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MODELING, SIMULATION, AND TECHNO-ECONOMIC ANALYSIS OF A VIRTUAL POWER PLANT: A CASE STUDY IN THE PERSPECTIVE OF BANGLADESH

by

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A thesis

submitted as partial fulfillment of the requirement for the degree of

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CERTIFICATE OF APPROVAL

The thesis entitled as "**Modeling, Simulation, and Techno-economic Analysis of a Virtual Power Plant: A Case Study in the Perspective of Bangladesh.**" submitted by **Khaled Arju**, bearing Matric ID. **ET-163018** and **Borhan Uddin**, bearing Matric ID. **ET-163023** of session **Spring 2020**, to the Department of Electrical and Electronic Engineering, International Islamic University Chittagong, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Bachelor of Science in Engineering and approved for the examination held on **28th May 2021** .

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DECLARATION

It is hereby declared that this work has been done by us and no portion of the work contained in this thesis has been submitted elsewhere for the award of any degree or diploma.

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Borhan Uddin

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Authors

ABSTRACT

Bangladesh is a developing country and it's population density is about 1265 per square kilometer. In comparison to all other energy sources, fossil fuels account for the majority of electricity production in Bangladesh. Due to the lacking of smart distribution of energy, the country unable to meets with proper demand of electricity. So this paper has been taken virtual power plant (VPP) to develop smart energy distribution system in the country. The concept of a virtual power plant (VPP) has arisen in order to control distributed generation and improve its exposure in power markets, also it can qualify the sharing of those renewable energy resources to electricity market. A series of distributed generators (DGs), Energy Storage Systems (ESSs), and regulated loads that are compiled and then operated by an energy management system (EMS) called a virtual power plant (VPP). Just like any other developing countries, Bangladesh is also facing a major power crisis. We have to think economically because of our limited resources. We know that virtual power plant is playing an important role in American & European electricity markets .By using information and communication technology(ICT), distributed generation units, active users, and energy storage can be linked and aggregated into an intelligent plant network. This makes fresh trading opportunities as well as prospects for frequency management in the energy industry, stability of the power supply grid and voltage. Moreover, through the market-oriented integration of clean energy and efficient technology through VPP, greenhouse gas emissions can be reduced effectively. This thesis represents the conception & types of virtual power plant (VPP). The simulation of this model for IIUC describes that the developed system in this thesis is capable of sharing power to the grid. The VPP model & simulation of the curves displayed by using MATLAB- SIMULINK. This thesis mentions three DG control unit which is controlled by auto control system (ACS). Also the total harmonic distortion analysis on various signal of VPP has been figured out in this paper. Finally, this thesis has been tried to set up a discussion about the techno-economic analysis of the proposed VPP that has been designed in the perspectives of IIUC. The per kWh cost reduction by this system is about 45.32 million Taka annually which is 53% of total cost. So this will make a great contribution to the power sector of Bangladesh.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

DER	Distributed Energy Resources
RE	Renewable Energy
ACS	Auto Control System
CHP	Combined Heat and Power
VPP	Virtual Power Plant
DG	Distributed Generation
DGC	Distributed Generation Center
IEA	International Energy Agency
ESS	Energy Storage System
EMS	Energy Management System
ICT	Information & Communication Technology
OECD	Organization for Economic Cooperation and Development
GHG	Green House Gas
CCC	Control Coordination Center
PSMP	Power System Master Plan
SCADA	Supervisory Control & Data Acquisition
TDMA	Time Division Multiple Access
ADDC	Area Distribution DispatchCenter
RES	Renewable Energy Sources
HTG	Hydraulic Turbine & Governor
CHP	Combined Heat and Power
FY	Fiscal Year

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter describes an introduction and the current state of virtual power plant research are defined. In this chapter, the research background, motivation, and objectives are also illustrated.

1.2 Background

Traditional power grids are primarily focused on large central power stations that are linked to high-voltage transmission networks and then provide power by medium and low-voltage delivery systems to end users. For decades, such an overall image of one direction of power flow has not been changed. These has been presented with following characteristics -

- Comparatively poor energy efficiency: it accounts for almost 60% of primary energy Lost during generation, transmission, and distribution in the form of heat [1].
- Generation located in a very clustered area: this contains a large high degree of concentration. In order to preserve the security supply.
- Quite high level of emissions: fossil-fuel power plants satisfy much of the power requirements demand and are responsible for a significant proportion of carbon dioxide emissions.

A significant number of Distributed Generations (DGs) have recently appeared in the power grid to supplement the previous method of supplying power. Firstly, the total energy loss via the transmission system is significantly minimized as they are installed closer to the end consumers. Moreover, DG's implementation typically postpones the need for grid renewal [2]. Since several DG units are either powered by renewable resources such as wind or have much higher energy efficiencies such as combined heat and power plants (CHPs), it is widely accepted that DG penetration growth can make a big difference to sustainable development.The trend in the advancement of DG technology persists today and the sizes are much smaller for many DG devices, making them ideal for either residential use or small commercial applications. These DG technologies are referred to as DER those are typically less than 250KW, alongside small-scale active demand and energy storage technologies.While the DER offers considerable advantages, certain problems emerge along with the ever-increasing amount of units deployed. For instance, as the generation capacity of one region with a number of DERs exceeds local demand, the power flow can reverse. Not only does such reverse power flow threaten traditional protection systems, but it can also result in connectivity.It is vital to know that microgrid and VPP are two of the desirable technical strategies that provide synchronization and aggregation for the DER, among many revolutionary paradigms that promote the convergence of the DER.The microgrid is characterized by [8] DER and multiple electrical loads. It can act as a single independent system linked to or "isolated" from the current power grid of the utility. Whereas the VPP is a "Internet of Energy" built on the basis of advanced ICT, without a firm concept yet. Actually, all the generation assets, demand side and network assets are handled by a Microgrid within it, while a VPP is only responsible for the generation assets. However, since both definitions have one essential aspect in common: the capacity to aggregate the DER at the stage of delivery, a VPP may also be used as microgrids cluster.In exchange, microgrid may also have several VPP-like entities operating under its preselected operating schemes.

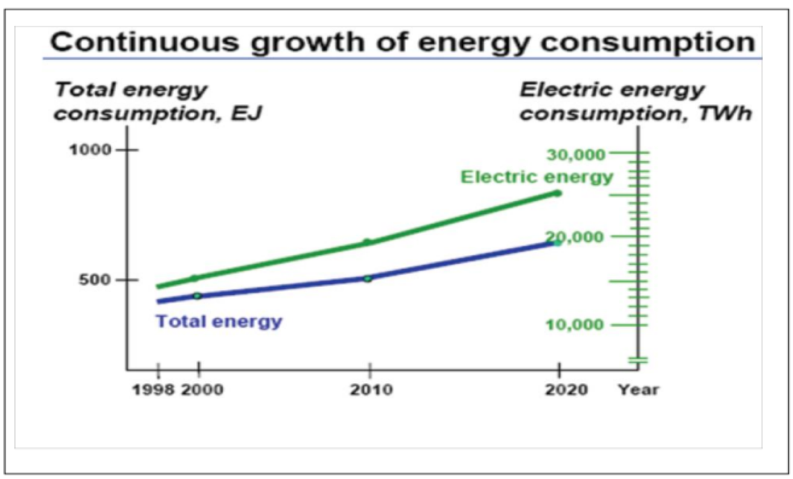


Fig. 1.1 Continuous energy consumption growth [3]

The need for electrical power never ceases as seen in **Fig. 1.1**. For the past few decades, the abundance of resources has changed the course of mankind. Not only were new energy sources unlocked-first fossil oil, followed by nuclear, hydropower and now other renewable technologies-but also in the amount that we can generate and consume.We need to move fast away from them to low-carbon sources because three-quarters of global greenhouse gases come from electricity, the combustion of coal, oil and gas. Although we continue to add more renewables, fossil fuels already account for the bulk of the world's electricity. 84% of it in 2019. This is seen in the **Fig. 1.2** that includes a source-by-source overview of the global energy mix.Low-carbon energy, about 11 percent from renewables and just over 4% from nuclear energy, accounted for just 16%. Other renewable energy resources includes geothermal, wave & tidal. It doesn't include traditional biomass which can be a key energy sources in lower income setting [4].

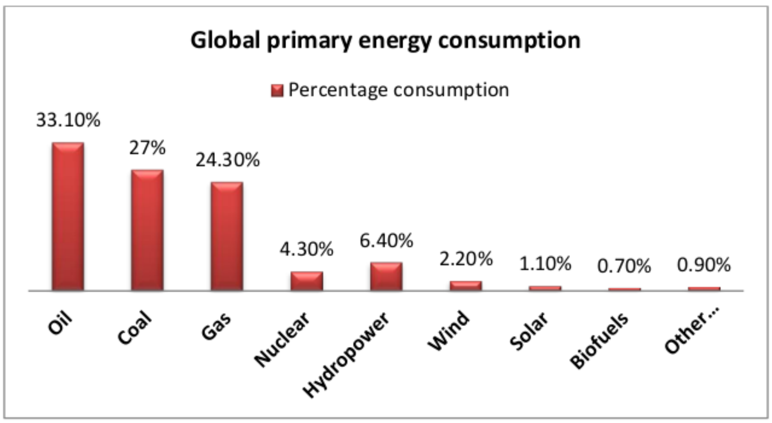


Fig. 1.2 Global primary energy consumption scenario

In 2018, global CO_2 emissions from fuel combustion hit a record peak of 33.5 $GtCO_2$, fuelled by robust population growth and economic development. Though displaying a small decrease (less than 1%) in 2019, primarily due to the power sector in advanced economies and milder continental weather conditions.

1.3 Motivation

The IEA in International Energy Outlook 2019 Reference case projects that from 2018 to 2050, global energy-related CO2 emissions will rise 0.6 percent per year. Future forecast growth in energy-related CO2 emissions, though, is not uniformly spread across the world: comparatively developing countries collectively have little growth in emissions. All the predicted potential increase in energy-related CO2 emissions is also part of a community of countries outside the Organization for Economic Cooperation and Development (OECD) shown in **Fig. 1.3**. Renewable energy technologies are now reducing GHG emissions from the energy industry, but on a small scale. Most long-term energy forecasts indicate that renewable energy will play a key role in global energy production in the mid 20th century, with capacity rising steadily over the first 3 decades.

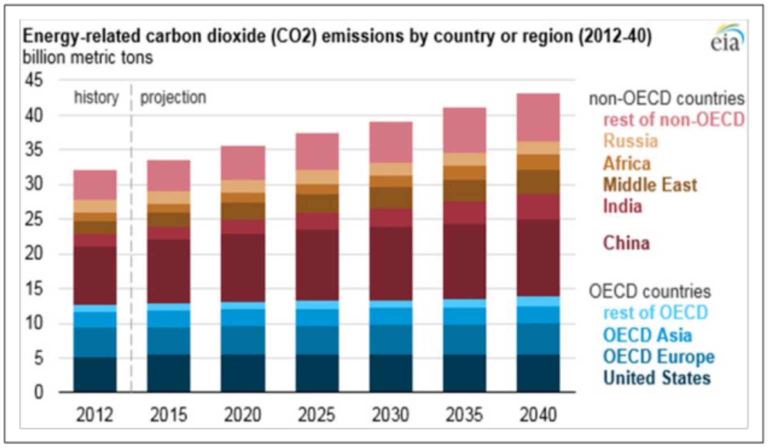


Fig. 1.3 Proposed increase in CO_2 emissions led by countries [5]

The study of the role of renewable energy in a carbon-restricted environment was presented [6].

The results based on the study are as follows:

- Global demand for electricity will continue to rise, growing by about 60% by 2030, unless significant steps are taken to improve energy production and reduce total energy consumption.
- In the coming decades, the supremacy of fossil fuels in existing energy sources will not inevitably change until renewable energy becomes more efficient in terms of quality. The most serious climate change risks will be minimized by restricting global warming to 2^{o}C over pre-industrial levels.Only substantial long-term emission reductions from several diverse and mixed choices, including wider markets for renewable energies, performance upgrades and cleaner fossil fuels, will accomplish this pace [6].

In different applications, small-scale power generation technologies, such as microhydro, photovoltaic, wind turbine and micro-turbine, are increasingly replacing traditional technologies.They are referred to as distributed generation (DG), DG technology is also grouped with distributed storage, and their mixture is referred to as distribution energy resources (DER) describing a compact power generation or consumer site built at storage.Dispersed generation, a subset of DER, leads to smaller generating systems typically located at consumer sites and separated from a utility grid [3].Many policymakers have embraced renewable sources of electricity. For environmental concerns, and the competitiveness for generation forced by the modernization of the energy sector, the production of DG technologies and their grid connections have been moved forward [7]. In addition, the confluence of globalization with modern telecommunications and information technology has streamlined new possibilities and distributed generation integration. This situation will directly affect the conventional/traditional positions of utilities as energy providers and customers as electricity consumers to transform quickly and the power grid system will be more complex.

In contrast, new technologies such as micro-grids and virtual power plants (VPP) have arisen for the penetration/deployment of DER at major grids. These principles are fundamentally new approaches for designing and running power systems and thus have the potential to deliver the high efficiency, reliability, stability and electrical service availability demanded by the developing digital society [8] . Coordination and aggregation control of DG units may ideally include reinforcing distribution networks, a heterogeneous generation structure, also decentralized dispatching and distribution of energy system in the future.That's the idea of a virtual power plant concept.

This paper represents the concept and types of virtual power plant and displays the simulation results with the control of distributed generation unit which is operated parallel with the main grid systems. To replace conventional power plant with greater efficiency & more reliability the virtual power plant (VPP) can be a great solution.

1.4 Research objectives

The objectives of this paper are given below-

- To model and simulation of the virtual power plant.
- To analyze the behavior of voltage, current,and power sharing between the VPP and main grid.
- To analyze the THD for various signals and Techno-economic analysis for the proposed model.
- To analyze the challenges and opportunities for using VPP in Bangladesh.

1.5 Thesis Outline

This thesis includes-

Chapter 1: This chapter describes an introduction and the current state of virtual power plant research are defined. In this chapter, the research inspiration and goals are also illustrated.

Chapter 2: A brief overview of previous work specific to our field is defined in this chapter. We also have identified a gap in analysis and provide a description of the work process.

Chapter 3: This chapter offers a brief idea of the virtual power plant. Also virtual power plant types as well as the ideal components that can be used to built a VPP for IIUC and other preliminaries. In this chapter also tried to find about the opportunities & challenges of VPP in the context of Bangladesh for more effective distribution of energy services.

Chapter 4: This chapter explains about the developing of virtual power plant model in the perspectives of IIUC. Here the model components of simulation of a virtual power plant has been done in the Matlab Simulink environment. Virtual power plant component modeling is divided into four major components: the main grid model, the distributed generation model, the dynamic load model and the measurement unit.

Chapter 5 : The findings of our proposed model for IIUC are briefly discussed in this chapter. This chapter has also shown about the power sharing of DGC with main grid in our proposed model.

Chapter 6 : This chapter has shown the techno-economic analysis of virtual power plant for IIUC by analyzing different parameters of cost effective calculations.

Chapter 7: The thesis is concluded in this chapter and the scope for future study is illustrated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A brief overview of the thesis work and related literature is mentioned in this chapter. First of all, previous studies that contribute to our sector have been discussed. Then, we attempted to identify the research gap and provide a description of the current work process.

2.2 Previous Research work

It has been an interesting subject since the progress of technology & communication infrastructure and has been studied by various researchers.In our study, we reviewed many recent virtual power plant related literature. There has been some work associated with the virtual power plant power delivery and management.

According to Dulau and his partners in [9], the key features of distributed generation (DG) and virtual power plants (VPP)are described .Lombardi & his group had introduced and debated in [10] about the concept and architecture of a complex virtual power plant (VPP).Their focus was aimed at the optimization of the VPP structure as well as its optimum operation. In [11] Pudjianto, Danny and his group proposed that a VPP has been created in order to improve awareness and regulation of DERs by providing an effective interface between these system components for system operators and other market participants. In [12] Naina, K.S. Swarup and their group explained the structure of VPP and also the participation of the market. An algorithm for VPP's energy control is also clarified. But their research had limited into two DG unit. Das, M. M. Islam and their group in [13] discussed about the virtual power plant can be a remedy to power crisis in Bangladesh.Fadli and his group in [14] had explained that the virtual power plant is a promising solution, especially when it comes to energy storage and transportation. According to their study they had proposed that driven by a single energy generator, VPP extracts energy from geothermal fuel, water, sun, wind and so on. The generated electricity is processed and assigned to many units. VPP has been widely introduced in the United States, Australia, Canada, and Japan. Their study was aimed to examine potential possibilities and obstacles for the successful delivery of energy resources through the use of VPP technology in order to realize the principle of sustainable energy. In [15] Mohamed and his companions investigated by considering distribution network limitations, the participation of a virtual power plant (VPP) containing distributed energy resources (DER) in the electricity sector.They also assumed that the virtual power plant operator has the maximum controllability and observability of traditional generators and renewable energy resources (RES) located within the VPP. Their goal was to optimize the profits of the VPP by refining its bidding strategy for the wholesale energy market.

2.3 Research Gap

From the literature described above, most of them neglect the use of more distributed generation center-based VPP architecture. In addition, most of them wanted to find out about VPP's viability & market presence, but by using various forms of distributed generation center, they ignored the power sharing functionality with grid. The THD analysis of a simulated power plant model was also not extracted from their analysis.

2.4 Summary of Present Work

In this thesis, we have found that the suggested virtual power plant model is capable of sharing power with the grid. They attempted to analyze the compatibility of the virtual power plant using single or double DGC from the previous work carried out by various researchers. We have tried three distributed generation centers from here that demonstrate properly the electricity transaction with the grid. It is noteworthy that as much as DGC used to develop VPP, it will allow the national grid to exchange more electricity. The most-looked area in this work was the power sharing of VPP with this proposed model. Techno-economic analysis of this proposed VPP for IIUC has been analyzed in this paper. THD analysis for virtual power plants is still incomplete. So we have tried to do something to analyze about the THD for virtual power plant. The total work of the modeling and simulation of VPP was done by using MATLAB-SIMULINK. In a developing country like Bangladesh, there are some challenges & chances to build a virtual power plant to reduce the power crisis. We also tried to set up a discuss about the opportunities & challenges for using VPP in Bangladesh perspectives.

CHAPTER 3

VIRTUAL POWER PLANT

3.1 Introduction

This chapter offers a brief idea of the virtual power plant. Also virtual power plant types as well as the ideal components that can be used to built a VPP for IIUC and other preliminaries. In this chapter also tried to find about the opportunities & challenges of VPP in the context of Bangladesh for more effective distribution of energy services.

3.2 Definition of virtual power plant

The roots of the word "Virtual Power Plant (VPP)" can be traced all the way back to 1997, when Dr. Shimon Awerbuch, within his book "The Virtual Utility: Emerging Industry Accounting, Technology& Competitive Aspects," interpreted the virtual utility as: The Virtual Utility (VU) identified as the establishment of flexible cooperation amongst public utilities. It helps individual participants to provide consumers with highly effective power service by digitally exchanging their private assets, which not only increases the quality of individual use, but also prevents redundant construction. The VPP principle focuses on virtual integration of DERs to extend the original idea of virtual utility, which mostly relies on the statistical combination of various energy resource cost curves [16].There are so many related ideas by many researchers andprogramme in Europe given below –

- Through their pilot project, Unna public utilities corporation and EUS GmbH Germany has been defined the virtual power plant as an overall monitored aggregation of DERs at different locations, if needed, in the distribution networks of various network operators [17].
- Koeppel (Nov 2003) wrote that VPP is defined as combining various types of renewable &non renewable generators as well as storage devices min terms of being able to come to the market like one power plant with specified hourly output or separate power generation and storage equipment, generators and storage devices with various limitations (e.g. stochastic output) and strengths (e.g. high energy short-term capacity) are mixed in order to cleverly multiply them [18].

- European Union (EU) programme of Virtual Fuel Cell Power Plant which is funded by the many electrical & gas companies , and defined as a community of interlinked decentralized residential micro CHP (Combined Heat & Power) using fuel cell technology, built in multi-family residences, small businesses and public facilities, etc., for individual heating, cooling and energy generation [19].
- Virtual Power Plant (VPP) termed as a smart grid system used to gather all power plant modules for service in a single power source capable of monitoring and controlling electrical currents back to multiple power units according to need. With both fossil fuels and clean energy options, the Virtual Power Plant will work well. In short, VPP functions by handling and organizing electric currents from the generator, regulating and restoring the power needed [20].
- "The definition of VPP in the FENIX project is reffered as: "A Virtual Power Plant (VPP) aggregates the power of several different DERs, produces a single operating profile from a combination of parameters that define each DER and can integrate the network's effect on the performance of aggregate DERs. A VPP seems to be a flexible image of a DER portfolio that can be used to create wholesale business contracts and to deliver servicesto the programmer of the machine [21].

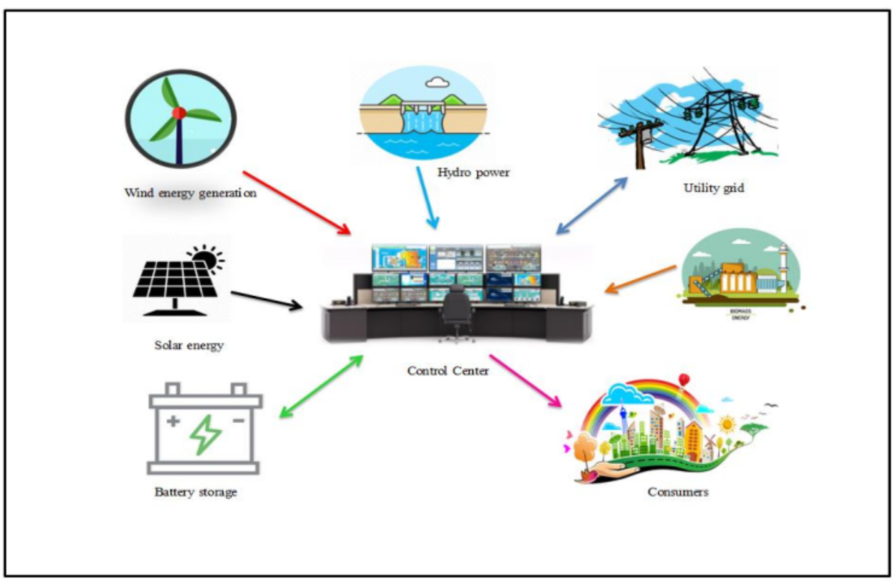


Fig. 3.1 Conception of virtual power plant

By analyzing all the proper definitions from different reviewers or researchers we can give a statement by **Fig. 3.1** about the definition of VPP from our point of view which describes that- a virtual power plant is a cluster of wind turbines, solar farms, combined heat and power (CHP) units, and considered flexible customers and storage facilities for localized, medium-scale power generation units. The integrated units are dispatched via the Virtual Power Plant's central controller, but their operation and ownership remain separate. In addition, also we can say that a virtual power plant operates remotely to integrate a variety of individual electricity supplies from various locations into a network that delivers stable power 24 hours a day. The plants utilize software-driven technologies based on the smart grid, which is comparatively new to the energy scene to build the network that provides this stable control. It uses the planning, scheduling, and bidding of distributed energy resources (DER).

3.3 Classifications of VPP

Because of many concepts of virtual power plant and a study of various aspects of distributed generation as previously stated, the idea of VPP can be simplified as: aggregation control of a number of distributed generation systems, grid interconnected and implemented nearloads. The aggregation function can be a centralized or decentralized system assisted by an algorithm of logic control and a communication infrastructure, which can then be treated like a single massive power plant. Few points are explained below to describe the definition:

- The DG units have been interlinked and mounted near the loads to the main grid.
- The huge DG unit capacity ranges from a couple of tens of kW to a few MW.
- The VPP network is enabled by a fast infrastructure for communication in order to Guaranteed sharing of information.
- The CCC (in centralized system) is the heart of the VPP . The CCC consists of an algorithm for device and logic control that can be used for certain basic reasons [3].

Now depending on the control topology, the classifications of VPP are categorized into two types, such as-

- Centralized VPP
- Decentralized VPP

3.3.1. Centralized VPP

The distributed generation systems in this section are centrally controlled by a Control Coordination Center (CCC) situated right in the center of the DG units. The signal loads are transported to the CCC and processed using a logic algorithm. The signals are then sent to each DGC (distributed generation controller) and the active power output is generated in accordance with the CCC signals (see **Fig. 3.2**). It is capable of performing both technical and economic functions with the CCC in order to benefit from distributed generation aggregation.

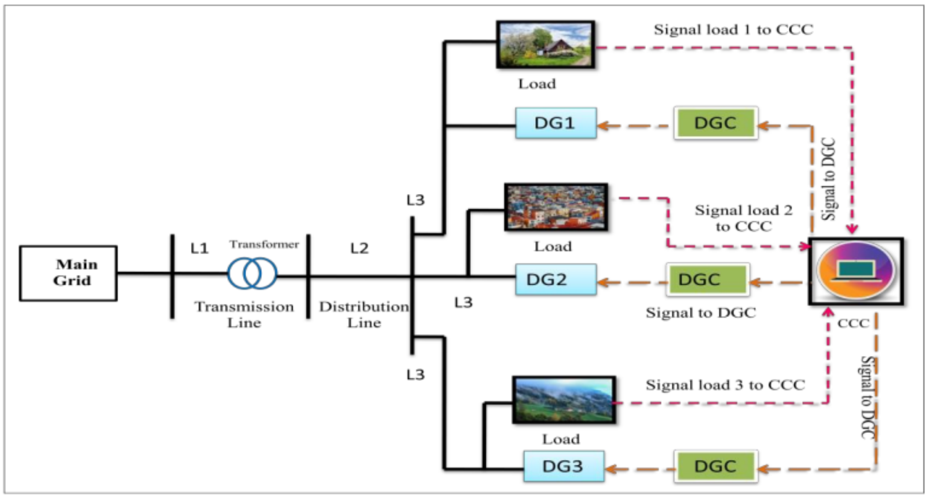


Fig. 3.2 Centralized virtual power plant

3.3.2 Decentralized VPP

Each DG unit is locally regulated by local controller (LC) in the decentralized process topology. DG's active power output is primarily regulated by the Distributed Generation Controller (DGC) and the DGC are controlled by local controls. Controller (LC) that has logic algorithms designed. The local controllers are attached to each other to implement an interconnected system, creating a ring network architecture by communication to allow the exchanging of signals, therefore coordinating and thus treating them as a single control center (see **Fig. 3.3**).In summary, VPP is responsible for the optimized scheduling of internal energy resources in the centralized control method, where sufficient communication bandwidth formulates the basis for information collection and decision-making .Central control VPP, limited by computational efficiency which is restricted on a reasonable scale.

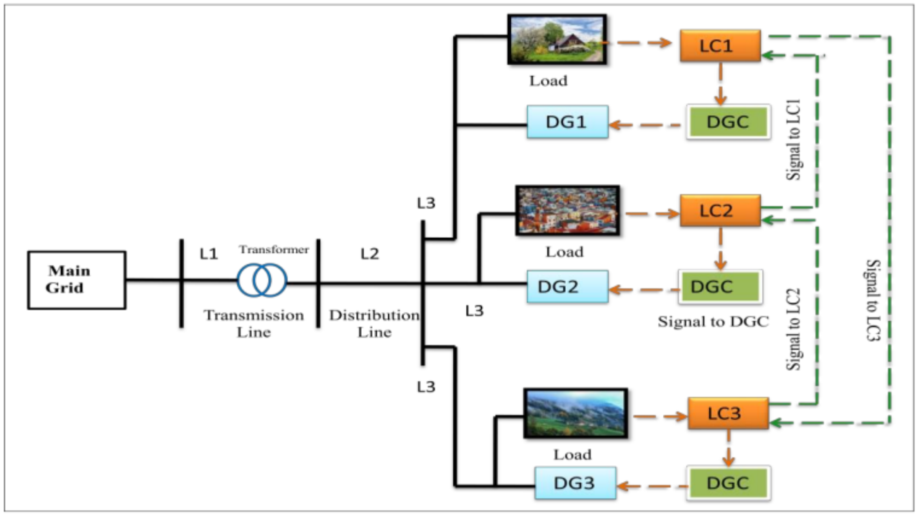


Fig. 3.3 Decentralized virtual power plant

Most of all, in the decentralized system VPP acts as a Communication server for the exchange of information. VPP helps to formulate a isolated loop by deploying distributed algorithms. Alliance between independent DERs, enhancing the overall Profit as long as the communication network connectivity is Pleased [22] . From **Table 3.1** we can see the characteristics , benefits and drawback of those control method used for virtual power plant.

Table 3.1: Comparison of characteristics, benefits and drawbacks of internal management methods for vpp

Type of control method	VPP authority	Market position	Computation burden	Function of VPP (CC)	DER compatibility	Market participation
Centralized control [15,16,17,18]	Completely control	Price maker	Large & concentrated	Central communication and computation	Complex & appropriate upgrading of algorithms	Very competitive
Decentralized control [19,20,21]	Self control	Mainly price taker	Completely distributed	Only communication	Flexible and open access solutions	Less competitive

3.4 Components Description of An Ideal VPP

3.4.1 Generation Technology

It is helpful for the DG configuration to broadly mention the spectrum of capabilities for different technologies, typically coming under the category of distributed generation as seen in **Table 3.2**. Also seen the electric power network interface, which plays a significant role in considering the different aspects of network activity relevant to distributed generation.

Table 3.2: Capabilities and utility interfaces for distribution generation [3]

Technology	Usual Range of Capability	Utility Interface
Solar/ PV	From a few – several hundred KW	DC to AC converter
Wind	A few hundred W – few MW	Inverter
Ocean	A few hundred KW – few MW	Four-Quad. Synchronous Machine
Geothermal	A few hundred KW – few MW	Synchronous Generator
Combined Cycle	A few tens of MW – several hundred MW	Synchronous Generator
Fuel cells	A few tens of KW – few tens of MW	DC to AC converter
Micro Turbine	A few tens of KW –a few MW	AC to AC converter
ICE*	A few hundred KW – tens of MW	AC to AC converter or Synchronous Generator

*Internal Combustion Engine

3.4.2 Technologies for Storing Energy

Today, energy storage systems can be seen as a modern way of adjusting the fluctuations in electricity demand to the scale of power generation provided. In the sense of the use of renewable energies or other distributed generation of electricity, it can also be used as an alternate source or as an energy buffer in the case of nonscheduled or stochastic generation, e.g. fuel cell and PV technology, especially in the case of poor distributed generation networks and renewable energies. **Table 3.3** includes an insight to the life and usefulness among most used storage systems.

Table 3.3 : Life Period and durability of various storage systems [23-24]

Storage Systems	Life period (Cycles)	Efficiency (%)
Compressed air	40 years	-
Flow batteries	1500-2500	70-85
Pumped Hydro	75 years	70-80
Lead acid	300-1500	60-95
Super-capacitors	10000-100000	93-98
Other advanced batteries	500-1500	90-95

3.4.3 Information Communication Technology (ICT)

Communication technology and networks are an essential prerequisite for VPP.It is possible to consider several different transmission technologies for communication in Energy Management System (EMS) , Supervisory Control & Data Acquisition (SCADA) and Distribution Dispatching Centre Program. Therefore, the most suitable networking technologies available for EMS and SCADA Distributed Dispatching Centre projects are listed to be priority order [25] in below:

- Fiber optic cable to each of the regions from the System Master Control Center Distribution dispatch center (if applicable) and to the fiber optic cable path substations.
- Time Division Multiple Access (TDMA) from the Area Distribution Dispatch Centers (ADDC) to the substation which is chosen.
- In the 450/900 MHz UHF P-T-P radio and Multiple Address Radio System (MARS) for distant substations and line switches with wireless monitoring. Several leasing circuits to very distant substations for SCADA correspondence.
- Metallic wire for neighborhood or construction use.

3.5 Challenges and Oppurtunities of VPP in Bangladesh

3.5.1 Overview of Energy Sector in Bangladesh

With a population of 163 million, one of the most populous countries in the world is Bangladesh. For the citizens of this region, agriculture used to be the principal source of income.In Bangladesh, however, the Gross Domestic Product (GDP) was 8.2 per cent in 2019 [26].Rapid urbanization fuelled by sustainable economic growth has created tremendous energy demand.

It's been well known that electricity plays a vital role in any country's poverty alleviation, economic expansion, sustainable development of infrastructure, and security. The most widely used form of energy is electricity in Bangladesh. So, the future economic growth depends substantially on the availability of the electricity.The government of Bangladesh should ensure that people have an affordable and environmentally friendly source of electrical energy. However, the country has continued to struggle to produce sufficient electricity to meet the demand since its independence from Pakistan in 1971. High electricity shortages affect state-owned energy utilities. Moreover, the energy industry has also failed to generate adequate private investment in the power industry due to poor pricing policies and other constraints. This investment shortage is a contributing factor to the energy crisis.In order to maintain its economic growth of over 7 percent, Bangladesh will need an estimated 34,000 MW of power by 2030 [27].

In 1901, only 19 years after New York and 13 years after London, NawabKhwajaAhsanullah [28] began the electrification of the capital city of Dhaka. Later, in 1948, in East Pakistan, an Electricity Directorate was established. In Siddhirganj (maximum size 10MW), Chittagong and Khulna area at that time, there were few Steam Turbines.In 1962, 40 MW Kaptai hydro-electric dam was constructed a 132kV transmission line between Dhaka and Chittagong was commissioned. In 1971, after the independence of Bangladesh only 3 percent of the population had access to electricity. It has been raised to 59.6 percent in 2012 [29]. However, 79 percent of the associated consumers suffer from load-shedding, and 60 percent of the consumers face low voltage supply [30]. Bangladesh decided to reduce import bills after the 1973 oil crisis. As a result, the Bangladesh government replaced natural gas as the front energy supply with natural gas [31] . Bangladesh extracted about 772 million cubic feet of natural gas in 2012, and the domestic markets absorbed the whole volume. The remaining gas reserve will last until 2031, according to Petro Bangla Statistics (Petro Bangla 2015). Petro Bangla is now focused more on drilling offshore gas wells using newer technologies. In addition, the expansion of the Bibiyana gas field has also been taken into account.In 2010, 2012, 2014, and 2016, the power production capacity installed was 5823MW, 8716MW, 10416MW and 12780MW respectively. In 2017, the total installed generation capacity was 15821MW until September, while the total demand was 9479MW (Bangladesh Power Development Board 2017). In order to increase the phase of growth, electricity is regarded around the world as a critical element (Ferguson 2000). Grid power alone is not enough to gain 100 percent electricity connectivity. The government is now promoting the production of off-grid electricity. Such as Solar Home Systems (SHS), biomass electricity, micro hydropower plants, etc. The policy on green energies was passed in December 2008. According to this proposal, 5% of the electricity produced will be provided by 2015 and 10% by 2020 [31].

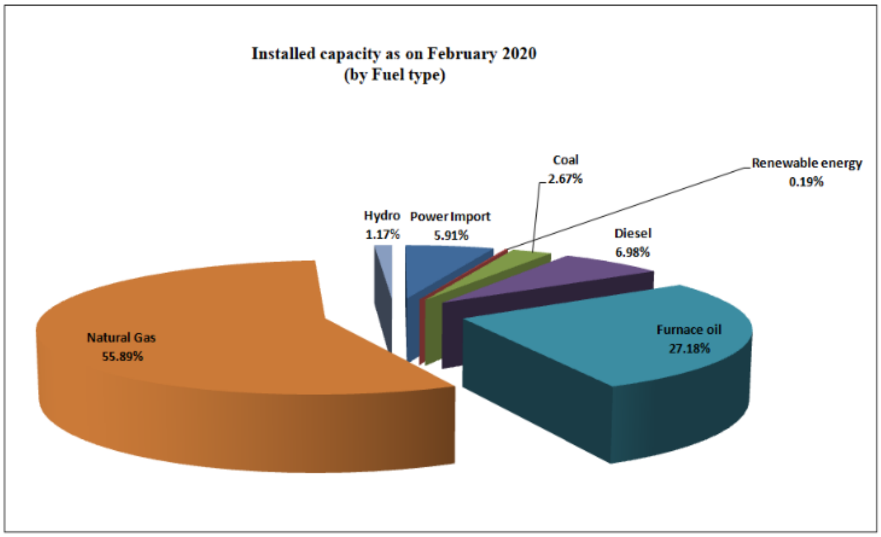


Fig. 3.4 Installed power generation capacity [32]

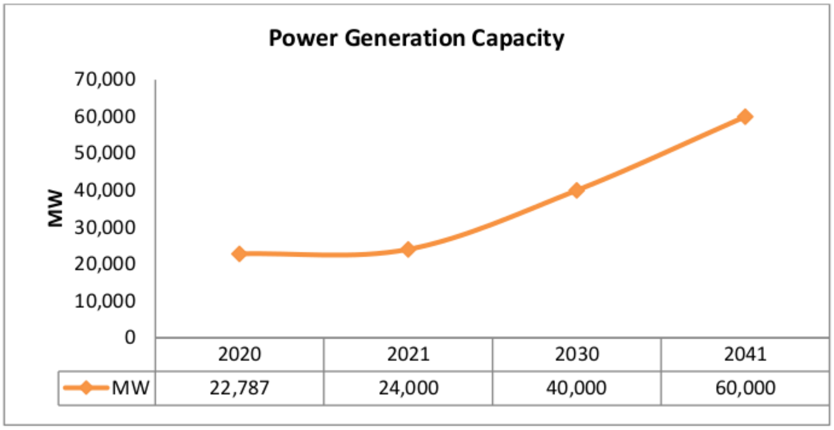
In FY 2018-19, the total installed capacity based on the grid was 18,961 MW, including 9,507 MW in the public sector and 8,294 MW in the private sector and 1160 MW from India's cross-border power exchange. The overall grid-based installed capacity is reportedly 19,630 MW (February 2020), including 9,740 MW in the public sector, 8,730 MW in the private sector, and 1,160 MW of electricity imported from India.Considering captive and clean electricity, Bangladesh's gross installed capacity is 22,787 MW. The maximum generation has been 12,893 MW so far (29 May 2019) [32]. In the pie chart below, the installed capacity by form of fuel and ownership for FY 2019-20 (February 2020) are shown in **Fig. 3.4.** Here **Table 3.4** shows the installed capacity of grid and maximum generation 2000 to 2019 fiscal year.

Table 3.4: Installed capacity (grid) and Maximum Generation

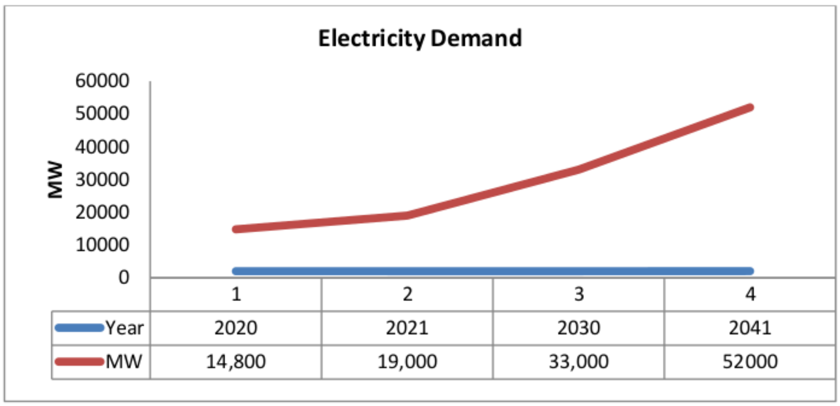
Fiscal year	Installed capacity (grid) (MW)	Maximum generation (MW)
2000-2001	4005	3033
2001-2002	4234	3218
2002-2003	4680	3428
2003-2004	4680	3592
2004-2005	4995	3721
2005-2006	5245	3783
2006-2007	5202	3718
2007-2008	5305	4130
2008-2009	5719	4162
2009-2010	5823	4606
2010-2011	7264	4890
2011-2012	8716	6066
2012-2013	9151	6434
2013-2014	10416	7356
2014-2015	11534	7817
2015-2016	12365	9036
2016-2017	13555	9479
2017-2018	15953	10958
2018-2019	18961	12893

3.5.2 Power Supply & Future Plan

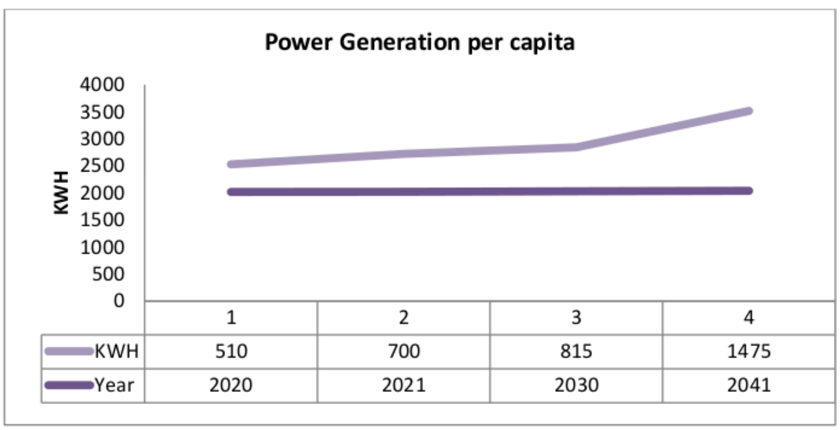
Based on the availability of primary fuel sources, the generation extension plan has been prepared to alleviate the rising need for power and to provide energy for everyone by 2021. Coal, imported electricity from neighboring nations, gas and nuclear power would be generated under the current generation program which will be used for power plants with base loads. LNG can be used for domestic gas enrichment conversely. on the other hand, The government has prepared power system master plan (2016). The power generation capacity will then be 24000 MW by 2021, 40000 MW by 2030 and 60000 MW by 2041, as per PSMP 2016 [32].The future growth plan for the power sector up to 2041 is mentioned in the graph below:


Power Generation Capacity
MW
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
2020
2021
2030
2041
MW
22,787
24,000
40,000
60,000

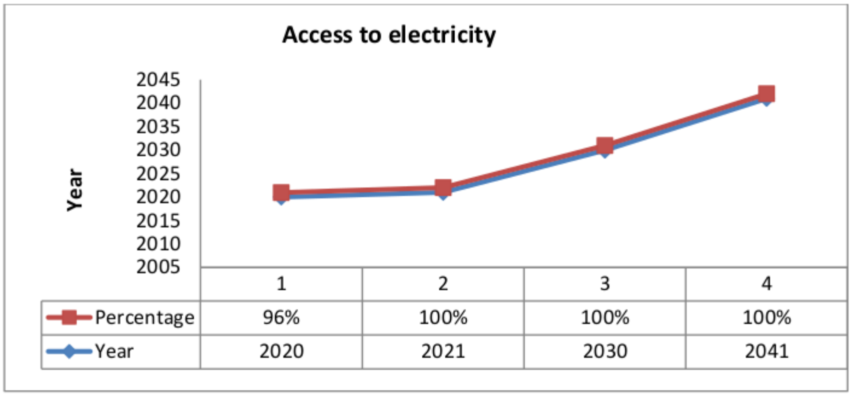
(a)


Electricity Demand
MW
60000
50000
40000
30000
20000
10000
0
1
2
3
4
Year
2020
2021
2030
2041
MW
14,800
19,000
33,000
52000

(b)


Power Generation per capita
KWH
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
KWH
510
700
815
1475
Year
2020
2021
2030
2041

(c)



(d)

Fig. 3.5 Power generation plan as per PSMP 2016 (a)power generation capacity (b) electricity demand (c) power generation per capita (d) access to electricity.

3.5.3 Generation Units Under Construction

A number of public and private sector power stations are under construction. At present, 18 projects in the public sector with a capacity of 9,812 MW and 30 projects in the private sector with a capacity of 7,063 MW are under construction.under construction Projects in Khulna 336 MW CCPP, Ghorasal 3rd & 4th Unit Repowering, 1320 MW BIAF power company ltd, Rupsa 880 MW, coal-based Patuakhali 1320 MW, Bibiyana 383 MW CCPP are admirable.Meghnaghat 583 MW CCPP, Meghnaghat 750 MW CCPP, Narayanganj 584 MW CCPP, Maowa-Munshiganj 522 MW coal-based, Chattogram 1224 MW coal-based and Khulna 565 MW coal-based projects in the private sector are also impressive [32].

3.5.4 Energy Demand

Bangladesh is situated between 20° to 26° North and 88° to 92° east . It's also bounded on the west, north and east along India, on the south-east by Myanmar, and on the south by the Bay of Bengal. Bangladesh's geographical position provides greater solar irradiation [33]. While there are six seasons a year, Bangladesh usually enjoys a sub-tropical monsoon climate, with three being more prominent, namely the winter, summer and monsoon seasons. In November, winter begins and ends in February. There is little temperature fluctuation in the winter, ranging from a minimum of 7 ° - 13 °C to a maximum of 24 °C - 31 °C. The maximum temperature recorded during the summer months is 37 ° C, although this sometimes increases to 41 ° C (105 ° F or more) in some places [33]. As the temperature increases, cooling has increased the demand for electricity due to refrigeration, while the demand for base load is higher than the generation of electricity. There are three main seasons in Bangladesh: the monsoon or wet season between late May and early October; the cold season between mid-November and late January; and the hot season between March and mid-September [34].

The power generation capacity will then be 24000 MW by 2021, 40000 MW by 2030 and 60000 MW by 2041, as per PSMP 2016. Electricity usage in the residential sector is rising dramatically in the Normal Development scenario, when almost the whole world is linked to the electricity network. In 2005, the overall intake of the residential sector was 7.69 TWh and is expected to rise nearly 8-fold to 64.46 TWh shown in **Fig. 3.6** in 2035, with an estimated annual growth rate of 7.34 percent [35] . Consumption in the urban residential market rose by 4.51 TWh in 2005 and by nearly 8-fold by 2035. Similarly, in the rural residential market, access to electricity will increase by about 9.35 times by 2035, as access to electricity will grow dramatically from 23% in 2005 to 84% in 2025.The World Bank currently has $2.1 billion to assist the energy sector in developing power, producing sustainable energy, improving the quality of generation and transmission and system operations, reducing technological losses, and increasing access to grid and renewable electricity. The World Bank wing of the International Development Association added 2,604 MW to the national grid and 100 MW to the solar home systems grid [36].

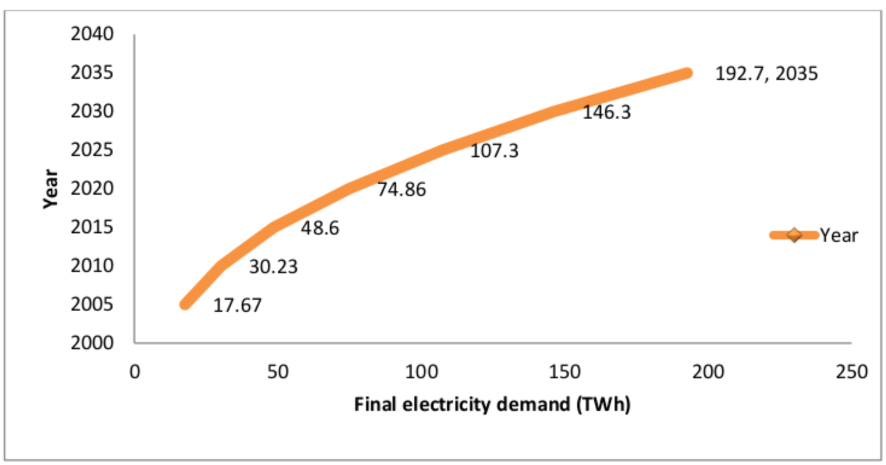
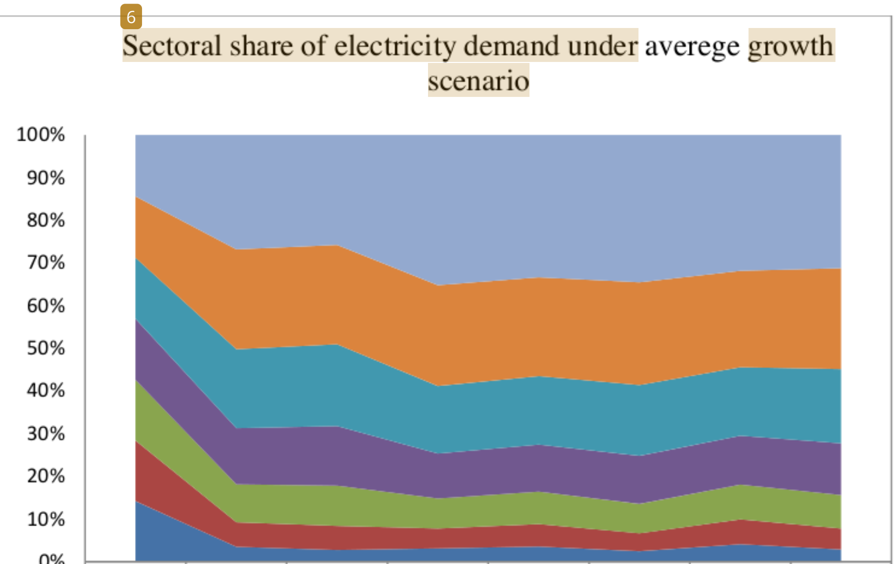


Fig. 3.6 Final Electricity Demand



	Category	Urban residential	Rural residential	Agriculture	Commerce	Industry	Other	Total
Series7	2035	34.61	29.85	10.67	12.96	101.5	3.09	192.7
Series6	2030	30.29	27.03	7.16	9	70.65	2.19	146.3
Series5	2025	23.88	22.16	4.79	6.23	48.64	1.56	107.3
Series4	2020	16.99	16.19	3.2	4.3	33.07	1.11	74.86
Series3	2015	11.49	10.93	2.13	2.95	20.31	0.79	48.6
Series2	2010	7.4	6.56	1.42	2.03	12.26	0.56	30.23
Series1	2005	4.51	3.19	0.94	1.39	7.24	0.4	17.67

Fig. 3.7 Sectoral share of electricity demand under averege growth scenario 2005-2035

In the manufacturing sector, energy usage in the Typical Energy Production is expected to rise nearly 14-fold by 2035. The drastic rise in the demand for electricity in this sector is due to the economic change from the agriculture sector to the manufacturing one. Demand in the agricultural sector has also improved considerably over the study period. Total consumption was just 0.94 TWh in 2005, a rise of nearly 11.35 times by 2035. As a consequence of the ongoing construction of additional pumps around the country to achieve self-sufficiency in food production, the sharp rises in this sector are attributed to the use of electric motors instead of diesel engines for irrigation pumps. In 2035, 33.45% and 5.54% are consumed by the residential and agricultural sectors, respectively, while 52.67% and 6.72% are consumed by the manufacturing and commercial sectors [35], respectively in **Fig. 3.7**.

3.5.5 *Visibility of Renewable Energy in Bangladesh*

Bangladesh is fortunate to have a generous amount of RES and to take advantage of these obligations successfully to fulfill the country's energy needs. Biomass is considered to be the significant RES available in the country among the accessible energy reserves, which may limit the usage and consumption of non-RES dependence. Solar energy is also very promising, because of its geographical position, the country gets an incredible amount of sunshine. It may be important to point out that the benefits of installed solar photovoltaic (PV) panels have been enjoyed in the rural and coastal areas of Bangladesh.In addition, many government agencies and NGOs have undertaken several activities to supply energy from small-scale hydro-power plants and wind turbines, despite the fact that hydro-power and wind power for power generation are not very sufficient for the region. Therefore, it is possible to use RE tools, such as biomass and solar, to ensure energy stability [37]. From the **Fig. 3.8** as above mentioned, it describes the renewable energy resources & technologies that are existed throughout the world. Therefore, It can be revealed that there is an enormous amount of RES in Bangladesh. Even though the use of RE technologies has become a global trend, the nation is still struggling to make use of these outlets.

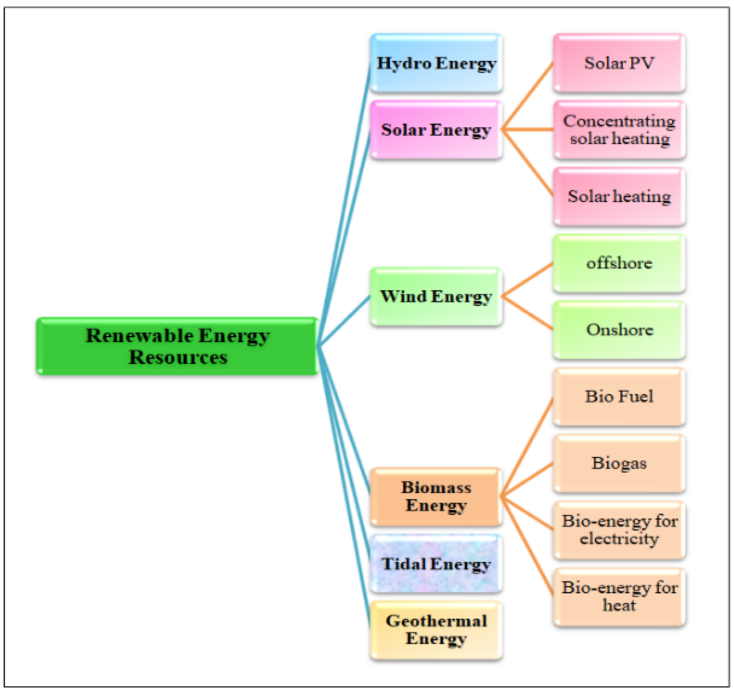


Fig. 3.8 Renewable energy resources and technologies

Biogas, biomass, and solar are considered among the list of likely, favorable, and efficient sources of renewable energy generation in the world. A analysis of RE capital and capacity in Bangladesh is provided in **Table 3.5** which describe the potentiality of RES in Bangladesh [38].

Table 3.5: Potentiality of renewable energy in Bangladesh

Energy Resources	Potential	Entities involved
Solar energy	Abundant	Public & Private sector
Hydro	Required resource mapping	Public sector/PPP
Wind	Restricted micro or mini-hydro potential (max. 05 MW).Approximate projected hydro potential 500 megawatts	Mainly public entities
Biogas system (Domestic)	8.6 million cubic meters of biogas	Public & Private sector
Biomass gasification power plant (Rice husk based)	300 MW considering husk absorption of 2 kg/ kwh	Private sector
Biogas power plant (Cattle waste based)	350 MW and 0.752 cubic metres of biogas consumption per kwh	Private sector

3.5.6 Present Energy Development Policy

Electricity's central role in transforming the world economy is generally understood nowadays. No nation has continued to grow beyond a subsistence economy without maintaining minimum access to energy for a significant portion of its population. No exception to this provision is Bangladesh. Owing to a lack of access to electricity, poor connectivity and mismanagement of energy resources, the pace of construction activities in various sectors of Bangladesh has been significantly affected. For example , access to electricity by the population was just 50.0 percent and more than 80.0 percent of Bangladesh's electricity was provided by natural gas until 2009 [39] .The energy industry has been one of the government's main fields of growth over the last decade. Between FY09 & FY20, from (mid-June). Installed capacity for energy production increased from 5,823 MW to 20,514 MW (252.3 percent). Total electricity generation increased from 4,606 MW to 11,119 MW (141.4 percent). Electricity emissions per capita has improved: from 165.3kWh to 374.6kWh in FY2019 (126.6%). The number of users in major economic areas is increasing gradually: 8.7% in FY19 (126.6%) [40].Under Bangladesh's current generation scenario, the share of renewable energy in total generation is very limited. So far, the share of renewable energies has surpassed 1 percent. The Government is prioritizing the production of Renewable Energy Resources to boost energy stability and the creation of a clean energy framework alongside traditional energy sources. The '500 MW Solar Power Mission' has also been initiated by the government to encourage the use of green energy to meet the growing demand for electricity.The Bangladesh government has taken a systemic approach to the utilization of natural energy. The Bangladesh Power Development Board established the Directorate of Renewable Energy and Research & Development in 2010 in line with the Government's approach. The Directorate has been committed to holding a signal for the development of the use of renewable energy in the power sector from the very beginning of its establishment. In Bangladesh, there is a fair variety of solar, wind, biomass and micro/mini hydro power generation [41].

As the main priority of **VISION 2041**, the Government of Bangladesh has announced its intention to improve the country in order to become one of the developed nations by 2041. **PSMP 2016** in describes the desired objective and "five key points of view" listed below in order to accomplish the vision [42]:

- ❖ Enhancement and versatile operation of imported energy infrastructure.
- ❖ Effective production and use of domestic natural resources (gas and coal).
- ❖ Building a robust, high quality power network.
- ❖ Maximizing solar energy and encouraging its adoption.
- ❖ Improvement of human capital and mechanisms connected to a reliable energy supply.

The purpose of the draft PSMP 2016 is to assist Bangladesh in formulating a detailed energy and power growth plan for the period up to 2041. It includes the balance of electricity, the balance of control and tariff policies. Bangladesh targets to become upper middle-income nation by 2021 and high income country by 2041.The International Energy Agency (IEA) measures the proportion of "modern" renewable energy (excluding conventional solid biomass) would raise the world's overall energy demand from 14 percent to 19 percent by 2040.As per the 2008 Bangladesh Renewable Energy Plan, the aim was to reach a share of 5% of the overall generating capacity (MW) of renewable energy by 2015, as well as 10% by 2020. The government plans to extend the 10% target for renewable energy by 2041 beyond 2020, but this is not predetermined in the current strategy. Bangladesh has immense potential beyond its borders to explore renewable energy, i.e. regional hydropower production in the countries of South Asia. Bangladesh is expected to be able to import around 5,000 MW of hydropower from Bhutan, Nepal and north-eastern India about 2041. There are problems in achieving this goal with its domestic renewable energy. However, if the import of cross-border electricity from hydropower production is counted as hydropower (about 4,000 MW from domestic renewable energy and 5,000 MW from cross-border hydropower) and the hydropower can easily be reached [42].

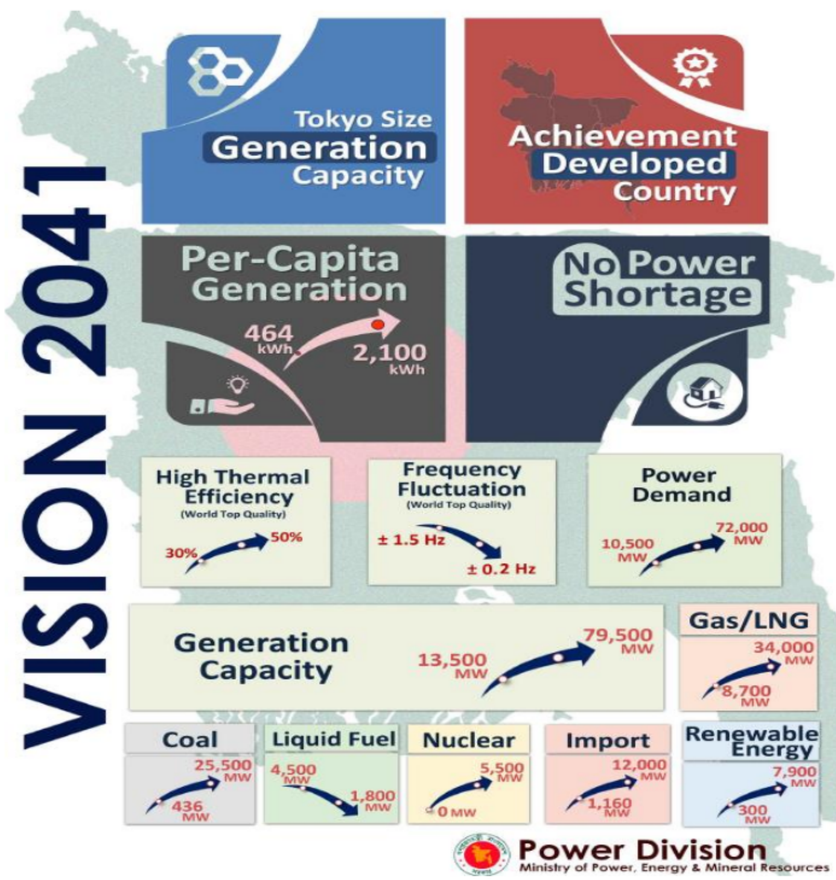


Fig. 3.9 Vision 2041 from PSMP 2016 [42]

The vision 41 **Fig. 3.9** describes that the per capita generation will increase from 464 KWh to 2100 KWh also the increase of generation capacity from 13500 MW to 79500 MW estimated in 2041.This policy will also make increasing of renewable energy resources for the fullfillment of energy demand of Bangladesh.The estimated result says that liquid fuel will decrease to 4500 MW to 1800 MW.Gas or LNG power plant production will also increase in a good number which will be 8700 MW to 34000 MW in 2041 according to PSMP 2016 by Ministry of power , Energy & Mineral Resources.No power shortage describes that Bangladesh is going to make a sustainable development in future energy system.

3.5.7 Challenges & Chances

3.5.7.1 Challenges

Bangladesh is a country where power is not uniformly distributed. . There are some areas in Bangladesh to date that do not have Electrical currents obtained. Electrical currents are unreliable in some remote areas and blackouts can occur without indication.Coal, imported electricity from nearby nations, gas and nuclear power can be used for base-load power plants under the current generation programme. LNG can be used for domestic gas supplementation. For the peak load power station, on the other side, liquid fuel might be required. The government has prepared the master plan of the power grid PSMP 2016. The power generation capacity will be 24000 MW by 2021, 40000 MW by 2030 and 60000 MW by 2041, as per PSMP 2016 [32].In the future, electricity market is anticipated to expand by half in addition.In contrast to the massively increasing urbanization, half are new and modern cities and the use of digital technology. The infrastructure used for the distribution of electricity must therefore be excellent, robust, and flexible. Demand in respect of with stable transmission, but with sustainable and eco-friendly energy, electrical power must be achieved. Despite the following obstacles to the use of virtual power plant (VPP) in Bangladesh, the use of VPP is crucial in order to realize the possibility. These are follows-

i. An effective energy strategy that is not technology-based.

The Virtual Power Plant is new to Bangladesh's energy management. There was no legislation regulating the strategy and technological framework relating to the application of VPP in energy delivery.

ii. Shortage of VPP support resources

Since VPP is relatively recent in Bangladesh, the Information and Communication Technology (ICT) framework is linked to the use of VPP is not available in the region. In addition, software for calculating electrical power is required to run and distribute the VPP. With complex infrastructure the use of VPPs can be expensive.

iii. Participation of the societies in electricity collection

The main factor in the effectiveness of the use of VPP is social interest of companies interested in the production of small-scale electrical networks are still reluctant to fully compete in the industry at the moment, because the market is still not active. Most procurement is dominated by the administration.

iv. Cyber security intimidation

In terms of cyber security risks, technologies may be in a weak role. Because of digitalisation and network connections across Bangladesh, in the event of an internal and external technical threat.The government should have additional protection for the threats .

v. Business Challenges

One of the characteristics is also the lack of interconnectivity between producers, since different producers integrate different technologies into their smart technology systems, making it impossible to engage in the public pool. This leads to poor market models from a prosumer's view point.The bulk of misleading examples of industry was compromised by two basic challenges:

- Large capital and cost of operations

The big chunk of fixed costs related to connectivity was consumed by capital and operational costs. Although there is no substantial economic inflation attributable to the expense of hardware, there are significant threats when it comes to software integration and distribution activities. The reality that intelligent technologies are Costly, when it comes to execution on the budget side, which currently remains a bottleneck, there are other considerations that need to be taken into consideration, in particular with respect to the related distribution threats.

- Framework of Legislation

Legislative structure analysis faces a larger challenge in terms of regulatory frame work. Organizations appear to be cautious in measuring incentives and shareholders in what they will receive as cash profits.

3.5.7.2 Opportunities

The potential offered in Bangladesh for the creation of sustainable energy management by VPP is considerable. It is expected that the successfully implemented application of the new energy efficiency strategy would minimize 2 % of electricity consumption by 2025. It is estimated that implementing the new legislation and policy strategy that has not been adopted would minimize up to 4.5 percent of energy consumption relative to the policy-free scenario [44].There have been other methods of reducing energy consumption substantially that can be achieved with VPP. There are some suggested opportunities from our point of view in Bangladesh's perspectives given below-

i. Cumulative need of renewable energy

In the power market, capacity growth can be accomplished cost-effectively by renewables and energy efficiency solutions, which not only minimize greenhouse gas emissions, but also boost employment and enhance people's health through air pollution reduction. The effects of increasing renewable energy in Bangladesh's energy production mix compared to 'business-as-usual' could produce the following composite outcomes by 2030, according to a study from the Low Emission Growth Strategies Global Partnership (LEDS GP) and based on comprehensive modeling analysis.Reduce greenhouse gas emissions by up to 20%. And it will Create domestic demand of up to 55,000 full-time equivalent positions. Additional power generating capacity of 30 GW [44].The electrical transmission infrastructure is also very flexible to renewable energy technologies, such as solar panels or microgrid networks by the use of VPP.

ii. The improvement in the use of electrical energy

The transition of technologies also affects the behavior of potential electrical energy usage. Each user obviously wants to find out the electricity consumption meters be reliable and precise, also have the access to electricity consumption monitoring, and definitely use electricity effectively. As proactive users who not only access electrical power but also generate electrical power. People expect to be interested when it is carried out early ,the investment by VPP is useful for suppliers.

iii. Awareness of the community for better environment

People are becoming more mindful of the nature of the use of eco-friendly energy options in the future. The transmission grid and network are no longer industrial (power generator for customers). The conventional business model of cost-revenue that remains is no longer valid in the future when electricity can now be generated by customers.

iv. A much more complicated market

Using solar panels and windmills, customers will be able to generate their electricity by micro-grid. The bottom line is that the flow of energy is not in one direction from the central generator to users. More modern and more intelligent infrastructure is needed. The smart grid consists of integrated modules in which it is possible to easily collect data related to as problem analysis. The problem is identified before the problem takes place to allow for expectation.

v. Growing participation in VPP in developed countries

There is a rise in interest in the VPP mechanism for demand response (DR), based on the new study report from Pike Research. It has totally transformed VPP's business environment and stimulated significant growth in the economic field. In 2011 and 2017, VPP power grew to 65 percent, from 55.6 GW during the era to 91.7 GW worldwide. VPP's transaction volume has grew and reached $5.3 billion in revenues anually in 2017 [45].When the VPP system in Bangladesh will be accessible, the VPP system shall improve the power generation and distribution will be more uniformly spread.

CHAPTER 4

DEVELOPING OF VIRTUAL POWER PLANT

4.1 Introduction

This section offers an explanation of the VPP components which is built by using Matlab-Simulink library models for simulating the Virtual Power Plant theme which is proposed in the perspective of IIUC.

4.2 Centralized Virtual Power Plant for IIUC

The components are separated into four major elements of the model: the main grid model, the distributed generation model, the complex load model and the units of electrical and mechanical calculation that means measurement unit. **Fig. 4.1** explains the MATLAB model of the centralized VPP and the main grid. The VPP consists of three distributed generation units running parallel to the main grid and three dynamic loads in a simulation. The following subsections present a detailed model overview of the VPP that is discussed on this paper.

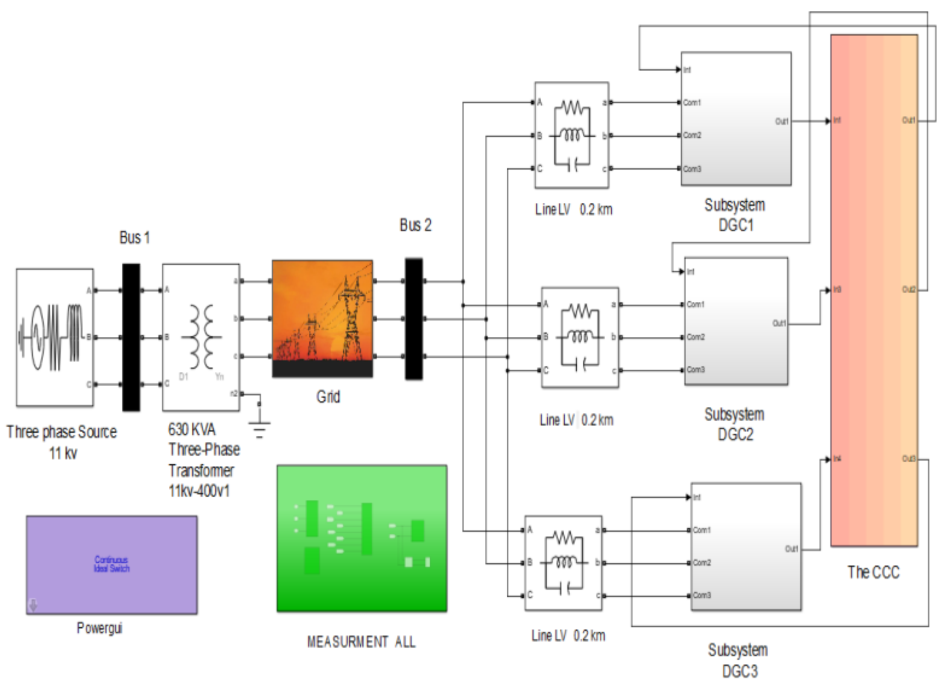


Fig. 4.1 Matlab model of Centralized VPP

4.2 Components Used in Simulation

The components are separated into four major elements of the model: the main grid model, the distributed generation model, the complex load model and the units of electrical and mechanical calculation that means measurement unit.

4.2.1 Main Grid Model

For simulation, we have used MATLAB 2016a. The modules are available in the Matlab-Simulink power system library and the parameters of each model are satisfied with the correct reference grid information .Here the main grid model consists with-

i. Three phase Ac source
ii. Fixed loads
iii. Medium transmission & distribution line
iv. Step down Transformer

i. Three phase AC source

A balanced three-phase voltage source with internal RL impedance is introduced by the Three-Phase Source block. In Y, the three voltage sources are linked with a neutral relation that can be grounded internally or made usable.

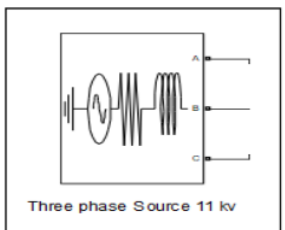


Fig. 4.2 Three phase Ac voltage source block

The internal resistance and inductance of the source are either by means ofdirectly joining the R and L values or inherently defining the degree and X/R ratio of the source inductive short-circuits. The base voltage is 11 kV (rms) and the the system's frequency is 50 Hz.

ii. Fixed Loads

Resistive load is the reflection of fixed loads. So the three phase active power is in watts (W), the nominal phase to phase voltages is in RMS (Vrms) volts .In transmission side 1000 KW fixed loads. The fixed loads attached to distribution line is linked to a 5.5 MW at Zone1 , 3 MW at Zone2 also 3 MW for Zone 3 fixed load shown in **Fig. 4.3**.

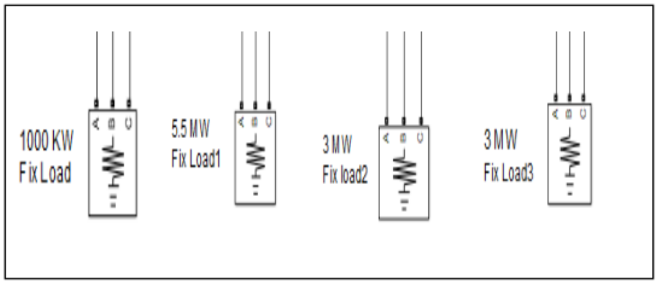


Fig. 4.3 Fixed loads block

iii. Distribution Line

Each of the branches that transfer electric power is defined in this section. Normally, the parts are cable or lines. At 11 kV and 0.44 kV voltage levels, there are aerial lines that are responsible for supplying electricity at lower voltage levels. Each branch is defined in detail and the values are explained.

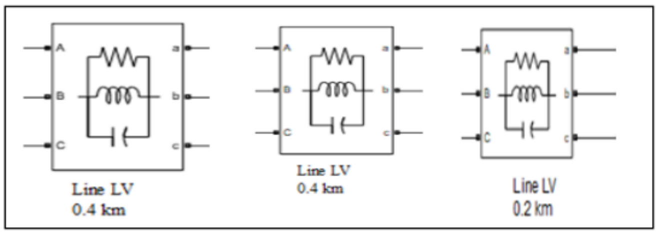


Fig. 4.4 Low Voltage distribution line

For the electrical parameters used three balanced branches consisting of each of a resistor (in Ohms- Ω), an inductor (in Henries-H), a capacitor (in Farads-F), or a mixture of these in parallel .There is a summary of each branch data in **Table 4.1**. The calculation have been done in in **Appendix A**.

Table 4.1: value of Line parameters

No	Type	X(ohm / km)	R (ohm/km)	C (nF/km)
1	Distribution line (L1)	0.155	0.156	235
2	Distribution line (L2)	0.314	0.2426	10.15
3	Distribution line (L3)	0.302	0.437	10.3

iv. Step Down Transformer

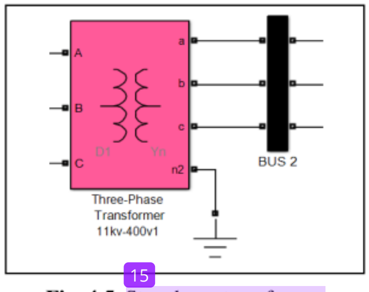


Fig. 4.5 Step down transformer

The transformer has a nominal power rating of 630 KVA and a nominal frequency of 50 Hz. The connection of the transformer is $D_{11}Y_g$. 11 kV is the primary side busbar, and 400 V is the secondary busbar. The secondary busbar is connected to the 400 V distribution line.The designated resistance and inductance of the windings are in per unit (p.u), in order to ensure compliance with the simulation. Assumptions are based on the transformer rated power Pn in *VA*, rated frequency fn in *Hz* & rated voltage Vn in volt of the respective winding.

4.2.2 Distributed Generation Center

The framework includes of a synchronous machine (SM) fitted with a distributed generation controller (DGC). The DGC consists of two essential components: the hydraulic turbine governor and excitation. The SM model is a dynamic model of a synchronous three-phase round-rotor or salient-pole machine which works in the style of the generator or motor. The mode of operation is determined by a mechanical power symbol (positive for generator mode, negative for motor mode). A collection of predefined electrical and mechanical parameters for different synchronous machine power ratings (kVA), phase-to-phase voltage (V), frequency (Hz) and rated speed (rpm) etc. given by the Synchronous Machine model. The all three DGC in this proposed model are connected with low voltage (400 V) with each capacity of 250KVA & 50 Hz. The DGC model was taken from the Matlab-Simulink library's hydraulic turbine governor model and an excitation model.Input and output units differ according to block parameters see in **Fig. 4.6**.

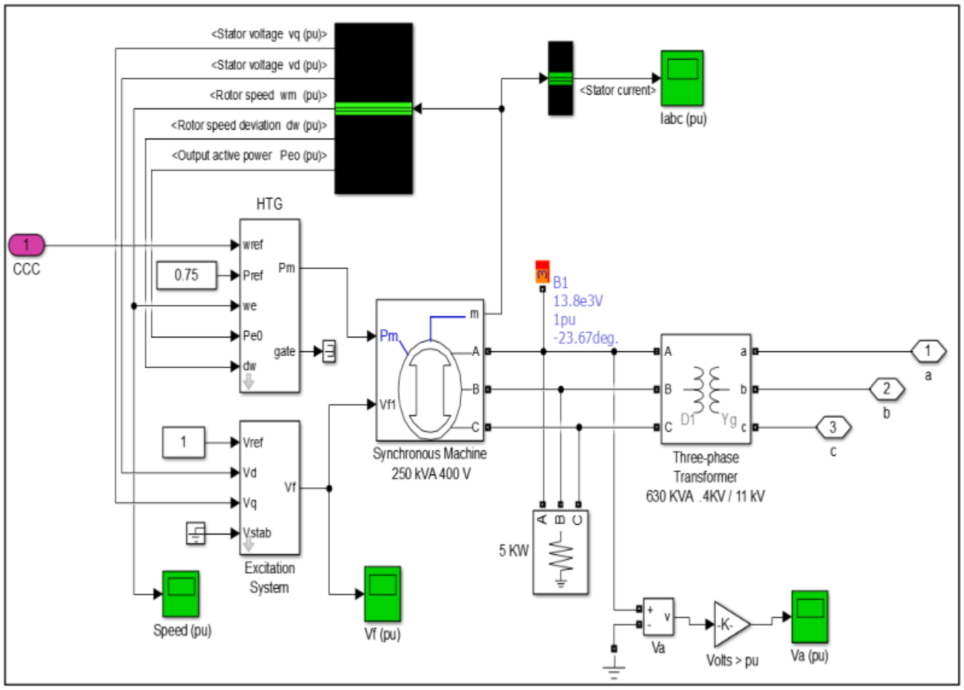


Fig. 4.6 Distributed generation center

If the basic parameters are used in SI units, the inputs and outputs are in SI units, with the exception of the revolving deviation of velocity (*dw*) in the internal vector, which is always p.u. and the angle which is always radian. The inputs and outputs are otherwise stored in p.u.

4.2.2.1 HTG System

The mechanical power (Pm) on the shaft of the machine is the first Simulink input of the synchronous machine. This input may be a positive constant or function or the output of a prime mover block in the generating mode (see the HTG block). The second input of the block Simulink synchronous machine is the field voltage (*Vf*). A voltage regulator will supply this voltage in generator mode (see the Excitation System block). From the measurement block shown in top of the figure where stator voltage (vq), stator voltage (*vd*), rotor speed (*wm*), rotor speed deviation(*dw*), output active power (*peo*) all are in pu.

The inputs and outputs of the system of governors are:

- Wref : ideal speed (in p.u). The comparison speed of the simulation varies according to the signal from CCC in pu.

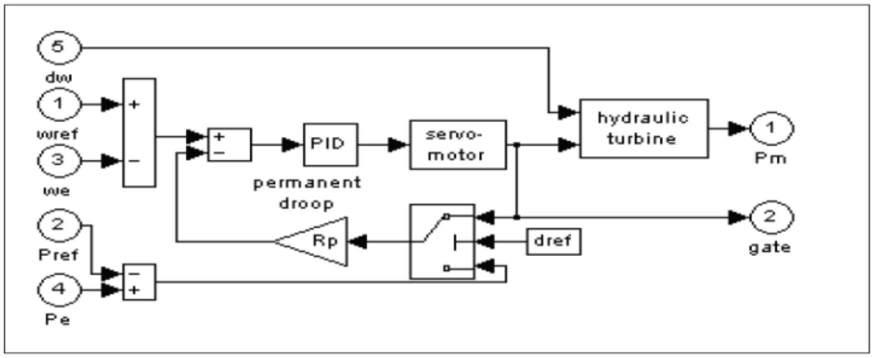


Fig. 4.7 Input and output of the HTG system [3]

- Pref : Required electrical power in p.u. If the gate point is used as an input to the feedback loop instead of the power deviation, this input will be left unconnected.
- we or wm : actual speed of SM in p.u.

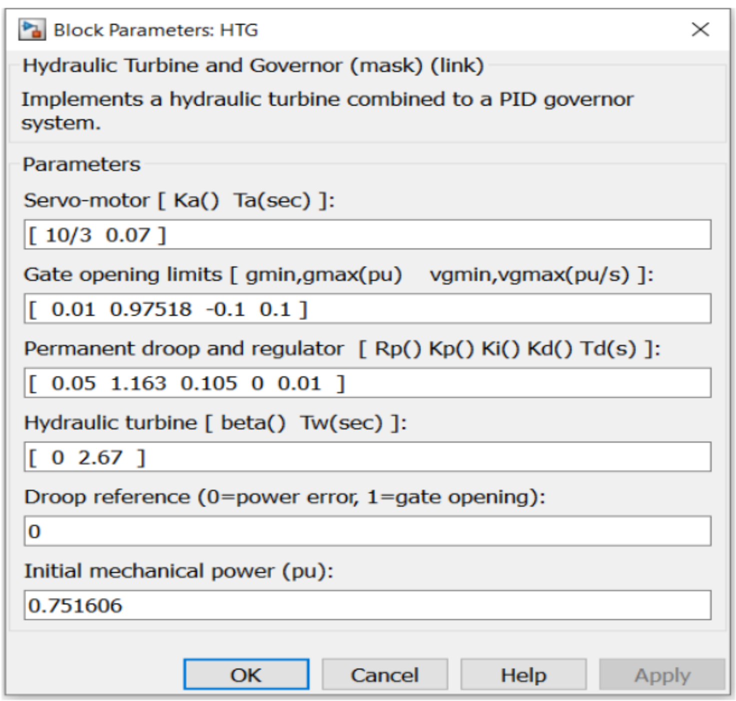


Fig. 4.8 Block parameters of HTG

- Peo in p.u. :If the gate location is used as an input to the feedback loop instead of the power deviation, this input will be left unconnected.
- Dw in p.u.

- The very first output is the mechanical energy *Pm* for the synchronous system block,is in p.u. And the second is the opening of the gate, in p.u. Opening of the gate is minimal. The speed between g_{min} and g_{max} is constrained between v_{gmin} and v_{gmax}.

The high-frequency PID gain is restricted by the first order low-pass filter with the time constant *Td* (s). During the simulation, the relative gain is determined by a particular value, the integral and the derivative gains are set to zero. The hydraulic turbine is modeled on the following nonlinear method.

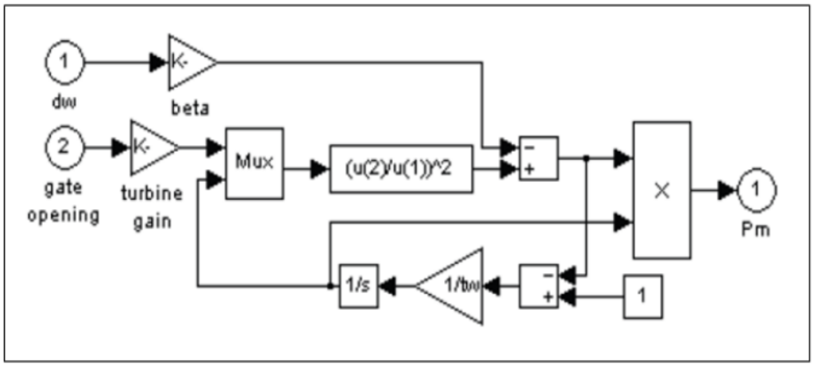


Fig. 4.9 Hydraulic turbine block [3]

The governor's static gain is equal to the reciprocal of the permanent droop Rp in the feedback loop. The PID regulator has a proportional gain (*Kp*), an integral gain (*Ki*) and a derivative gain (*Ki*) (*Kd*). Gate servomotor is modeled on a 2nd order system.

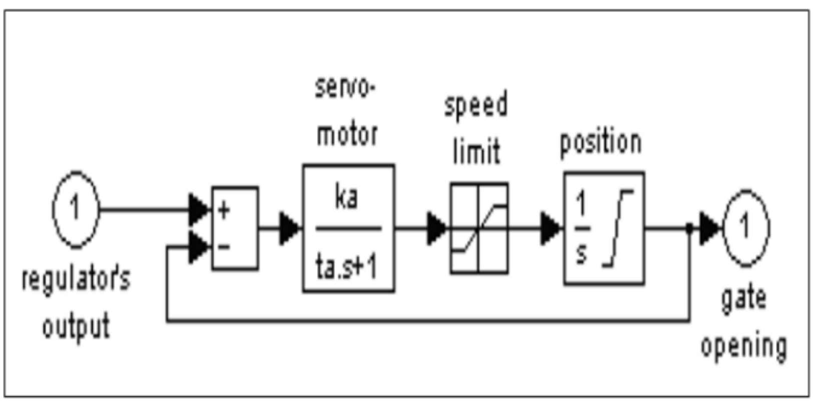


Fig. 4.10 Gate servo motor block [3]

4.2.2.2 Excitation System

Excitation provides an excitation mechanism for the synchronous machine and controls its terminal voltage in the mode of generation. The Excitation System Block is a

Simulink system that implements the DC exciter defined in [46] without the saturation feature of the exciter. The SM excitation is carried out by the regular excitation block given in the system library.

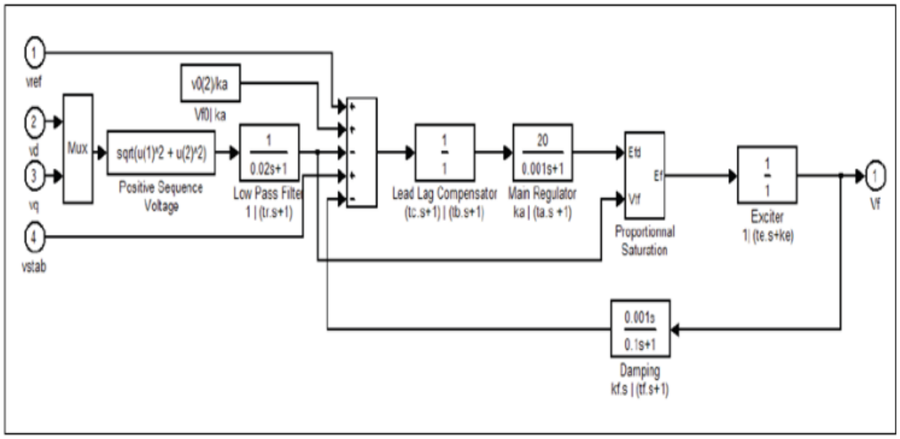


Fig. 4.11 Excitation system block diagram [46]

The fundamental elements that make up the Excitation Device block are the voltage regulator and the exciter.Excitation device block implements an IEEE type 1 synchronous machine voltage regulator coupled with an exciter.

- First input: Vref, the target voltage of the stator terminal (p.u). The Vref is set to constant 1 p.u.
- Second input: *Vd* terminal voltage part (p.u).
- Third input: *Vq* terminal voltage part (p.u). *Vd* and *Vq* are the contribution of m signal from the synchronous system.
- The fourth input: *Vstab* stabilization voltage from the user-supplied control system stabilizer (p.u).
- Output: Field voltage *Vf* to be added to the 2nd input synchronous computer block (p.u).

4.3 Dynamic Load

A three-phase dynamic dynamic load with active power is introduced in the dynamic load model. In the simulation, three dynamic loads with same desired value are assumed to consume active power only. The signal output (active power demand) is then sent from the dynamic load to the controlcoordination center.

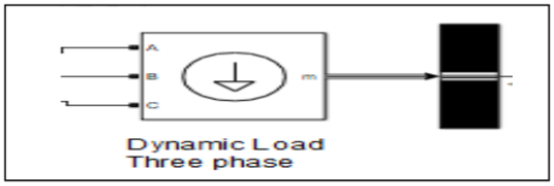


Fig. 4.12 Three phase dynamic load

4.4 Measurement Unit

Electrical parameters such as voltage, current, frequency, instantaneous and rms-value active power, DG units, loads and lines are calculated at the time of measurement all block (green block) seen in **Fig. 4.13**. To test three-phase voltages and currents in a circuit, the three phase V-I measuring block is used. The dynamic load curve also shown by using this block.

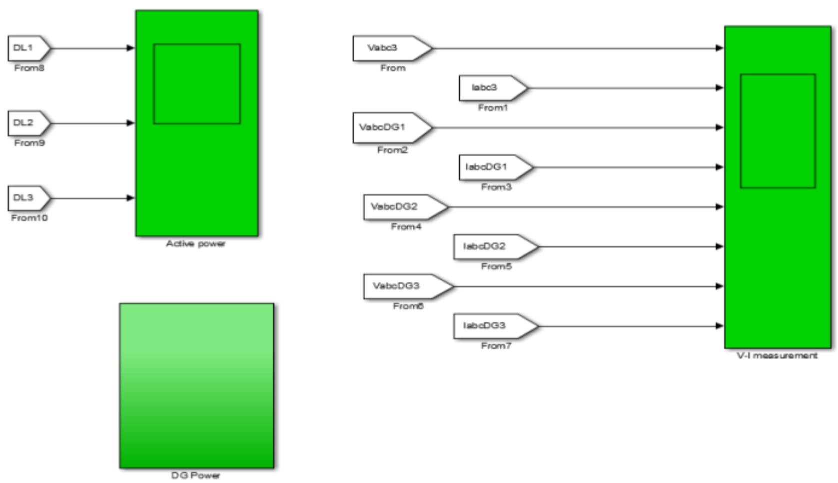


Fig. 4.13 Measurements block

4.5 Control Unit

The control system built in here is isthe auto control system (ACS), which has a central control system. The controller is used to activate the three DG units to organize and dispatch control. Auto control device schemes in simulation are as follows:

- The DG generator runs at the same time as the main grid.
- The power output of the DG device from the central controller is controlled according to the load signal (active power demand).
- The DG supplies the load with peak or base load capacity and supplemental/back-up power is given by the main grid.

- Fast infrastructure for communication is provided between CCC to DG units in order to guarantee the signal exchange

The overview list of the VPP method in the simulation for the built VPP model is below in **Table 4.2** .

Table 4.2: List of components used in simulation

No	Components	Descriptions
1	Main Grid	11kv , 50 Hz
2	Line	Distribution Line at Low voltage 11 KV ; L1 is 0.5 km and L2 is 0.4 km. L3 is 200m
3	Transformer	630 KVA ; step down transformer 11 KV to 400V; connection *YgD11*
4	Dynamic load	Considering as active power demand
5	Fixed Loads	Considering as resistive load
6	Distributed generation & control	Consisting of 3 synchronous machine units of 250 KVA ,50 Hz,400 V Prime mover (hydraulic turbine governor) & excitation
7	Control coordination center	The control centre is equipped with an algorithm to allow signal exchange synchronization. The purpose of the ACS is to coordinate the dispatching capacity during the dynamic load of three DG units.

CHAPTER 5

RESULTS AND ANALYSIS

5.1 Introduction

A centralized virtual power plant is developed in MATLAB-SIMULINK shown in Appendix B. The model is developed by using three DG unit which are controlled by control coordination center . We have developed the control center by using logic algorithm that is shown in Appendix C. The developed model in this paper is capable of sharing power to grid. Some preliminary units like distributed generation center, dynamic loads , excitation system & hydraulic turvine governor sytem were developed first in this proposed model. Finally the developed distributed generation centers were attached with main grid that completed the whole proposed model.In this chapter it is briefly conducted that a virtual power plant with three DG unit is able to share power with grid that contribute to the national grid by calculating and analyzing the results of current , voltage & power curves. As well as total harmonic distortion have been analysed for the different signal of this proposed model.

5.2 Results and Discussion

In an electric generator or electric motor, the stator is the stationary part of the rotor assembly. In the stator windings, the moving magnetic field generates an AC voltage.

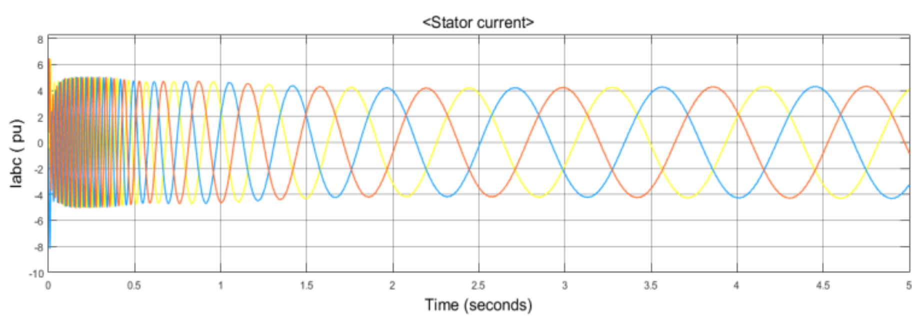


Fig. 5.1 Starting period of stator current

There are also three sets of stator windings, mechanically offset such that three phase currents are generated by the moving magnetic field, moved by one-third of a time relative to each other. **Fig. 5.1** describe the starting period and **Fig. 5.2** describe the running period of stator current that is measure in pu. During the starting period of stator there is fluctuations between 0-0.9 sec.

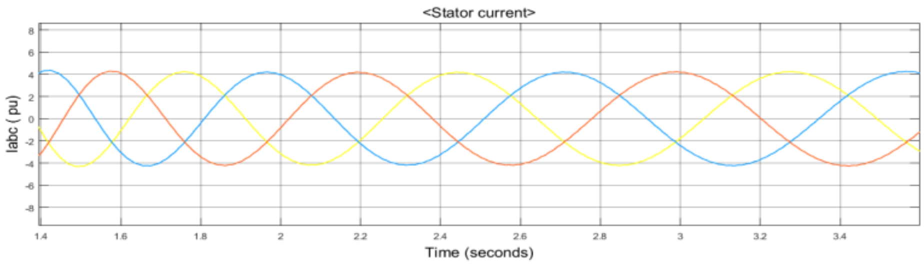


Fig. 5.2 Running period of stator current

Stable period occurs on *0.9- 1.5 sec* as we seen from **Fig. 5.1**.The running period from **Fig. 5.2** shows that stator current stable from *1.5 sec* approximately.

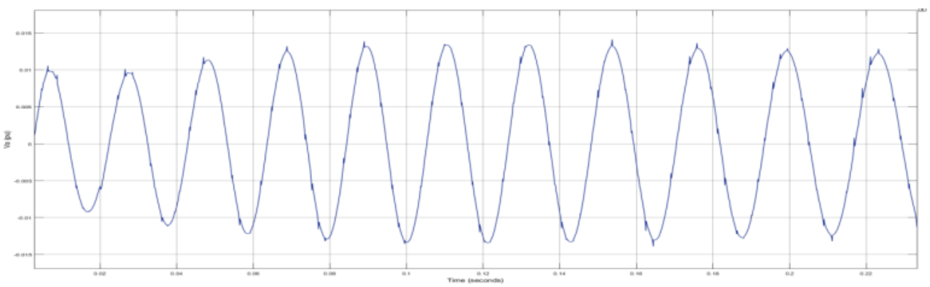


Fig. 5.3 Terminal voltage Va(pu)

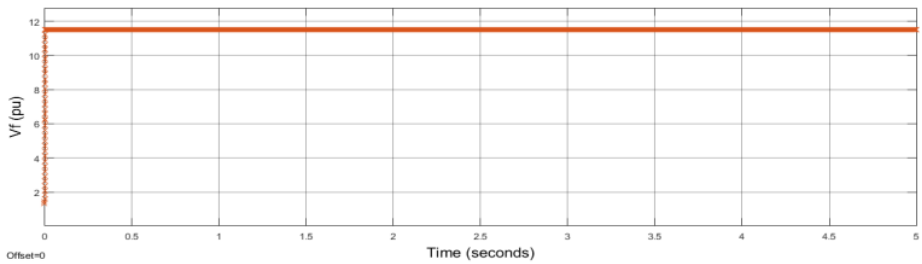


Fig. 5.4 Excitation system output Vf(pu)

The initial terminal voltage at pu is set. At the start of the simulation, the terminal voltage *Va is 0.01 pu*. The rise time is *10.462 ms*, and the fall time is *6.162 ms*. As seen in **Fig. 5.3** , it decreases to around *0.015 pu* during the fault and easily returns to normal after the fault is removed. This rapid reaction in terminal voltage is due to the fact that, as seen in **Fig. 5.4**, the excitation device output *Vf* will exceed *11.5 pu* during the fault and progressively returns to nominal after the fault is cleared.

5.2.1 DGC1 Scenario

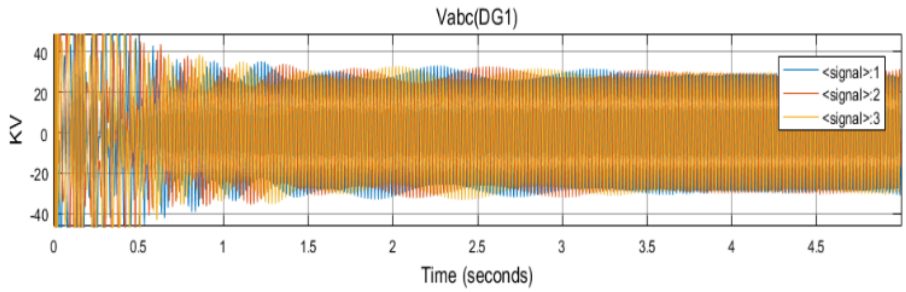


Fig. 5.5 Voltage scenario on DGC1

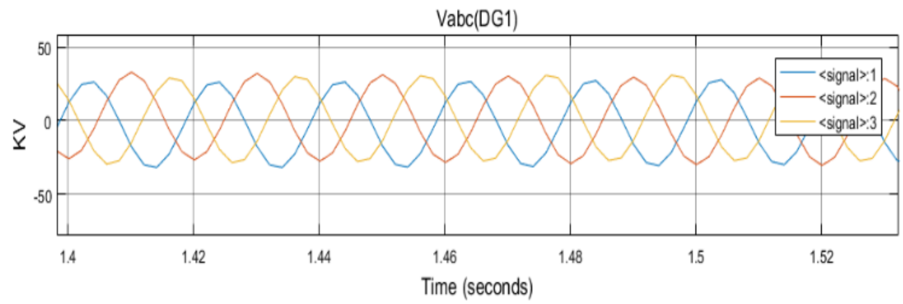


Fig. 5.6 Voltage scenario on DGC1

Fig. 5.5 shows the voltage scenario of DGC1. whereas **Fig. 5.6** shows that the DG voltage stable at *32.3 kv* for *Vabc*. At the starting period of simulation the fluctuation on *Vabc* occurs between *0-0.96s* approx. stable condition occurs at 0.97s shown in **Fig. 5.6**. For signal 1 the max voltage *35.63* kv occur at *0.943s* . Maximum voltage *32.18 kV* on signal 2 occurs at 1.02s as well as for signal 3 max voltage *35.2 kv* occurs at 1.1s.

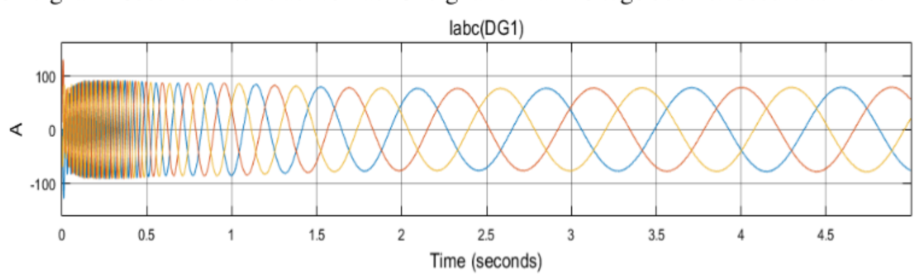


Fig. 5.7 Current scenario on DGC1

From the current scenario of DG1 as we can see that the unbalance of *Iabc* on DG center occurs approx. 1.3s. After that it shows the stable period of Iabc throughout the whole simulation process.. The current at stable condition *76.45 A* on Iabc of current profile on DG1.

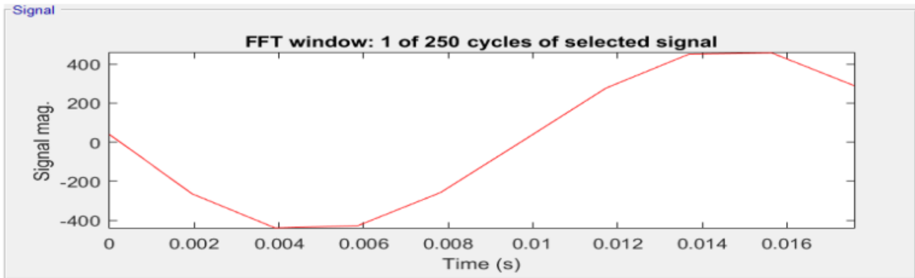


Fig. 5.8 Signal analysis of Vabc from DGC1

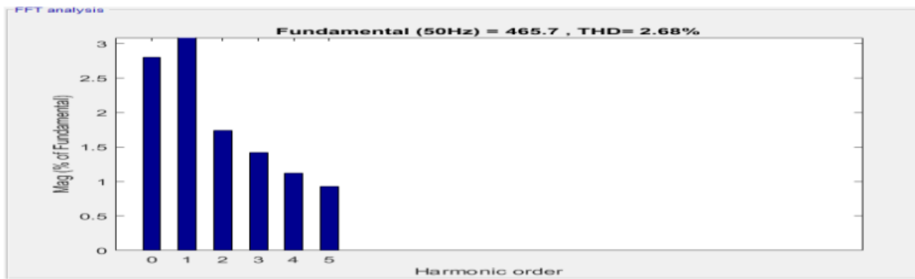


Fig. 5.9 THD analysis of Vabc from DGC1

For V≤ $11kv$, The max *VTHD* in under 8% in our whole system which is appreciated & it has been fulfilled the ***IEEE 519*** standard value of Voltage Total Harmonic Distortion. Based on simulation it can be analyzed from **Fig. 5.8** and **Fig. 5.9** that the fundamental of the grid voltage is *465.7 V* with *2.68%* total harmonic distortion.

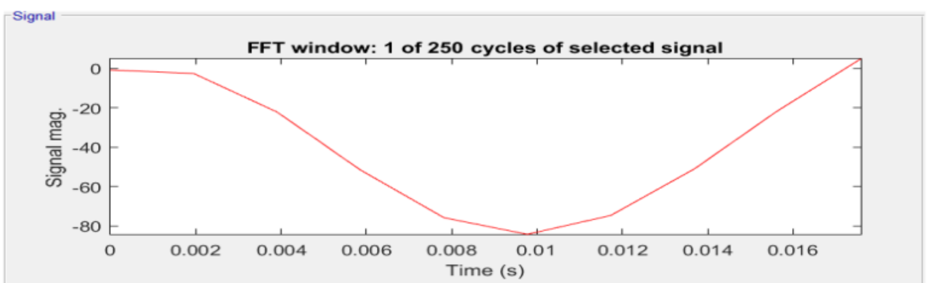


Fig. 5.10 Signal analysis of Iabc from DGC1

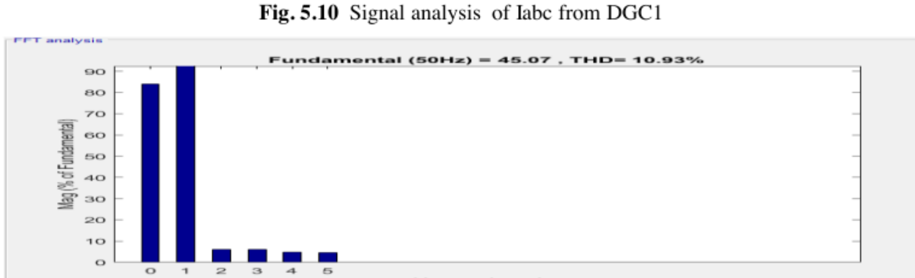


Fig. 5.11 THD analysis of Iabc from DGC1

For I ≤100I, In *ITHD* even harmonics limited into 25% and Odd harmonic are 25% above. Based on simulation it can be analyzed from **Fig. 5.10** and **Fig. 5.11** that the fundamental of the grid current is *45.07A* with 10.93% total harmonic distortion.

5.2.2 DGC2 Scenario

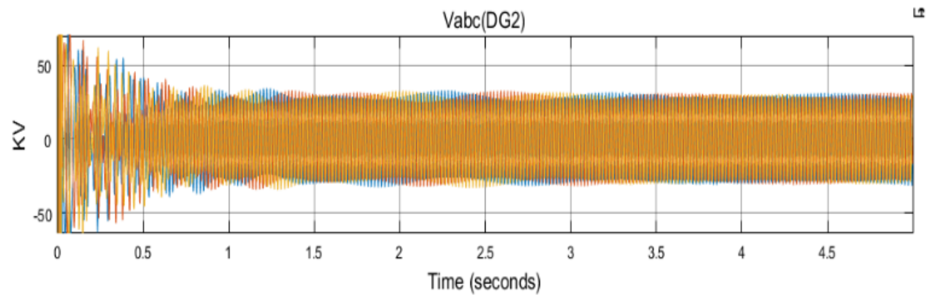


Fig. 5.12 Voltage scenario on DGC2

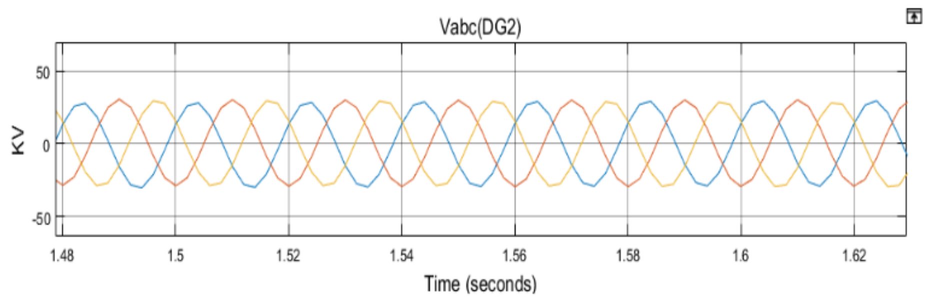


Fig. 5.13 Voltage scenario on DGC2

Fig. 5.12 shows the voltage scenario of DGC2. whereas **Fig. 5.13** shows that the DG voltage stable at *27.9 kV* for *Vabc*. At the starting period of simulation the fluctuation on *Vabc* occurs between 0-0.9s approx. Stable condition at 1.79s shown in **Fig. 5.13** .For signal 1 the max voltage *27.6 kV* occur at 1.92 s. Maximum voltage *29.83kV* on signal 2 occurs at 1.88 s as well as for signal 3 max voltage *32.2 kV* occurs at 1.9s.

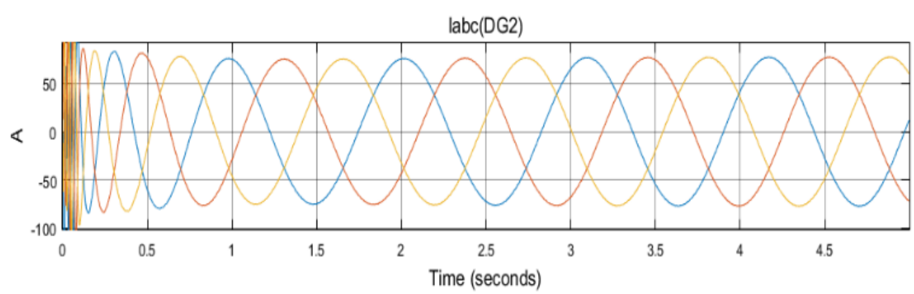


Fig. 5.14 Current scenario on DGC2

From the current scenario of DG2 as we can see that the unbalance of *Iabc* on DG center occurs approx. 0.2s. After that it shows the stable period of *Iabc* throughout the whole simulation process.. The current at stable condition *79.4A* on Iabc of current profile on DG2.

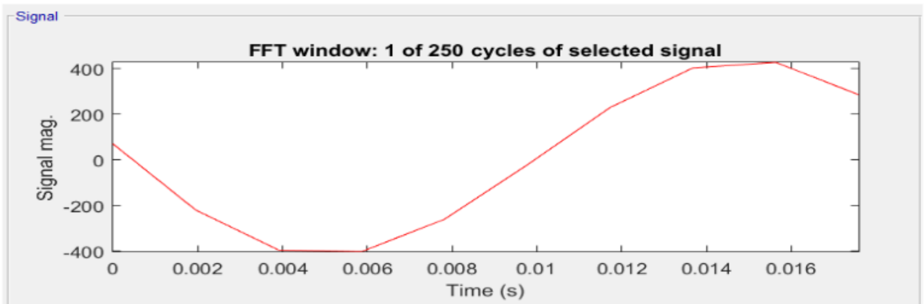


Fig. 5.15 Signal analysis of Vabc from DGC2

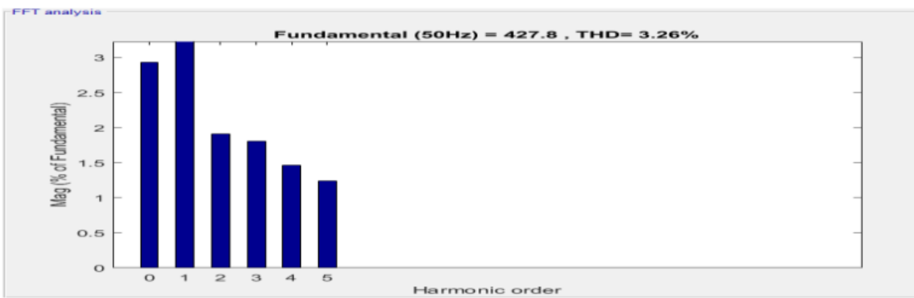


Fig. 5.16 THD analysis of Vabc from DGC2

For V$\leq 11kv$, The max *VTHD* in under 8% in our whole system which is appreciated & it has been fulfilled the **IEEE 519** standard value of Voltage Total Harmonic Distortion. Based on simulation it can be analyzed from **Fig. 5.15** and **Fig. 5.16** that the fundamental of the grid voltage is *427.8V* with 3.26% total harmonic distortion.

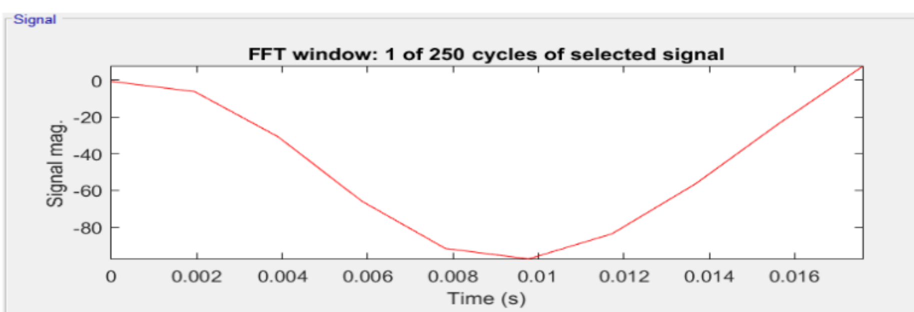


Fig. 5.17 Signal analysis of Iabc from DGC2

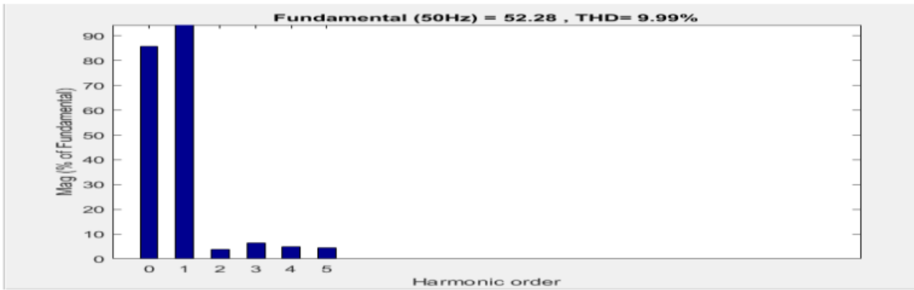


Fig. 5.18 THD analysis of Iabc from DGC2

For I ≤100I, In *ITHD e*ven harmonics limited into 25% and Odd harmonic are 25% above. Based on simulation it can be analyzed from **Fig. 5.17** and **Fig. 5.18** that the fundamental of the grid current is *52.28A* with 9.99% total harmonic distortion. .

5.2.3 DGC3 Scenario

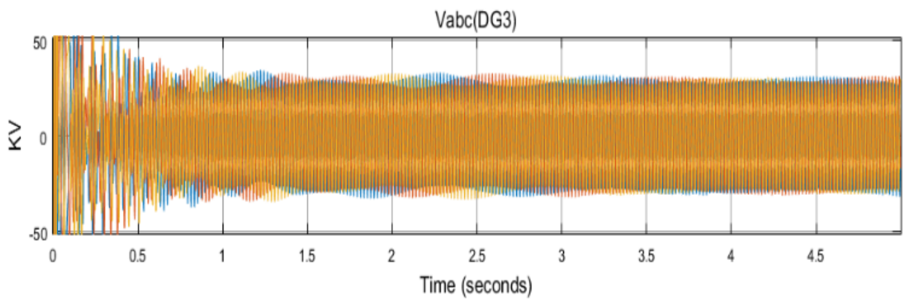


Fig. 5.19 Voltage scenario on DGC3

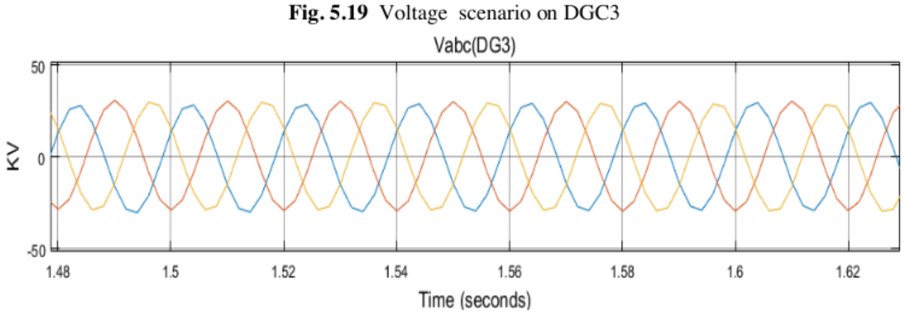


Fig. 5.20 Voltage scenario on DGC3

Fig. 5.19 shows the voltage scenario of DGC3. whereas **Fig. 5.20** shows that the DG voltage stable at 29.55kv for *Vabc*. At the starting period of simulation the fluctuation on *Vabc* occurs between 0-1.12s approx. stable condition at 1.5s shown in **Fig. 5.20**. For signal 1 the max voltage *34.17 kv* occur at 1.56s. Maximum voltage *33.4kv* on signal 2 occurs at 1.49s as well as for signal 3 max voltage *29.6 kv* occurs at 1.51s.

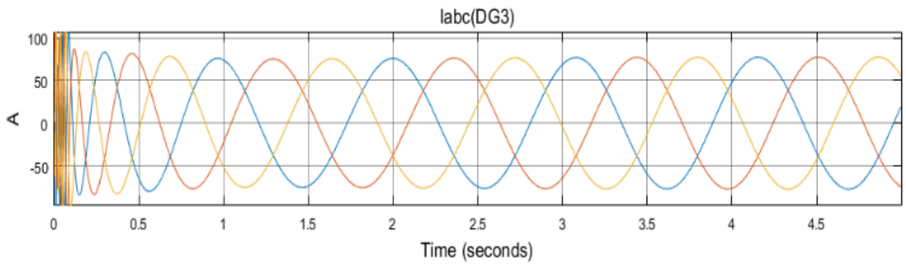


Fig. 5.21 Current scenario on DGC3

From the current scenario of DG3 as we can see that the unbalance of *Iabc* on DG center occurs approx. 0.4s. After that it shows the stable period of Iabc throughout the whole simulation process.. The current at stable condition *74.4A* on *Iabc* of current scenario on DGC3.

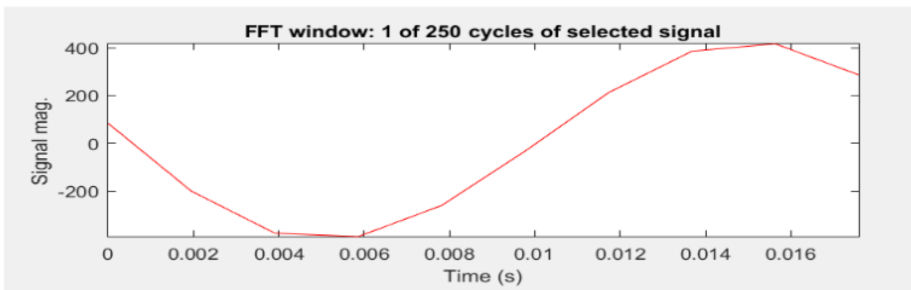


Fig. 5.22 Signal analysis of Vabc on DG3

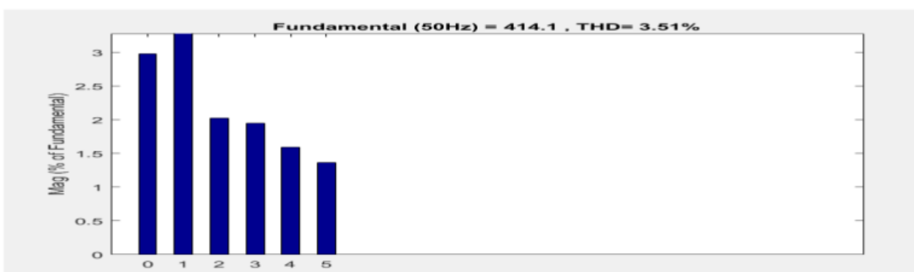


Fig. 5.23 THD analysis of Vabc on DG3

For V$\leq$ $11kv$, The max *VTHD* in under 8% in our whole system which is appreciated & it has been fulfilled the ***IEEE 519*** standard value of Voltage Total Harmonic Distortion.Based on simulation it can be analyzed from **Fig. 5.22** and **Fig. 5.23** that the fundamental of the grid voltage is *414.1 V* with 3.51% total harmonic distortion.

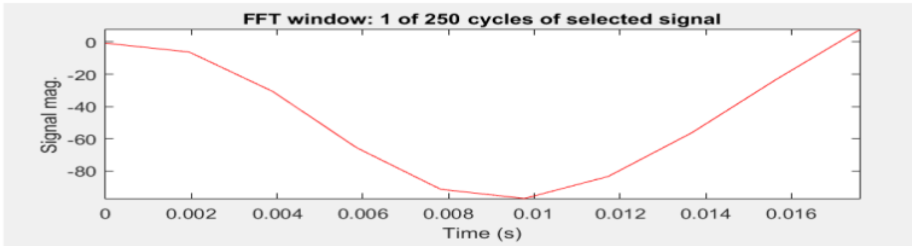


Fig. 5.24 Signal analysis of Iabc on DGC3

Fig. 5.25 THD analysis of Iabc on DGC3

For $I \leq 100I$, In *ITHD* even harmonics limited into 25% and Odd harmonic are 25% above. Based on simulation it can be analyzed from **Fig. 5.24** and **Fig. 5.25** that the fundamental of the grid current is *52.26A* with 10.11% total harmonic distortion.

5.2.4 Active Load Scenario

Fig. 5.26, **Fig. 5.27** and **Fig. 5.28** shows the active load scenario of zone1, zone2 & zone3 respectively. DG1 produces power to cover the average load in zone1 of *105.42 kW* at 1.5s approximate. Also DG2 is covering average load in zone2 of *69.96 kW* at 1s approximate. as well as DG3 covering average load in zone3 of *62.5 kW* at 0.8s approximate.

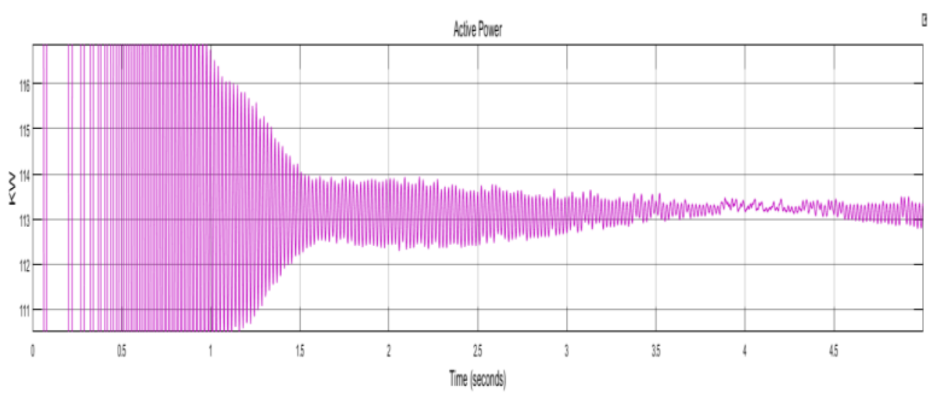


Fig. 5.26 Active Power scenario on zone1

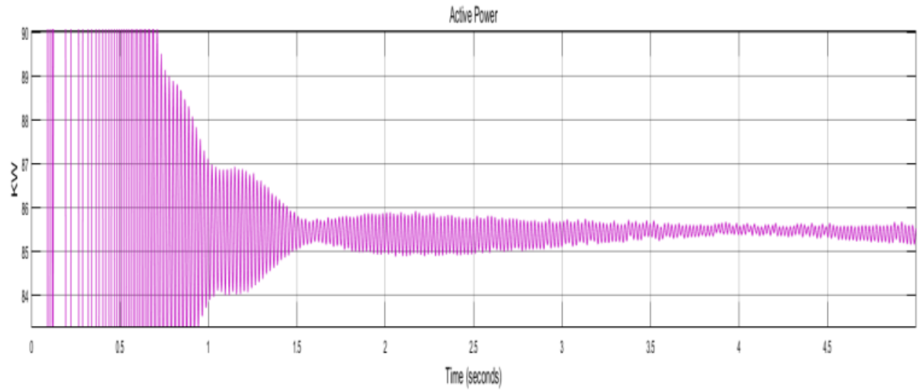


Fig. 5.27 Active Power scenario on zone2

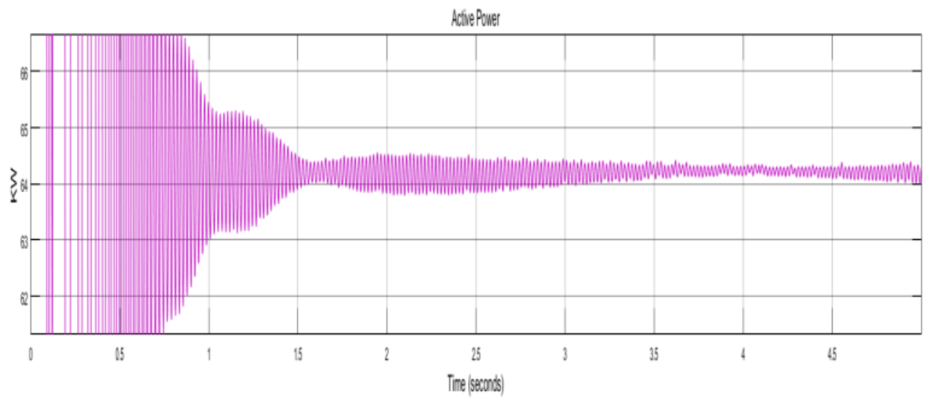


Fig. 5.28 Active Power scenario on zone3

Based on simulation it has been shown that the average peak load in 1s-2.5s for zone 1 , zone2 and zone3 respectively are *113.6 kW , 85.64 kW* and *65.15kW*. Again in 2.51s-4s , for zone1 *113.4 kW*, for zone2 *84.97 kW* and *64.40* kW for zone3 has been shown from the simulation. Minimum average load at 1s-5s in simulation for zone 1 is *104.8 kW,* zone2 is *48.4 kW* and zone3 is *30.14 kW*.

CHAPTER 6

TECHNO-ECONOMIC ANALYSIS

6.1 Introduction

This chapter indicates to the techno-economic analysis of a virtual power plant which has been model for IIUC. First of all daily average load profile for three zones has been discussed. Then, we attempted to identify the cost calculation of energy usage in IIUC by comparing VPP as well as without VPP.

6.2 Centralized Virtual Power Plant for IIUC

A case study in the perspective of Bangladesh: considering IIUC as a reference model of our proposed design. **Fig. 6.1** explains the block diagram of the centralized VPP for IIUC . The VPP consists of three distributed generation units running parallel to the main grid and three dynamic loads in a simulation. The following subsections present a detailed model overview of the VPP that is discussed on this paper.

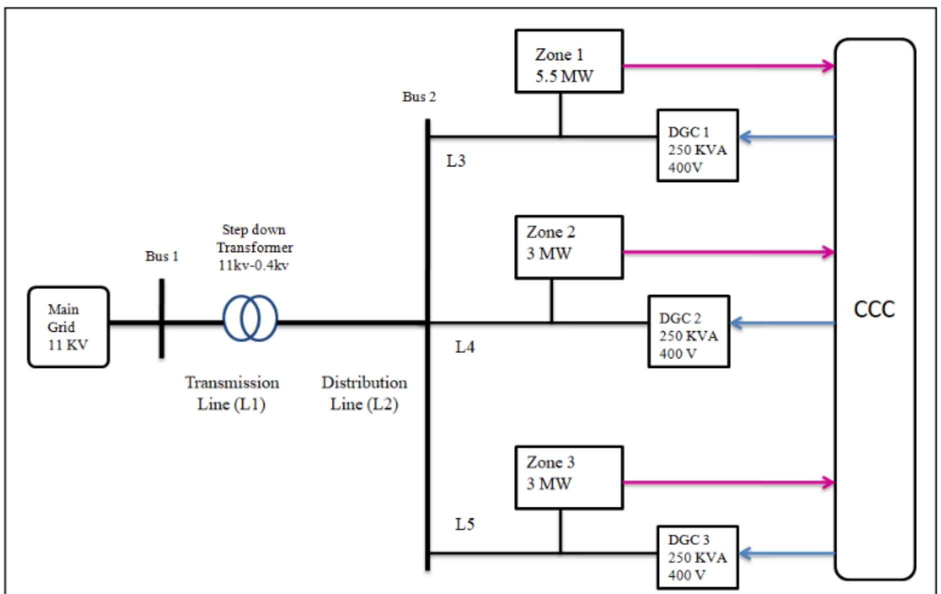


Fig. 6.1 Centralized VPP for IIUC

We have divided the whole IIUC campus in three zones, these are-

Zone 1: Science building, CE and CSE building, BBA building, Academic buildings & Language building , Shariah and Pharmacy building, Library, Workshop, Student halls & Canteens.

Zone 2: LAW Building , Medical centre ,Transport section, Central Mosque, IIUC school, Auditorium, Central Cafeteria.

Zone 3: Teachers Dormitory, Female Campus, guard shed, street light & water pump.

6.3 Load Profile

In **Fig. 7.2 ,Fig. 7.3** and **Fig 7.4** shows the average daily load profile for zone 1, zone 2, zone 3 for IIUC which has been found by using Homer pro . Average demand for zone 1 is *105.42 kW* where peak demand is *198.64 kW*. The total energy demand for zone 1 is *9234479.2 kWh* annually.

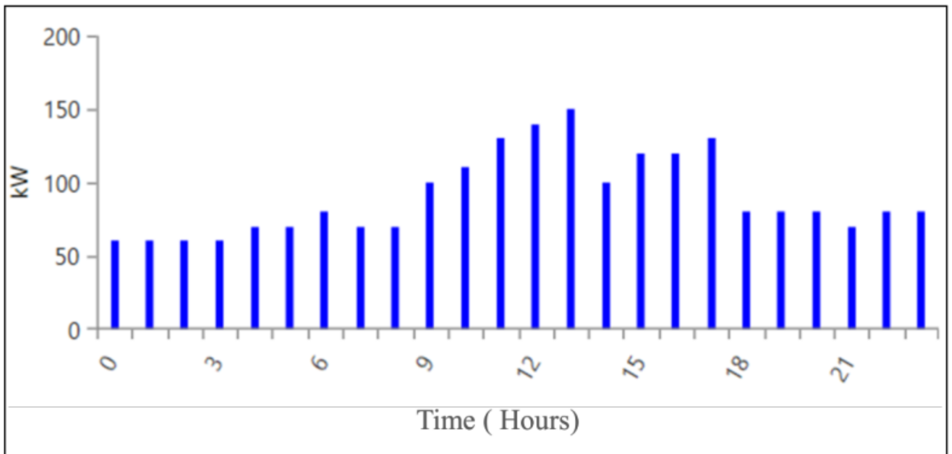


Fig. 6.2 Average daily load profile for Zone 1

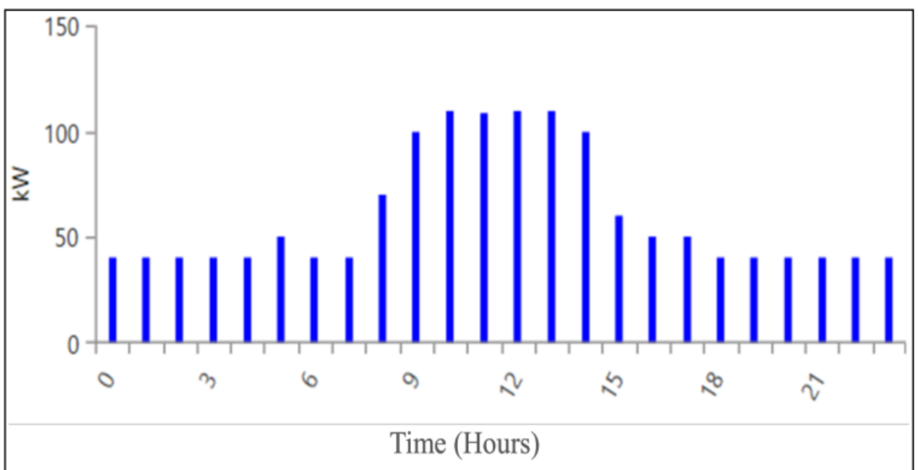


Fig. 6.3 Average daily load profile for Zone 2

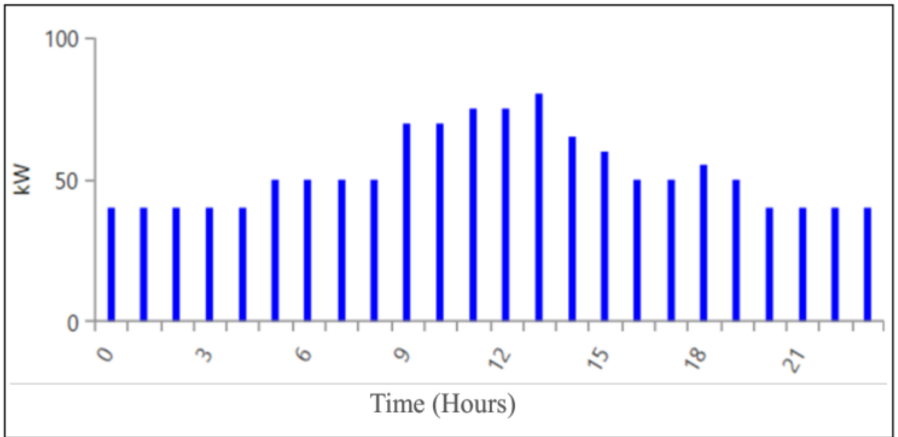


Fig. 6.4 Average daily load profile for Zone 3

Average demand for zone 2 is *69.96 kW* where peak demand is *159.64 kW*. The total energy demand for zone 2 is *612849.6* kWh annually. Average demand for zone 3 is *62.5 kW* where peak demand is *90 kW*. The total energy demand for zone 3 is *547500 kWh* annually shown in **Table 6.1**.

Table 6.1: Load specification

Load Type	**Zone 1**	**Zone 2**	**Zone 3**
Average Demand	105.42 kW	69.96 kW	62.5 kW
Peak Demand	198.64 kW	159.64 kW	90 kW
Annual Energy Demand	9234479.2 kWh	612849.6 kWh	547500 kWh

6.4 Technical parameters of Generator

For the development of DER of virtual power plant in IIUC campus we have used three diesel generators for three different zones in IIUC. We have used *250 KVA* Diesel generator which is manufactured by Cummins . The engine speed is *1500 rpm* & which is a 4 stroke as well as compression ignition generator. Gross engine power is *295 kWm*.

Table 6.2: Parameters of used generator in simulation

250 KVA Diesel generator	**Brand: Cummins**
Price	1920000 /- Tk
Prime Output	200 kW
Country of manufacturer	China
Frequency	50 Hz
Cycle	4 stroke, Compression ignition
Engine Speed	1500 rpm
Control panel	Deep sea electronics
Warranty	12 months
Fuel consumption	25%- 8L/hr 50%- 12 L/hr 75% - 15 L/hr 100%- 20 L/hr

And Net engine power is *268 kWm*.The prime output of the generators are *200 kW* also used water cooling system.Compression ratio is 16:1 and the alternator is brushless, AVR controlled & self cooled as weel as self excited.

6.4.1 Fuel Consumption

Fuel consumptions by three different generators has been calculated in this **Table 6.3**. The total approximate average fuel consumption by three generators of three different zones in daily , monthly and annually has also seen from the calculation.

Table 6.3: Consumptions of fuel

	Daily	Monthly	Annually
Average Fuel consumption	864 L	25920 L	315360 L
	228.24 Gallon	6847.2 Gallon	83307.6 Gallon

6.5 Utility normal & weekend days

We have calculated weekdays and weekend days for IIUC in a year. This may vary in different years according to the holidays. we have found total *106 weekend days* and *259 weekdays* in **Table 6.4** from the academic calendar of IIUC. During the weekend days most of the loads has been unused except students halls, canteen , mosques , teachers dormitory , water pumps , street lights as well as some load used for MBA classes .

Table 6.4: Utility normal & weekend days

Month	Weekdays	Weekend Days
January	22	9
February	19	9
March	23	8
April	20	10
May	23	8
June	20	8
July	21	10
August	23	8
September	21	9
October	22	9
November	22	8
December	21	10

6.6 Energy Cost

Energy generated from zone 1 = Ez1

Energy generated from zone 2 = Ez2

Energy generated from zone 3 = Ez3

Total energy generated , E_t = Ez1 + Ez2 + Ez3

= (9234479.2 + 612849.6 + 547500) kWh

= 10394828.8 kWh = **1.03× 10^7 kWh**

Capital Cost, Cc = 3× 1920000= 5760000 Tk = **5.76 million Tk**

Average daily fuel consumption for three generators = 864 L

Fuel Cost, Fc = (864 × 365 × 65) = 20498400 Tk **= 20.49 million Tk**

Operating Cost, Oc = Service + Maintenance + Reparing + Extension

= (8040000 + 750000 + 570000 + 600000)

= 9960000 Tk = **9.96 million Tk**

Total Cost , Tc = Cc + Fc + Oc

= (5760000 + 20498400 + 9960000) = 36218400 Tk = **36.21 million Tk**

Annual Cost / kW $= \frac{36218400}{10394828.8}$ = 3.847 Tk ≈ **3.85 Tk**

6.7 Financial Parameter of VPP

6.7.1 Tariff Data

This section offers the Time of Day (ToD) tarrif from BPDB energy tariff march 2020.The main objective of this tarrif is to decrease the loads in peak hours by encouraging the customers to shift the load from peak to off peak hours. IIUC follows the tarrif data from **Table 6.5** beacuse it has the main grid of *11 kV* and the load capacity up to *11.5 MW*.

Table 6.5: BPDB ToD tarrif [47]

MT-2: Commercial & Office	Energy rate/ Charge (Tk/kWh)	Demand rate/ Charge (Taka/kWh/m)
Flat	9.12	60.00
Off- Peak	8.21	
Peak	11.40	

6.7.2 Techno-economic Analysis

This section describes the per unit generation cost for energy in IIUC by using VPP as well as without using VPP. **Fig. 6.5** shows the cost comparision between VPP & without VPP usage in IIUC campus. From the data it has been found that the per unit

Table 6.6: Generation cost

Per unit cost for generation	With VPP	Without VPP
	3.85 Taka	8.21 Taka

Taka savings by proposed VPP model for IIUC = *(8.21 – 3.85) = 4.36 Tk* which has been a great things to look out for IIUC authority. Now the energy cost from grid purchases is around *8.21 Tk*. By using VPP it will be approximate *3.85 Tk*.

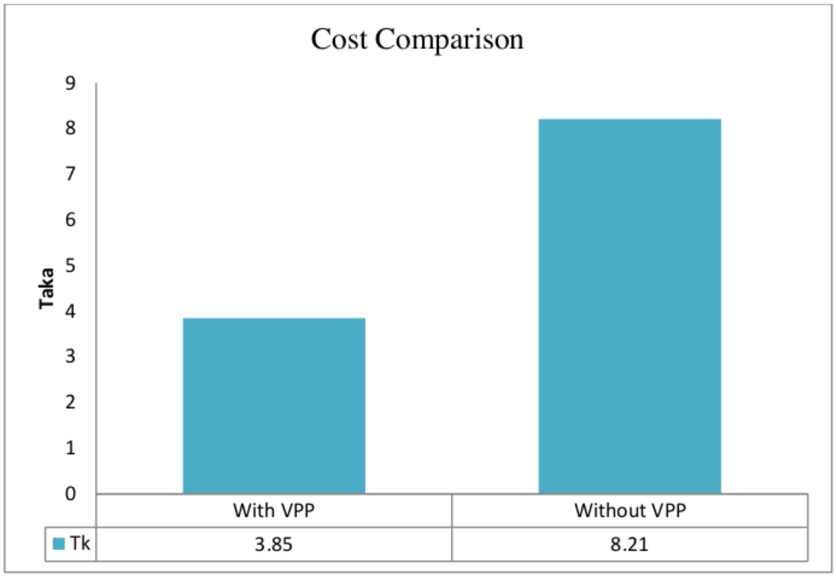


Fig. 6.5 Cost comparison of with VPP vs without VPP

The total annual energy cost of IIUC is around *85341544.45 Tk,* whereas by using VPP in IIUC campus the total approximate total annual energy cost will be *40020090.88 Tk*. The annual savings will be *45321453.57 Tk* which will be a huge benefit for IIUC.

Table 6.7 Techno-economic analysis

DER Investment	**Without VPP**	**With VPP**
Generator Capacity	-	600 kW
Total annual generations	-	1.03×10^{7} kWh
Total annual energy cost (Taka)	85.34 million	40.02 million
Annual savings (Taka)	-	45.32 million

CHAPTER 7
CONCLUSION

7.1 Introduction

The study in this thesis has been introduced the principle of virtual power plant by focusing on the development of three DG unit aggregation control to share power with the distribution grid. Also the calculation for minimizing the cost has been analyzed properly in this chapter.

7.2 Conclusion

This thesis starts by proposing the concept and forms of virtual power plants and proceeds to present the simulation results of different DGs. In case of decentralized system the centralized control of VPP is more efficient because of the control operations have been done from one place. So we have developed a centralized system for IIUC campus in our proposed model. In a centralized control system there is a control coordination chamber (CCC).The Control Coordination Centre (CCC) in this structure is responsible for the control of a variety of DG units. Coordination control of DG units and loads is carried out by the sharing of information and the algorithm. We have developed whole model & simulation by MATLAB-SIMULINK for IIUC. The simulation results shows the contribution of VPP by energy sharing through different distributed generation center to the grid section of the university. From the simulation the total energy sharing of three DG unit with main grid also described.

Since the VPP is a modern technology. To involve this technology in our system, the cost calculation will be in top priority lists. So in this thesis have calculated the different parameters of VPP by calculating its techno-economic analysis for IIUC which has been ensured that the integration of VPP in IIUC campus will be work as a comprehensive cost minimizing factor. The annual savings will be 53%. This study proposed that economically it will be a tremendous contribution for a developing country like Bangladesh.

7.3 Advantages

Our proposed model of virtual power plant for IIUC has the flexible configurations by merely adding additional distributed energy services to the virtual platform. This flexibility is not offered by traditional power plants. Involvement in the sharing of energy with the main grid is the great advantage for the national grid. By implementing this proposed VPP, it has been shown from our analysis that the total annual saving from IIUC will be *45321453.57 Tk*. It has been shown that our proposed plays an important role for the economy of Bangladesh .

7.4 Limitations

It should be implemented by own to search limitations of any works. Because of our country has no virtual power plant, we could not implement our work. So the main fact and limitation is that this thesis work is simulation based not on practical basis. Because of the memory acquisition problem caused by MATLAB, the speed of the simulation is unstable. Limitations of the whole system:

- Transmission capacity, actual grid & electricity storage costs are comparatively higher.
- Via the communication channel, fault can occur.

7.5 Application

The proposed model of VPP can be used to promote DER trade in wholesale electricity markets (e.g. forward markets and power exchanges) and to provide transmission system operation support services for transmission networks (e.g. various types of reserve, frequency and voltage regulation and so on).The VPP framework is able to provide the following opportunities, as previously explained.

- **Energy trading:** Presence in the wholesale sector representing the owners of the negotiated DER.
- **Network services:** Promoting the control of loads and congestion and increases the performance of electricity .
- **Balancing:** VPP can be used In order to improve system stability and reliability to assist in energy balancing. Restricted supply and demand regulation at local and regional levels and peak shaving efficiency.

7.6 Future relevant works

Future relevant works:

- There is still scopes left to implement the model. Experiments should be carried out to test the control system. It is necessary to develop a controller to process the load signals that will be transmitted to the DG controller. It will require a fast infrastructure for communication. In future we will try to use more than three DG unit to built the system. Different types of renewable energy resources can be used to install that system by proper research.

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APPENDIX

Appendix A. shown the calculation of RLC line parameters . In the simulation, each branch is represented by a three-phase parallel RLC branch.The length of overhead line (L1) is 500 m , Thus R-L-C can be obtained

R=0.156ohm/km×0.5km=0.078ohm

X= ωL = $2.\pi.f.L$

L=$\frac{X}{2\pi f}$ = $\frac{0.155}{2\pi(50)}$ = 9.99e-4 H/km ;9.99e-4 H/km ×0.5km = 4.99e-4H

C= 235 nF/km ×0.5km =117.5 nF

Thus R-L-C value of overhead line (L2) can be calculated

R=0.2426Ohm/km× 5km=1.213 Ohm

X= ωL = $2.\pi.f.L$

L=$\frac{X}{2\pi f}$ = $\frac{0.314}{2\pi(50)}$ = 9.99e-4 H/km ;9.99e-4 H/km ×5km = 4.99e-3H

C= 10.15 nF/km ×5km =50.6nF

Length of distribution line (L3) from distribution bus to transformer is 400m. and to each load/DG units are 200 m (L4). Thus the R-L-C value of L3 & L4 can be obtained

For length 400 m

R=0.437Ohm/km×0.4km=0.1748 Ohm

X= ωL = $2.\pi.f.L$

L=$\frac{X}{2\pi f}$ = $\frac{0.302}{2\pi(50)}$ = 9.99e-4 H/km ; 9.617e-4 H/km ×0.4km = 3.846e-4H

C= 10.3nF/km ×0.4km =4.08nF

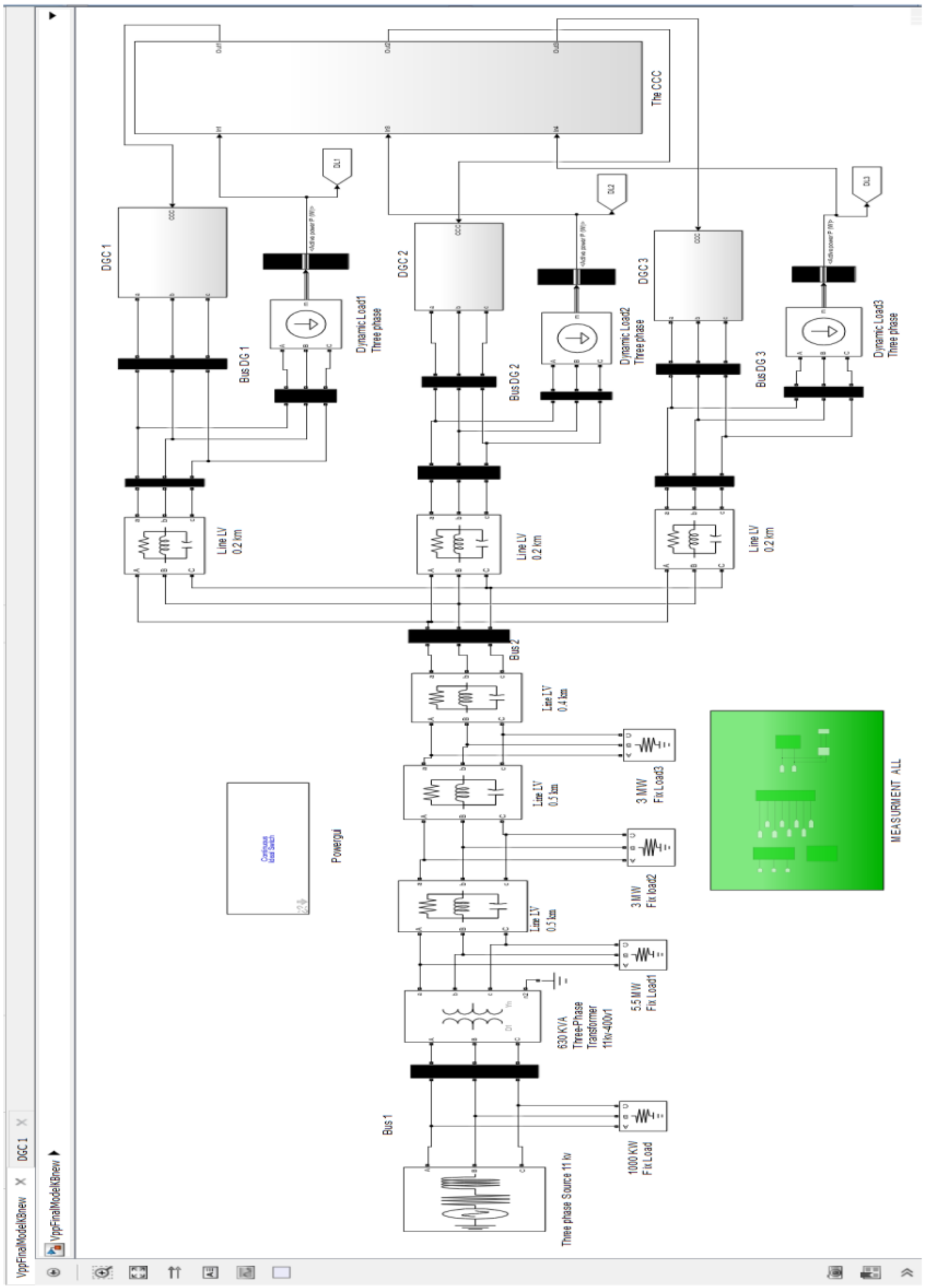
For length 100 m

R=0.437 Ohm/km×0.2km=0.0874 Ohm

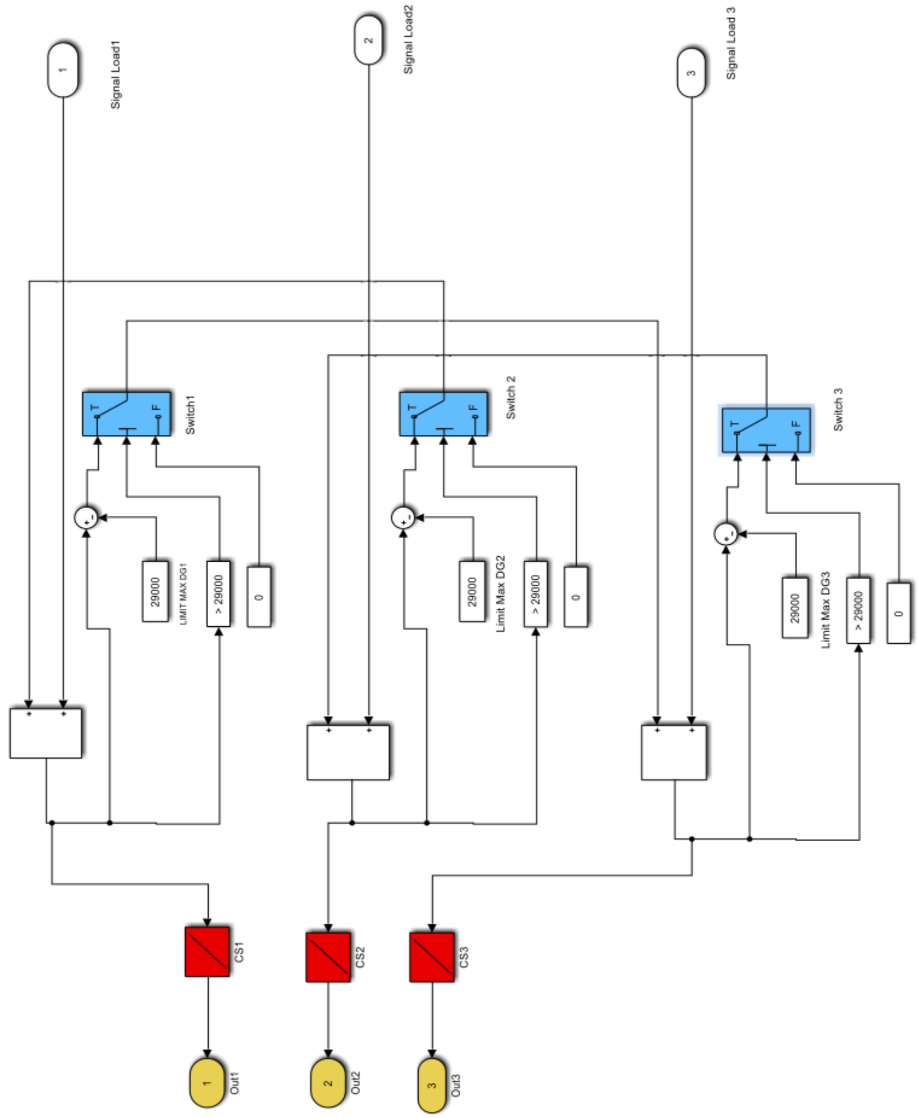
L= 9.617e-4 H/km ×0.2km= 1.833e-4H

C= 10.2nF/km ×0.2km =2.04 nF

Appendix B. Centralized Virtual power plant (MATLAB-SIMULINK)



Appendix C. Control coordination center algorithm (MATLAB-SIMULINK)



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