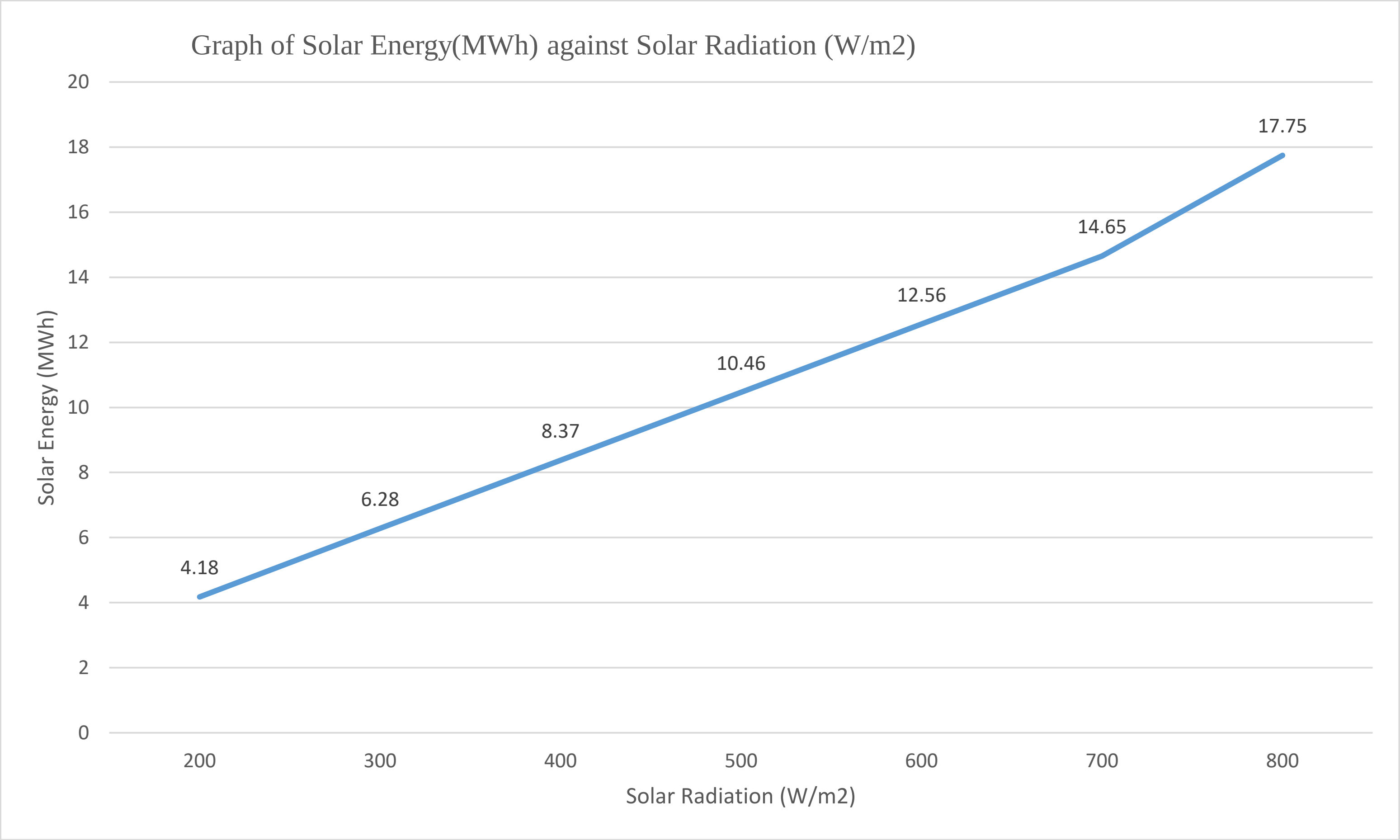


Figure 4. 1 Graph of Solar Energy against Solar Radiation

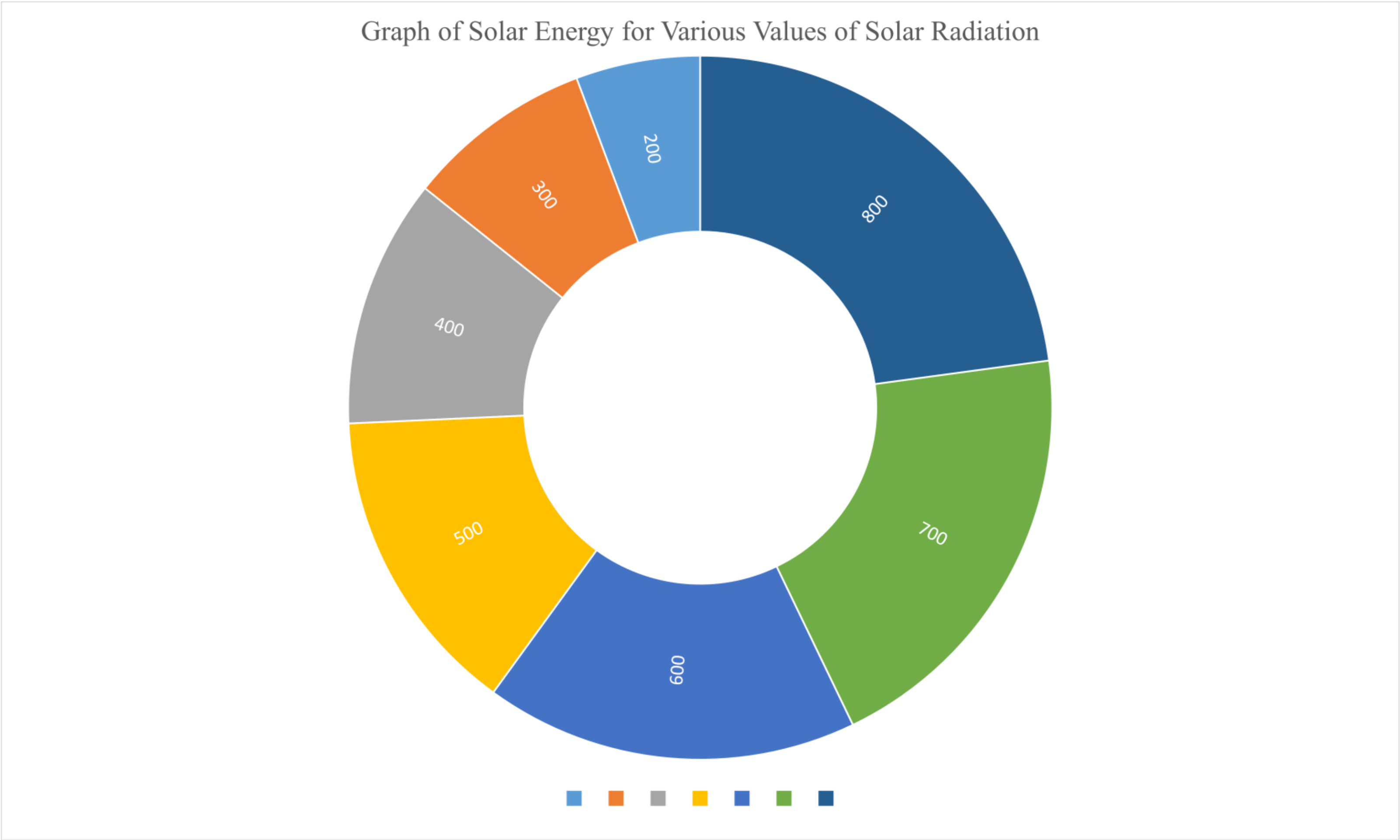


Figure 4. 2: Graph of Solar Energy for Various Solar Radiation

From Fig 4.1 and Fig 4.2, we can conclude that a potential site for setting up a solar farm should have a solar radiation ranging from **500W/m2** to **800W/m2.** To obtain a maximum energy of 17.75MWh, 4000 solar panels are required with an area of 1.62m2 and a rating of 250W.

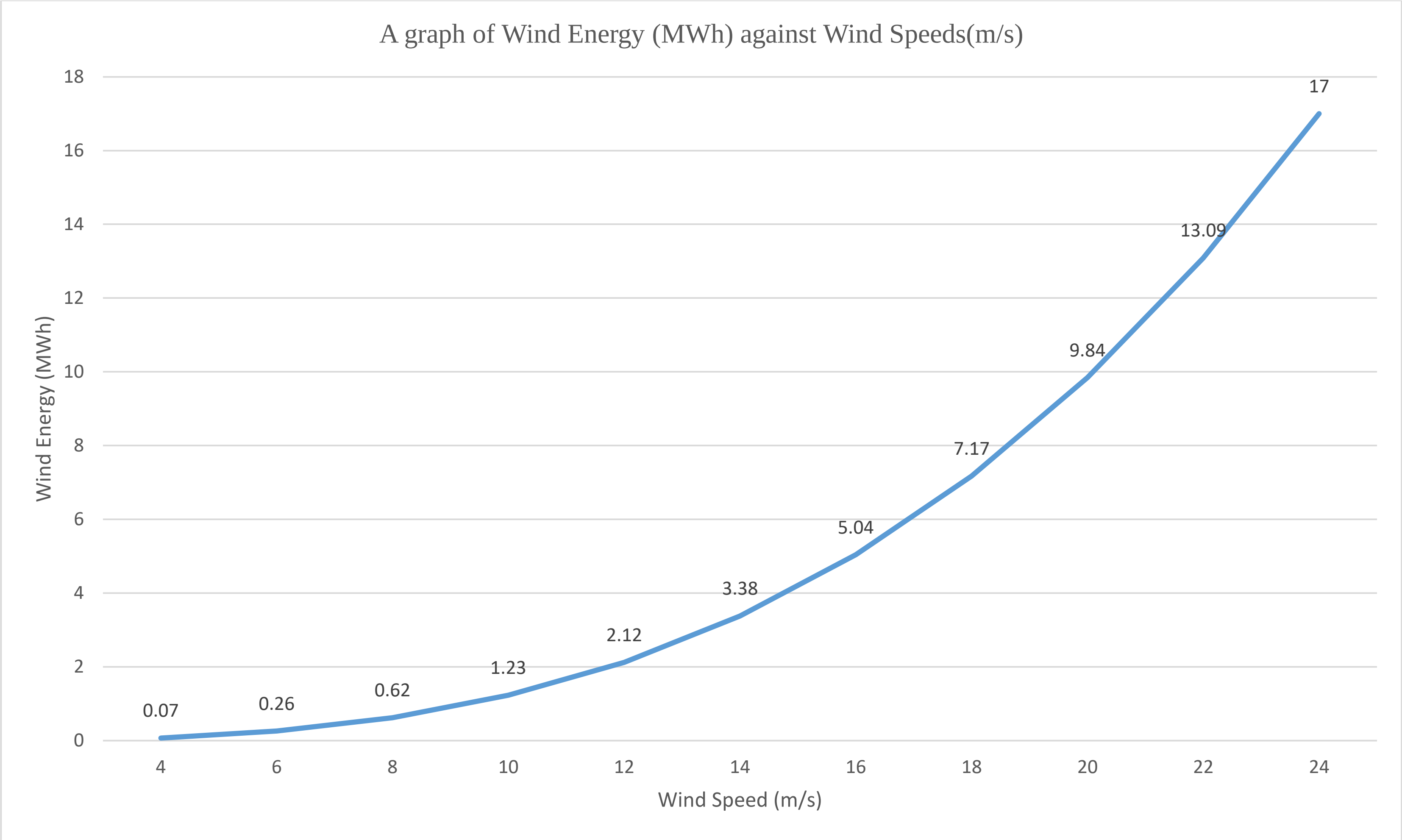


Figure 4. 3: A graph of Wind Power Against Wind Speed

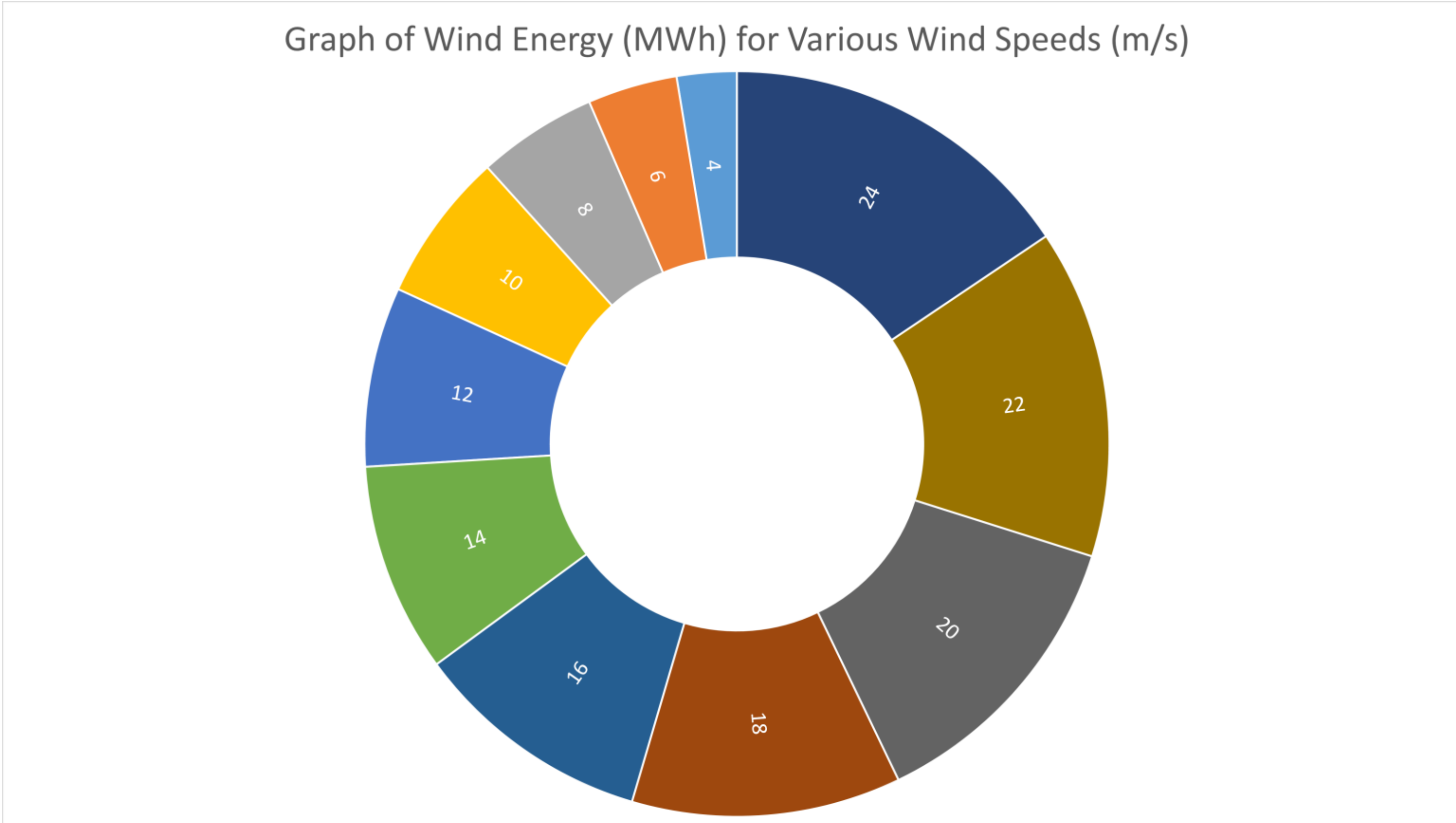


Figure 4. 4:A graph of Wind Energy for Various Wind Speeds

From Figure 4.3 and Figure 4.4, a potential site for setting up a wind farm should have an average wind velocity of between **18 m/s** to **24m/s.** For maximum energy 20 turbines should be used each with a rating of 850kWh.

4.2.2 Improving Existing Power Systems

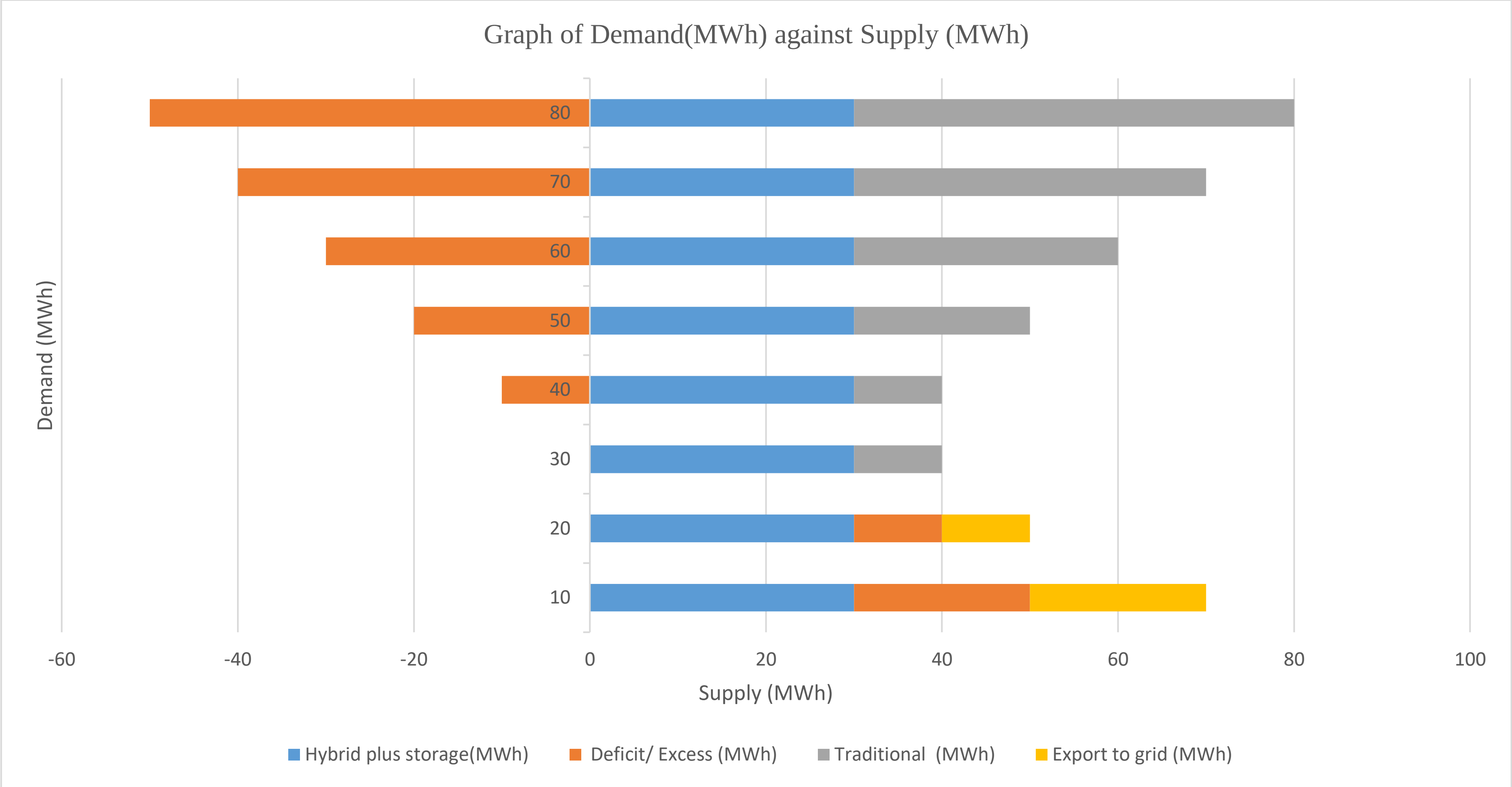


Figure 4. 5: A graph of Wind Energy for Various Wind Speeds

From Figure 4.5, the capacity of the hybrid including the battery storage was taken as 30MWh.Various demands were considered ranging from 10MWh to 80MWh. The hybrid unit was given priority to meet the demand. The existing traditional unit supplied to meet the deficit in demand. When the hybrid unit generated more than the demand, the excess energy was sold to the grid. The solar and wind hybrid and storage improved the existing power system by reducing the cost of energy production since the cost of production of solar and wind is lower than that of producing both hydro and thermal. The cost of production of solar and wind is 0.08$/kWh and 0.08$/kWh respectively. The cost of production of hydro and thermal is 0.07$/kWh and 0.19$/kWh respectively.

4.2.3 Uncertainties

4.2.3.1 Uncertainties Due to Drastic Change in Demand

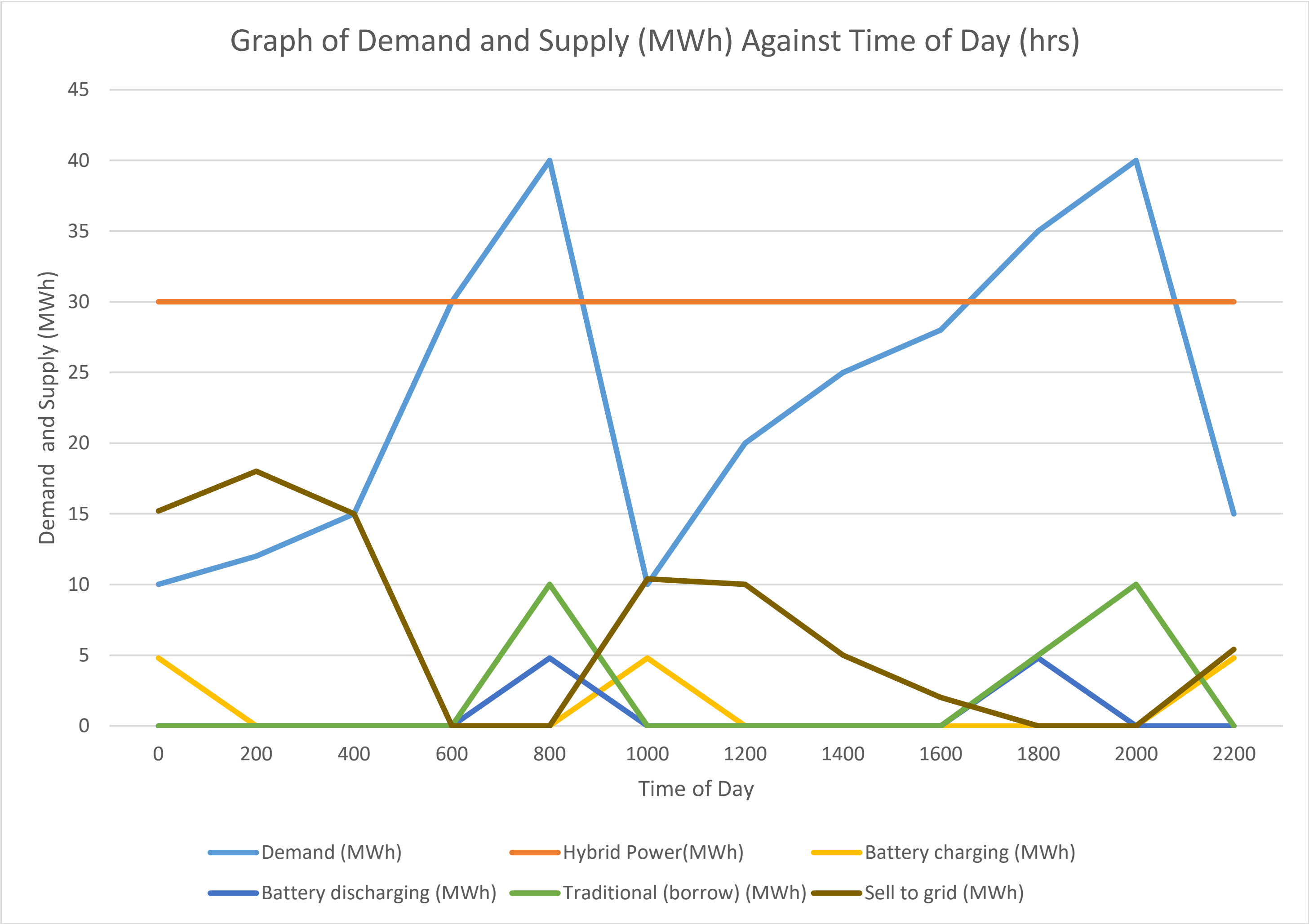


Figure 4. 6 A graph of Demand Against Supply

Figure 4.6 shows a load curve for a day with drastic change in demand. To deal with this uncertainty, the deficit is borrowed from the traditional unit. In the case of over generation from the hybrid unit, the excess is exported to neighboring grids. The supply from the hybrid unit is assumed to be a constant of **30MWh**. The demand is seen to vary drastically from as low as **10MWh** to **40MWh.** The maximum capacity of the storage unit is 4.8MWh consisting of 2000 batteries of 2.4kWh each. The battery is assumed to be fully charged at the beginning of the cycle. Once the battery is full, the remaining energy is sold to the grid. A battery cannot store any more charge once it is full. The storage unit discharges to a minimum of 0.8MWh. Energy is borrowed from the traditional unit if the hybrid and storage unit cannot meet the demand.

4.2.3.2 Uncertainties Due to Drastic Change in Generation

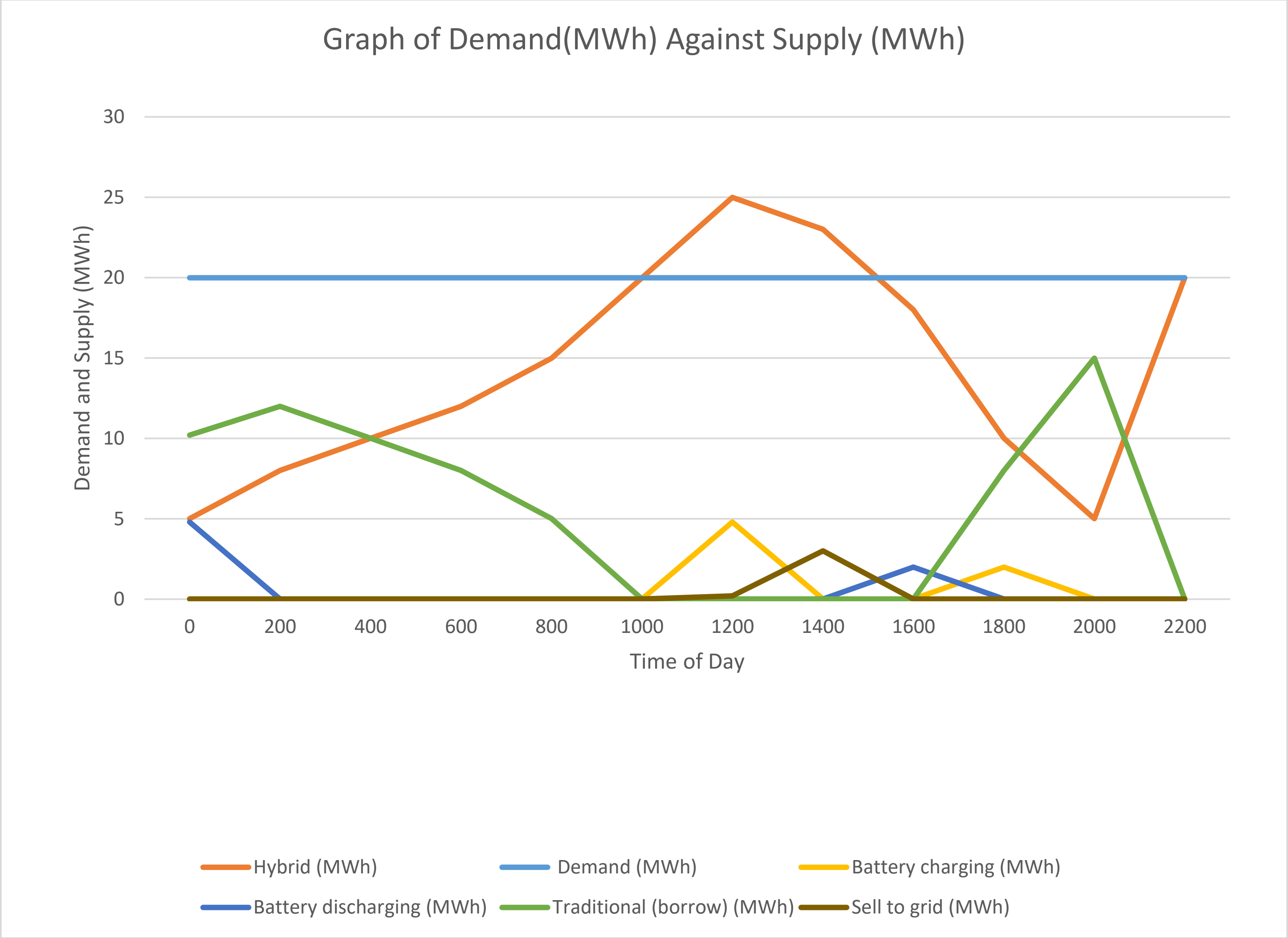


Figure 4. 7: A graph of demand against Supply

In this case, the demand is assumed constant at 30MWh and the generation is seen to vary drastically from 5MWh to 25MWh. When the generation exceeds the demand of 30MWh, the excess energy is stored in the batteries until they are full. If there is any excess after that, it is exported to the neighboring grid. When the generation is less than 30MWh, the deficit is met by discharging the storage unit first. If the demand is still not met after discharging the storage unit, the remaining deficit is met by borrowing from the traditional unit.

4.2.4 Costs

4.2.4.1 Investment cost

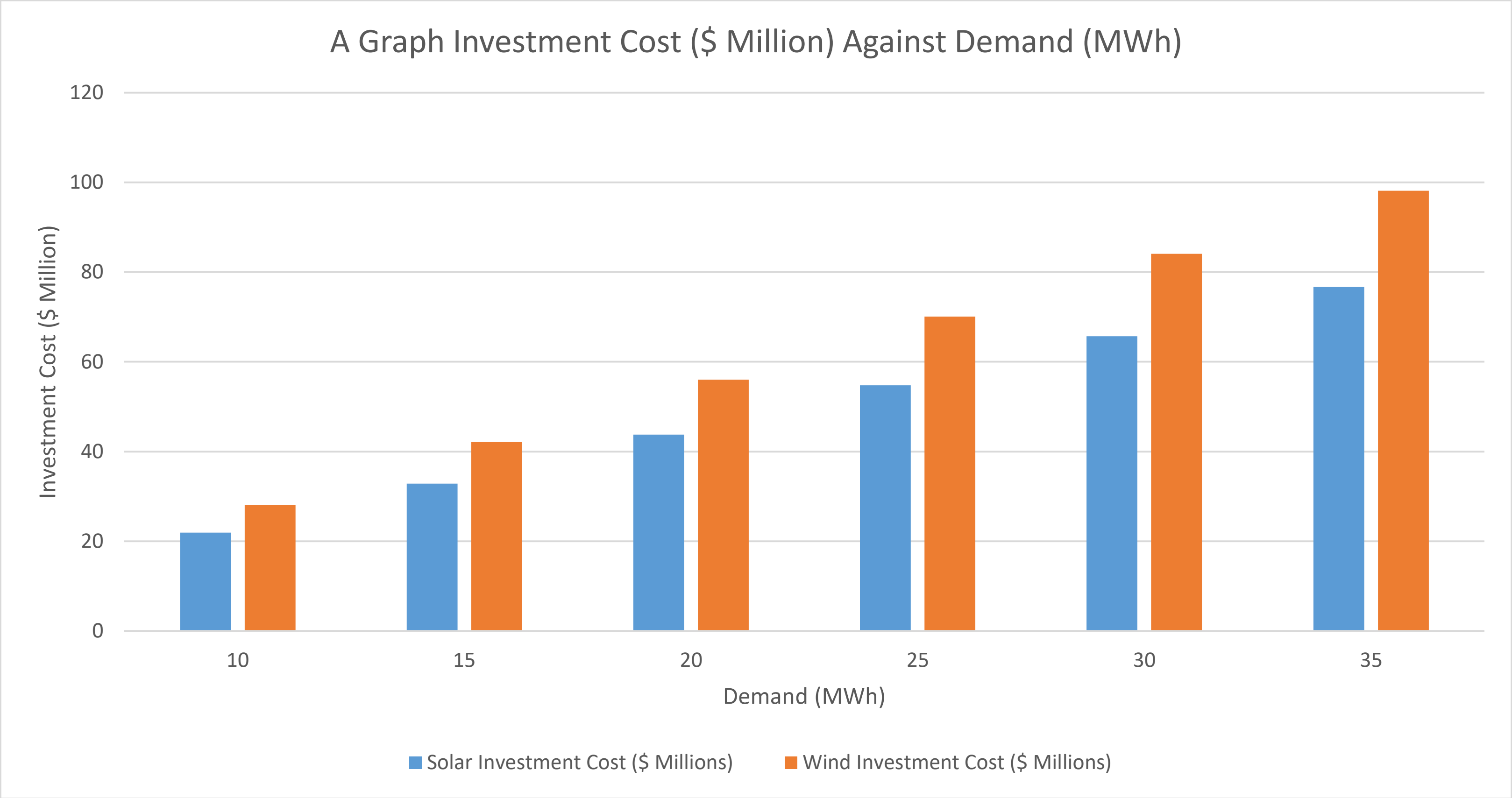


Figure 4. 8: Graph of Solar and Wind Investment Cost Against Plant Capacity

4.2.4.2 Production Costs

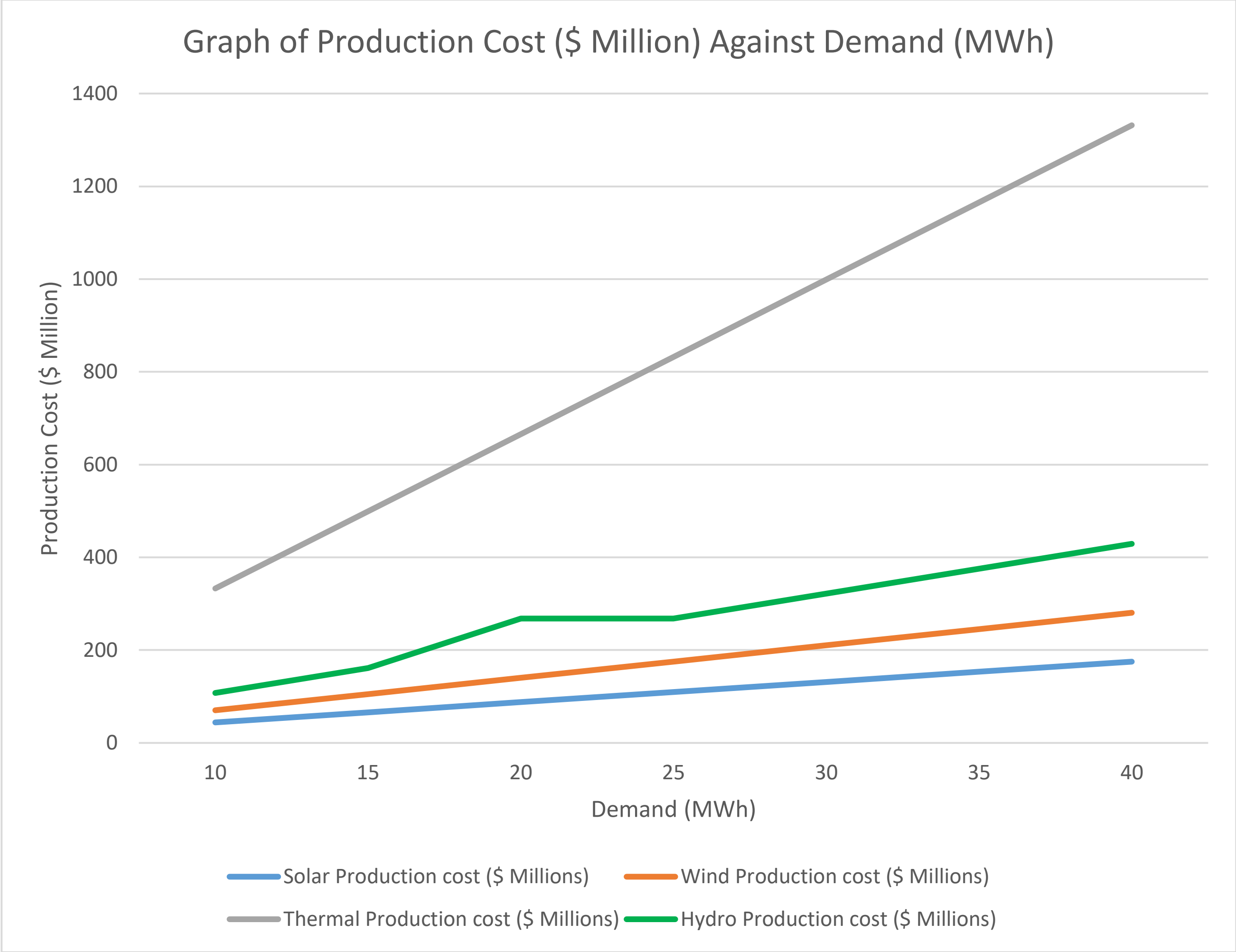


Figure 4. 9: Graph of Production Costs Against Demand

The costs of production are as shown in figure 4.9. Solar, wind and hydro generators have relatively lower operational costs as compared to thermal generators. Thermal generators are used during peak hours when the hybrid unit cannot meet the demand. Even though the cost of production of thermal generators is high, they are easily dispatchable. The cost of production is directly proportional to the demand. In order to minimize the production costs, we can conclude that the renewable energy generators should be given priority over the thermal generators. This condition is only viable if the hybrid unit can actually meet the load demand. If they cannot meet the demand, the traditional generators are used to meet the deficit.

4.2.4.3 Total Costs

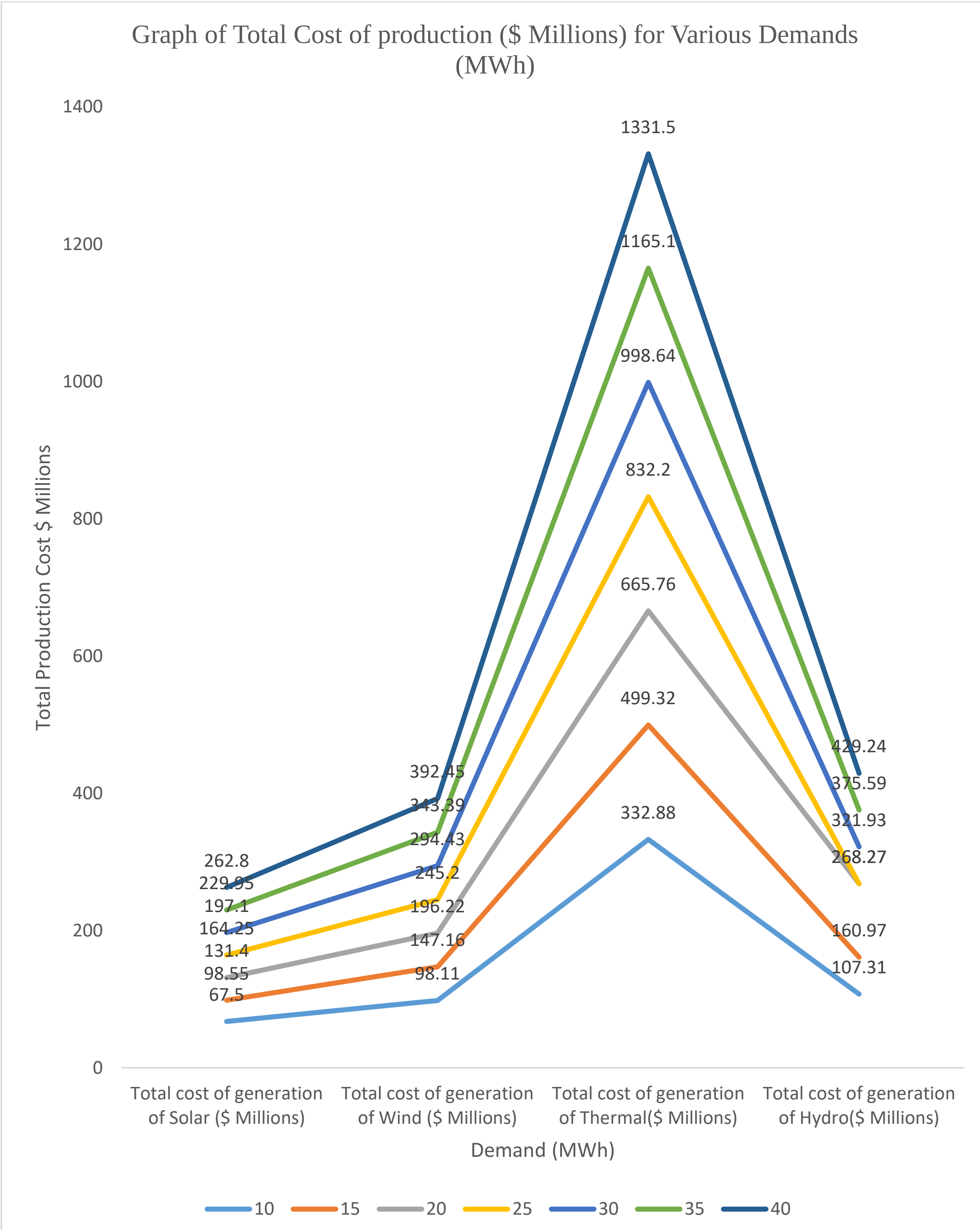


Figure 4. 10:A graph of Total Cost of Generation ($Million) Against Demand(MWh)

he total costs of generation for different generators are shown in figure 4.10. The total costs were considered for a period of 25 years which is the lifespan of our project. The generation costs for solar and wind include both investment and production costs. For a demand of 10MWh, the cost of generation for solar is **67.5$ Million, 98.11$ Million** for wind, **107.31$ Million** for hydro and that of thermal is **332.88$ Million**.

For a demand of 30MWh, the cost of generation of solar is **197.10$ Million**, **294.43$ Million** for wind ,**321.93$ Million** for hydro and **998.64 Million** for thermal generator. The total costs incurred in meeting a demand can be minimized by choosing the plan that has lower generation cost. Solar and wind are integrated into the grid to meet the demand. Due to their intermittent nature, the solar and wind hybrid cannot be relied on fully. Other costs incurred when meeting a demand are the costs of production of the traditional generators

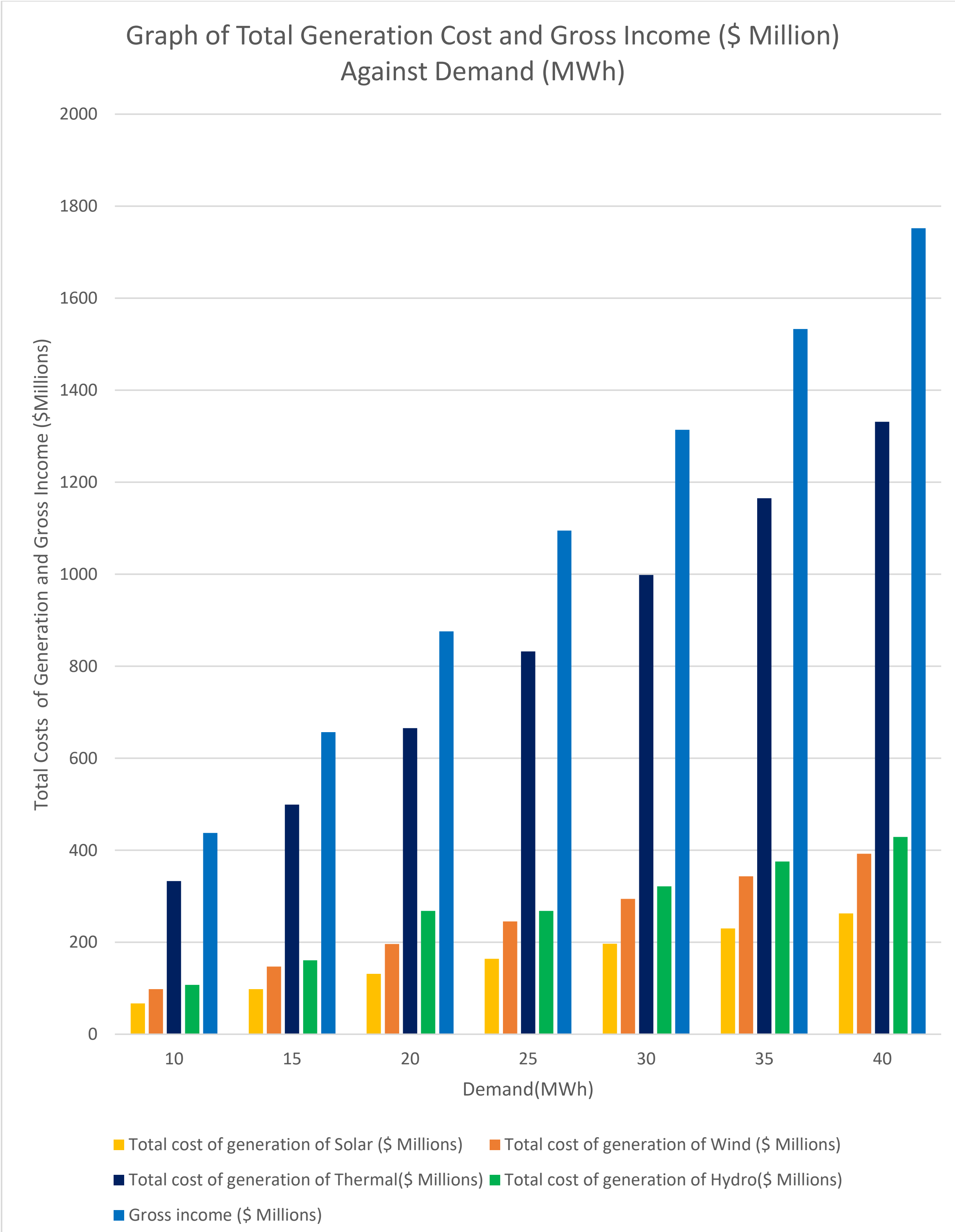


Figure 4. 11: Graph of Total Cost of Generation and Gross Income ($ Million) Against Demand (MWh)

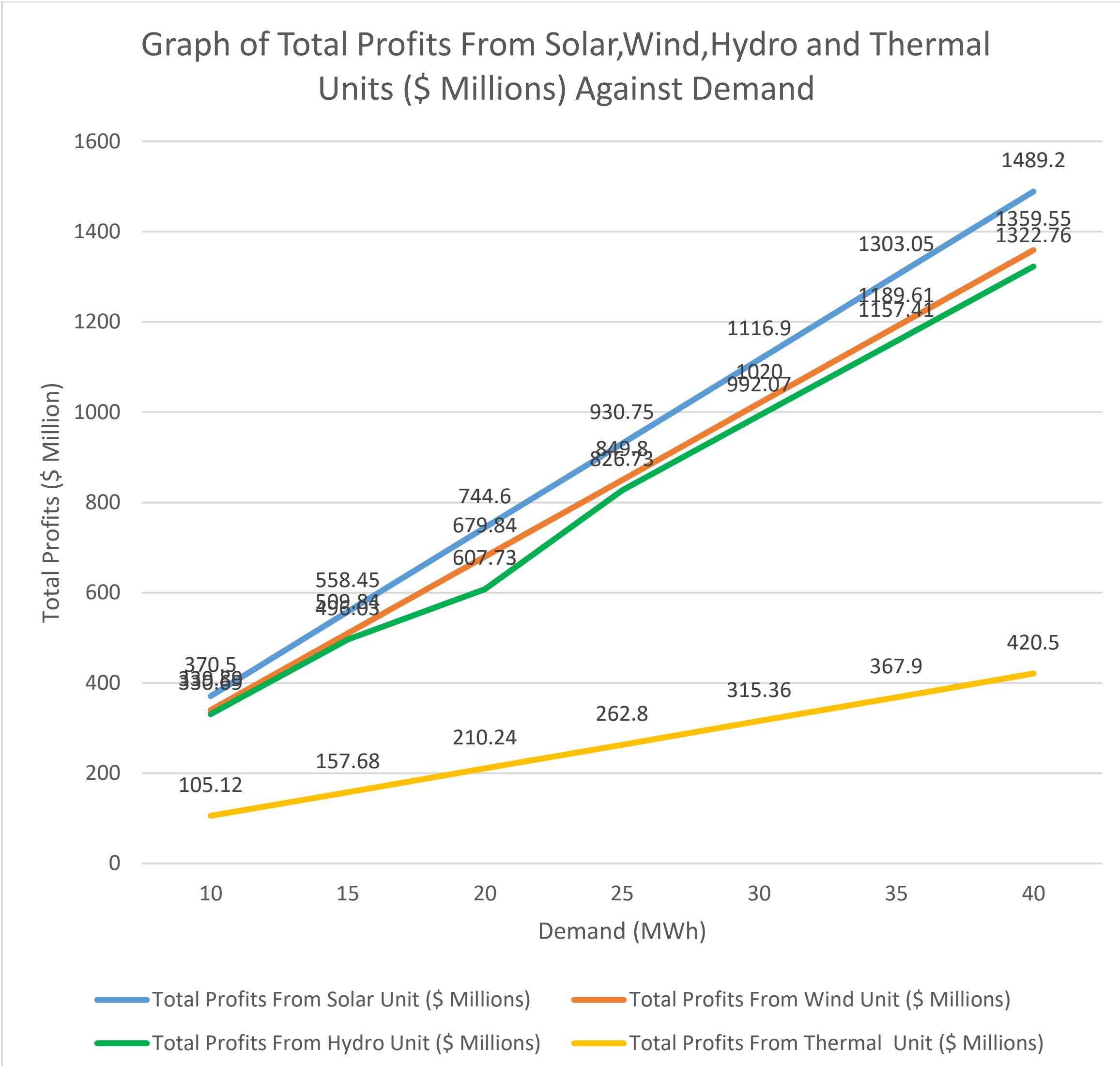


Figure 4. 12:A Graph of Total Cost of Generation and Gross Income ($ Millions) Against Demand (MWh)

In order to encourage investors to build in new units, it is important to establish whether the new unit can meet the demand. The plan must also minimize on costs and maximize on profits. Once the plan meets these objective, the problem of GEP for integrated hybrid of solar and overall objective is to come up with a plan that maximizes and is cost effective by solving the problem of GEP for integrated hybrid of solar and wind.

From figure 4.11 and 4.12, the gross income over a duration of 25 years is higher than the generation cost of any unit for a given demand. From figure 4.13, the profits from the renewable energy generators are much higher than those of those from the thermal unit. In order to maximize on profits, it is advisable to choose the solar and wind hybrid generators over the thermal generator.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The main objective of the project was met since the problem of coming up with a plan that minimizes costs by solving the problem of GEP for integrated solar and wind hybrid was formulated. The location and size of the new generating unit was determined. The best location for a wind generator should have a minimum average speed of between 18m/s and 24 m/s. The best location for solar should have an average solar radiation of between 500 to 800 W/m2. The capacity of both solar and wind generators was 30MW. A hybrid of solar is better than either solar or wind alone. This is because solar power cannot be generated during the night hours and wind power is maximum during night hours. The existing power systems were improved by adding solar and wind hybrid plus battery storage with a capacity of 4.8MWh.

A power system model was formulated to integrate solar and wind hybrid into generation expansion planning. The hybrid was given priority because the cost of production of solar (0.08$/kWh) and wind (0.08$/kWh) is lower than that of hydro(0.07$/kWh) and thermal (0.19$/kW). Thermal and hydro generators are engaged only when the demand cannot be met by the hybrid of solar and wind. Due to the intermittent nature of the renewable sources, we did not consider a standalone system.

From the financials, it is noted that the three major expenses for our system are the costs of the wind turbine, solar modules and the batteries for energy storage. Due to technological advances, the prices of these components are steadily dropping as their efficiencies climb thus improving the viability of such projects. With a payback period of 10 years, the investor is guaranteed of 15 years of profit generation from this system. We can therefore advise investors to invest in new units that are reliable and those that meet the demand. The nature of the power generation method is environmentally friendly and practical implementation of the system can be carried out.

The Bat algorithm was implemented in Matlab while simulating the formulated model. From the results of chapter 4, the simulation was effective.

5.2 RECOMMENDATIONS

Further research has to be done on this subject: "Solar and Wind Hybrid Integration Using Generation Expansion Planning". These include the following:

i. The integration of renewables in the grid should be accompanied by the conversion of the current conventional grid into a smart grid.
ii. Distributed PV and wind generators close to the point of use to mitigate power loss and minimize costs over large solar projects.
iii. Evaluate the cost of switching from solar and wind to grid and vice versa and how the switching affects the stability of the system.

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APPENDIX

Table 4. 10: Datasheet for 250W Solar Panel

Type of Module	250W
Maximum Power	250W
Tolerance	$\pm$ 3%
Open Circuit Voltage	37.8V
Module Efficiency	15.3%
Maximum System Voltage	1000V DC
Dimensions	1650mm * 992mm *40mm
Weight	17kgs

Table 4. 11: Datasheet for 850Kw Wind Turbine

Rated Power	850 kW
Cut-in Speed	4.0 m/s
Rated Wind Speed	14.0m/s
Cut-out Speed	25.0m/s
Survival Wind Speed	60.0m/s

Table 4. 12 Data 4.12: For 5-Generators 14 Bus Bar IEEE System

Generator	**Minimum Power**	**Maximum Power**	**Investment Cost $/kWh**	**Production Cost $/kWh**
Solar	0 MW	18 MW	1000	0.08
Wind	0 MW	18 MW	800	0.08
Hydro	10 MW	30 MW	-	0.07
Thermal	10 MW	20 MW	-	0.19
Thermal	10 MW	20 MW	-	0.19

PROGRAM LISTING

```
clc;

clear all;
close all;

plots_pop_up = 'on';
```

Assign wind variables

```
Cp = 0.5; % Operating efficiency factor
wind_density = 1.23; % kg/m3
turbine_area = 400; % m2
wind_vel = (4:2:24); % 4<velocity=<25
N_turbines=20; %20 turbines with a rating of 850kWh each
```

Assign solar variables

```
annual_av_rad_W= (200:100:800); %annual_av_rad_W
a = 0.11;
k = 0.0047;
A=1.62;
Tr=25; %Room Temperature
T_air=20;
Te=T_air +30;
N_panels=4000; %4000 panels each with a rating of 250W
```

calculate power

```
turbine_power = N_turbines * 0.5 * Cp * wind_density * turbine_area * wind_vel.^3

turbine_power_MW = watts_to_meg(turbine_power);

solar_power = N_panels*250* annual_av_rad_W  * a * A * k*(Te -Tr)+1

solar_power_MW = watts_to_meg(solar_power); %Solar power in MW

turbine_power_MW=turbine_power_MW'; %Wind power in MW
wind_vel=wind_vel';
table1=table(wind_vel,turbine_power_MW)


solar_power_MW=solar_power_MW';
annual_av_rad_W=annual_av_rad_W';
table2=table(annual_av_rad_W,solar_power_MW)
```

```
fig1 = figure('Visible', plots_pop_up);
% plot wind pow againt velocity
plot(wind_vel,turbine_power_MW,':','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',7);
% set a title and key (legend) for the figure
title('Graph of Wind Turbine Power against Wind Velocity');
legend('Wind Turbine Power','Location','southeast');
%label axes
xlabel('Wind Velocity (m/s)');  % x-axis label
ylabel('Wind Turbine Power (MW)'); % y-axis label
grid on;                        %enable grid on the graph
%saveas(fig1,'images\turbine_power_MW.png');  % saves the graph to file


fig2 = figure('Visible', plots_pop_up);
% plot wind pow againt velocity
plot(annual_av_rad_W,solar_power_MW,':','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',7);
% set a title and key (legend) for the figure
title('Graph of Solar Power against Solar Annual Average Radiation');
legend('Solar Power','Location','southeast');
%label axes
xlabel(' Annual Average Solar Radiation (W/m2)');  % x-axis label
ylabel('Solar Power (MW)'); % y-axis label
grid on;                        %enable grid on the graph
%saveas(fig2,'images\anual_av_rad_W.png');    % saves the graph to file

% Initializing bat parameters
function [best_r_mtx_1, best_col_mrx_2, best_value] = process_data(r_mtx_1, col_mrx_2, 
input_power)
    best_value = max(max(input_power));
    [R,C] = find(input_power==best_value, 1);

    best_col_mrx_2 = col_mrx_2(R);
    best_r_mtx_1 = r_mtx_1(C);
end

function out_y = watts_to_meg(val_x)
    out_y = val_x./1000000;
end

function out_y = kilo_to_watts(val_x)
    out_y = val_x*1000;
end

function out_y = watts_to_kilo(val_x)
    out_y = val_x./1000;
end
```

```
clc;

clear all;
close all;
```

Assign variables

```
P_loss = 0;

p_limit_thermal = [10 20];

p_limit_hydro = [10 30];

batery_max = 4.8;
```

drastic change in demand

```
P_demand_values = (10:10:80);

P_deficit = zeros;

P_generation = zeros;

batery_pow = zeros;

borrow_sell = zeros;

for value = 1:numel(P_demand_values)% looping through P_demand

    %
[best_wind_velocity,best_wind_Cp,best_wind_power,best_solar_power,best_anual_av_rad] =
sites();
    P_hybrid_MW = 30;
    % P_hybrid_MW = best_wind_power + best_solar_power;
    P_generation(value) = P_hybrid_MW
    pow_demand = P_demand_values(value)
    if pow_demand >= 0
        deficit_pow = P_hybrid_MW - pow_demand - P_loss
        if deficit_pow < 0
            % -ve deficit | 1. borrow from battery | 2. borrow from grid
            if abs(deficit_pow) < batery_pow(value)
                % borrow from batt
                what_to_borrow = deficit_pow
                batery_pow(value) = batery_pow(value) - what_to_borrow
```

```
            else
                % borrow max from batt
                what_to_borrow = batery_pow(value)
                batery_pow(value) = batery_pow(value) - what_to_borrow
                % borrow remainde from grid
                deficit_pow = deficit_pow - what_to_borrow
            end
        else
            % +ve deficit | 1. take to battery | 2. sell to grid
            if deficit_pow < batery_pow(value)
                % store to bat
                what_to_store = batery_max - batery_pow(value)
                batery_pow(value) = batery_pow(value) + what_to_store
            else
                % fill batt
                what_to_store = batery_max - batery_pow(value)
                batery_pow(value) = batery_pow(value) + what_to_store
                % sell to grid
                deficit_pow = deficit_pow - what_to_store
            end
        end
        borrow_sell(value) = deficit_pow;
        batery_pow(value+1) = batery_pow(value);
        P_deficit(value) = deficit_pow;

    else
        disp('Invalid! negative Demand value')
    end
end
batery_pow(end)=[];

borrow_or_sell = borrow_sell';
batery_stored_pow = batery_pow';
Power_generation = P_generation';
Power_demand_values = P_demand_values';
Power_deficit = P_deficit';

demand_Table =
table(Power_demand_values,Power_generation,Power_deficit,batery_stored_pow,borrow_or_s
ell)
clear all;% to clear the workspace
clc;% to clear all previous commands

%%solar parameters
Ia=1000;   %Annual investment cost for solar farm
P_solar_values = (10:5:40); %Capacity of solar generator in KW
Cf_solar=0.25; % Capacity factor of solar generator
h_solar=8760;   % average utilization hours
O_solar=0.08; % Cost of producing 1kW of solar energy in $
```

```
%%wind parameters
Ib=800;   %Annual investment cost for wind farm
P_wind_values = (10:5:40); %Capacity of solar generator in KW
Cf_wind=0.4; % Capacity factor of solar generator
h_wind=8760; %average utilization hours
O_wind=0.08;  % Cost of producing 1KW of wind energy in $

%%Thermal parameters
C_fuel=0.19;  %Cost of producing 1KW of thermal energy in $
P_thermal=(10:5:40); %Capacity factor of hydro generator
Cf_thermal=0.8; %Capacity factor of hydro generator
h_thermal=8760; % average utilization hours from two hours to 24 hours in steps of 2
%Hydro parameters
O_hydro=0.07;   %Cost of producing 1MW of hydro energy in $
P_hydro=(10:5:40);   %Capacity of hydro generator in MW
Cf_hydro=0.7;  % Capacity factor of hydro generator
h_hydro=8760;  %  average utilization hours from two hours to 24 hrs in steps of 2

P_demands1 = (10:5:40);
P_demands2 = (10:5:40);
P_demands3 = (10:5:40);
plots_pop_up = 'on';
%Investment costs
solar_investment_cost = Ia *P_solar_values *Cf_solar * h_solar *1.0e-06;

wind_investment_cost = Ib * P_wind_values *Cf_wind *h_wind *1.0e-06;

hybrid_investment_cost=solar_investment_cost+wind_investment_cost;

% Cost of production of solar,wind,hybrid,thermal and hydro units for 25 years

solar_prod_cost =O_solar * P_solar_values * Cf_solar * h_solar*25 *1.0e-03;

wind_prod_cost =O_wind * P_wind_values * Cf_wind * h_wind*25 * 1.0e-03;

hybrid_prod_cost = solar_prod_cost + wind_prod_cost;

hydro_prod_cost =O_hydro * P_hydro * Cf_hydro * h_hydro*25 *1.0e-03;

thermal_prod_cost =C_fuel * P_thermal * Cf_thermal * h_thermal*25 *1.0e-03;


%Investment costs
P_demands1 =P_demands1';
solar_investment_cost=solar_investment_cost'
wind_investment_cost=wind_investment_cost'
hybrid_investment_cost=hybrid_investment_cost'
Table1 =
table(P_demands1,solar_investment_cost,wind_investment_cost,hybrid_investment_cost)
```

```
%Total_production_costs
P_demands2 =P_demands2';
hybrid_prod_cost=hybrid_prod_cost'
thermal_prod_cost =thermal_prod_cost'
hydro_prod_cost = hydro_prod_cost'
Table2 = table(P_demands2,hybrid_prod_cost,thermal_prod_cost,hydro_prod_cost)


%Total costs
P_demands3=P_demands3';
solar_investment_cost=solar_investment_cost;
solar_prod_cost=solar_prod_cost';
wind_investment_cost=wind_investment_cost;
wind_prod_cost=wind_prod_cost';
Table3 =
table(P_demands2,solar_investment_cost,solar_prod_cost,wind_investment_cost,wind_prod_
cost)

%%Plots of investment cost against demand
fig7 = figure('Visible', plots_pop_up);
% plot wind pow againt velocity
plot(P_demands1,wind_investment_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',7);
hold on
plot(P_demands1,solar_investment_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',7);

% set a title and key (legend) for the figure
title('Graph of investment costs against demand');
legend('wind_investment_cost','solar_investment_cost','Location','southeast');
%label axes
xlabel('Demand(MW)');  % x-axis label
ylabel('Wind and solar and hybrid investment cost(M$)  '); % y-axis label
grid on;                   %enable grid on the graph
saveas(fig7,'images\hybrid_power_MW.png');    % saves the graph to file



%%Plots of Production costs against demand
fig8 = figure('Visible', plots_pop_up);
% plot wind pow againt velocity
plot(P_demands2,hybrid_prod_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','y','MarkerSize',7);
hold on
plot(P_demands2,hydro_prod_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',7);
hold on
plot(P_demands2,thermal_prod_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','m','MarkerSize',7);
hold on
```

```
plot(P_demands2,solar_prod_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',7);
hold on
plot(P_demands2,wind_prod_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',7);


% set a title and key (legend) for the figure
title('Graph of production costs in million dollars against demand');
legend('wind_prod_cost','solar_prod_cost','hydro_prod_cost','thermal_prod_cost','Locat
ion','northwest');
%label axes
xlabel('Demand(MW)');  % x-axis label
ylabel('Production cost(M$)  '); % y-axis label
grid on;                    %enable grid on the graph
saveas(fig8,'images\hybrid_power_MW.png');    % saves the graph to file

fig9 = figure('Visible', plots_pop_up);
% plot wind pow againt velocity
plot(P_demands1,Total_wind_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','b','MarkerSize',7);
hold on
plot(P_demands1,Total_solar_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','g','MarkerSize',7);
hold on
plot(P_demands1,Total_hybrid_cost,'--ro','LineWidth',2,...
    'MarkerEdgeColor','k','MarkerFaceColor','r','MarkerSize',7);

% set a title and key (legend) for the figure
title('Graph of total costs in million dollars against demand');
legend('Total_wind_cost','Total_solar_cost','Total_hybrid_cost','Location','southeast'
);
%label axes
xlabel('Demand(MW)'); % x-axis label
ylabel('Total cost(M$)  '); % y-axis label
grid on; %enable grid on the graph
saveas(fig9,'images\hybrid_power_M
```