School of Information Technology and Engineering at the ADA University

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THE PRINCIPLES AND CONTROLS OF THE DISTRIBUTED GENERATION OF THE RENEWABLE ENERGY SOURCES

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Seymur Nasrullayev

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THESIS ACCEPTANCE

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Approved:

Pasha Pashazada	
(Adviser)	(Date)
Aynura Mammadova	
(Co-adviser)	(Date)
Wisam Al-Dayyeni	
(Program Director)	(Date)
Abzatdin Adamov	
(Dean)	(Date)

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ABSTRACT

The integration of renewable energy sources and load represents challenges for the economical operation of the grid, while also giving rise to power quality issues. Extensive research has been undertaken in order to mitigate the difficulties associated with the resilience of the grid, principle, and control system of the integration of RES, and power quality interruptions. Moreover, there is a big emphasis placed on the topics of voltage variation and reactive power regulation. The interdependence of voltage and reactive power necessitates the utilization of a shared instrument for their resolution. The notion of volt-var control (VVC) has been extensively discussed in the existing literature, as thoroughly examined in this review work. The primary objective of this work is to analyze methodologies for advanced VVC applications. Furthermore, it offers the reader an in-depth overview of optimization of the distributed generations, encompassing the minimization of loss, voltage deviation, energy consumption, and operating with minimal control variables.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
RES	Renewable Energy Source
DC	Direct Current
AC	Alternating Current
GDP	Gross Domestic Product
DFIG	Double Fed Induction Generator
HAWT	Horizontal Axis Wind Turbine
DG	Distributed Generation
SVR	Static Var Compensator
PCC	Point of Common Coupling
PLL	Phase-locked Loop
VSI	Voltage Source Inverter
MC	Microsource Controller
MGCC	Microgrid Central Controller
DMS	Distributed Management System
DNO	Distributed Network Operator
ESS	Energy Storage System
EMS	Energy Management System
CBs	Circuit Breakers
OLTC	On-Load Tap Changers
VRs	Voltage Regulators
VVC	Voltage and VAR Control
FACTS	Flexible AC Transmission Systems

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The exponential growth of the global population is directly correlated with a substantial increase in energy consumption, so making the creation of energy a highly consequential concern. The old models of energy production sources are limited. They are not environmental friendly. Engineers try to produce electricity by using renewable energy sources. They have a reasonable amount of impact on the production of electricity [1]. The main sources of renewable energy include hydroelectric power, wind power, solar power, and biofuels. These modern energy sources have garnered significant attention due to their capacity for long-term sustainability. As a result, energy production from traditional sources will be decrease. Renewable energy sources reduce negative impact on the environment [2]. Energy resources have a key role to increase countries' economic growth. Empirical evidence suggests that in a typical developing nation, a one percent rise in the Gross Domestic Product (GDP) is associated with a corresponding one point four percent increase in demand for energy [3]. According to recent projects, there is an anticipated increase in energy consumption of almost forty percent by the year 2035. This growth is estimated to occur at an average annual rate of 1.4 percent [3]. Additionally, there is a substantial and growing demand for the utilization of renewable energy sources in the forthcoming two decades or beyond. Renewable sources of energy make up around 16% of global energy consumption, as reported in reference [4]. Within this percentage, traditional biomass accounts for 10%, primarily utilized for heating purposes.

1.2 MOTIVATION

Renewable energy are used in several areas. One of them is electricity generation. Generating electricity are consumed for heating water and other energy supplement services in urban locations [5]. The most important aspect related to the advancement of renewable energies have the potential to producing numerous benefits. Renewable energy sources are able to address in a certain amount of global warming [6, 7]. Electric power generation over the world are shown in the picture below [8]. In this picture, we can easily observe future vision for RES. According to the picture, the contribution of renewable energy sources to the whole energy supply amounts is 31%, and it will reach 49% of the total quantity of energy supply in 2050. The preservation of electrical energy obtained from renewable sources is of the highest priority in the context of global energy production.

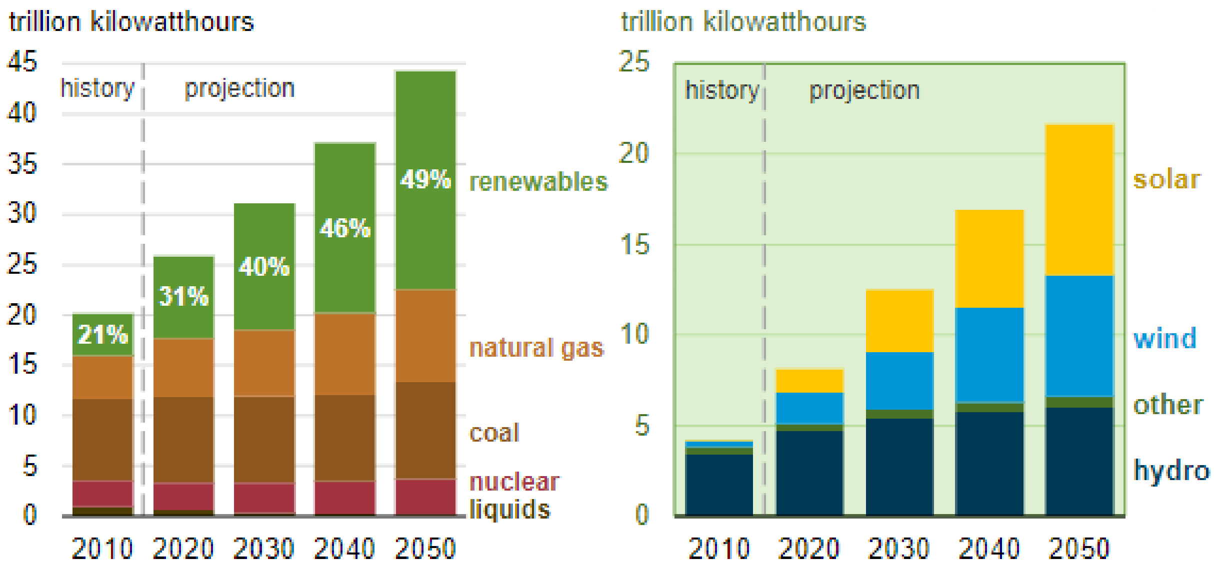


Figure 1.1 The global generation of electric power [8]

1.3 THESIS STRUCTURE

Distributed generation units are located near to the consumer. In this kind of units we can get several benefits. We can increase grid resilience, and during peak demand we can get help from these units. The favorite sources for distributed generation are wind and solar energy system. They have cost-effective outcomes. However, they are dependent from weather condition, they can keep their own familiarity [9]. Hence, the reliability of the distributed generation of RES represent a research area of interest for controlling engineers. The objective of this study is to provide a comprehensive examination of the challenges and complexities associated with the integration and controls of renewable energy sources. This paper additionally introduces the control methods and high technology employed in the distributed generation of RES. The main purpose of this study is to reduce transmission losses by using voltage, reactive power control methods. Also special electronic devices which is called STATCOM has enough positive outcome to support reactive power and voltage control issues.

CHAPTER TWO

REVIEW OF THE LITERATURE

2.1 Renewable Energy Sources (Wind & Solar power plant)

In this research, we will look at renewable power generation from wind and solar power plants. Because they are so familiar nowadays. This kind of sources have been existing on the nature and they are not limited for the future. The most important point is to find the best appropriate area for building these energy plants. In this study, we focus on the power generation from wind and solar power plant and integration of them into power grid. The aim of this study to eliminate main control and principle of the distributed generation of RES.

2.2 Wind Turbine

Wind energy is widely acknowledged as a very useful and renewable source of electricity generation [10–12]. The wind energy industry is seeing substantial expansion due to breakthroughs in turbine technology and the development of innovative power system technologies. Figure 2 illustrates a comprehensive global statistical analysis of wind generation extending from 2001 to 2020, as referenced by sources [13]. This figure serves as tangible proof of the growing interest in wind turbines. Wind generators utilize either an induction motor or a synchronous motor. [14]. Induction motors are extensively utilized in various applications attributed to their compact size, lightweight construction, and ease of maintenance. The mathematical calculation formulas of a wind generator are shown in the below [15].

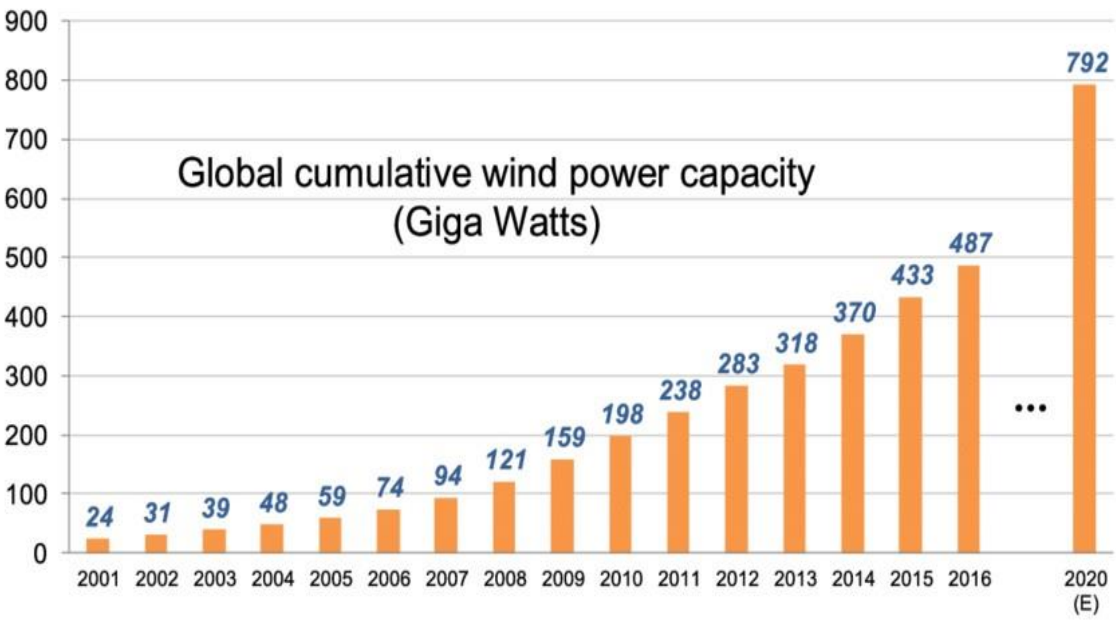


Figure 2.1 Wind Energy Generation in Global Scale [13]

$E_k =$ Kinematic energy (J);

$P_w =$ Power (W);

m = Mass (Kg);

$V_w =$ Speed of wind (m/s);

ρ = Density (Kg/m3);

$A_s =$ Swept area (m2);

ς = Speed ratio;

α = Pitch angle of blade (deg);

r = Radius of wind turbine (m);

$\omega_w =$ Angular velocity of wind turbine (rad/s);

$\frac{d_m}{d_t} =$ Mass flow rate of wind.

The kinematic energy produced by the blade of the wind turbine due to rotation is,

$$E_k = \frac{1}{2}\, m{v_w}^2 \qquad (1)$$

The power of the wind generation is equal the rate of change of energy,

$$P_w = \frac{dE_k}{dt}$$

$$P_w = \frac{1}{2} v_w{}^2 \frac{d_m}{d_t} \quad (2)$$

Mass flow rate can be represented by

$$\frac{d_m}{d_t} = \rho A_s V_w \quad (3)$$

The power of the wind turbine can be defined by

$$P_w = \frac{1}{2} \rho A_s v_w{}^3 \quad (4)$$

The total wind power,

$$P_{T=} \frac{1}{2} \rho C_p \varsigma A v_w{}^3 \quad (5)$$

Where, $\varsigma = \frac{\omega_w r}{V_w}$

$$C_p = 0.5(\vartheta - 0.022\alpha 2 - 5.6)\mathrm{e} - 0.17\vartheta$$

And

$$\vartheta = \frac{3600r}{1609\varsigma}$$

2.3 Solar (PV) Energy System

The implementation of photovoltaic (PV) energy systems has been shown to reduce the reliance on fossil fuels and serve as a sustainable and dependable source of renewable energy [16]. Figure 3 depicts the statistical enhancement of solar energy installation on a global scale [8]. Figure 4 shows the solar PV power generation within the context

The conversion of energy in photovoltaic (PV) systems occurs through the utilization of two distinct processes. Photovoltaic technology involves the direct conversion of sunlight into electrical energy through the utilization of photovoltaic effects [17]. The photovoltaic system experiences swings in DC current as a result of the variability in sunlight intensity. The implementation of an inverter that provides the desired voltage and current serves to mitigate this variation. The utilization of concentrated solar power systems involves an indirect approach wherein mirrors or lenses are employed to generate electric current. This procedure involves the utilization of a steam-driven turbine to transform the thermal energy derived from solar radiation [18].

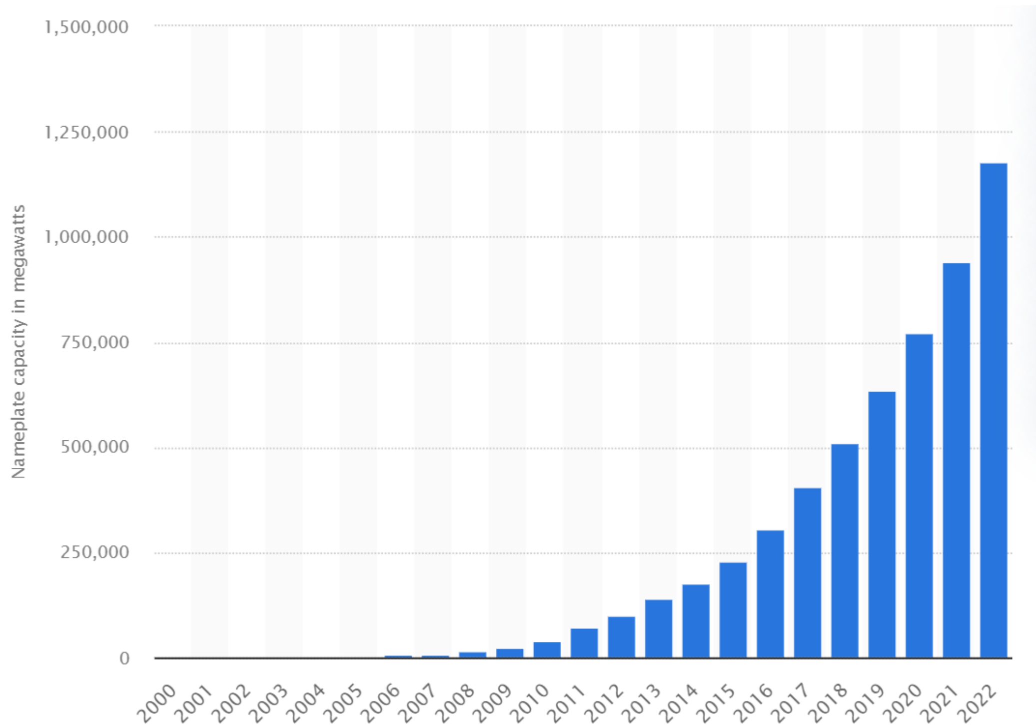


Figure 2.2 Global cumulative installed solar PV capacity [8]

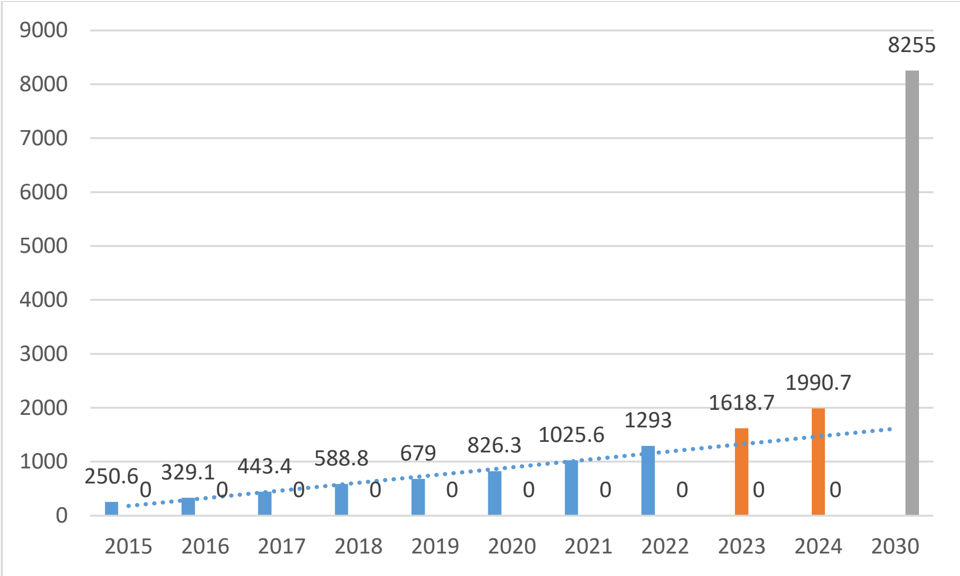


Figure 2.3 Solar PV power generation [8]

Table 2.1 The mathematical calculation formulas of a solar PV system [4]

I_{pc} = Photo current (A); I_{scc} = Short circuit current (A); I_{cc} = Short circuit current of the solar cell (A); I_{sr} = Irradiation of solar (W/m^2); I_{ms} = Module saturation current; T = Actual cell temperature; T_{rc} = Cell temperature at reference condition; R_{sr} = Intrinsic shunt resistance (Ω); R_s = Series resistance (Ω); Q = Charge of electron; V_{oc} = Open circuit voltage (V); N_{cs} = Cell number connected in series; N_{cp} = Cell number connected in parallel; N = Ideality factor of the diode in the circuit; K = Boltzmann's constant = $1.38 * 10^{23}$ J/K; ε_{be} = Energy of material band-gap.	The module photo-current I_{pc} of the solar cell can be represented by, $$I_{pc} = \frac{[I_{scc} + I_{cc}(T - 298)] * I_{sr}}{1000} \quad (6)$$ The Module reverse saturation current I_{rsc} is defined by, $$I_{rsc} = \frac{I_{scc}}{exp(Q * V_{oc}/N_{cs}KNT) - 1} \quad (7)$$ With the variation of cell temperature, I_{ms} can be represented as, $$I_{ms} = I_{rsc}\left[\frac{T}{T_{rc}}\right]^3 exp\left[\frac{Q * \varepsilon_{be}}{NK}\left(\frac{1}{T} - \frac{1}{T_{rc}}\right)\right] \quad (8)$$ The photovoltaic module having output current I, $$I = (N_{cp}I_{pc} - N_{cp}I_{ms}) * \left[exp\left(\frac{V/N_{cs} + IR_s/N_{cp}}{NV_{dt}}\right) - 1\right] - I_{rc} \quad (9)$$ Where, the thermal voltage of diode V_{dt} can be defined by, $$V_{dt} = \frac{K * T}{Q}$$ and , Current through shunt resistance I_{rc} is, $$I_{rc} = \frac{VN_{cp}/N_{cs} + IR_s}{R_{sr}}$$

2.4 Electricity Production from Wind Power Plants

Figure 5 is a primitive block diagram illustrating the process of generating power through the utilization of a wind turbine. These wind turbines operate based on a straightforward premise, harnessing the full potential of the wind's force, which serves as a key energy source in this context. The energy output of a wind farm is contingent upon factors such as its geographical placement, the dimensions of the turbines, and the length of their blades. Wind turbines are often categorized based on the orientation of the axle:

A vertical axis wind turbine consists of blades that revolve around a central, vertical axle.

A horizontal axis wind turbine refers to a type of turbine where the blades rotate in a direction that is at a right angle to the speed of the wind. There are two distinct types of propellers that are employed in wind turbines, specifically the drag type and the lift type [19]. The leading edge of an object generates lower air pressure, whereas the tail edge generates higher air pressure. The induction generator exhibits a higher consumption of reactive power. In order to address this issue, the implementation of the double-fed induction generator (DFIG) has been extensively used [20]. The utilization of an inverter is employed to regulate the torque, as well as the active and reactive power of the machine, through the manipulation of the current.

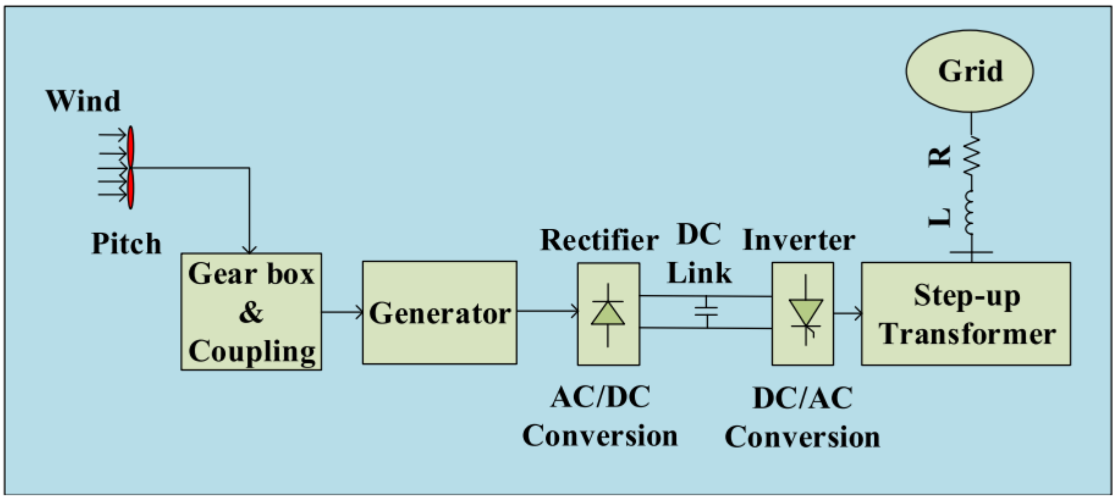


Figure 2.4 Wind Energy Generation Process [19]

2.5 Electricity Production from Solar PV Power Plants

Figure 6 depicts a basic schematic diagram for producing power using a solar system. Making use of the sun's radiation, solar panels transform their energy into usable electricity. Electricity and heat are the two main ways in which the sun provides us with energy. One of the is small-scale distributed generation units. For example, rooftop installing of solar panel. The second case is a bigger form of distributed energy sources. We called this form solar power plant or Solar power station. Solar power is a limitless and sustainable energy resource. That produces no detrimental greenhouse gas emissions. As long as the sun remains shining, energy will be generated. The electrical current created by the solar system is commonly referred to as light-generated current [21]. Solar panels typically consist of silicon or another semiconductor material enclosed within a metal panel frame and covered with a glass enclosure. When this substance is subjected to photons of sunlight (minuscule units of energy), it emits electrons and generates an electrical charge. In the operation time of solar panels, it produces direct current from sun light. The next, we use inverter to get AC from DC. AC, or alternating current, is the specific form of electrical current that is utilized for connecting appliances to standard electric sockets.

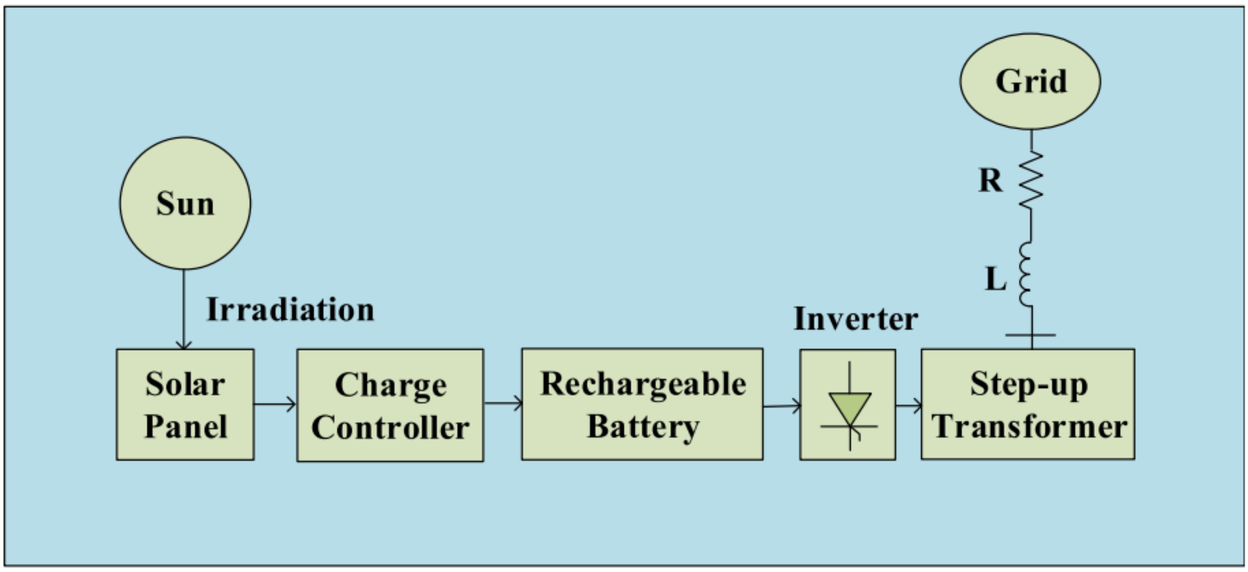


Figure 2.5 Solar Energy Generation Process [20]

CHAPTER THREE

CASE STUDY

3.1 Integration of RES

Energy supply systems have advanced to efficiently transmit electricity, gas, heat, and transportation fuel. The integrating of renewable energy sources into pre-existing systems is essential for expanding the penetration of renewable energy. Diverse systems and marketplaces possess intricacies that necessitate systematic long-term planning and a comprehensive strategy. This has the potential to result in an integrated energy system that supplies electricity, heating, cooling, and transportation, which might potentially contribute to a rise in world electricity consumption.

The generation of electricity from solar panels exhibits a high degree of predictability. Electrical power systems in the modern era have undergone significant advancements since the late 19th century and exist in diverse forms across the globe. Certain technologies are sophisticated and dependable, while others are less mature but undergoing rapid development. China experienced a significant rise in electricity consumption, surpassing 50%, during the period from 2004 to 2008, thanks to the addition of 85 GW of power plants. Autonomous or micro-scale systems are designed to cater to the needs of small communities, single buildings, or industrial operations. Although these systems may differ in their characteristics, they all share a common objective: to deliver a dependable and economical electricity supply to loads through the suitable generation and utilization of network infrastructure [22]. The incorporation of renewable energy (RE) into an electrical power system presents several difficulties, which are often similar to those encountered with other technologies and advancements, for the designers and operators of said system. To effectively tackle these difficulties, it is essential to have a fundamental comprehension of the attributes of electrical power systems.

Typically, Controlling of electricity generation, we can solve power supplying problems. If the electricity demand are increase, we can generate more power to meet that demand. As we know, if demand increase, generation of electricity will increase too. But it will take some time. As a result, in the power system we observe fluctuation of voltage or reactive energy and other constraints will get effect. Dispatchable devices, such as wind generators, possess little control over their output, which can potentially lead to a decrease in production. The predictability of wind energy generation system is comparatively lower when compared to solar energy systems [22]. The wind turbine is located in a geographically distant and isolated location, separate from the primary power distribution network. This phenomenon results in an increasing of the economic expense and the amplification of transmission inefficiencies. Insufficient calculation of voltage loss may result in a decrease in load voltage. The wind's motion exhibits temporal variability during the daily and seasonal cycles. During the nighttime and winter seasons, there is a notable existence of strong wind currents. When the level of production exceeds the level of demand, there is a resulting reverse flow of current, which in turn diminishes the level of protection provided to the loads. In order to address these issues, it is necessary to include an additional control mechanism that effectively reduces the voltage. Electrical energy stored by Capacitor banks and it generate reactive power into the main grid. The load current is reduced, resulting in an increase in the load voltage. The capacitor bank alone is insufficient to resolve this fluctuation. The static var compensator (SVR) is utilized as a replacement.

Distributed generation units are subject to voltage fluctuations, flickers, and instability as a result of the inherent variability of distributed generation (DG) units. These fluctuations have a significant impact on the dynamic and transient responses of the Distributed generation system. The issue of integrating distributed generation (DG) units has a significant impact on both active and reactive power, resulting in abrupt and substantial fluctuations in power. The inherent variability of distributed generation (DG) units necessitates the utilization of various power electronics components, including as converters and filters, in order to introduce harmonics into the Distributed generation units. The utilization of DG units in a fixed performance setting eliminates the need for a power converter, hence enabling effective management of harmonic distortion. The utilization of reactive power in wind turbines leads to voltage fluctuations at the point of common coupling (PCC).

Distributed generation are interconnected with a significant quantity of distributed generation units (DG Us), and establishing appropriate connections among them is imperative for achieving maximum performance. Power electronics are essential for establishing the connection between distributed generation (DG) units. They are responsible for controlling the maximum power transfer, safeguarding the system against load dynamics, and ensuring the maintenance of power quality, as well as active and reactive power on the grid side. In addition, they effectively mitigate the presence of harmonics inside the system. The microgrid is structured with two distinct loops: the current controller, responsible for regulating power quality through current regulation, and the voltage controller, responsible for managing grid voltage and ensuring system stability [23]. In synchronization techniques regulation, both active and passive power demand are essential in the control action. The primary objective for this study is to explain the integration, control, and principles governing the utilization of renewable energy sources inside distributed generation systems. This paper additionally outlines the technical obstacles associated with managing the performance of Distributed generation systems, as well as the control technologies employed to address these problems.

3.2 Distributed generation systems

Distributed Generation (DG) is a method of generating electricity in a decentralized manner, where power is produced at or close to the place where it will be consumed. Unlike conventional centralized power generation, which depends on big power plants to distribute electricity over vast regions, distributed generation (DG) implies smaller-scale power generation units that are networked inside local energy distribution systems. This concept is based on the notion of improving energy efficiency by predominantly employing renewable energy from various technologies and sources, such as solar, wind, and combined heat and power systems, perhaps alongside energy storage solutions. These technologies enable households, businesses, and communities to produce their own electricity, so revolutionizing not only how it is generated but also how it is consumed and shared. The process of creation required a significant amount of time. However, it is important to note that the availability of natural resources is inherently finite on a global scale. In the future, the decreasing availability of nonrenewable sources will provide a significant challenge to power production, as their finite nature implies their eventual expiration. In order to address this issue, experts have a tendency to explore novel methodologies that might effectively meet the growing global electricity demand. The implementation of Distributed generation systems has proven to be a reliable and advantageous approach in the generation of electrical power, while at the same time mitigating the reliance on nonrenewable energy sources. A Distributed generation systems (DG) refers to a compact network that has the capability to generate electricity independently when it disconnects from the primary grid [24].

In recent years, solar photovoltaic (PV) systems have gained widespread popularity and are now the most commonly utilized. These systems entail the installation of photovoltaic solar panels on rooftops, facades, or carports, among other locations. Often, they are linked to the traditional electrical grid, allowing for the transfer of energy between the generation location and the grid [25]. For instance, when the primary grid do not meet the demand ,distributed generation sources possess the capability to function autonomously at a local level. Adequate capacity is necessary to meet the demands of the load needs. Additionally, the minimal capital investment required and ease of operation contribute to its global popularity.

The schematic of the DG control is depicted in Figure 8. Utility grids and distributed generation units share many similarities. Both have the same purpose, which is to supply electrical power to users. Both are bound by same limitations, which require that electrical generation and electric load remain in equilibrium at all times. Nevertheless, their constituents vary. The distributed generation sources are composed of various elements. Including distributed generation (DG) with a particular focus on renewable energy sources. The point of common coupling (PCC) and energy storage devices, and the inverter of source voltage (VSI) [26, 27]. Distributed generation (DG) sources or generation units, including wind turbines, solar systems, photovoltaic systems, biomass technologies, hydroelectric energy sources, and fuel cells. They are compact energy sources situated in close distance to or directly at the consumption point. The energy supplied by the distributed generation (DG) source is in the form of direct current (DC). The conversion of DC power to AC power can be achieved by the utilization of a VSI unit, which involves the implementation of either a rectifier and inverter or just an inverter. In certain instances, a filter may be employed to enhance the stability of voltage and current (figure 7).

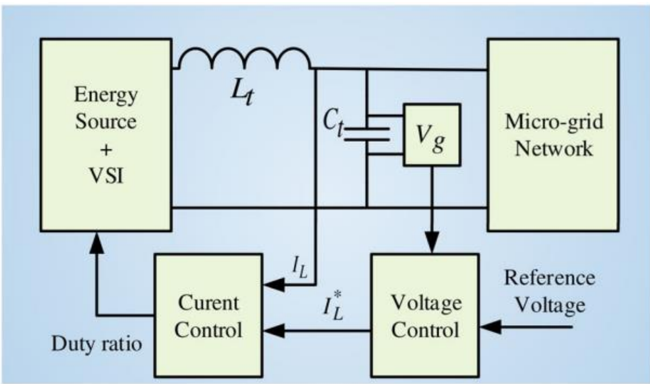


Figure 3.1 The utilization of a closed-loop control strategy [27]

The conversion of both voltage and frequency can be achieved using VSI (Voltage Source Inverter) machines. Energy storage is employed in situations when there is a geographical gap between the locations of generation units and loads. The system has the capability to store and deliver energy to meet the specific demands of the loads. Additionally, this energy system has energy storage devices. Which it can store energy, and possess backup power functionality. The main electricity storage elements are battery, and super-capacitor. The interconnection between a microgrid and the main grid is commonly referred to as the point of common coupling (PCC).

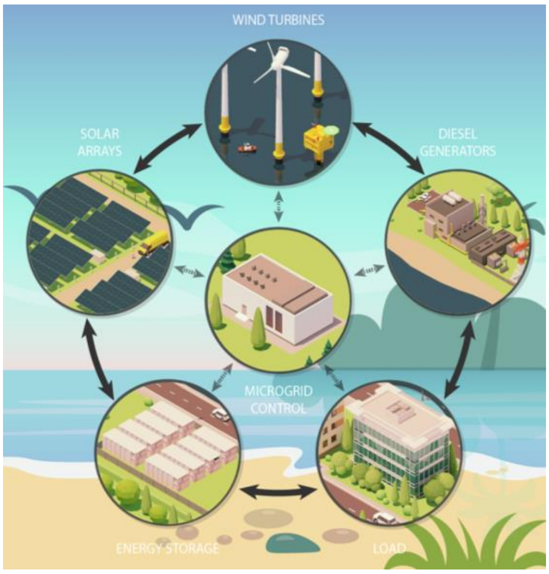


Figure 3.2 An Illustration of DG control Scheme [25]

The DG unit has the capability to connect or disconnect from the primary grid. There are two main types of connections. First one is called grid-connected type. Second one is called islanded mode [28]. In the context of the first mode operations, between the primary electrical grid and the DG unit connected directly. The main grid maintains control over voltage and frequency, whereas the DG unit functions as a stable and constant power supply. As a result of the remote location, a significant voltage drop is experienced. The grid-connected DG unit is associated with several drawbacks, including loss of voltages, weak power quality level, substantial capital requirements, and significant loss in transmission [29]. For distributed generation sources, working in secondary mode is much effectice.

The main purpose in electricity generation from the distributed generation sources is to stabilize voltage and frequency inside of distributed generation. If the distributed generation cannot avoid from stabilization of quality constraints, it will made incapable of generating a voltage of 50 Hz. Consequently, the voltage will experience oscillations for a specific duration [30]. Once renewable energy sources see further growth, the system becomes increasingly complicated and gives rise to numerous technical challenges. The performance, whether it be in terms of steady state or transient response, may be influenced as a consequence. Additionally, it has the potential to generate short circuits or malfunctions, while also lowering the overall power quality. The primary necessity is to regulate the voltage of the microgrid in order to ensure its dependable and consistent performance.

3.3 Principle of Distributed Generation

One of the most important ideas in renewable energy is distributed generating. Distributed generation is an alternative to relying entirely on centralized power facilities for the production of electricity. It involves using renewable energy sources that are placed near or directly at the customers. This strategy has a number of key principles and advantages.

Decentralization: It is well known fact that, the traditional power plants are situated far from end users. Energy production is transmitted via transmission lines over great distances to the consumers. However, renewable energy sources like solar panels, wind turbines, small-scale hydroelectric systems, and biomass generators are installed closer to where the electricity is needed. In this way, we can prevent some costs and a certain quantity of power outages. For example, in the renewable energy sources no need to install long distance transmission lines, and at the same time power flow losses will be reduce respectively.

Energy Independence: Communities and customers can achieve energy independence through distributed generating. By powering their own homes, offices, and communities with renewable energy, people may lessen their impact on the environment and the grid.

Grid Resilience: Distributed generation can improve the electrical grid's resilience. Excess electricity can be supplied back into the grid when a distributed energy system is connected to it, which can assist stabilize it during periods of high demand or during crises.

Less Transmission Losses: There are less transmission and distribution losses when power is produced closer to consumers. Long-distance electricity transmission lines have a great amount of resistance, therefore, energy losses are increased during power flow. This can be minimized with distributed generation.

Environmental Benefits: Compared to fossil fuels, electricity produced by distributed generation using renewable energy sources like solar and wind emits substantially fewer greenhouse gases. This lessens the impact of carbon emissions and slows down global warming.

Energy Efficiency: By capturing waste heat for combined heat and power (CHP) applications, distributed generation systems can be made to be more energy-efficient overall.

Scalability: The capacity to scale distributed generation systems to meet individual energy needs is a key feature. They are flexible enough to meet a variety of needs, ranging from tiny residential solar panels to big commercial and industrial installations.

Grid Support: Distributed generation systems have the capacity to perform grid support tasks including voltage control, load balancing, and peak shaving, which can increase the grid's stability and reliability.

Local Economic Benefits: Local economies may benefit from investments in distributed generation projects if they lead to the development of jobs in renewable energy system production, installation, and maintenance.

Energy Security: By increasing the variety of energy sources and lowering the susceptibility to supply interruptions, distributed generation can improve energy security.

In essence, the distributed generation principle of renewable energy sources advocates for a transition towards an energy system that is more resilient, sustainable, and decentralized. The technology enables individuals, businesses, and communities to locally produce renewable energy, thereby making a positive contribution towards a more sustainable and dependable electricity grid.

3.4 Control of Distributed Generation

3.4.1 Centralized Control

In order to effectively manage a flexible DG in both On-grid mode and Off-grid mode, it is important to possess a comprehensive understanding of the system's architecture, planning, and the various topologies associated with DG units. The monitoring and safeguarding of the DG is a crucial concern. The integration of many electrical devices, energy storage systems, and telecommunication technologies contributes to the complexity of the system. There are several controls for the DG units. The central controlling method is considered as one of them [31]. The centralized controller operates on a hierarchical control methodology. The hierarchical system consists of three control elements [32]:

1) the local microsource controller (MC) with load controller (LC)
2) the microgrid central controller (MGCC)
3) the distributed management system (DMS)

In a centralized control system, a central controller acquires data from all individual components. The central controller serves as the fundamental component of the system, responsible for executing all calculations and generating control actions for all interconnected units at a singular location.

The local microsource controller (MC) is employed for the purpose of managing the power electronics interface in the absence of a communication system. This controller is specifically designed for the distributed generator that is connected to the microgrid, as referenced in sources [33, 34]. The local microsource controller (MC) consists of three components, specifically a voltage source inverter (VSI), a primary mover, and a DC interface. The Voltage Source Inverter (VSI) unit is responsible for regulating output voltage's amplitude and phase. The Active and reactive power is also regulated by this controlling system. The units information is obtained via MC. Based on the provided data, the DG effectively regulates both the voltage and frequency. The load controller, situated at the controlled load, is responsible for regulating the electrical load inside the microgrid.

The Microgrid Central Controller (MGCC) serves as a link between the distributed management system and the DG [35]. The power allocation for the microgrid is estimated based on the capacity of the distributed generation (DG) units. The system generates a control signal that is transmitted to both MC and LC in order to optimize the electricity usage . During grid-connected mode, the order of MGCC is executed by the MCs and LCs. However, during islanded mode, the MCs and LCs have independent control. The DMS), alternatively referred to as the Distribution Network Operator (DNO), is a term used to describe this concept [31]. The system governs the functioning of areas with low and medium voltage levels.

3.4.2 Decentralized Control

The decentralized control technique is a form of hierarchical control where each unit is equipped with its own local controller [36]. These units are autonomously operated by their own local controllers. The local controller collects data from the local units and generates control commands to ensure their correct operation. The controllers operate independently and are not reliant on the actions of other controllers. The system's components must be strongly coupled to one another.

A decentralized control system is completely contradictory to the centralized control approach. In decentralized control, local microsource controllers are tasked with optimizing production to meet demand. It optimizes the independence of the micro-sources and loads. An advantage of the decentralized control strategy is the utilization of many intelligent processes. The control mechanism of decentralized control relies on peer-to-peer algorithms, such as multi-agent algorithms and gossip-based algorithms. The characteristics of a decentralized control approach for microgrid are as follows:

1. Micro-source is consisting of multiple owners, with each choice being made at the local level.
2. The microgrid's controller for each unit operates using an intelligent algorithm.
3. A local micro-source supplies electricity to the distribution networks and generates heat for local installations. It also serves as a backup power source in case of emergencies. Additionally, it maintains the voltage at a specific level.

The primary benefit of decentralized control is its ability to include various distributed generation (DG) units into the microgrid without requiring any adjustments to the controller settings. However, in this scenario, the coordination must be sufficiently resilient. The feasibility of the decentralized control strategy for the energy management system (EMS) is high. The energy storage system, functioning as a voltage source, can be regulated through either constant I (Amper) mode or constant U (volt) mode. The electrochemical energy storage system (ESS) autonomously regulates the state of charge (SOC) while operating in constant current mode. The EMS takes data from the SOC and generates control commands for the DG units. Subsequently, the DG units uphold the state of charge (SOC) at a constant level [37].

A major drawback of decentralized control is the absence of state of charge (SOC) information for the distributed generation (DG) units when the energy storage system (ESS) is utilized as a voltage source. A decentralized control approach does not utilize any communication mechanism. Consequently, the State of Charge (SOC) data is not transmitted to dispatchable Distributed Generation (DG) units, resulting in the instability of the Energy Storage System (ESS).

The centralized technique necessitates significant communication and computing across a large geographic region. This requirement renders the centralized control technique unfeasible. Furthermore, achieving a completely decentralized control strategy is unattainable due to the necessity of a highly robust interconnection between the functioning of the units. The local variables lack the capacity to provide the necessary level of coordination among the units in the system. According to Figure 9, there are three levels to the hierarchical control technique that can be used to address these challenges: primary, secondary, and tertiary.

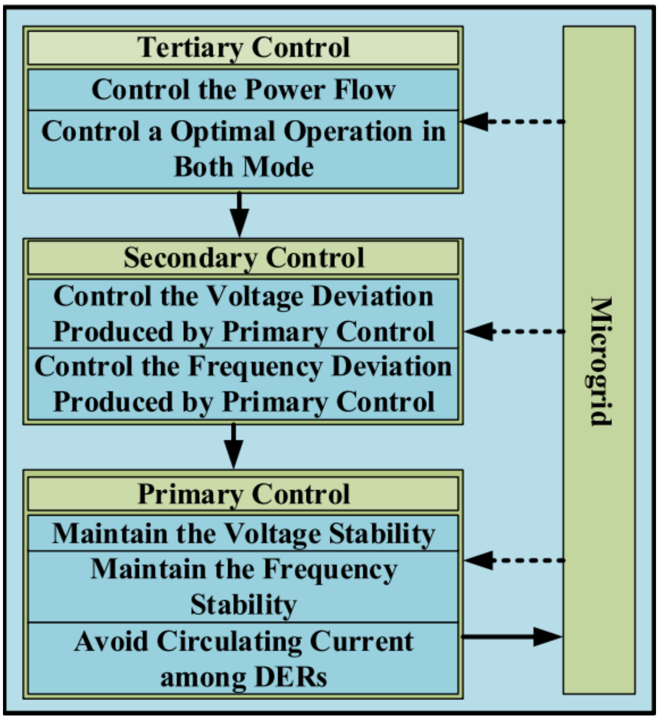


Figure 3.3 Block Diagram of Hierarchical Control System [36]

The first controlling level often employs droop control, which distributes the load among the converters in a microgrid. Conversely, the second controlling level mitigates the steady-state error generated by the droop control, while in the last controlling level is responsible for the import or export of energy in the microgrid.

CHAPTER FOUR

RESEARCH RESULTS AND ANALYSIS OF RESULTS

4.1 Control Action in Voltage and VAR Control (VVC)

4.1.1 Slow response

The management of reactive power in distribution networks is dependent on the utilization of conventional voltage and var control (VVC) devices, such as circuit breakers (CBs), on-load tap changers (OLTC) transformers, and voltage regulators. These VVC devices exhibit effective performance in handling gradual variations, but encounter difficulties in handling with rapid fluctuations due to inherent physical and structural limitations. They are private, can't be changed often, and switching them on and off too often wears them out. This study proposes a multi-objective voltage and VAR control (VVC) strategy for distribution networks that accommodate a significant number of prosumer distributed energy resources (DERs). The primary objectives of this strategy are to minimize energy loss and optimize the cost of voltage control devices, including circuit breakers (CBs), on-load tap changers (OLTC), and voltage regulators (VRs). In order to effectively tackle the multi-objective problem and identify the optimal solution, a perfect approach founded in sensitivity is introduced.

4.1.2 Fast response

Conventional VVC devices are subject to regulation on a longer time scale as a result of their inherent physical limitations. In contemporary times, distribution networks have been increasingly integrated with diverse renewable resources that exhibit inherent uncertainty. In order to achieve accelerated and dependable regulation of Voltage Var Control (VVC), it is vital to employ quick and highly responsive mechanisms. Advanced VVC devices, including Soft Open Point (SOP), Inverter based Distributed Generator (IDG), STATCOM, and static-var compensator (SVC), exhibit rapid response characteristics and provide a broader range of capabilities for injecting or absorbing reactive power. From all of these devices, STATCOM and, static-var compensator (SVC) are most popular.

4.2 Introduction of STATCOM

The dynamic nature of electric power networks necessitates the existence of certain attributes such as reliability, flexibility, rapid reaction, and accuracy. The development of innovative technology has allowed the growth of Flexible Alternating Current Transmission Systems (FACTS), which effectively regulate the varying voltage and phase angle. Real power and reactive power are regulated in a power system by the phase angle and voltage difference between the sending and receiving ends, respectively. Real and reactive power can be regulated through the impedance of the transmission line. To improve the power transfer capacity of the transmission line, Flexible AC Transmission Systems (FACTS) are installed. There are different fact devices such as, thyristor control reactor, thyristor switched capacitor, static var compensator, thyristor switched series compensator, static compensator, self-commutated compensator, unified power flow controller. These devices permit to enhance the loading capacity of lines in relation to their thermal capabilities. Improve the security of the system by increasing the transient stability limit. Give access to control of the power flow and reduce the reactive power flow intentionally.

Modular Multilevel Converter Valves

The composition of Static Synchronous Compensators (STATCOM) involves the integration of a voltage source converter (VSC) with the grid through the utilization of phase reactors and a step-up transformer. Insulated Gate Bipolar Transistors (IGBTs) are employed in the configuration of modular multi-level converters (MMCs) for the operation of STATCOMs. The STATCOM has the ability to produce or absorb reactive power by precisely regulating the voltage waveform it generates.

4.2.1 Basic Operation Principles

The STATCOM system is connected in a shunt configuration to the transmission grid. The STATCOM is equipped with voltage transformers (VTs) that are responsible for measuring the voltage of the grid. The Advanced Digital Control (ADC) system utilizes the VT input to regulate the operation of the different sub-modules, thereby generating a voltage waveform that can be categorized as either:

• The same as the system, when there are no grid issues

• Lower in magnitude than the system, making the STATCOM act as an inductive device and absorbing reactive power from the grid

• Higher in magnitude than the system, making the STATCOM act as a capacitive device and generating reactive power to the grid

The STATCOM serves the purpose of continuously monitoring the voltage of the power grid and making frequent adjustments to its reactive power output in order to effectively respond to system disturbances, hence enhancing the stability of the grid.

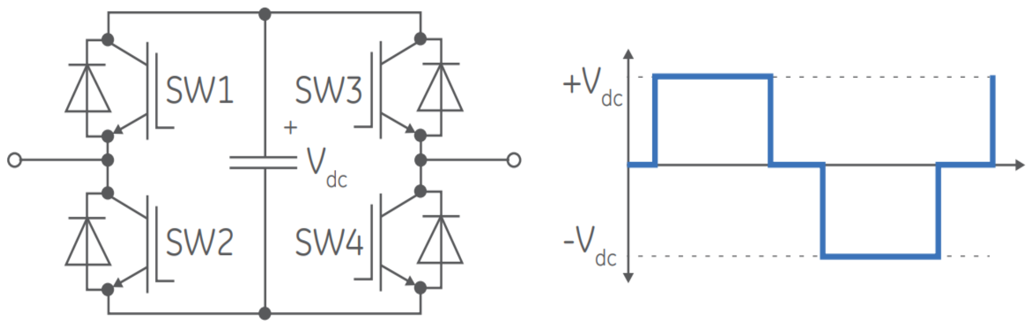


Figure 4.1 Typical full bridge valve sub-module and its output waveform [26].

The diagram presented in Figure 10 depicts the manner in which the IGBT valves inside a single sub-module are strategically manipulated to provide regulated switching. This process generates the fundamental three-level waveform, which is ultimately used by the STATCOM to effectively regulate the reactive power contribution to the grid. When many sub-modules are connected in series, as depicted in Figure 11, it becomes obvious how the voltage waveform can be gradually constructed with greater accuracy resulting in enhanced performance, increased rating, and improved controllability of the STATCOM.

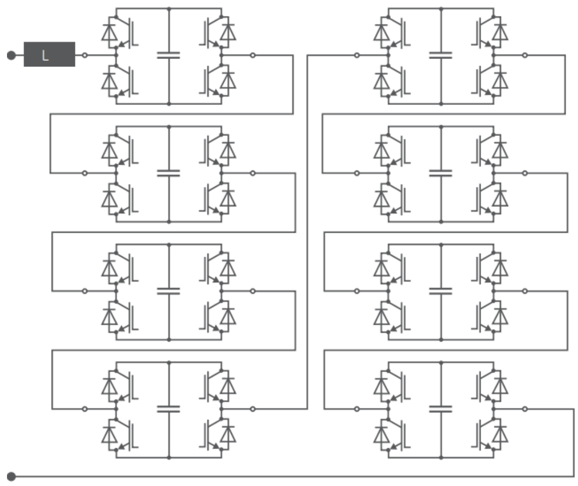
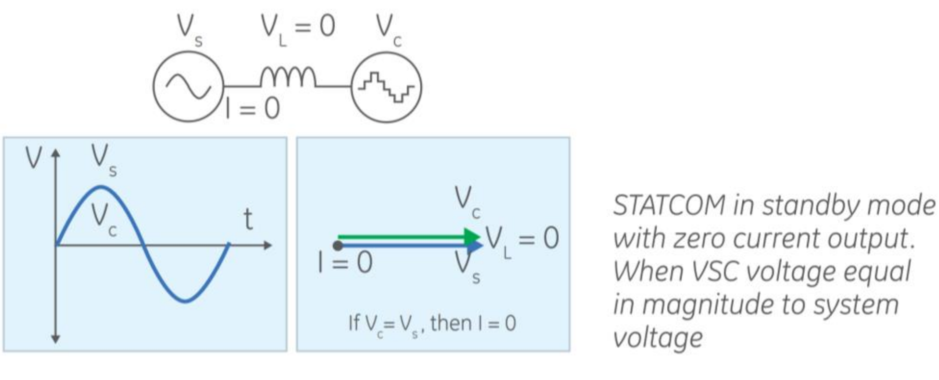
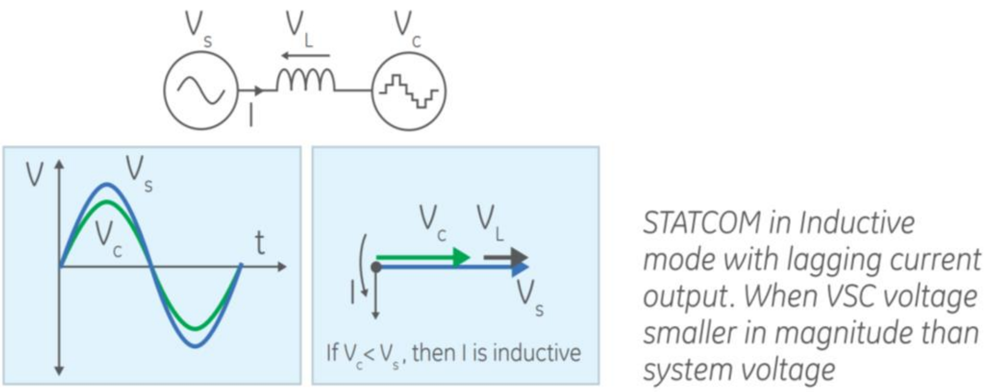
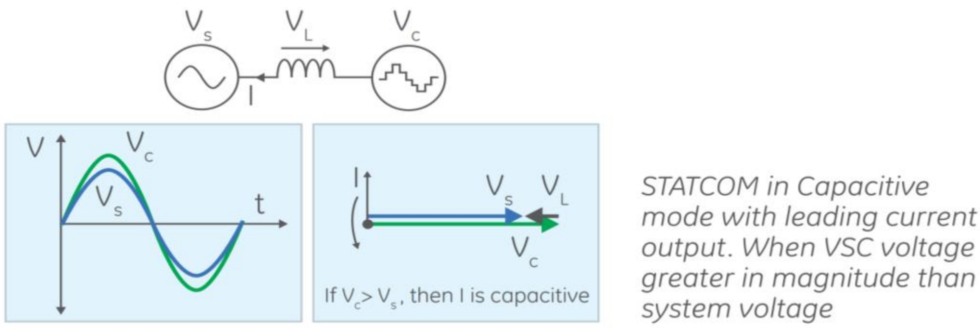


Figure 4.2 Multiple sub-module operation [26]

The reactive power output of the STATCOM can be adjusted to zero, inductive, or capacitive by manipulating the magnitude of the voltage waveform generated by the voltage sourced converter and preserving synchronization with the system voltage. This behavior is illustrated in the diagram (figure 12) provided.







The STATCOM configuration employed by GE incorporates eight sub-modules within each module, serving as the fundamental components of the STATCOM design. The setup depicted below creates a sinusoidal waveform that closely approximates an ideal shape. The valve's very low switching frequencies result in reduced system losses and the need for minimal or no high frequency filtering.

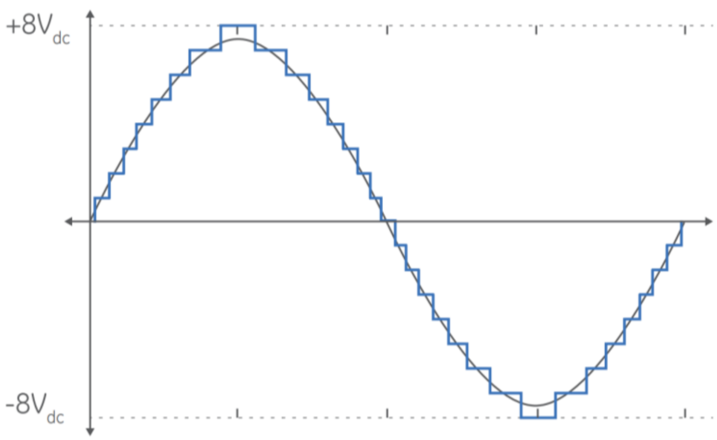


Figure 4.3 During Multiple sub-module operation, resulting waveform [26]

4.3 Simulations

To simulate renewable energy source integration into the main grid we used a program which called DIgSILENT. It is so effective to gain load flow analysis for this research. On the other hand, we can also observe how reactive power and active power changed over the network. For a simulation, we take the Azerbaijan power grid's model for 2025. In this power grid, we look 4 different points voltage, active and reactive power values that how they are changed. How much are these values, before the integration of Renewable energy sources into main grid and after the integration of Renewable energy sources into the main grid. These 4 points are shown below.

1) 330/220/110 kV Janub Electrical Station
2) 330/110 kV Jabrayil Sub-station
3) 330/220/110 kV Qobu Power plant
4) 330/220/110 kV Yashma Sub-station

Two of them are Power plant or Electrical station, and other couple are called Sub-stations. Before the integration of RES we can regulate each part of the system voltage by using changing amount of the generation or load. Reactive power is changed respectively over the system in this scenario. From the simulation, we can easily observe before the connection of RES the voltage values of each section are small than after connection of them. The main reason for this changes happen is our transmitting energy amount increase and if powers are increase they will effect each point where they are connected. In our case, there are four points that get first impact from integration of RES.

In this load flow analyzing is going in maximal regime which is equal to 4500 MWt. Some part of this load come from renewable energy sources which is equal 730 MWt. The rest of the power is produced by conventional energy sources. Voltages are changed because of increasing transmitting power. In this case, we need to control voltage or reactive power. For this purpose we use static var system (STATCOM). The simulations and Results are shown below.

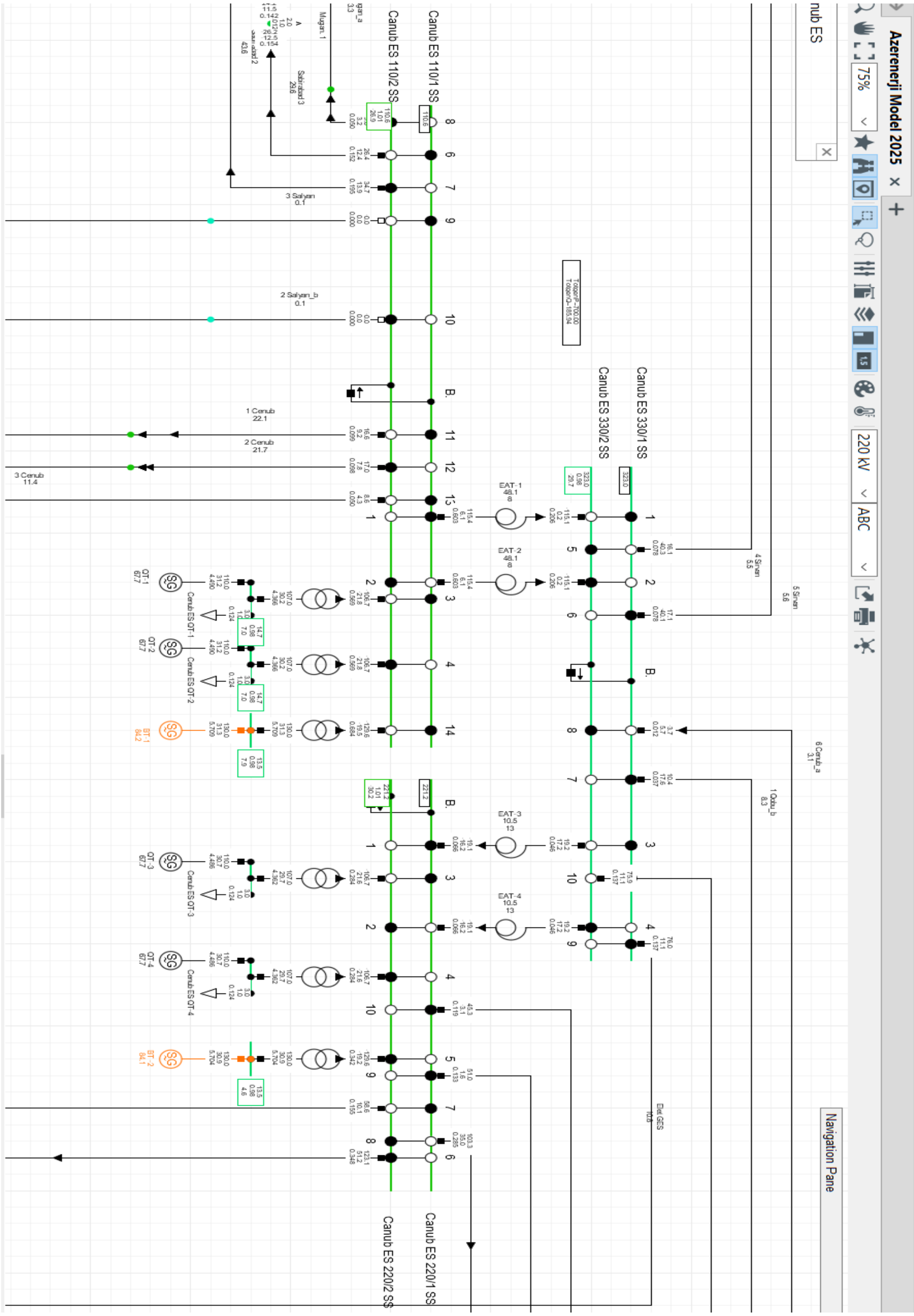


Figure 4.4 330/220/110 kV Janub Electrical Station, before integration of RES into the main grid.

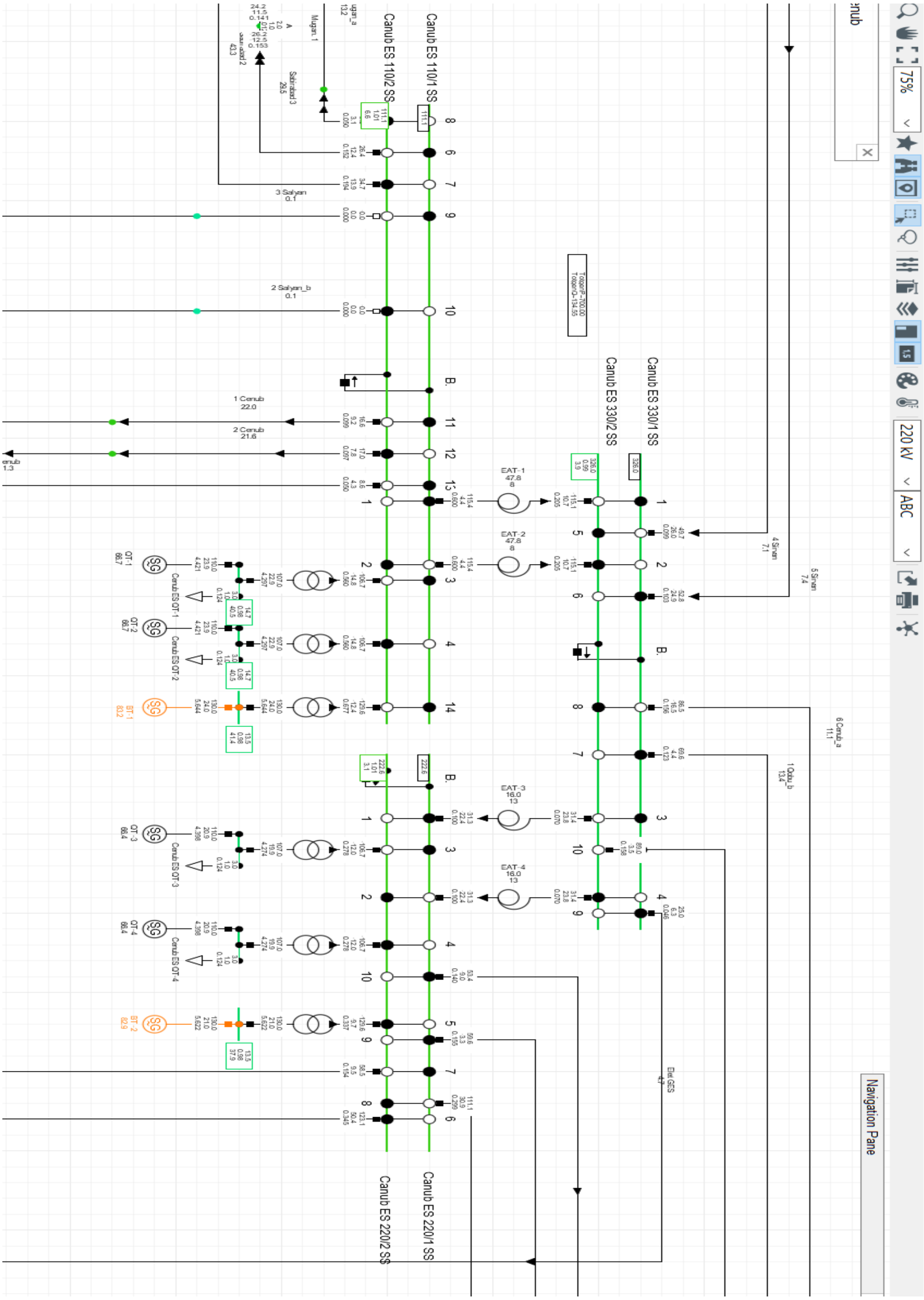


Figure 4.5 330/220/110 kV Janub Electrical Station, after integration of RES into the main grid.

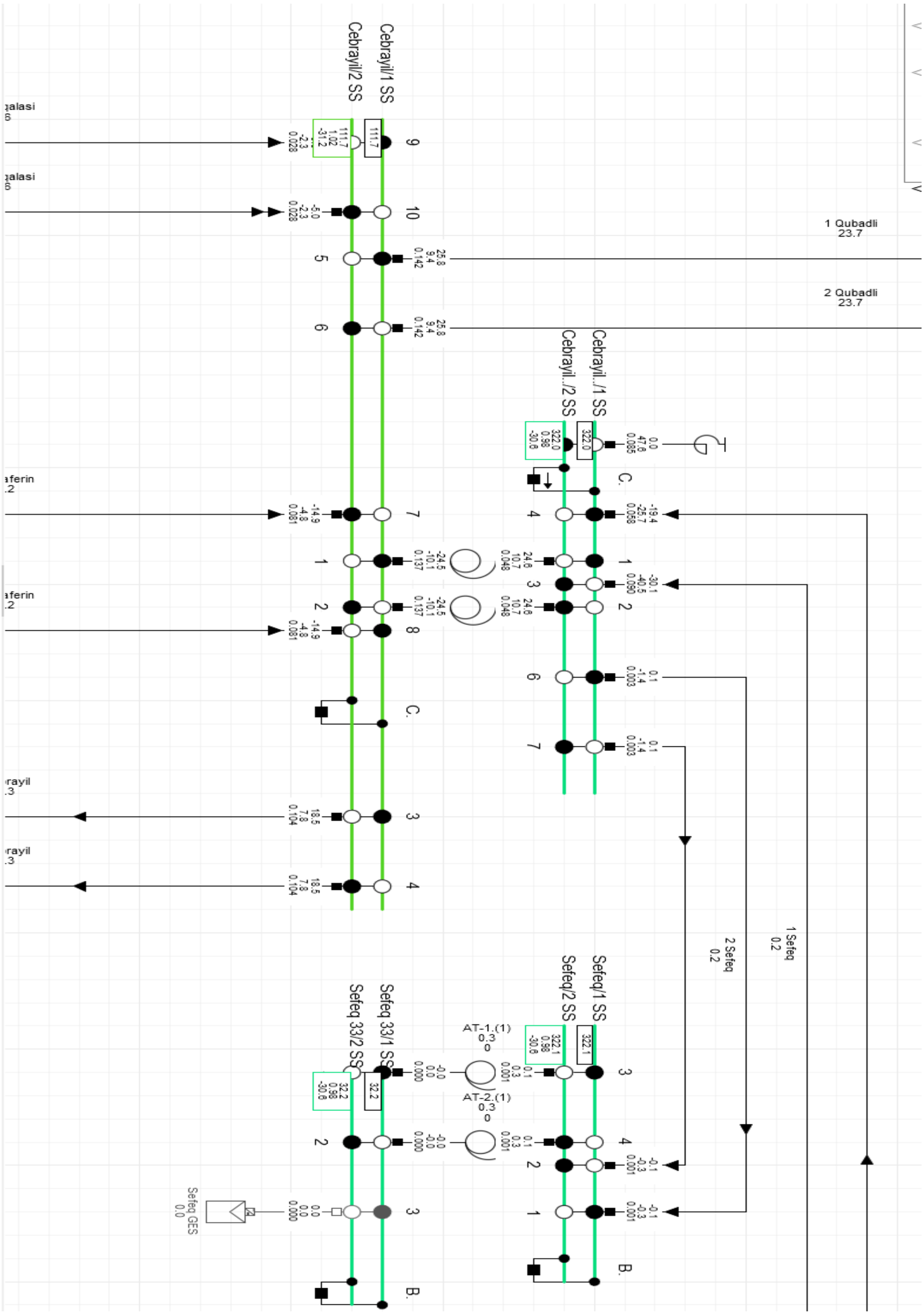


Figure 4.6 330/110 kV Jabrayil Sub-station, before integration of RES into the main grid.

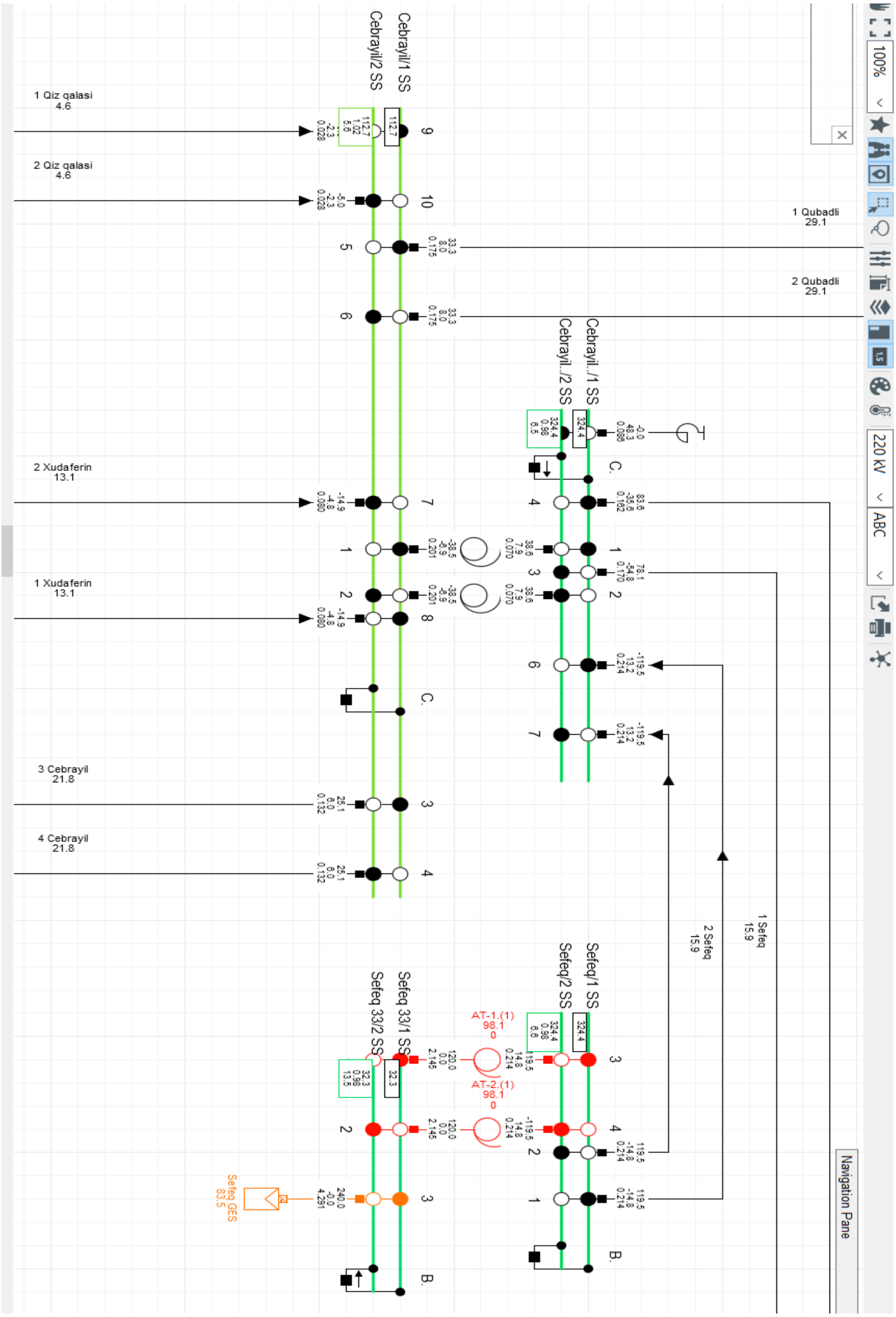


Figure 4.7 330/110 kV Jabrayil Sub-station, after integration of RES into the main grid.

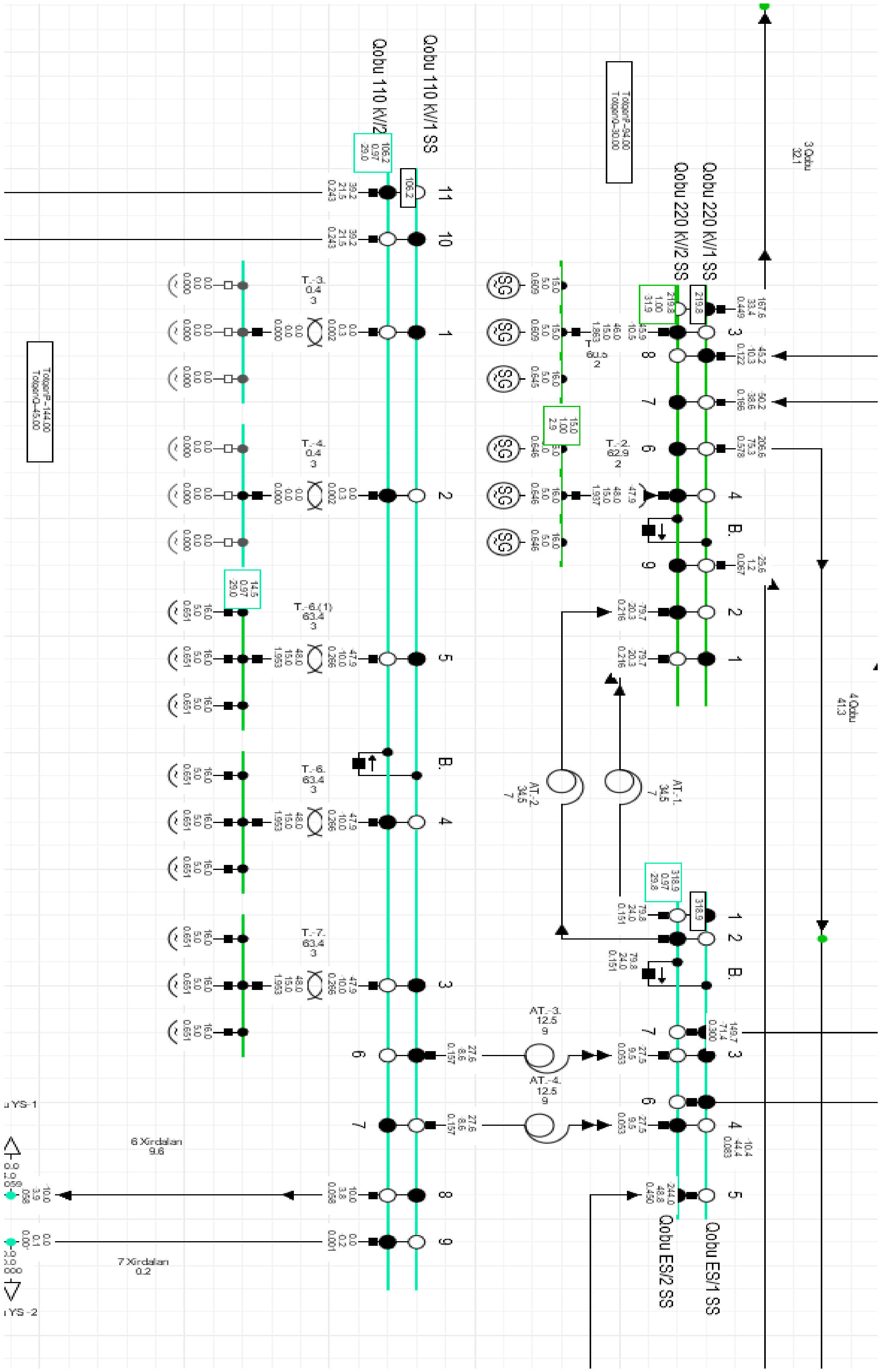


Figure 4.8 330/220/110 kV Qobu Power Plant, before intergration of RES into the main grid

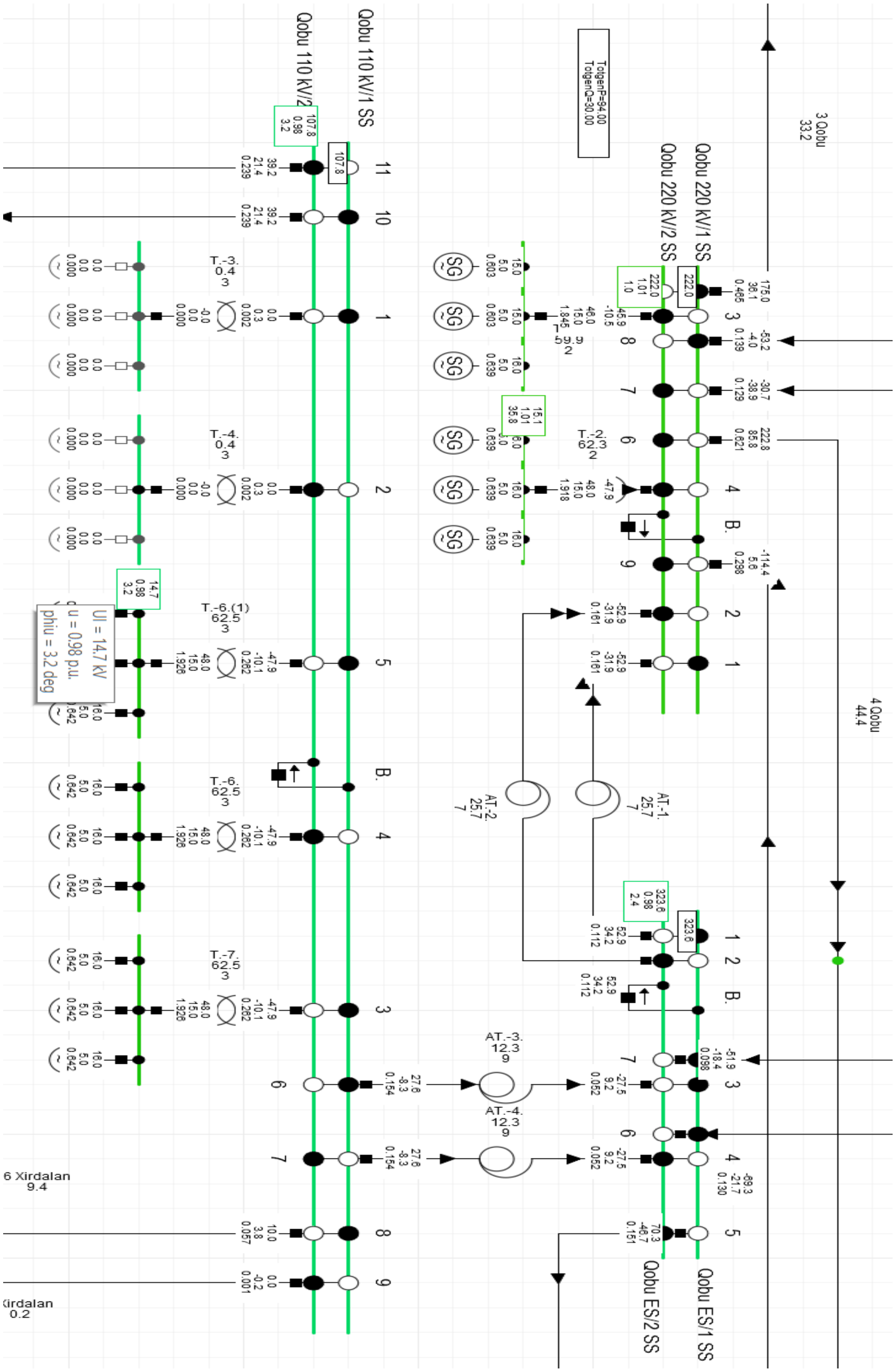


Figure 4.9 330/220/110 kV Qobu Power Plant, after intergration of RES into the main grid

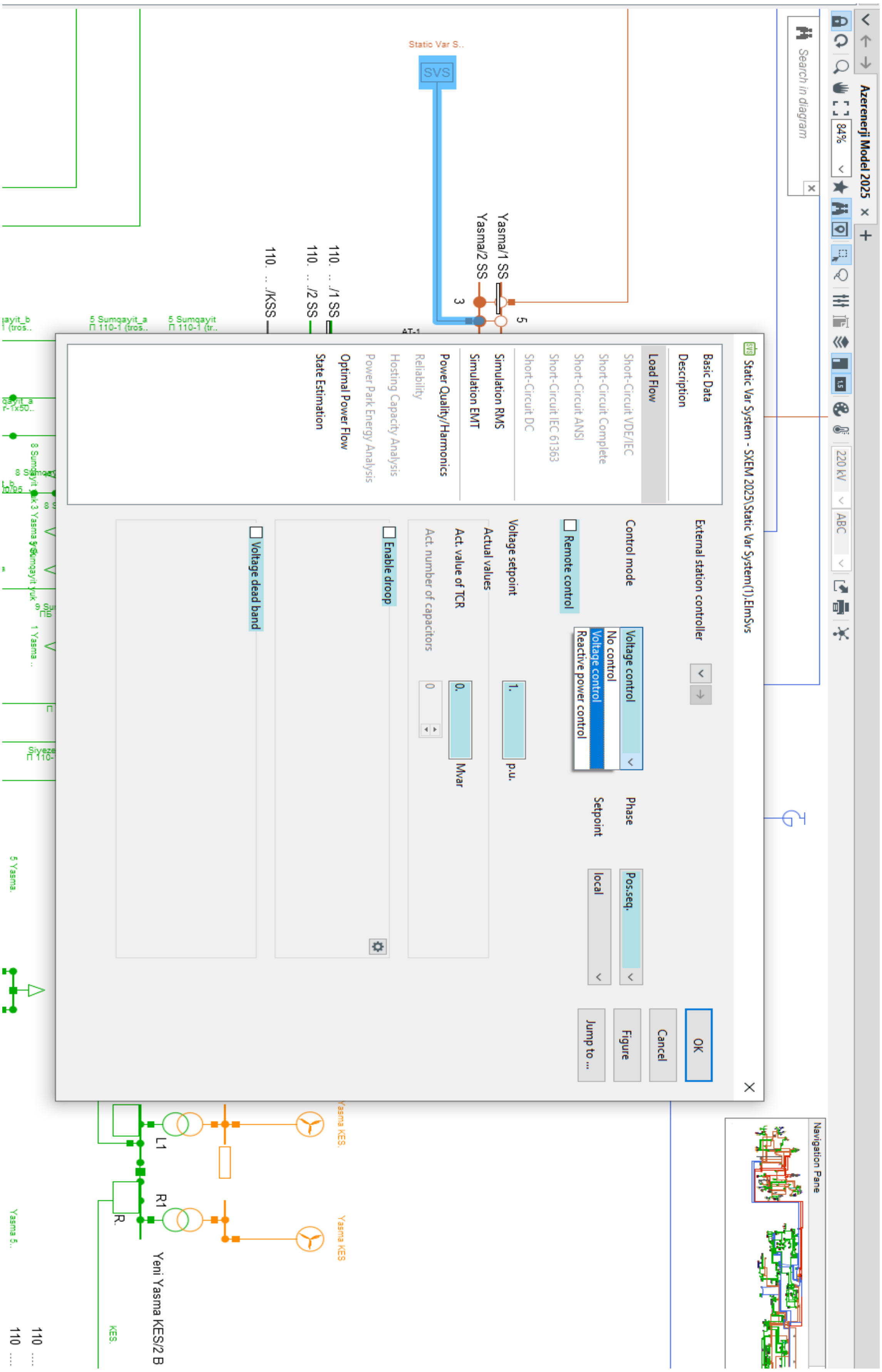


Figure 4.10 Static Var System in DIgSILENT Program

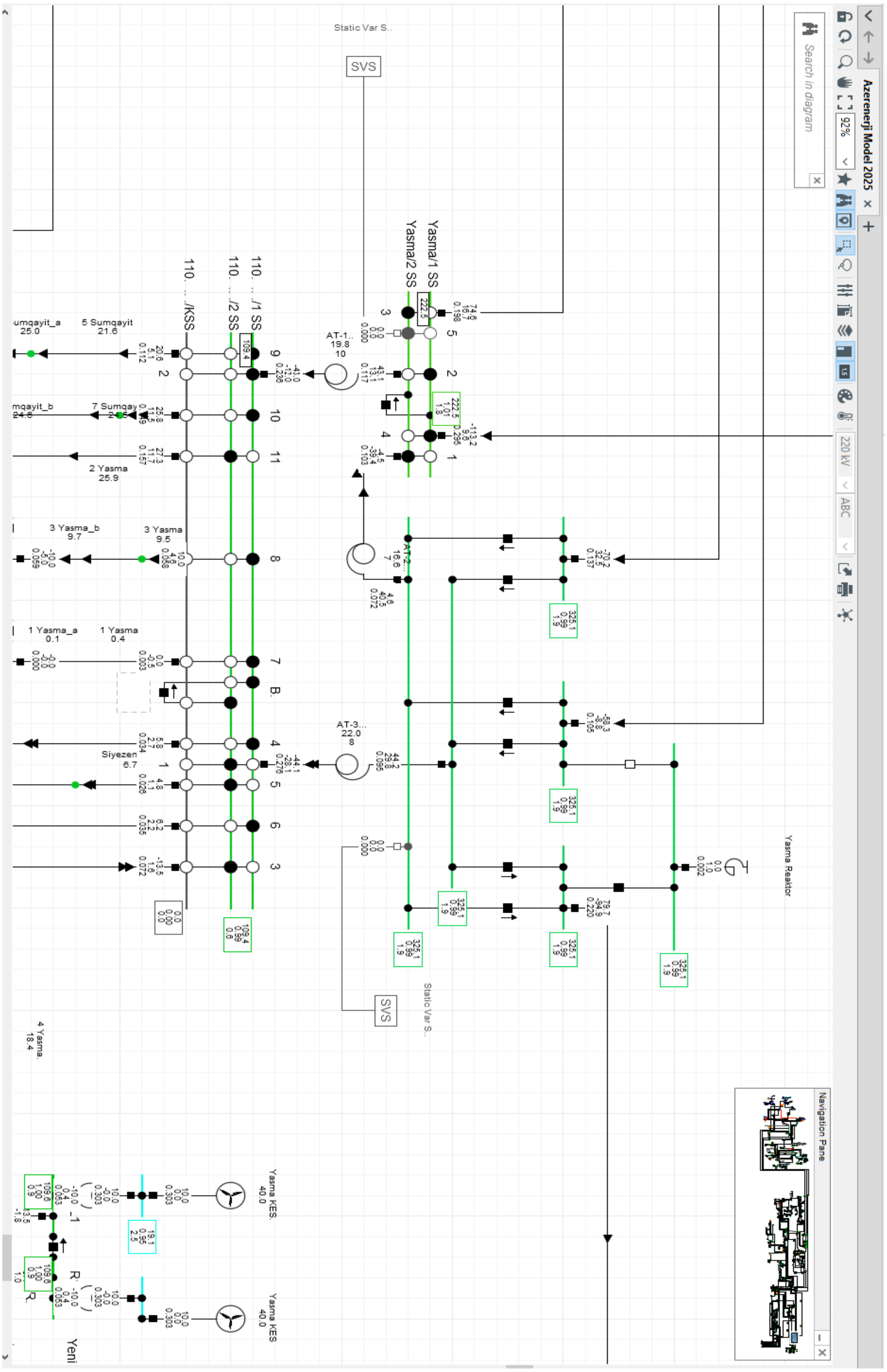


Figure 4.11 330/220/110 kV Yashma Sub-station, before intergration of RES into the main

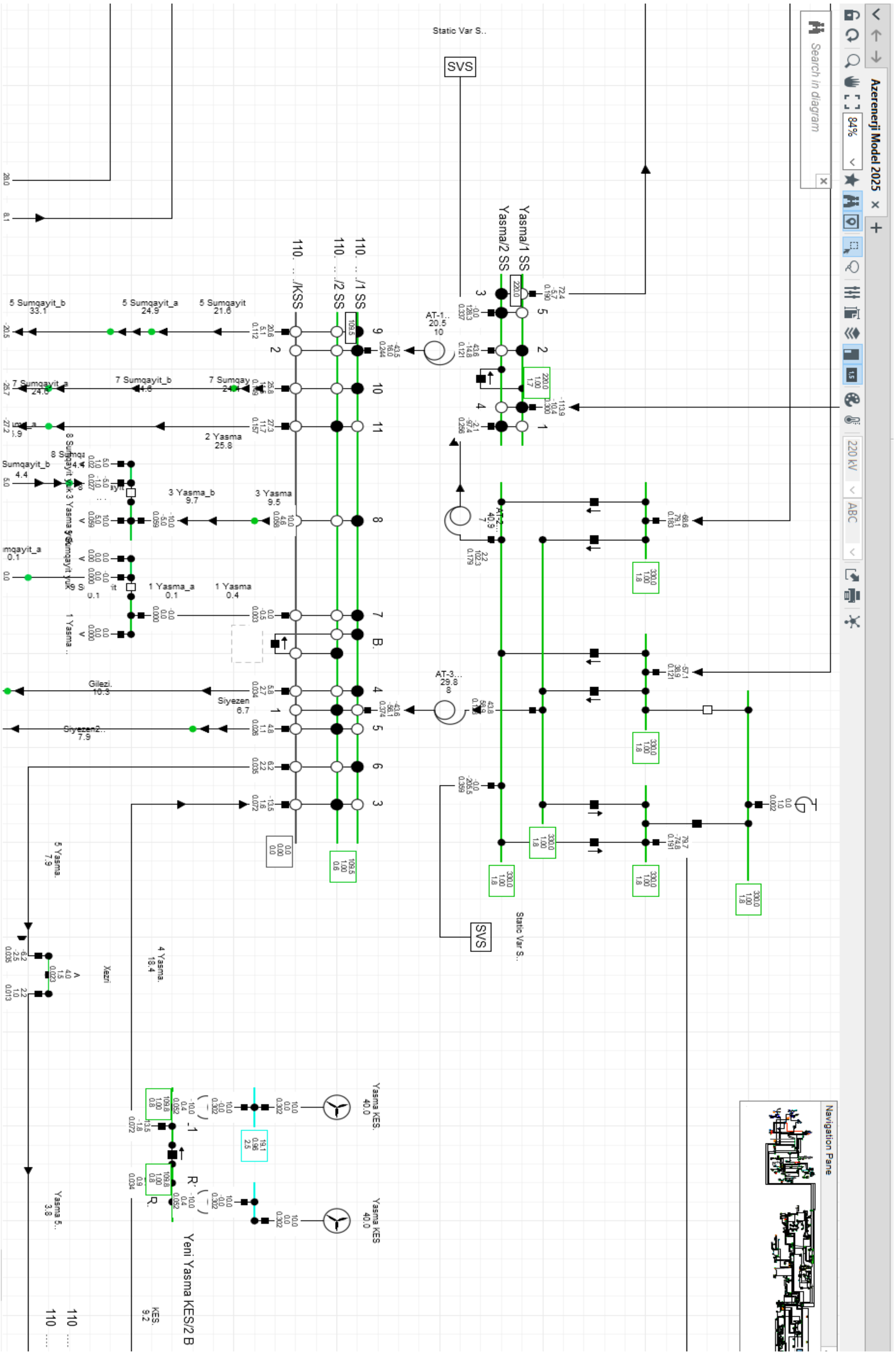


Figure 4.12 330/220/110 kV Yashma Sub-station, after intergration of RES into the main grid

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

5.1 Conclusion

As a conclusion, this research covers a case study of wind and solar energy sources. By using these sources, create distributed energy systems over the different parts of the grid. Before the operation, need to be well-informed about the main principles of distributed generation. The next, control action for system voltages and reactive energy in the power grid should be taken into account. Future vision for renewable energy sources and its positive, and negative impacts. In the end, real case simulation gives deep insights into understanding the main goal. Finally, distributed generation units influence more positive ways than negative into the main grid. Although a great amount of them reduce the power grid inertia factor, they are so friendly to the environment.

The outcome of this research is to integrate Static var system (STATCOM) devices in the DIgSILENT program for load flow analysis, and able to see the controlling of voltage and reactive power.

5.2 Future Work

After the integration of 730 MW renewable energy sources into Azerbaijan's energy grid, the system voltage control and system reactive power regulation issues arose over the energy system. For the next 30 years, electricity generation from RES will reach approximately 50 % of cthe overall generation of electricity. Electricity generation will be increase, and transmission losses will increase by using the same transmission lines too. For future vision, reduced power losses in transmission part of the energy system can be considered as one of the main problems. To solve this trouble, using high advance technology lines can be effective.

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