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Voltage and Frequency Control in Renewable Rich Microgrid

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THESIS ACCEPTANCE

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ABSTRACT

The increasing integration of renewable energy sources into microgrids has resulted in a fundamental transformation of the power distribution framework. This study examines the essential elements of voltage and frequency boundaries in microgrids with a significant amount of renewable energy sources, focusing on the specific difficulties arising from the intermittent and variable characteristics of renewable energy generation. In the context of the global shift towards sustainable energy solutions, it is of the highest priority to comprehend and proficiently handle the voltage and frequency dynamics within microgrids. Renewable-powered microgrids, which involve the incorporation of sources such as photovoltaics, wind turbines, and energy storage devices, exhibit a dynamic and complicated operational setting. In contrast to traditional power systems, the fluctuating nature of renewable energy generation requires the use of sophisticated control mechanisms in order to ensure the voltage and frequency remain within acceptable thresholds.

This thesis highlights the importance of employing advanced control algorithms capable of accommodating the natural oscillations associated with renewable power generation. The exploration of voltage regulation is conducted within the framework of reactive power control and voltage support provided by inverters. Similarly, the examination of frequency regulation involves the coordination of energy storage systems and intelligent inverters. The analysis of the interplay among these variables is conducted in order to obtain full insights into the operational dynamics of microgrids that have a high proportion of renewable energy sources. In addition, this discourse addresses the difficulties associated with upholding grid resilience and stability in light of the intermittent characteristics of renewable energy sources. It emphasizes the significance of adopting a comprehensive methodology that integrates sophisticated control tactics, energy storage systems, and communication technologies.

In summary, this study makes a valuable contribution to the current scholarly conversation surrounding the effective administration of voltage and frequency in microgrids that include a significant presence of renewable energy sources. The results emphasize the importance of using novel control systems and incorporating advanced technologies to effectively tackle the distinct issues associated with the shift towards sustainable energy sources. The findings reported in this paper provide significant recommendations for engineers, researchers, and politicians who are interested in improving the dependability and performance of microgrid systems in the context of the growing adoption of renewable energy worldwide.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	Explanation
DC	Direct Current
AC	Alternating Current
MG	Microgrid
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
CAGR	Compound Annual Growth Rate
BESS	Battery Energy Storage System
LV	Low Voltage
MV	Medium Voltage
SCADA	Supervisory Control And Data Acquisition
EMS	Energy Management System
DG	Distributed Generation
TSO	Transmission System Operator
WAM	Wide Area Measurement
DNO	Distribution Network Operators
VSI	Voltage Source Inverter
HVDC	High Voltage Direct Current
EV	Electrical Vehicle
PF	Power Factor

CHAPTER ONE

Introduction

1.1 Introduction

Rapid growth in the use of renewable energy sources has changed the global energy landscape, resulting in a sustainable, decentralized power generation model. Microgrids help towns, colleges, and industrial complexes develop locally and resiliently. As dynamic ecosystems like renewable-rich microgrids become essential to the future energy grid, regulating voltage and frequency becomes increasingly important. Renewable-dominant microgrids use solar photovoltaic, wind turbines, and energy storage. Innovative control systems that can handle renewable generating variability are needed to ensure reliable energy delivery to end-users. This paper examines the complex dynamics of voltage and frequency constraints in microgrids with substantial renewable energy penetration. This study seeks to understand renewable source fluctuations and their solutions. The investigation covers reactive power control, inverter voltage support, and energy storage system frequency regulation. This study examines the complex dynamics of renewable energy-powered microgrids to understand system stability and also critically evaluates voltage and frequency control norms and regulations while acknowledging the energy sector's dynamic nature. This work may influence the development of advanced control methods and technology as the world adopts sustainable energy sources. The stability and effectiveness of microgrid systems that use renewable energy will improve. The next parts will analyze voltage and frequency regulation, focusing on technological advances and legal frameworks that enable microgrids to integrate renewable energy.

Significance of study

1.2 Significance of study

The importance of studying Renewable Rich Microgrids lies in their capacity to tackle pressing issues in the present energy scenario while also promoting sustainable development. The following are essential points that underscore the significance of this subject: *Energy sustainability* is achieved by the utilization of renewable-rich microgrids, which harness clean and sustainable energy sources like solar, wind, and hydropower. These microgrids enhance the sustainability and resilience of our energy future by decreasing reliance on non-renewable resources. In definition of microgrid's operating form classifies into two structures: centralized and decentralized. *Centralized control* is characterized by one unit controls all system. In case of reliability of the whole system, network management possibilities are reduced. *Decentralized Energy Generation* is when Microgrids function based on a decentralized framework, enabling the production and usage of energy at a local level. This can improve energy security by decreasing dependence on centralized power plants and susceptible grid infrastructure. Renewable-rich microgrids bolster grid resilience due to their distributed nature. During natural catastrophes or other interruptions, microgrids can persistently provide electricity to nearby towns, reducing the duration of power outages and improving the overall dependability of the electrical grid. Grid independence refers to the ability of microgrids to function autonomously from the main power grid, hence granting communities increased self-sufficiency in terms of energy supply. This is especially crucial in distant or secluded regions where establishing a connection to the primary power network may pose cost or logistical difficulties.

Economic Benefits: The financial and economic aspects of introducing and expanding the microgrid concept are also interesting. Using distribution networks as an example, the use of microgrids improves the performance of SAIDI/SAIFI in socio-economic terms and helps reduce CO2 emissions into the atmosphere. The global microgrid market size is estimated at US $30.5 billion in 2022 and is expected to exceed approximately US $168.64 billion by the end of 2032, recording a compound annual growth rate (CAGR) of 18.7% from 2023 until 2032.

Key findings: By type, the AC microgrid segment contributed 59.6% of revenue in 2022 and will grow at a CAGR of 15.7% from 2023 to 2032.

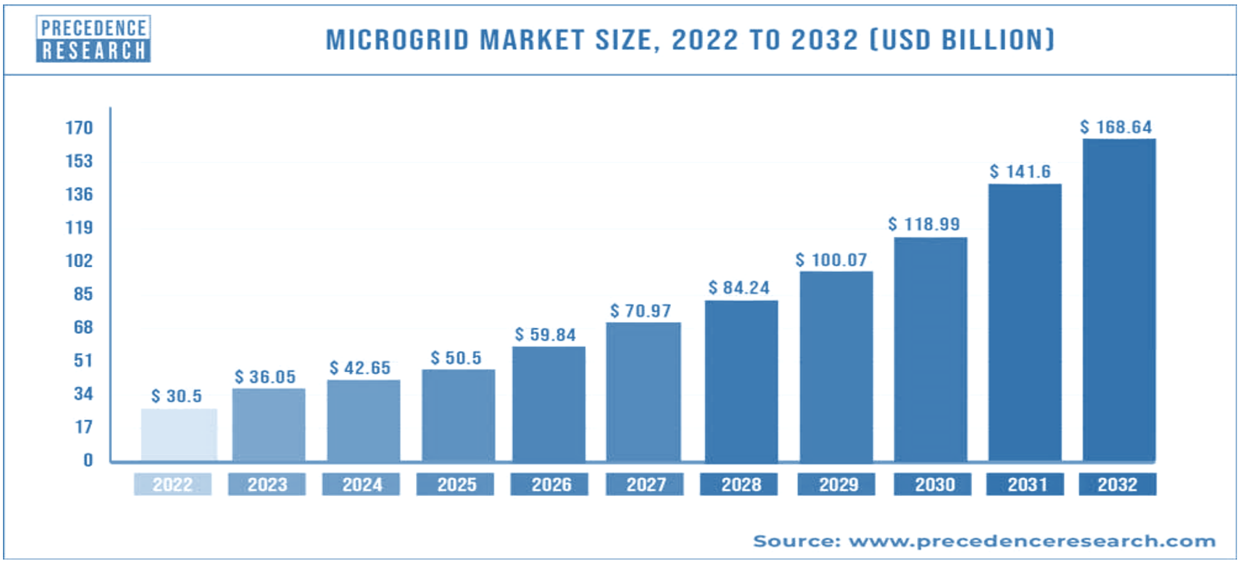


Fig.1.1. Market size of Microgrid for 10 years [2].

North America accounted for 40.9% of total revenue share in 2022; The market share of the Asia-Pacific region in 2022 accounted for 21.50% of revenue; In terms of the number of connections, the segment connected to the network received 62% of revenue in 2022; In 2022, the share of the autonomous connections segment was 38.50%.

At the same time, it is necessary to take into account the fact that the segment of natural gas energy sources will grow by an average of 23% in the period from 2023 to 2032. So, a Microgrid is an energy system that operates simultaneously with or independently of the main electrical grid and **integrates loads and dispersed energy resources**. **This improves grid efficiency and stability, reduces peak loads**, fuel consumption, and congestion, and improves reliability and resilience. Microgrids can be combined with a variety of renewable energy sources, including solar power, small hydropower, wind systems, waste-to-energy systems, geothermal, and combined heat and power systems, **as they are more efficient than traditional electrical grids**. Thus, optimistic forecasts give us reason to believe that a paradigm shift towards the use of reliable and safe power units and the constant development of advanced technologies to ensure energy resilience to grid instability will complement the market picture. We are obliged to do this by two main factors, which merge into a single, global goal. These factors are: 1. Growing urbanization*****; 2. Carbon Reduction

* Because cities can reduce carbon emissions by creating policies that encourage the use of the renewable energy sources, such as wind or solar power.

Key market drivers*:* The use of microgrids to generate electricity in rural areas is growing rapidly.

Microgrids are becoming more common around the world. They can be used to remotely electrify remote sites, develop resilient networks at grid-connected sites, and support local energy communities. The IEA estimates that by 2020, approximately 860 million people worldwide will lack access to electricity. 87% of them lived in rural or isolated areas. Microgrids can be created in small areas and provide electricity at a lower cost than traditional networks, which makes them an acceptable socio-economic tool for overcoming the current situation in terms of accessibility to an electrical resource. Increasing government support and a surge in microgrid project implementation are additional factors influencing the microgrid market for electrification of remote and hard-to-reach areas. Growing demand for smart control solutions in remote locations and shifting customer focus towards implementing low-emission energy solutions will improve business dynamics. The industry development scenario will be improved by supporting government initiatives to build network infrastructure in line with the development trends of decentralized networks.

Key Market Opportunities: **Governments are increasingly supporting microgrid initiatives**. [1] Reliable and efficient energy supply can be provided to many industries using microgrid technology, which is also becoming more cost-effective. For example, in October 2019, the Australian federal government launched a $50 million microgrid funding scheme. Of this amount, US$20 million was provided to the country for microgrid feasibility studies.

Review of Literature

1.3 Review of Literature

The transition towards a more sustainable energy landscape has underscored the importance of renewable energy integration into power systems. Microgrids, as localized power distribution systems, have garnered considerable attention due to their potential to accommodate a high penetration of renewable energy sources (RES). Voltage and frequency control, critical aspects of power system stability and reliability, become particularly challenging in microgrids with a substantial proportion of RES due to their intermittent and variable nature.

The integration of renewable energy sources, such as solar photovoltaics (PV), wind turbines, and battery energy storage systems, into microgrids presents unique challenges for voltage and frequency regulation. Unlike traditional fossil fuel-based power generation, renewable energy sources are inherently variable and intermittent, leading to fluctuations in both voltage and frequency within the microgrid. These fluctuations can disrupt the stability and reliability of the microgrid, impacting the quality of power supplied to consumers. Controlling both connected and standalone Microgrid is a tough job that requires huge amount of data. It has many tools and techniques that helps to keep parameters as voltage, current and frequency.

Voltage Regulation in Microgrid :Voltage regulation in a hybrid microgrid system along with frequency regulation is the key factor in providing high-quality of electricity. The method of voltage, current, and frequency regulation used in this master thesis is based to the four-port transformer [30]. This transformer is suitable for usage in a range of microgrid systems, including stand-alone facilities, residential houses, commercial buildings, and remote oil and gas drilling rigs located in remote oil and gas regions. For these purposes, the rated operational power for each port is 25 kW. The ports can represent various forms of energy generation, such as wind turbines and photovoltaic systems.

Frequency Regulation in Microgrid

One of the main issues of electrical energy quality is the frequency that should keep some constant value.. In this thesis, it has been proposed to make frequency regulation in the DC bus of the microgrid. Also to make this process more reliable, centralized control system of the power quality can be used. With this method, more precise electronic control and continuous monitoring of v/f can be obtained. Disadvantages of this method are, more weak structure of centralized control system, and requirement to application of digital measure modules for all parts of the system.

The main issues in MG are v/f control. For this purpose, different methods such as voltage control in battery energy can be adapted to apply it in both AC and DC. However, studies show that applying control systems in DC buses is easier and more reliable.

Problem Statement

1.4 Problem statement

1. Intermittent and Variable Characteristics of Renewable Sources:

The integration of renewable energy sources, such as solar and wind, into microgrid systems heralds a promising era of sustainable and decentralized power generation. However, the inherent intermittency and variability of these renewable sources pose significant challenges to the stability and reliability of microgrid operations.

Due to the fact that, sometimes wind energy production reach its peak at night time of the day, when consumption is lower than the average, sometimes “excess” renewable energy production has been observed. Intermittency refers to the frequency to which a power source has accidentally interruptions or unavailability. However, it is sometimes used interchangeably with the term variability, which pertains to the extent of fluctuations in the output of a power source.

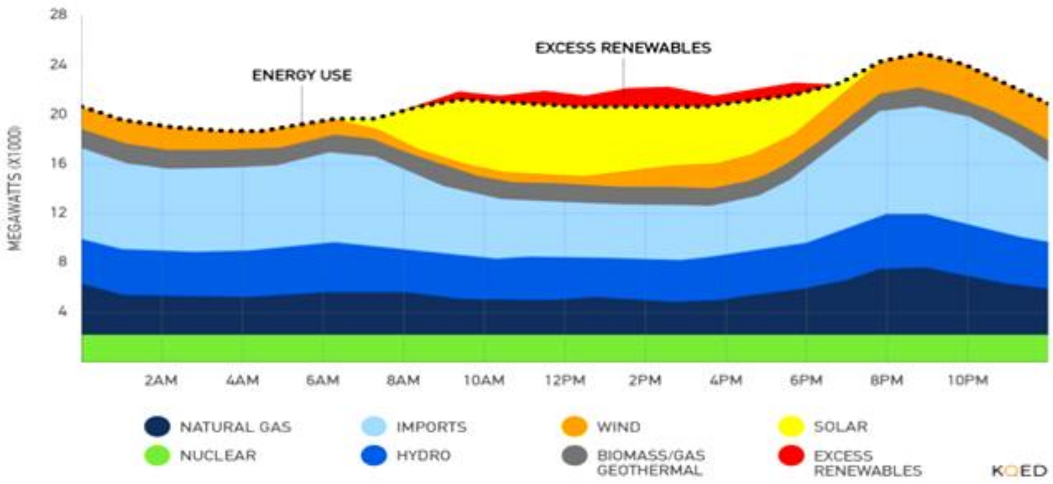


Fig.1.2. Intermittency of solar and wind renewable sources (orange and yellow parts) and “Excess” renewable energy production graph (KQED).

2. Challenges of Microgrid Integration

The future advancement in smart grid and decentralized power systems lies in the implementation of a hybrid AC/DC microgrid [2]. It has numerous benefits compared to microgrids and utilities. The practical obstacles in establishing effective and feasible future networks encompass operation, coordination management, protection, and market trends. The primary concern in islanded mode for a hybrid microgrid is ensuring its stability, as the AC and DC subsystems do not have the necessary support for frequency and voltage. The following are the primary operational challenges faced by hybrid AC-DC microgrids.The challenges related to hybrid AC/DC microgrid issues, as depicted in Figure 2.2.

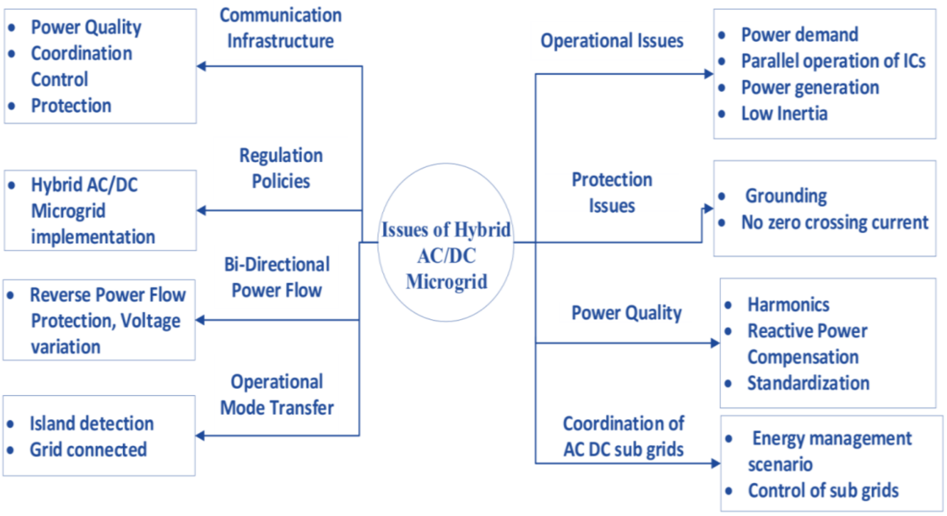


Fig.1.3 Some challenges in Hybrid AC\DC Microgrid system.

Power-sharing under diverse operational conditions is a major hybrid microgrid stability concern. The power exchange across the interface converter makes it dependent on both the AC and DC subsystems. Converters offer system reliability, low-rating converters for high-power applications, and more. However, parallel IC operation causes major concerns including converter non-linear load behavior, grid operational mode re-synchronization, and circulating current [3].

Challenges of Microgrid Control

Several control challenges have been outlined as follows:

The occurrence of unbalanced loads leads to the emergence of a second-order harmonic component in the load current, hence causing distortion in the output voltages of the distributed generation/microgrid system. The presence of non-linear loads leads to the generation of higher order harmonics. Therefore, the current and voltage exhibit a higher degree of distortion. In the given situations, conventional methods of voltage and frequency regulation prove to be ineffectual.

Voltage and Frequency Regulation Issues.

In an electrical system, it is necessary for the active and reactive power generated to be in a state of balance with the power used by the loads, taking into account any losses that may occur in the transmission lines. The imbalance arises from a difference in kinetic energy between the rotating generators and motors that are linked to the system, resulting in a variation of the system frequency from its designated value of 50Hz. The primary objective of voltage and frequency control is to maintain both voltage and frequency within predetermined limits around the desired set point values. This is achieved by regulating the active and reactive power generated or consumed. One of the challenges encountered in the operation of a microgrid is the management of multiple distributed generating sources on the island. The implementation of a voltage vs reactive power droop controller is crucial in microgrid operation to ensure the regulation of voltage, hence enhancing local dependability and stability [6]. During islanded operation, it is common for each distributed generator to be provided with the power frequency droop characteristic [7]. Additionally, recommendations are offered for the design of controllers that comply with the performance standards outlined in the IEEE P1547 standard *(Standard for Interconnecting Distributed Resources with Electric Power Systems).* The establishment of efficient voltage and frequency management mechanisms is essential for the effective functioning of a microgrid based on a low-voltage network. Insufficient control of the storage unit inside the microgrid hinders the effective management and restoration of voltage and frequency to levels close to the desired set values.

CHAPTER TWO

Methodology

2.1 Methodology

The methodology used in this master thesis is based on research articles, digital libraries, textbooks, and software simulation to analyze renewable energy-based microgrids, modes of operation, complexities, and possible solution methods of energy. The simulation process of adding a renewable energy-based microgrid to the main grid and using PSS SINCAL software is described in chapter5. Description, economics, benefits, typical challenges, and possible solutions have been reviewed based on research papers and journals about smart and microgrid systems. Possible solutions for challenges of renewable-based microgrids are given in the chapter four.

Simulation of connecting the microgrid to the overloaded system will help to better understand how microgrids can help to perform reliability and decrease interruption. The methodology description can be found in *Fig*. 1.1.:

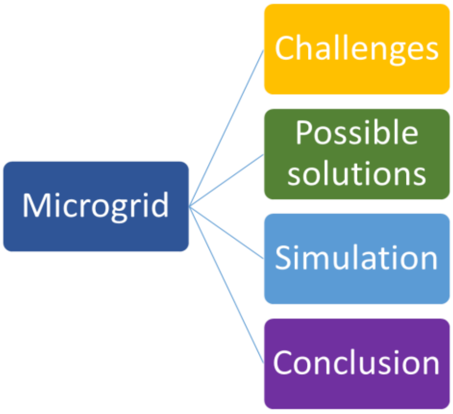


Fig.2.1. Methodology diagram

Limitations of the study

2.2 Limitations of the study

With the benefits of studying of integration of renewable rich microgrids to the bulk grid, some aspects take place that make this process more difficult to realize. First, financial aspects take place. Although a microgrid can considerably increase the reliability of the system, it has many components including wind turbines, solar panels, battery energy storage systems, protection hardware, and control units making the process of the microgrid design expensive. As the main purpose of all electricity production and distribution systems is to provide consumers with an uninterruptable and sustainable power supply, consumers should be informed about the microgrid system, how it works, and how it increases overall reliability. To solve the abovementioned problems, governmental support and mass media resources can be needed.

Definitions and requirements for microgrid

2.3 Definitions and requirements for microgrid

A microgrid is defined as a small topologically connected network and including renewable energy resources to make the electrical grid more reliable and resilient for consumers [8]. It is a little section of a power distribution system that includes programmable loads, energy storage devices, and distributed generators that can eventually lead to a self-sufficient energy system. When a fault impacts the main grid, a microgrid can effortlessly detach and function independently, much like an analogous generator from the utility grid perspective [9].

Microgrid Structure and Topology

Microgrids are small-scale smart grid types that connect distributed generation, energy storage systems (ESS), and loads inside the same grid. Three main categories can be defined among microgrid topologies: hybrid, DC, and AC. [10]. The most popular option is the AC microgrid as it offers a simple way of integrating DG units with the existing utility grid with the least amount of adjustments. This architecture is distinguished by its high fault management capabilities, which include the ability to detect and handle problems with a variety of safety devices, and by making it easier to modify voltage levels using transformers. Nevertheless, it has certain disadvantages, like the requirement for DG unit synchronization or reactive power circulation, which raises transmission system power losses.

Coupled AC Microgrid

The primary characteristic of this setup is the direct connection of the AC network to the power grid via a transformer. Furthermore, the implementation of a connected AC microgrid is more cost-effective compared to the disconnected alternative. This is because a smaller AC-DC converter is required to manage the power transfer between the utility grid and the DC network. Two primary approaches have been discovered for organizing the sequence of conversion phases in interconnected AC microgrids. There are two primary methods that can be employed to organize the conversion phases in paired AC MG's. Initially, a transformer is located at the point of connection with the electricity network, as depicted in Figure 3.1. This device reduces the voltage level in order to generate low voltage alternating current (AC) and direct current (DC) networks. It also provides galvanic isolation for the entire microgrid. The architecture consists of three primary levels: the combo-source level, which accommodates the AC-link and the inverter for linking the connections between links., the

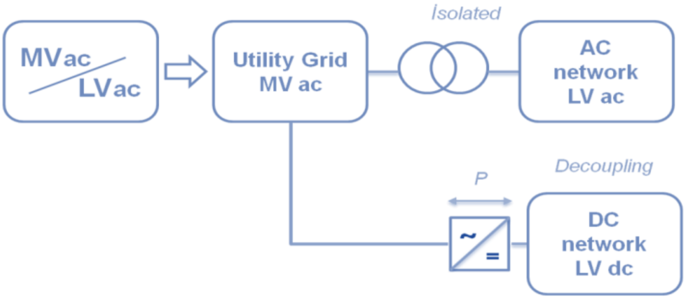


Fig.2.2. Coupled AC, partially İsolated hybrid microgrid configuration

micro-source level, which houses the DC-link, DG, and ESS units, and the microgrid level, which handles the connections between the power network and the lower level facilities.

Protection Schemes

An improved protection system is crucial for a microgrid because it facilitates the bidirectional power transfer between the microgrid and the primary power grid. Additionally, the microgrid protection system must successfully handle both grid-forming failures and grid-following problems.. The initial protection strategy needs to isolate the second-part components of the microgrid, while the subsequent scheme should isolate the microgrid from the utility grid. Additionally, the fault current magnitude and direction of flow are determined by the mode of operation and nature of the fault. The development of a microgrid necessitates addressing the significant difficulty of designing a sufficient protection scheme. The primary factor contributing to this phenomenon is the existence of inverter-based distributed energy resources (DER) and the inherent ability of microgrids to flexibly modify their structure and operational characteristics. The relay settings typically utilized in traditional protection methods for distribution systems may not be suitable for microgrid protections, particularly for microgrids capable of operating in both grid-connected and islanded modes. In microgrid systems, it is important to note that the minimum values of short circuit currents in the islanded mode may not be accurately determined due to potentially significant differences from those seen when the microgrid is connected to the main distribution grid. [11-13] .

Microgrid Operation

The main control schemes recommended for microgrid operation are covered in detail in this subsection

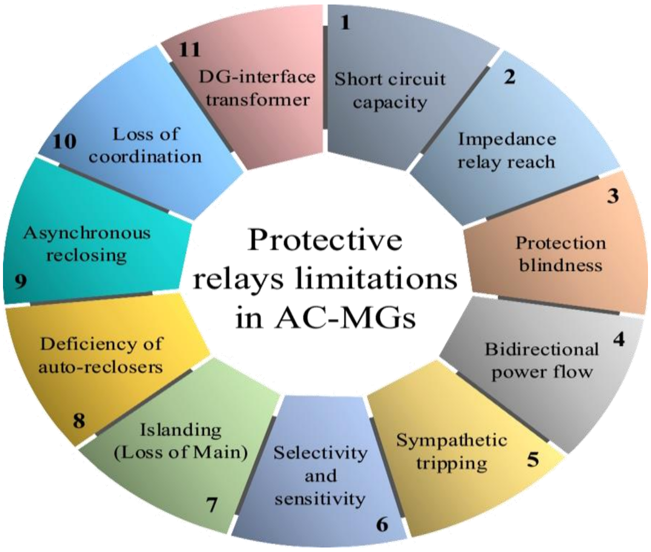


Fig.2.3 Protection components of AC-microgrid [11]

The goal is to determine the fundamental core-control functions that must be included into the SCADA/EMS system to guarantee a high degree of strength, durability, and protection during all operational states and transitions. The different possible operational modes and transitions of a microgrid can be shown visually in Figure 6, from a systematic standpoint.

On-grid Operation

In terms of grid-connected operation, a microgrid often remains in a condition of normal for the majority of its operational duration. In the present operational condition, the controllable energy sources are strategically planned to operate at the minimum cost, considering factors such as energy storage, nonprogrammable energy sources, and the projected load.

Transition from On-grid to Off-grid Mode

The transition to off-grid operation in a microgrid can be executed by either a contingency event, known as Emergency Islanding, or through a scheduled operation. In this particular scenario, the EMS must know the necessary capabilities to effectively oversee the operations of the microgrid, hence guaranteeing a smooth transition into islanding mode. To meet this requirement, it is necessary to activate an appropriate control mechanism.

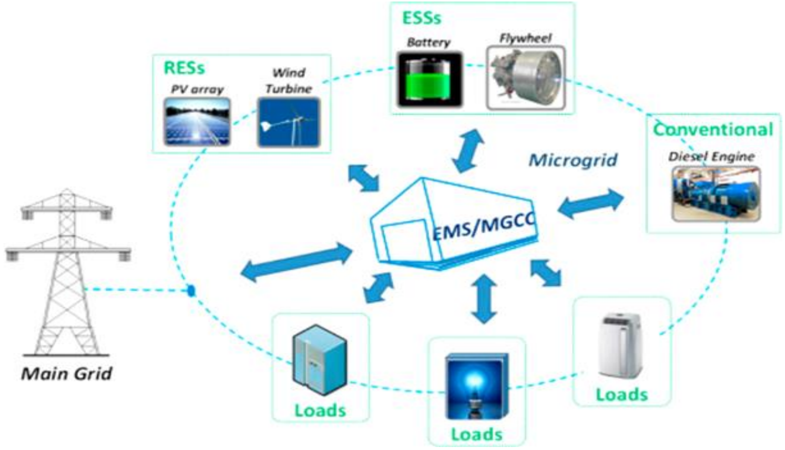


Fig. 2.4. Microgrid supervisory controllers and energy management systems [14]

Reserve Management

In the context of microgrids suitable of operating in islanded or isolated mode, the EMS gets the responsibility of optimizing the necessary quantity of spinning reserve. In order to adhere to this stipulation, numerous control mechanisms have been developed. [14].

Scheduled Islanding

An intended island is created using the dispatch means of the power system operator or the DER operator, such as automatic generation control action or energy management system, or through joint action. The implementation of a planned and deliberate islanding strategy guarantees improved dependability, economic power dispatch decisions, and proactive measures taken by the power system operator in anticipation of adverse weather conditions.

Unscheduled Islanding

An unplanned deliberate island is autonomously formed in response to the identification of anomalous conditions inside the power system. Afterwards, the relay will trigger the control operation to separate the intentional island from the power system. An unannounced intentional islanding event may take place when specific conditions are fulfilled, leading to a deliberate disconnection from the electrical grid.

Black Start

In both on-grid and off-grid scenarios, the activation of corrective control measures on the system may fail to restore the microgrid to its normal operating condition, potentially resulting in a widespread power outage. During this phase, it is imperative to initiate black-start protocols to reinstate the functionality of the microgrid. The pertinent black-start protocols can be categorized into two modes: on-grid and off-grid. The abovementioned topic is not covered in this master's thesis.

Active Power Loss Calculation In Microgrid

2.4 Active power loss calculation in microgrid.

For power loss calculation in microgrids, several parameters are needed. As MG has a complex structure that includes solar photovoltaic (PV) Panels, energy storage, and loads, all these parameters can be calculated. In fig.1, a typical microgrid circuit is described:

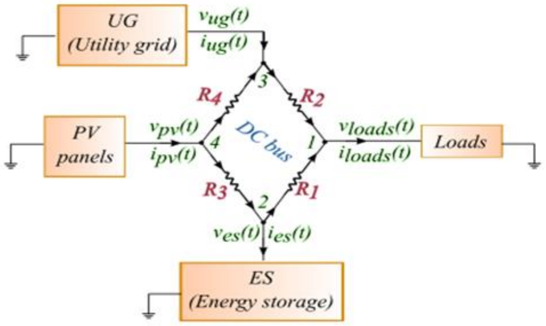


Fig.2.5. Method of power loss calculation (Meshed DC) in DC microgrid [15]

So, for calculation, meshed analysis mode can be used. For this method current for every node should be calculated (For wiring, copper cable with the resistance of 0.58 ohm per km is used). Parameters for typical MG circuit are: $V_{es} = 400\,V, V_{loads} = 378\,V, V_{ug} = 380\,V, R_1 = 0.58\,Ohms, R_2 = 0.97\,Ohms, R_3 = 0.25\,Ohms, R_4 = 1.16\,Ohms$

$$i_{loads} = iR_1 + iR_2 = \frac{v_{es} - v_{loads}}{R_1} + \frac{v_{ug} - v_{loads}}{R_2} = \frac{400v - 378}{0.58} + \frac{400 - 378}{0.97} =$$

$$= 37.93 + 22.68 = 60.61\,A$$

$$i_{es} = iR_3 - iR_1 = \frac{v_{pv} - v_{es}}{R_3} - \frac{v_{es} - v_{loads}}{R_1} = \frac{398 - 400}{0.25} - \frac{400 - 378}{0.58} = 37.93 - 8$$

$$= 29.93A$$

$$i_{ug} = iR_4 - iR_2 = \frac{v_{pv} - v_{ug}}{R_4} - \frac{v_{ug} - v_{loads}}{R_2} = \frac{398 - 380}{1.16} - \frac{380 - 378}{0.97} = 15.51 - 18.55$$

$$= 3.046\ A$$

$$i_{pv} = iR_3 - iR_3 = \frac{v_{pv}(t) - v_{es}(t)}{R_3} - \frac{v_{ug}(t) - v_{pv}(t)}{R_4} = \frac{398 - 400}{0.25} - \frac{380 - 398}{1.16}$$

$$= 15.51 - 8 = 7.51\ A$$

As transmission lines have some power losses, **voltage deviations** may occur. For this reason voltage regulation methods should be carefully analyzed. After calculation formulas (1)-(4), power losses for each part of the microgrid can be calculated:

$$P_{ug} = v_{ug}i_{ug} = v_{ug}[iR_4 - iR_2] = v_{grid}\left[\frac{v_{ug}-v_{pv}}{R_4} - \frac{v_{load}-v_{ug}}{R_2}\right] = 380\ \left[\frac{380-398}{1.16} - \right.$$

$$\left. - \frac{378-380}{0.97}\right] = 5111\ W$$

$$P_{es} = v_{es}i_{es} = v_{es}[iR_3 - iR_1] = v_{es}\left[\frac{v_{pv} - v_{es}}{R_3} - \frac{v_{es} - v_{loads}}{R_1}\right] =$$

$$= 400 \cdot \left[\frac{398 - 400}{0.25} - \frac{400 - 378}{0.58}\right] = 11972\ W$$

$$P_{pv} = v_{pv}i_{pv} = v_{pv}[iR_3 - iR_4] = v_{pv}\left[\frac{v_{pv} - v_{es}}{R_3} - \frac{v_{ug} - v_{pv}}{R_4}\right] =$$

$$= 398 \cdot \left[\frac{400 - 398}{0.25} - \frac{398 - 380}{1.16}\right] = 2988\ W$$

$$P_{loads} = v_{loads}i_{loads} = v_{loads}[iR_1 - iR_2] = v_{loads}\left[\frac{v_{es} - v_{loads}}{R_1} - \frac{v_{loads} - v_{ug}}{R_2}\right] =$$

$$= 378 \cdot \left[\frac{400 - 378}{0.58} - \frac{378 - 380}{0.97}\right] = 13558\ W$$

Obviously, for the DC bus in terms of voltage and frequency, keeping the frequency at stable values contributes to faster voltage regulation. With this, the renewable energy based microgrid can be more easily integrated into the power system.

CHAPTER THREE

Case Study: Microgrid Simulation.

3.1 Case study: Microgrid simulation

For the simulation of the microgrid integration, PSS SINCAL power system planning and analyzing software has been used. The simulation object is a real 6kV substation 431, which is located in the Khazar district of Baku City, Azerbaijan. Transformer overload is a mode of operation in which the degree of insulation wear is significantly higher than in normal operation. This mode is characterized by a higher current value than at rated power. This leads to a significant deterioration of network parameters, in particular voltage drops and frequency spikes. To identify the impact of microgrid to main grid parameters, several variants of substation loading were analyzed (the simulation of modes did not consider the variant without substation load). Mains overload is when the power of the connected electrical appliances (current consumption) exceeds the authorized power (allowable current) of the mains. Consequently, an increase in the allowable current for specific equipment and network elements leads to destabilization in both the distribution and transmission networks. The variants of simulation of network loading and dependence of voltage and frequency indicators on factors of substation operation in compliance with technical requirements are considered. Depending on the operating mode, transformers may be subject to systematic overloads, the value and duration of which are regulated by the standard operating instructions. At the same time, the recurrence of each situation during the year was taken into account. In photo 1a, 50% overloading of substation has been demonstrated. In this case, the voltage drop (ΔU) reaches 16%. Similarly, in photo 1b, 70% overloading of the system with a voltage drop of 31%. During the simulation, for both overload cases, renewable rich microgrid (blue circles) has been added to the main grid nodes. From photos 2a and 2b, the system has returned to normal operation (indicated in pale green) and the voltage drop has decreased to the permissible nominal value, respectively

Umin = 0,5 Unominal   ΔU = 16%

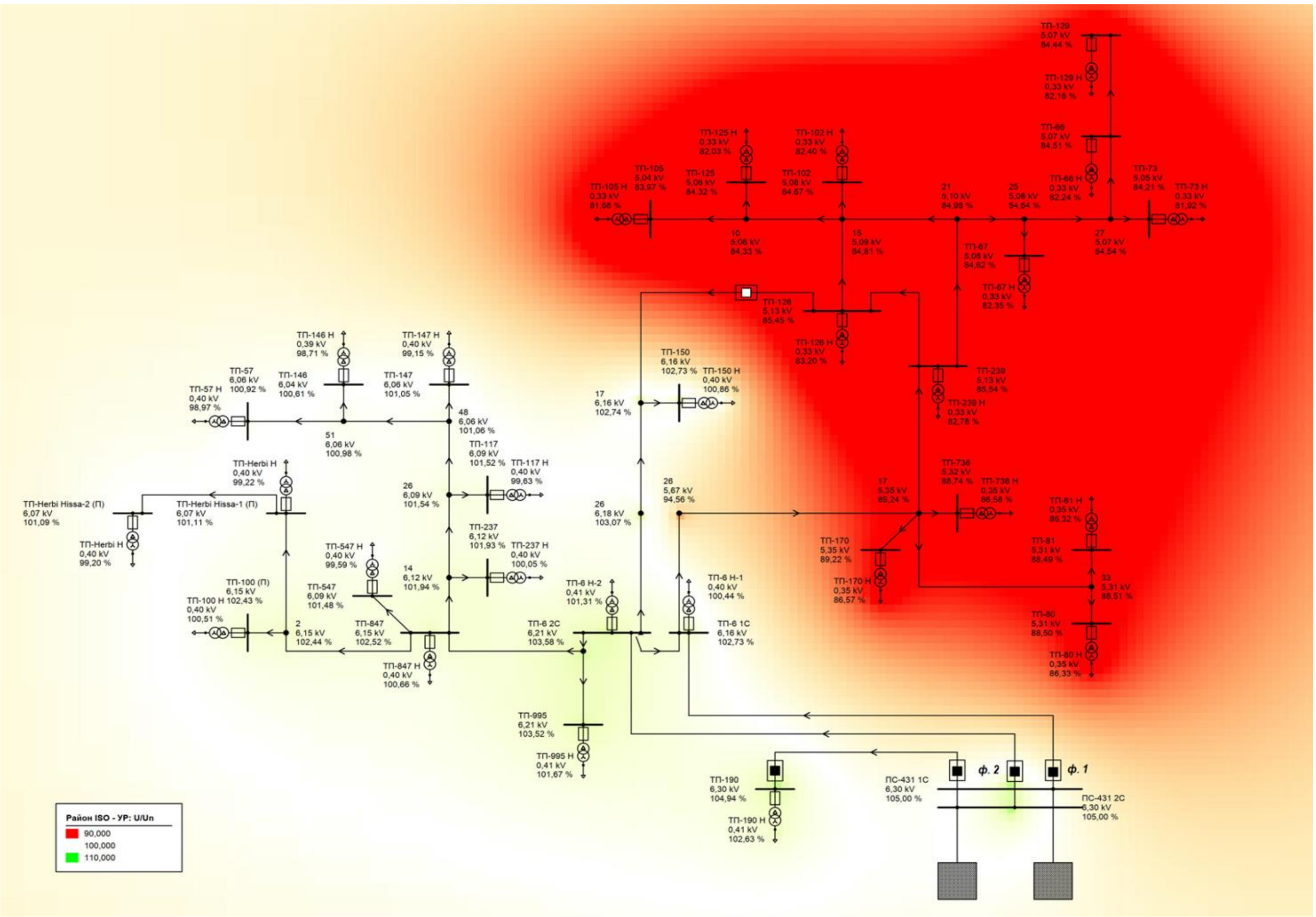


Fig. 3.1 Cases of system overload. The overloaded part of the system indicated with a red color

Umin = 0,7 Unominal   ΔU = 31%

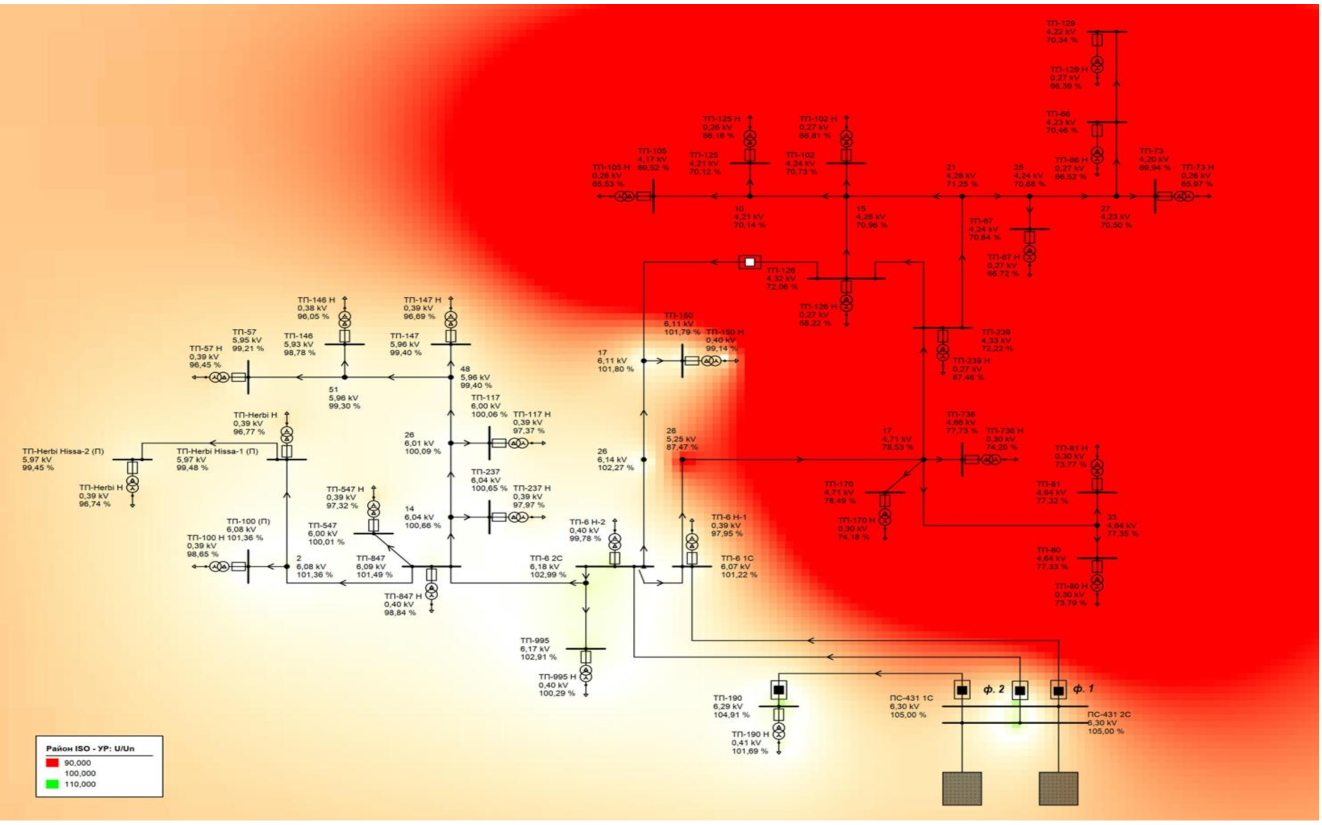
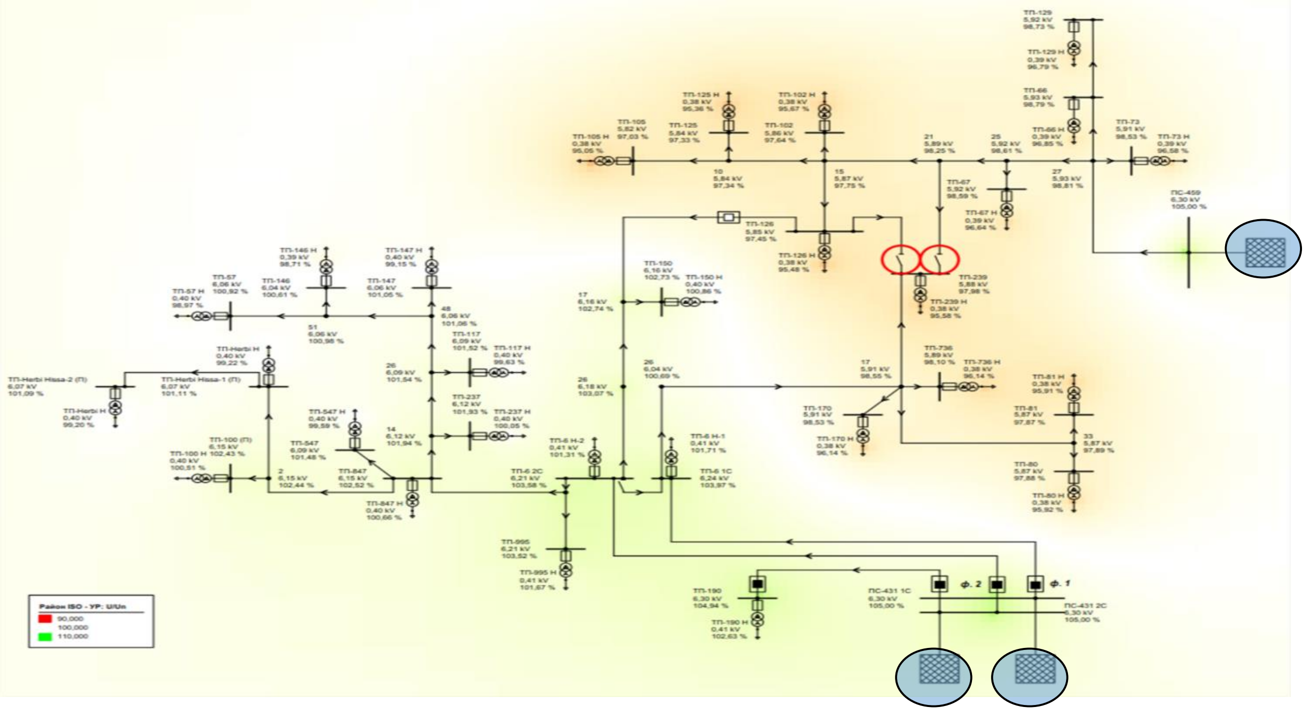


Fig. 3.1 (second part. Cases of system overload. The overloaded part of the system indicated with a red color

Umin = 0,5 Unominal   ΔU = 8%



Umin = 0,7 Unominal **ΔU = 10%**

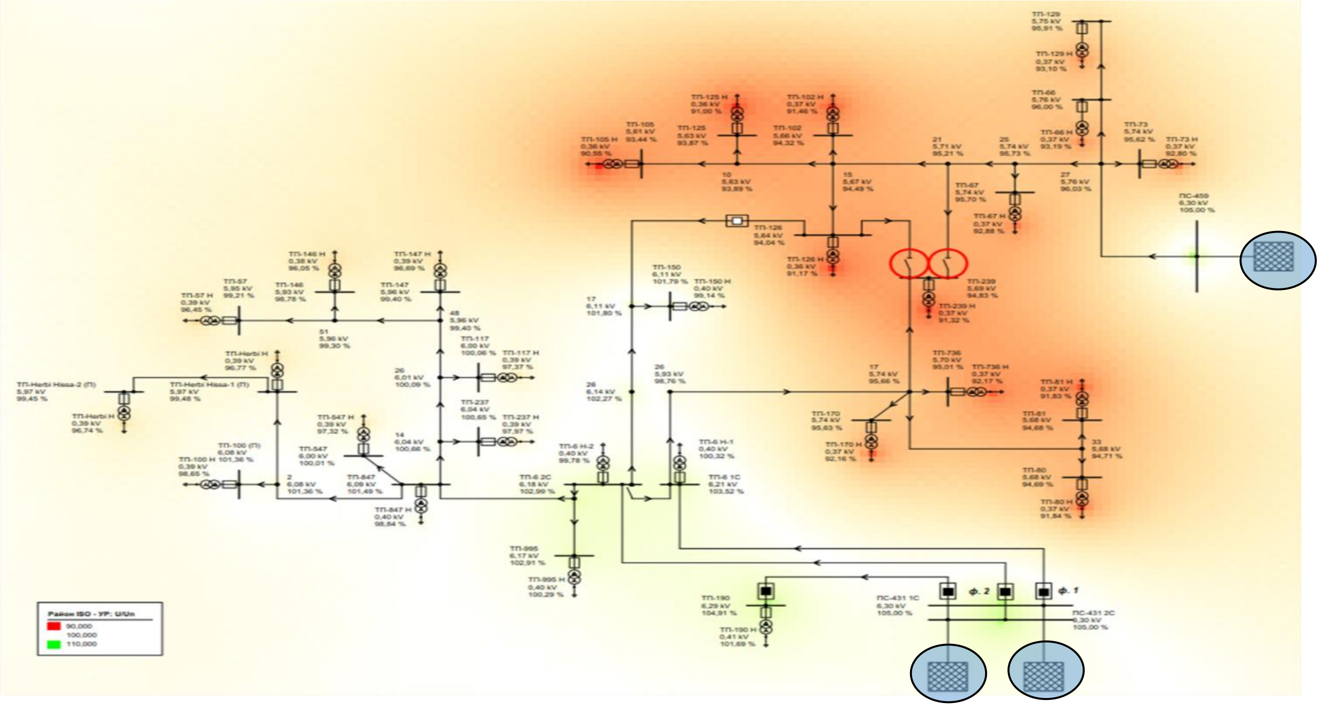


Fig. 3.2. A microgrid (marked with blue circles) has been added to both overload cases.

CHAPTER FOUR

Possible Solutions

4. Possible solutions

4.1 Applying Advanced Forecasting Methods to Reduce the Impact of the Intermittent Nature of Renewable Sources.

Problems stated in the first part of this work were related to the integration and operation of renewable-rich microgrids. First and the most considerable issue is related to the changeable character of the abovementioned sources. Wind turbines and solar panels are often used distributed energy resources (DERs) in microgrids, and their installation has been successfully implemented. The time horizon for forecasting is categorized into different intervals based on the energy management requirement. These intervals include the very short-term, which spans from seconds to half an hour, the short-term, the medium-term, and the long-term. Short-term forecasting is employed to facilitate the efficient allocation of energy flow between power sources, loads, and storage devices. Commonly employed statistical approaches include auto regression (AR), moving average (MA), auto regression moving average (ARMA), and auto regression integrated moving average (ARIMA). The commonly employed individual models encompass fuzzy logic, artificial neural network (ANN), support vector regression (SVR), wavelet transform (WT), genetic algorithm (GA), and expert systems. The hybrid system aims to enhance forecasting accuracy by integrating one or more algorithms. The adaptive neural fuzzy inference system (ANFIS) is considered the most extensively recognized hybrid model. The forecasting methods are presented in Figure 10. In the context of a microgrid, which involves the interconnection of diverse power production systems with varying technologies and power ratings, the implementation of a hierarchical control structure is needed.

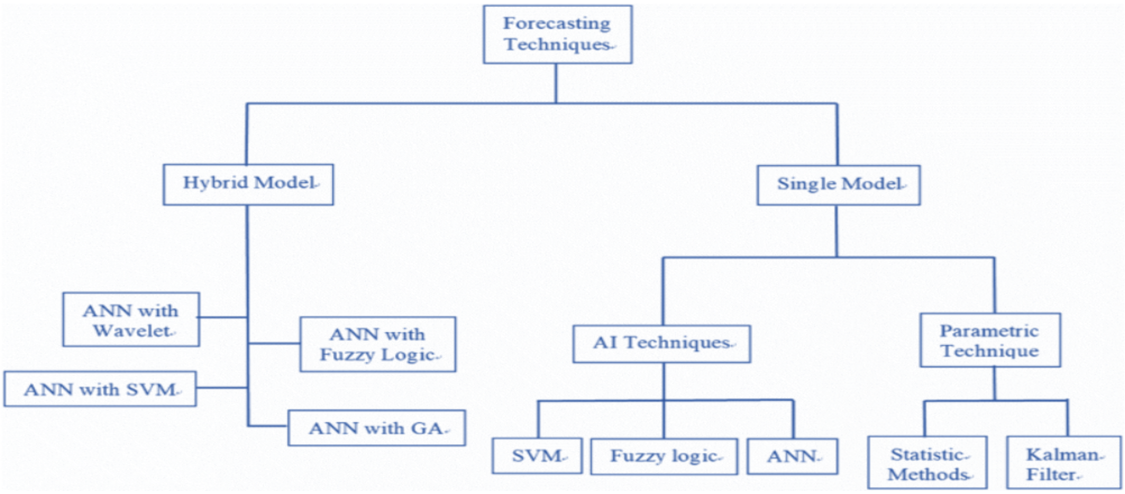


Fig.4.1. Overview of advanced forecasting techniques. [15]

4.2 Integration of Microgrid Intelligent Controlling Systems for Integration to the Bulk Power Grid.

This control structure is designed to prioritize the minimization of operational costs, while simultaneously maximizing efficiency, dependability, and controllability [16].

The key factors to be taken into account when calculating the optimal operational state of a microgrid are power ratings, load distribution and generating systems, market prices for electricity, generation costs, and the availability of energy from uncertain primary sources [17]. Hence, in order to provide effective management of the operating set point, the hierarchical control structure of microgrids can be divided into three fundamental layers: primary, secondary, and tertiary control, as illustrated in Figure 7.2. Additional supplementary services, a significant number of which are executed at the local level within the generation units, have also been incorporated into the same figure. *The primary control*, commonly referred to as local control, is responsible for regulating local variables, **including frequency, voltage, and current** injection. The secondary control function operates as a centralized automatic generation controller, effectively addressing steady-state **defects in the voltage and frequency of the microgrid**.

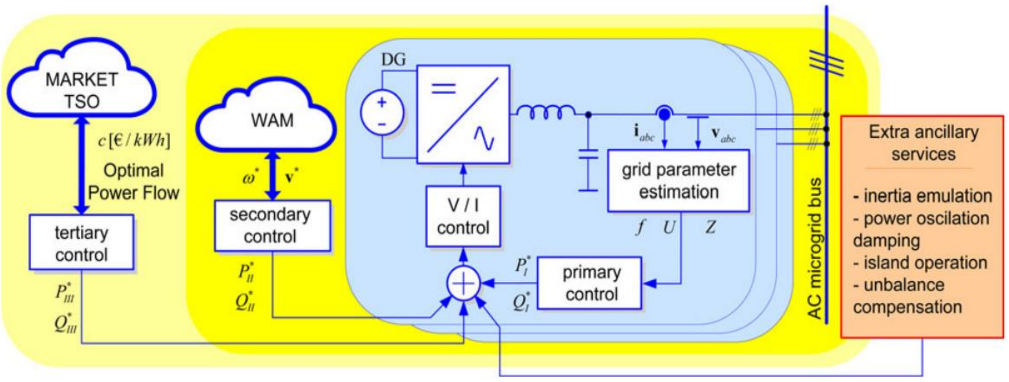


Fig.4.2. Primary, Secondary and Tertiary Control Voltage and Frequency for Intellectual AC Microgrid system [18]

The tertiary control level assumes the responsibility of optimizing the operation of the microgrid and establishing its connection with the distribution network through the regulation of active and reactive power references for each distributed generation unit. *The Transmission System Operator (TSO)* and Distribution System Operator (DSO) play crucial roles in the electrical industry. Additionally, the prize signals offered by the electrical system are of significant importance.

4.3 Load Type Analysis and Choosing Best Control Strategy.

One of the main obstacles that limited the impact of renewable energy sources is the lack of direct control over Distributed Generation (DG) by Distribution Network Operators (DNOs) [19] .The number of generation equipment being connected to the network is increasing, and their behavior is unpredictable. As a result, the amount of data acquired for centralized control will significantly increase. A decentralized strategy utilizing microgrids is offered as a means to minimize the complexity of the network. The centralized control is characterized by sophisticated central processing units that manage the entire system. The communication system comprises a core system, analogous to the human brain, as well as sensors and control devices. The sensors provide their data to the central system. The central system collects all data and computes the control variable for each control equipment as the nature of micro sources differs; variable interfaces (inverters) required in order connecting to the network. The PQ inverter control is utilized to establish specific set points for both active and reactive power provided by the inverters. **The regulation of the Voltage Source Inverter** (VSI) involves regulating the inverters to provide the load with predetermined voltage and frequency settings. **The VSI's active and reactive power output will be determined based on the load.** [20] In the connected mode, the primary focus is on energy management. In island mode, the primary objective of the system is to regulate voltage and frequency. When integrating the distribution of energy sources with a utility network, the inverter typically operates in two modes: grid-connected mode and isolated mode. The controller operates in two distinct modes: Power-Control Mode (PCM) and Voltage-Control Mode (VCM), each corresponding to specific operating conditions. The grid-connected mode of operation necessitates the deactivation of the Power Management System (PMS) in order to make voltage adjustments. Therefore, a sensible option for controls is to employ current regulation. The Voltage and Current Magnitude (VCM) control mode is not suitable for controlling a microgrid in island mode due to the limitations of balancing the load demand and the reference voltage [21].In island mode, the control operation differs from the grid-connected mode. In this mode, the system is already isolated from the upstream network.

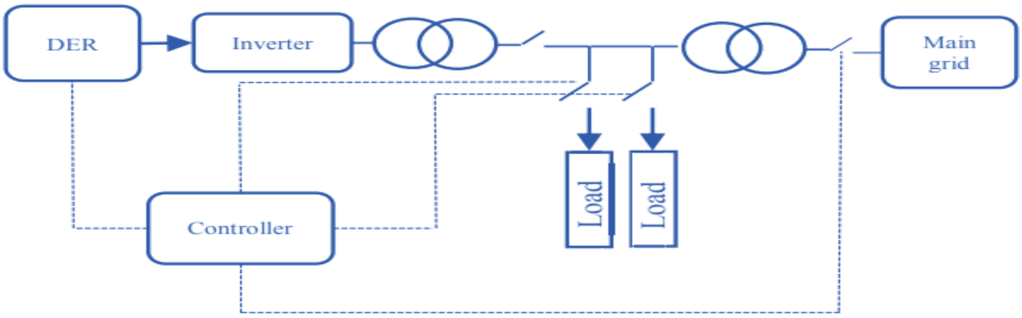


Fig.4.3. Typical Microgrid with De-centralized control strategy [21] .

4.4 Proposed Battery Energy Storage System (BESS) Control For Voltage Regulation in Photovoltaic Powered Microgrid

In order to address issues related to voltage fluctuations, a battery energy storage system (BESS) is employed as an ancillary service to moderate voltage difficulties in low voltage microgrids. Droop-based regulation is used to compensate for active power from Battery Energy Storage Systems (BESS).The droop-based Battery Energy Storage System (BESS) regulation, shown in Figure 7.3, is designed to have a gradual response to minor voltage deviations. On the other hand, a significant amount of power injection or absorption is controlled according to substantial voltage deviation. Additionally, the voltage limitations are carefully controlled to remain within a range of ±5% of the nominal voltage. This is done to prevent the activation of the over/under-voltage safety mechanism [22].

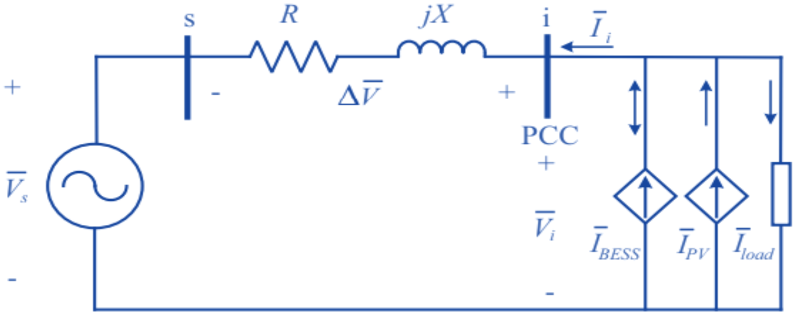


Fig.4.4. Schematic diagram of Microgrid with BESS[22].

4.5 Intelligent Load Control for Frequency Regulation in Microgrid.

A microgrid refers to a network operating at a low voltage (LV) level, consisting of controllable loads and local generators known as micro sources. Micro sources refer to compact power generation units with a capacity of up to 100 kilowatts. These units are typically connected to the low voltage (LV) network via power electronic converters. The converters offer versatile operation and precise control of the micro sources [23]. Microgrids typically rely on a medium voltage (MV) network for connectivity, but they must also possess the capability to function independently in the event of a disconnection from the MV network. **The Microgrid frequency must always be** maintained within permissible thresholds. During grid-connected operation, the frequency is determined by the primary system. During autonomous operation, **a local frequency control mechanism** is required to regulate the frequency. [24]

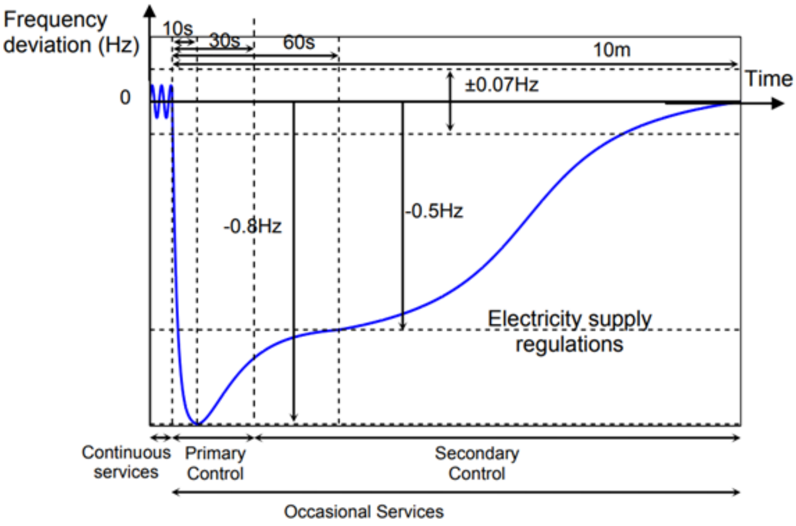


Fig.4.5. Characteristics of Frequency Control [25]

It was presumed that every consumer possesses two separate circuits: one that provides power to all the critical and important loads, and another that distributes power to the non-critical loads. The Intelligent Load Management Controller (ILMC) controls the circuit that supplies the noncritical loads. The ILMC determines the frequencies at which non-critical loads are shed and restored. The system offers an initial response to control frequency variations in the Microgrid, maintaining it within the range of 52.0 Hz and 42.5 Hz within duration of two minutes. It then provides a secondary response to restore the frequency to a range of 49.5 Hz and 49 Hz within the following eight minutes. The frequency range for secondary load management is deliberately set lower than that of microsource control in order to prioritize the restoration of more loads, provided there is sufficient generation capacity. All loads inside the microgrid are disconnected when the frequency falls below 42.5 Hz. The Microgrid Central Controller (MGCC) is responsible for restoring power to each load individually. Additionally, it was presumed that there exists a communication link connecting the Individual Load Management Controller (ILMC) of each consumer to the Microgrid Central Controller (MGCC). V/F control is a control method that provides an output voltage proportional to the frequency, so it maintains a constant flux, preventing the occurrence of weak magnetic field and magnetic saturation phenomenon.

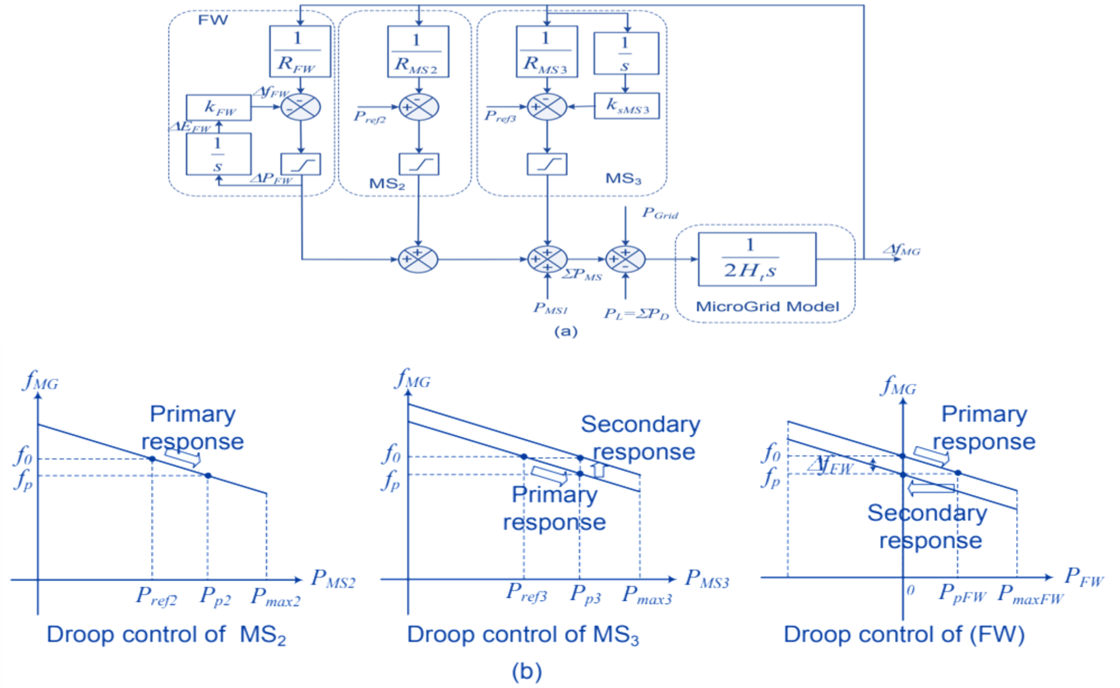


Fig.4.6. The Microgrid model (a) block diagram and (b) active power/frequency droop characteristics. [25]

The development of distributed generation (DG) is important for the production of electricity from renewable sources, which helps solve economic and environmental problems.

4.6 Two parallel connected invertors and electronic – active filter.

The interconnection between the distributed generation (DG) and the electricity system is facilitated by a microgrid. It is important to remember that the primary function of a microgrid is to synchronize the operation of different power producers in order to distribute active and reactive power, as well as regulate the frequency and voltage of the system. The two operational modes of a microgrid are islanded mode and grid-connected mode. In islanded mode, the absence of support from the main grid poses challenges to the management of the microgrid. The primary level control encompasses voltage drop control, current loop control, and voltage loop control.. At this stage of control, noteworthy is the fact that in the case when two inverters are connected in parallel to a microgrid, their **voltage and voltage drop are controlled sequentially** (Figure 4.7).

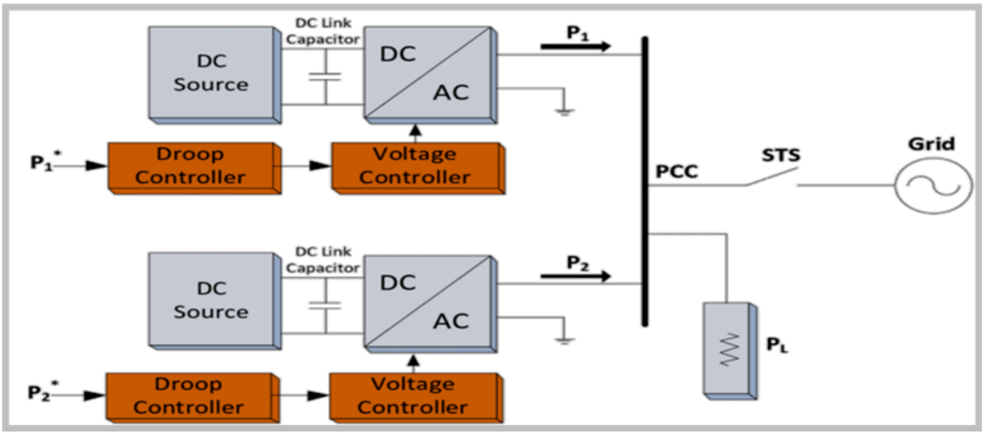
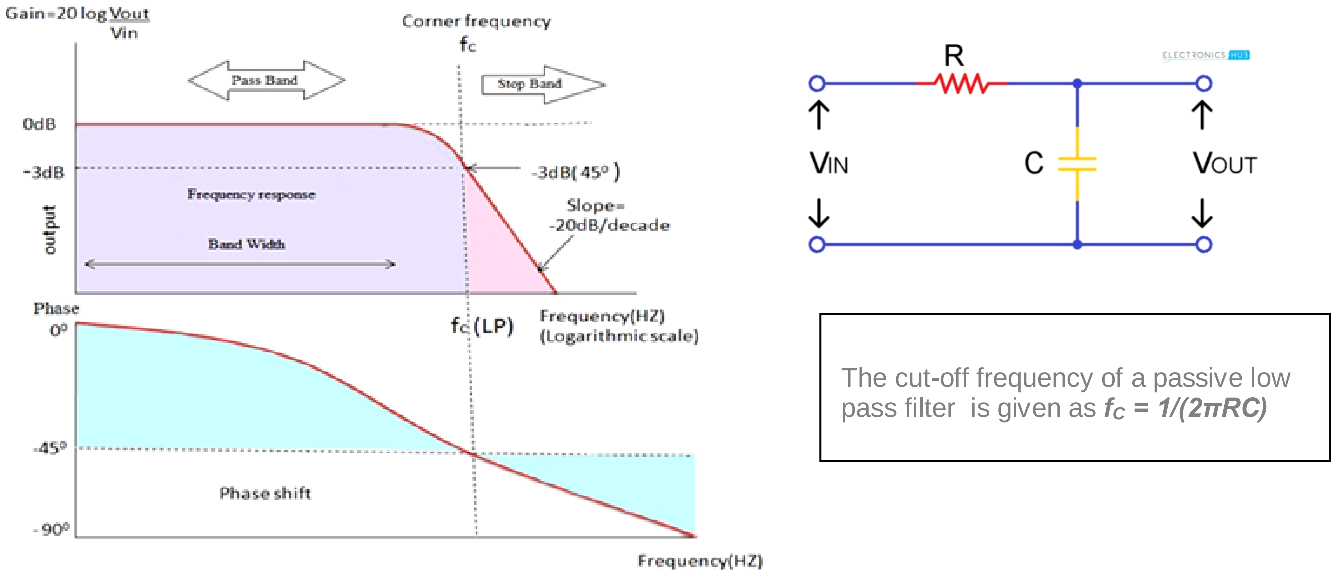


Fig. 4.7. Two inverters in microgrid and their voltage and droop control[25]

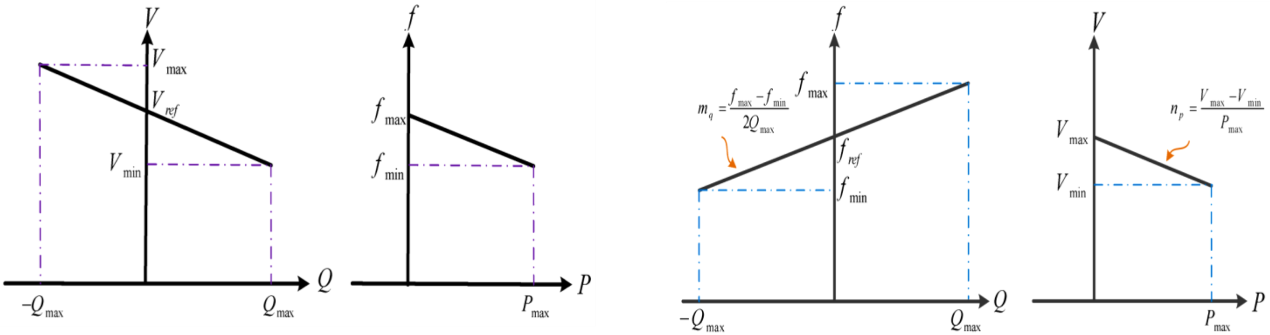
The conventional droop method is associated with several drawbacks, including sluggish dynamic response, a compromise between voltage regulation and load sharing, inadequate distribution of harmonics among parallel inverters when non-linear loads are present, and line impedance mismatch between parallel inverters, which impacts the segregation of active and reactive power. The adaptive voltage drop control approach for multi-pole HVDC transmission, which is based on voltage converter, allows for the appropriate distribution of active and reactive power by each converter based on its standby power. The enhanced control strategy for grid-connected inverters relies on classical techniques to minimize the P - ω and Q - V parameters. This method relies on the utilization of a low-pass filter.Instead of using the standard power measuring approach, a real-time integral filter (also known as an electronic-active filter) is employed for the first order. At the primary control level, voltage and frequency are regulated in the voltage and current loops, in addition to droop control. The graph illustrates that the magnitude |H(jω)| of the filter is considered as the gain of the circuit. The gain is quantified using the formula 20 log (Vout/Vin), and for every RC circuit, the slope remains constant at -20 dB/decade. The frequency range below the cutoff frequency is referred to as the "pass-band", while the frequency range above the cutoff frequency is known as the "cut-off band". Figure 7.8 illustrates that the passband corresponds to the bandwidth of the filter.



The cut-off frequency of a passive low pass filter is given as $f_C = 1/(2\pi RC)$

Fig. 4.8. Low Pass Filter Frequency Response.

As we see, even such relatively new methods of controlling frequency characteristics in AC networks do not satisfy the requirements for stabilizing the frequency and maintaining the voltage level within acceptable limits. The first reason is the **high cost of high-power electronic filters**. The second reason is the narrow range of regulation of both frequency indicators and the voltage level in general. In this case, there is no need to filter unwanted components of the main signal and additional adjustment of the network frequency. Since, one of the 2 basic principles of regulating reactive and active power (Fig. 4.8.) is automatically excluded.



*The **inductive principle** of voltage–reactive power (V−Q) and frequency–active power (f−P) droop control*

The **resistive principle** of frequency–reactive power (f−Q −) and voltage–active power (V−P −) droop control

Fig. 4.9. Inductive and resistive principles of regulating reactive and active power.

With this approach to the problem of stabilizing the main parameters of the network, it is necessary to take into account some possible difficulties in implementing microgrids with initially-AC control:

1. The resistive principle (f-P & V-Q) offers simple implementation (plug-and-play), low communication requirements, and high reliability. However, it does not provide proper power-sharing, voltage regulation, or frequency regulation. Additionally, the physical parameters of the system can affect the system's performance, including harmonic load sharing and slow dynamic response.

2. The inductive concept (V-P & f-Q) ensures non-communication, making it straightforward to apply (plug-and-play) and highly reliable for the resistive line. Constraint: low-voltage grid; Lacks Q sharing capability.

But even with such specific difficulties, carrying out full-scale and effective parameter adjustment in the part of the DC network is quite acceptable in terms of the stability and functional accuracy of this method. In the meantime, let's look at a specific example of how to use the proposed method of adjusting the voltage (and frequency) in the DC-bus. From the point of view of communication and information exchange, control of the regulation process on the DC bus also expands the possibilities of using digital remote control technologies. Figure shows a standard block diagram of a microgrid in a mixed design (according to the type of AC and DC network). Here, the main problems arise at points 1, 2 and 3.

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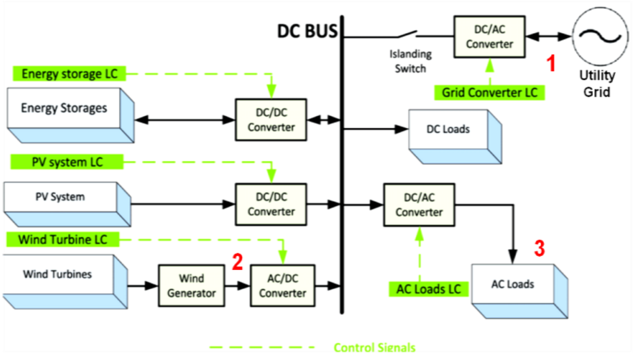

Fig.4.10.1 and 4.10.2 Diagram of mixed circuit [26]

As can be seen from the schematic image, the main sources of difficulties for maintaining voltage and frequency indicators are the energy exchange points of the AC and DC. But, all these problem points are somehow connected by the main energy exchange bus in the DC parts of the network. *(Figure 4.10.2)* That is why a favorable environment is created for solving potential difficulties at one point: from the point of view of centralized management of microgrids, this approach also provides a technically simplified scheme with subsequent economic benefits. In this situation, the pricing of microgrids becomes more attractive and less difficult to manage.

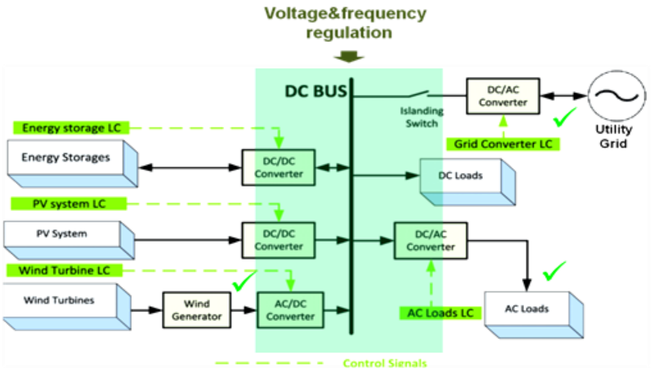

Fig. 4.10.2 [26]

A microgrid rich in renewable energy sources will in any case have a hybrid network-type structure. As we see from Figure 4.10.2, in the traditional design, a microgrid circuit consists of a utility AC network, wind and solar stations (other sources of renewable energy may also be present), converters (in duplex mode), energy storage stations, a voltage and frequency control unit in DC bus and AC/DC consumers.

4.7 Microgrid with “Centralized” transformer.

With the category of consumers in a microgrid scheme, it is necessary to determine in advance their status: active and passive consumers. This need is justified by determining the mode of the distribution network at different times of the day, mainly during peak network load hours, which negatively affects the **stability of voltage and frequency parameters**. On the other hand, during off-peak hours, energy is transferred from active consumers to the network, which in turn increases the no-load current on the power transformer. As a result, the rate of technical losses increases. And that is why, in many developed schematic designs of microgrids, power transformers with an Amorphous core are widely used. The use of amorphous transformers in a microgrid allows us to consider in a broader format ways to implement innovative solutions to stabilize the main parameters of the network, due to their insignificant losses. In this regard, relatively recent research in the field of multifield power transformers in a microgrid deserves attention[27]. Transformers in this design have several windings on one core, which makes it possible to automatically stabilize the parameters of conditionally independent AC microgrid networks (Figure 4.11) There is a possibility that such a design of a microgrid circuit with a “centralized” power transformer makes it possible to take advantage of the classical principle of autotransformers.[27]

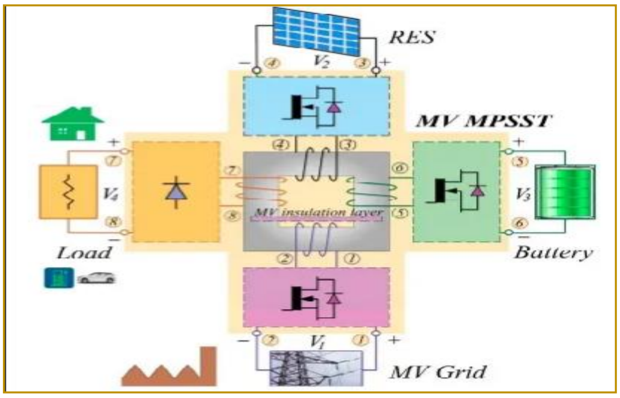

Fig. 4.11. Microgrid model with "centralized" Power Transformer [27]

As can be seen from Figure 4.11, the focus is on developing a four-port medium voltage transformer that allows the connection of four different loads or sources for the microgrid.

One port of the transformer is a medium voltage port supporting 6, 10, and 35 kV AC, while the other ports are for 0,4 kV low voltage. **The experimental data obtained show that the efficiency is 99%.**

Proposals on the topic of the master's thesis cover methods for improving the technical, economic and socio-ecological indicators of microgrids by stabilizing the voltage and frequency parameters of both AC and DC networks.

The first proposal on this topic relates to the schematic design and selection of microgrid hardware. The degree of availability of the parameter adjustment interval will depend on the choice of microgrid structure, and its quality will depend on the choice of equipment. **Regulating (or ensuring stability within a given interval) voltage and frequency *(V/f)* in the DC bus.** This approach to solving the problem of stability of two main network parameters allows: more precise electronic control of indicator values; filtering of network components in real time; continuous monitoring of the quality of current-voltage and frequency characteristics; reducing costs for additional equipment at microgrid connection points; use of intelligent (digital) control systems.

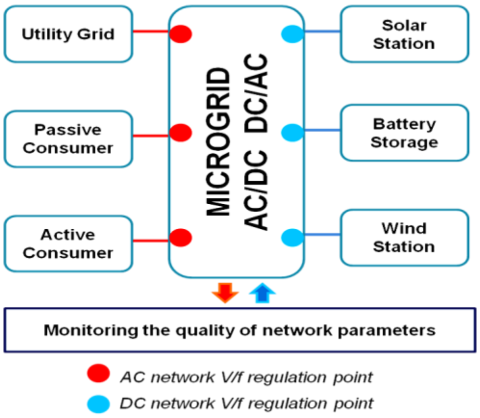

Fig. 4.12. Classic structure for quality control of AC/DC microgrid [28]

network parameters at all connection points.

The classic structure for quality control of microgrid AC/DC network parameters at all connection points is shown in Figure 4.12. The disadvantages of this microgrid design are the following : the requirement for the presence of control units at all connection points (the so-called “external regulation”); incomplete provision of feedback; poor coordination between microgrid network equipment; requirement for several network operation teams according to the AC and DC network type; complex architecture for digital control (in addition, there is a need for widespread implementation of analog-to-digital converters); low rates of forecasting accidents or interruptions in power supply, etc.For more precise control of microgrid parameters, it is proposed to carry out regulatory measures to stabilize the voltage and frequency parameters according to the “AC-DC-regulation-DC-AC” principle with the introduction of the concept of “DC-bus-hub” microgrid [28]. Here, increasing the accuracy and speed of information exchange between connection points throughout the microgrid scheme (Figure 4.13).

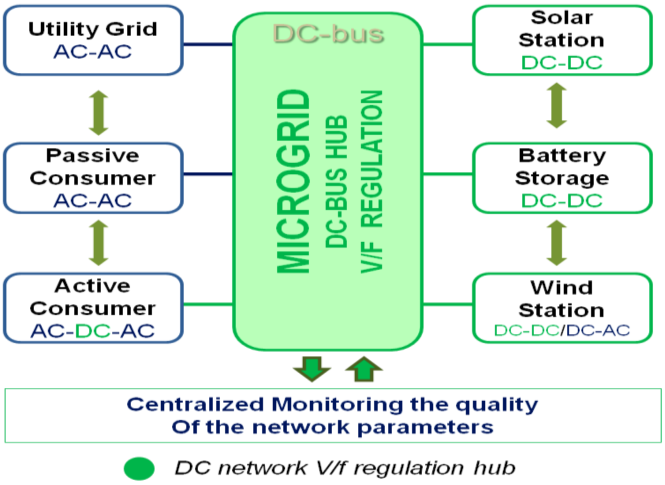

Fig.4.13. Proposed scheme for centralized microgrid power quality control in DC bus[29]

The proposed scheme for centralized control of power quality (including voltage and frequency) of a microgrid in a DC bus will provide [29]: high degree of coordination between connection points with operational feedback; high accuracy of forecasting emergency situations; reducing the requirement for the number of service personnel; increasing speed and ensuring automation of dispatch operations; integration into the SCADA system is simplified; access to global digital management of a microgrid group; reducing the cost of creating and expanding microgrids; increasing the reliability and stability of the power system, etc.

In the feasibility study of a microgrid with regulation via DC bus, we will consider the following points: Technological process of implementation; Requirements for infrastructure creation; Main equipment, fixtures and fittings; Personnel and labor costs; consolidated cost of production; Timing of the project; Economic efficiency; Environmental impacts. Let’s say the implementation of microgrid will require a 100% investment. Of this, about 30% goes to the creation of renewable energy sources. Approximately the same amount is required to create the appropriate infrastructure. The remaining 40% of investments are spent: on the construction of intermediate substations - about 25%; to fulfill technical requirements for integration - about 10%; personnel and labor costs - approximately 5%. In contrast to the classic control scheme “at all points of connection”, in the control scheme via the “DC bus” the costs for the following activities will be reduced by at least 12-15%:

1. Power MV/LV substations. When using a system for adjusting voltage parameters DC-to-DC in the DC microgrid bus, the need for voltage regulation in the substation facilities is eliminated, thereby reducing the number of cells with the necessary equipment for switching and automation systems. In turn, this reduces the annual indicators of operational switching and on-site visits. By simplifying the substation layout, the tendency for emergency situations to occur will also be reduced and the process of putting an energy facility into operation will be accelerated, which in turn **reduces costs by 2.5-3%.**

2. Creation of the necessary infrastructure and integration of renewable energy sources into the energy system. Integration problems are mainly related to the complexity of energy quality management across two types of networks: AC and DC. This is a truly complex process of harmonizing parameters under uniform control and regulation requirements. In the case of control and monitoring of a network using one type of current (or voltage), it makes it

possible to eliminate the double form of adjustment and coordination of parameters of different types of network. At the same time, the requirements for the created infrastructure are simplified by excluding AC control units. This **reduces the cost of creating infrastructure by about 4-5%.**

3. The economic feasibility of using the specified method of voltage and frequency regulation in a microgrid with an isolated operating mode in places remote from the power system is confirmed by the following compelling reasons: a) The demand for electricity consumed at such facilities is generally low; b) Losses of the carrier during its transmission from a centralized source are relatively large (in this case, the construction of power lines is unprofitable for reasons of economy); c) The costs of creating a microgrid, taking into account the rational use of digital control, pay off quite quickly.

4. Simplification of the overall microgrid control scheme **reduces the amount of labor costs to approximately 1.5%**. Thus, to create AC control units and their maintenance, additional time and personnel are not required, and the use of production processes and labor for these activities is reduced. At the same time, the volume of **CO2 is reduced** due to the elimination of costs for hydrocarbon fuels, which has a positive effect on the concept of introducing microgrids as a "green solution".

5. In contrast to the AC control methodology, DC control on semiconductor elements with the current development of power electronics allows to reduce the size of the equipment used. At the same time, the load capacity of the used devices is increased due to more energy exchange between DC buses. Therefore, it is suggested to attract inverter manufacturers to introduce voltage and frequency regulators into the design and circuit solutions. On the other hand, the integration of such inverters into a common network will not be difficult both in engineering and functional-management terms.

This is further simplified by the fact that the industrial inverters DC-AC and AC-DC already have integrated electronic units for digital power quality control. Many 20-500kW inverters are required by standards to have units for remote and fiber optic control. With this feature, as well as other digital capabilities of modern inverters, additional measures for creating an interface for connection to the SCADA system or to other information acquisition and grid management systems can be eliminated. Many microgrids are already being built based on the coordination of AC/DC and ADC/AC inverters. And in these microgrids, the network parameters are successfully regulated on the DC side, as it becomes much easier to automate the control and maintenance of operating modes. If we add to this the function of remote control, the issue of using microgrid (even isolated version) in case of power crisis is solved much more effectively. Parallel operation of industrial inverters (otherwise known as coordinated operation) also solves two other major problems in microgrid operation: power shortage and load shortage. In the first case, voltage performance deteriorates, in the second case, frequency performance deteriorates. In order to avoid such cases, it is proposed to carry out voltage and frequency regulation in the DC bus part with coordinated inverters. To solve the problems of power deficit and shortage of loads in microgrid, consider the following proposal.

4.8 Electrical vehicle- to- grid (E2V) concept against load and energy shortages.

Electric vehicle - as part of "green technology" is widely used to address both energy and environmental issues, it is charged from an electricity source that is outside the vehicle, it can be autonomous - from a solar panel or a hydrogen that changes fuel into electrical energy. The future of transportation **V2G technology** means that it is possible to organize a restrained and bidirectional electricity moving between the vehicle and the grid. Electrical energy flows from the grid to the vehicle in order to charge the battery. The car transfers electrical energy to the grid when the electric utility need additional energy, particularly for peak power supply. Research indicates that autos are utilized for active transportation less than 10% of the time. Thus, EM batteries can be used to supply electricity to markets while still used their primary purpose of using. V2G technology encompasses the principles of vehicle-to-home, which refers to the interaction between an electric car and a residential dwelling, or vehicle-to-building, which pertains to the interaction between an electric vehicle and a commercial structure. In such instances, the battery can be utilized to supply power to the electrical load. The battery of electric vehicles can use stored electrical energy to mitigate peak load and enhance the quality of electrical energy. Load peaking is the limitation of the current at overloaded times. In the grid concept, an electric vehicle can become vital segment of the grid and functions as a DG. Electric vehicles (EVs) will offer energy storage capabilities and contribute to grid stability by supplying the necessary electricity while minimizing pollutants. Prior to integrating electric vehicles (EVs) into the grid for power transfer, several requirements must be satisfied. According to the standard, the total harmonic distortion should not be more than 5% as it is directly linked to network contamination. Additionally, the PF should be close to unity, and EV must have an adequate reserve of charge in its battery.

Charging or discharging power involves three system components: the point of connection between the electric vehicle (EV) and the power grid, the EV power equipment that the vehicle is linked to, and the EV battery equipped with a charge control system. The EV can be connected to the electrical grid at several locations, including the owner's residence, a parking lot, or a public charging station.

EVs may be powered by DC or AC power sources at various power levels. All of these components play a role in determining modes of operation and functionality. Participants in accelerating the process of EV integration into the power system and in particular into the microgrid are:

-Electrical systems encounter some obstacles that hinder the widespread use of Vehicle-to-Grid (V2G) technology. The challenges for Vehicle-to-Grid (V2G) technology include interoperability requirements, developing standards, influence on electric vehicle (EV) battery life, and computer network latency requirements.;

-Automobile manufacturers: significant investments in research, development, and production. Nevertheless, Vehicle-to-Grid (V2G) technology has concerns regarding battery durability and storage capacity. Therefore, it is necessary to conduct demonstration experiments and do economic research in order to validate the concept and ascertain its viability for battery manufacturers and suppliers. Electric vehicle manufacturers are hesitant to permit energy discharge from batteries by any means other than the electric vehicle control syste.. EV manufacturers will face difficulties because they cannot know before the vehicle is delivered whether or not the owner wants to be part in V2G operations. Thus, they will need to either provide all vehicles with long term service options for a vehicle with V2G system or basic warranties on other metrics such as number of battery cycles;

-Electric vehicle (EV) holders: they will be motivated by the potential financial gains in comparison to the associated hazards. The advantages encompass financial, ecological, and networking benefits, which should be carefully considered in relation to the effects of battery longevity, vehicle accessibility, and user-friendliness.;

- Government: Due to the uncertainty of the new electric vehicle market, clear policies of directives, standards and market support are needed.

It is **proposed to use the EV-to-grid concept to solve several problems related to voltage and frequency stabilization** of microgrids (especially isolated designs). *Figures 4.14.1 and 2.*

Fig.4.14.1 G-to-EV [30]

Fig.4.14.2. EV-to-G [30]

The process of charging or discharging power encompasses three key system components: the interface between the electric vehicle (EV) and the electrical grid, the EV power equipment that the car is connected to, and the EV battery equipped with a charge control system. The electric vehicle (EV) can be linked to the electrical grid at several sites, such as the owner's domicile, a parking facility, or a public charging station.. EVs may be powered by DC or AC power sources at various power levels[30]. All of these components play a role in determining modes of operation and functionality.

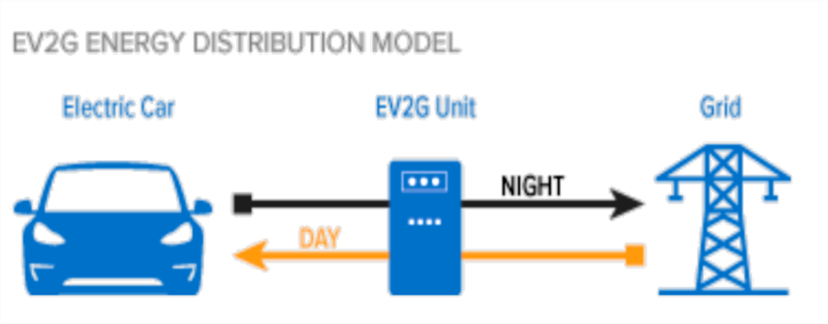

Fig.4.15. V2G Distribution system illustration [31]

Investigation of the possibility of covering the microgrid consumers' demand for electricity by means of electric vehicles.

- If the average statistical energy demand of the consumer is **350÷450kWh** per month, we can take the daily energy consumption as **0.48÷0.63kWh**. The annual consumption will be about **5400 kWh**.

- If the amount of one EV energy storage (drive reserve) is 60 kW, depending on the amount of energy required, the amount of EV energy will be enough for 5 days energy supply to the consumer on average.

- The capacity of the transformer substation is 400 kVA, with a load factor of 75%, if 4 EVs with a reserve volume of **120 kW** (or 6 EVs of 70 kW each) are connected in parallel to the 0.4 kV network, it is able to ensure normal operation of the substation for up to 2 hours.

- In case 1000 active consumers use EV as an **"energy bridge"** between RES and the place of electricity consumption, the reduction of CO2 emission will be about **2,700 tons/year** (*based on the calculation: 1 kWh/year = 0.5kg of CO2*).

CONCLUSION AND FUTURE WORK.

Conclusion

1. Conclusion

This master thesis has delved into the structure, benefits, and challenges of the microgrid system that uses renewable energy resources. Through the exhaustive review of the existing utility-scale and laboratory-designed models of microgrids, and reviewing of the research papers and journals we have covered some challenges and possible solutions.

The findings that have been reviewed in this master thesis help assess the role of the microgrid in increasing the overall reliability of the electricity supply system for interruption sensitive consumers, help to regulate SAIDI and SAIFI in economic terms and integrate the ecologically- friendly sources of energy that help to reduce CO2 emissions into the atmosphere.

Microgrid system is relatively a new technology designed to help power operators improve the quality of electricity supply. Although it is considered a new system, countries with advanced power generation systems have already created utility-scale and experimental types of microgrids. In this field, UK made world-scale innovations of integration microgrids to the system. Microgrids system projects such as Colchester Northern Gateway, London airport, Isle of Eigg made strong affect to the worldwide electricity supply that can be also integrated in Azerbaijan Republic.

Future Work

2 .Future Work

For creating microgrid system in Azerbaijan Republic and for correct voltage/frequency regulating in future, abovementioned steps required. First and most important is the investment. As microgrid has distributed energy resources and battery storge systems that have high capital and maintenance costs, the capital expenditures (CAPEX) can be met by governmental financing programs. Then, as this system has both wind and solar power stations, correct site with annual wind speed and solar radiation rate should be chosen. For voltage and frequency regulation, methods mentioned in this thesis can be applied. To connect microgrid to the main power grid, some on-grid, islanded, and blackout-mode working protocols required. To future expanding of microgrid system, networked microgrid topology can be used. All mentioned steps are vital to create power system with high reliability, low carbon dioxide emissions ,and voltage / frequency fluctuation.

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