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ANALYSIS OF INTEGRATING 240 MW WIND POWER PLANT INT0 AZERBAIJAN POWER GRID

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ABSTRACT

Azerbaijan has consistently depended on traditional fossil fuels to provide its energy requirements over the course of its history. This is despite the fact that the country possesses massive oil and gas reserves. On the other hand, in view of the growing concerns that are being expressed on a global scale regarding climate change and the necessity of expanding energy supplies, the majority of governments all over the world are concentrating their attention on renewable energy sources (RES). Azerbaijan has also committed to fulfilling a large obligation to make a contribution to the mitigation of climate change and to incorporate thirty percent of its energy production into environmentally friendly energy sources. The aim of this study is to examine the necessary conditions that need to be fulfilled in order to integrate a 240megawatt wind power facility into Azerbaijan's electrical grid. This investigation makes use of technical network analysis in order to investigate operational voltage levels in relation to the connection of generation to the power system at the local point of interconnection (POI). A thorough investigation and evaluation will be carried out on the voltages and power flows that are present at the substations that are connected to the wind power facilities. The Short-Circuit Ratio, often known as the SCR, is an important quantity that is applied in the process of determining power system resilience and stability. One crucial factor to think about is the integration of alternative energy sources like solar plants and wind farms. An extensive examination will be conducted to determine the levels of SCR at both substations where the wind farms are connected.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
RES	Renewable Energy Sources
POI	Point of Interconnections
SCR	Short Circuit Ratio
IEA	International Energy Agency
ROCOF	Rate of Change of Frequency
PCC	Point of Common Coupling
WPP	Wind Power Plant
MW	Megawatts
PU	Per Unit
RMS	Root Mean Square
AC	Alternating Current
DC	Direct Current

CHAPTER 1

INTRODUCTION

In the context of the ongoing 21st century, characterized by significant global industrialization and quick developmental changes, there has been a notable surge in the demand for energy, exhibiting an approaching exponential growth pattern. The power systems and energy markets are currently experiencing a significant and rapid process of revolution. The rapid expansion of the global industrial and economic sectors has resulted in a notable scarcity of energy resources due to the overreliance on fossil fuels. Global power systems have been dominated throughout history by synchronized generation plants propelled by fossil fuels, which are accompanied by passive consumer loads. RES are receiving a lot of attention from governments around the globe as a result of rising environmental concerns and the diminishing supply of fossil fuels. An essential part of moving towards a sustainable future is the energy industry, where a paradigm shift is expected. To generate electricity, RES offers a practical alternative that may both meet the growing demand for energy and reduce negative impacts on the environment. The International Energy Agency (IEA) has made a projection that variable sources of renewable energy will comprise 57% of the worldwide energy demand by the year 2050 [1]. In 2014, Portugal fulfilled 30% of its electricity needs with a combination of renewable energy sources, excluding hydropower. Similarly, Spain's energy needs were met by renewable energy sources, accounting for 29% [2]. In 2015, greater than 20% of the demand in Ireland and Germany was met by intermittent energy sources, while renewable generation accounted for 24.5% of the demand in the United Kingdom. [3]. The annual penetration level of renewable production is commonly employed to quantify the amount of intermittent energy generated within a specific region or country on an annual basis. The penetration of instantaneous renewable energy during some periods of the day can reach levels that are up to five times greater than the average penetration over the course of a year. There is considerable global interest in the shift from conventional electricity generation methods to renewable energy sources across numerous countries. Nevertheless, it is important to note that no nation has made a formal commitment regarding this matter. The Paris Agreement was officially ratified with the active participation of 195 states. The Paris Agreement, a global accord addressing climate change, was formally approved on December 12, 2015, at the 21st Conference of the Parties (COP 21) in Paris, France, under the United Nations Framework Convention on Climate Change (UNFCCC). This event represented a noteworthy achievement in the worldwide endeavor to address and mitigate the impacts of climate change. The primary goal of the Paris Agreement is to effectively mitigate global warming by imposing a limitation on the increase in average global temperature to a level much below 2 degrees Celsius over the temperatures observed during the pre-industrial period. Additionally, the agreement aims to actively pursue endeavors that would restrict the temperature rise to a mere 1.5 degrees Celsius. This is widely recognized as a critical measure for mitigating the most severe consequences of climate change. In the given scenario, China's objective is to ensure that RES account for about 35 percent of the country's overall energy consumption by the year 2030 [4]. The Moroccan government has set a definitive objective of achieving a 52% installed capacity of renewable energy by the year 2030 [5]. India has set a goal to include 175 GW of renewable energy into its power grid by the year 2022 and a further 450 GW by 2030, in accordance with the commitments made under the Paris Agreement [6]. Azerbaijan exhibits a notable level of concern over this agreement and intends to augment the proportion of renewable energy sources in its overall energy production to 30 percent by the year 2030 [7]. Azerbaijan possesses significant potential in the realm of renewable resources. The presence of substantial oil and natural gas reserves within the country has resulted in a predominant reliance on natural gas for electricity generation, thereby diminishing enthusiasm for renewable energy sources. Nevertheless, the Azerbaijani government has initiated the implementation of its obligations by commencing the construction of a wind power plant with a capacity of 240 MW and a solar power plant with a capacity of 230 MW [7]. This thesis aims to study the crucial needs pertaining to the integration of a 240 MW wind power facility into the energy system of Azerbaijan. The intermittent nature of wind energy, like other types of renewable energy, can have significant negative effects on the power system. Furthermore, given the relatively limited scale of the Azerbaijani power grid, these aforementioned repercussions have the potential to result in more significant ramifications. In order to reduce the likelihood of negative outcomes and put protections in place, it is critical to conduct a thorough analysis of wind energy grid integration.

CHAPTER 2

LITERATURE REVIEW

Wind power's integration into existing power grids is an enormous step ahead in the drive for renewable and environmentally friendly energy. Academic and industrial interest has been significantly piqued in harnessing the potential of wind as a viable power generation option as the global demand for renewable energy increases. Nevertheless, this process of transition is not devoid of complexities and obstacles. This segment explores the extensive corpus of literature review that supports the integration of wind energy, scrutinizing the fundamental tenets, approaches, and crucial factors that mold this ever-evolving discipline. Bayindir et al. conducted a study that examined the integration of a 400 MW wind power system into the electrical grid of Turkey. The researchers observed that the Ferranti effect, which causes voltage levels to increase in long transmission lines, results in a difference between the generation capacity and demand at the bus to which the wind farm is linked [8]. This disparity is especially significant during periods of minimal wind contribution and maximum demand [8]. The study conducted by Ismail et al. aimed to evaluate the electrical grid's dynamic stability in Morocco after extensive use of renewable energy sources. According to the data, the electrical grid in Morocco is expected to experience a significant decrease in inertia constant in the next years due to the widespread use of renewable energy sources [9]. Aforementioned decrease disrupts the capacity to effectively control frequency in response to abrupt variations in load or generation [9]. Ahmad et al. conducted a study encompassing multiple scenarios inside the Jordan Power system [10]. These scenarios were designed to accurately represent grid conditions pertaining to load, including peak demand and low load, as well as conditions involving high penetration of renewable energy. Power Grid's reaction to an applied event and the subsequent observation of grid behavior are examined [10]. It was determined that the power system is marginally stable with the loss of a conventional generation unit [10]. In their study, Gayatri et al. investigated renewable energy impacts full converters on various measures of system stability, including the rate of change of frequency (ROCOF), with a specific focus on Kundur region in India [11]. It has been determined that the substitution of traditional sources with RES leads to a significant increase in the frequency distribution and a substantial decrease in the lowest point of the frequency curve [11]. The utilization of RES may result in the insecure functioning of the system in specific scenarios, whereas a synchronous system ensures secure and reliable operation [11]. In their study, Haluk et al. conducted a thorough analysis of Turkey's capacity for renewable energy and investigated the challenges related to the integration issue in Turkey's electric energy grid [12]. The findings of their research indicated that the increased integration of wind energy into the power grid results in voltage fluctuations and stability concerns [12]. This is mostly attributed to the limited capability of wind turbines equipped with asynchronous generators to supply reactive power. Consequently, this places additional stress on grid components and has the potential to impact the accuracy of the power system [12]. The study conducted by Yan et al. examined the operational features and control methodologies of expansive wind energy installations, with a focus on addressing the unique challenges associated with integrating this centralized wind energy infrastructure on a large scale into Northwest and North China power networks [13]. The study specifically identified the challenges posed by wind energy integration into the electrical grid, including issues related to voltage, frequency, and stability, as well as their respective magnitudes [13]. Haiyan et al. conducted a study aimed at developing a scientifically sound and rational scenario system for the future growth of the power grid, with a specific focus on including a large part of renewable energy sources, using the China power system as a reference [14]. The increasing impact of renewable energy on power systems is emphasized, highlighting the need for sophisticated simulation techniques [14]. It strongly recommends that output plans be optimized in order to increase both consumption and reliability. Furthermore, the paper underscores the critical significance of conducting additional research in power grid morphology and associated technologies in order to guarantee a sustainable and resilient energy future [14]. Lima et al. did research on the effects of wind power on the electricity market for the Iberian Peninsula [15]. The study described above utilizes historical data spanning from 2008 to 2016 in order to provide a projection. The findings of this study revealed that significant challenges arise inside the power system when accurate wind power output estimates cannot be generated [15]. Fleury et al. examined wind power integration in the Brazilian power system, emphasizing the importance of unit generator controls in system performance, stability, and voltage/frequency regulation and addressing the challenges of integrating renewable energy sources with traditional generation methods [16]. It has been discovered that proper planning and regulation are critical for successful wind power integration into the electrical system, ensuring stability and reliability [16]. Moreover, given the growing presence of renewable energy, it is crucial to make ongoing efforts to enhance forecasting accuracy, optimize system performance, and ensure adherence to grid regulations [16]. Shafiullah conducted a study to investigate the possible adverse effects of incorporating high penetration of renewable energy, like wind and solar, to the high-voltage power system in Rockhampton, Queensland, Australia [17]. The analysis revealed a substantial rise in voltage harmonic distortion levels at all points as the incorporation of sources of clean energy increased. This emphasizes the influence that RES has on power quality [17]. The study conducted by Molina et al. examines the effects of several future development scenarios on the power matrix in Chile, with a specific emphasis on the technological advancements made by renewable energy sources [18]. The main barriers to incorporating renewable energy into the Chilean power system, as delineated in the scholarly article, encompass the imperative for significant financial resources to enhance the transmission infrastructure in order to accommodate the enhanced capacity of renewables [18]. Additionally, there is a requirement to find a balance between immediate cost reductions and enduring investments, particularly in light of the intermittent nature of renewable energy sources and the possibility of relying on fossil fuels in case of emergency [18]. Duan et al. applied Monte Carlo simulation and the Weibull Distribution Function to examine the effects of renewable energy to the transmission network while simultaneously evaluating its effects on the reliability and capacity of the network [19]. The findings of the analysis indicate that the involvement of wind power significantly affects the sufficiency of transmission lines, highlighting the necessity for a thorough assessment and the potential enhancement of transmission capacity as the penetration of wind power increases [19]. This study highlights the importance of taking into account the influence of wind turbines on the transmission network to ensure a reliable power system [19]. The research undertaken by Vasco et al. investigates the impact of forecast precision on the incorporation of significant proportions of RES in a power grid. More precisely, the authors concentrate on the production of electricity from RES that are subject to fluctuations, such as wind and solar. The study evaluates the efficiency of integrating and controlling the required reserves in relation to forecast accuracy [20]. The primary issues encompass the imperative for heightened operational adaptability in order to effectively manage the fluctuating generation of renewable energy sources [20]. Additionally, it is crucial to secure a sufficient provision of control reserves to effectively navigate risks while also optimizing the utilization of energy storage systems [20]. Furthermore, the precise prediction of renewable energy source generation is of utmost importance in order to minimize potential disturbances and enhance the efficiency of RES integration [20].

Katrin et al. examined how renewables, particularly wind energy, affects stability and quality of power grid by analyzing renewable energy fluctuations on short-term timescales where conventional load balancing mechanisms are ineffective [21]. The research confronts various issues pertaining to the modeling and simulation of intricate interconnections within power grids while considering the intermittent and non-Gaussian characteristics of wind power oscillations [21]. This research aims to examine the necessity of comprehending the impact of fluctuations on grid stability, specifically focusing on temporal correlations and intermittent increments. Furthermore, the research investigates the ramifications pertaining to frequency and voltage quality, which are fundamental components of power system evaluation [21]. Li et al. concentrated their investigation on studying the effects of using energy obtained from renewable sources, notably wind and photovoltaic electricity, on the stability and reliability of electrical networks. The technical requirements related to the integration of power systems are thoroughly examined by the authors [22]. It found a reduction in system inertia, which had an effect on frequency stability, and it highlighted the requirement for voltage resilience in wind turbines in order to prevent disconnections and guarantee grid stability, particularly in large-scale renewable energy installations [22]. These findings highlighted the necessity for substantial grid code updates in order to handle the ever-changing landscape of the integration of renewable energy sources [22]. Furthermore, the report extensively cited grid codes and technical laws from several countries and regions, demonstrating a comprehensive examination of established norms within the sector [22].

CHAPTER 3

CHALLENGES OF THE GRID

3.1 Spinning reserve and unit commitment

Large fluctuations in the amount of electricity generated at any given time and a lack of assurance of energy resource forecasts are characteristics of intermittent power generation. Production scheduling issues, higher unpredictability, and faster ramp-up/down rates might arise from high levels of intermittent generating penetration [23]. As a result, the operator of the power system may be required to maintain a higher level of generation reserve to ensure the system's security. Brouwer et al.'s analysis found that the demand for primary reserves increases when wind power is included in the energy mix, after the percentage of green energy integration reaches at least 30% [24]. Approximately 0.3–1.0% increase to the whole installed wind capacity to produce is what this increase is predicted to be [24]. Furthermore, the magnitude of this increase becomes more significant as the levels of intermittent generation penetration continue to rise. The unit commitment process involves making decisions on the activation, deactivation, and operation levels of power-generating units in order to meet projected energy demand at the most economical rate while also adhering to various operational limitations. The complexity of unit commitment processes is growing due to the increasing integration of renewable energy sources. Executing the Principle of Ohm's law, it learned that better forecasting methods, flexible operation of conventional power plants, and optimal exploitation of energy storage technologies are essential for properly managing the unpredictable characteristics of green energy production and variations in demand.

3.2 Transmission congestion

Higher intermittent generation levels affect power transmission lines, increasing the likelihood of transmission line temperature limitations being exceeded, particularly in places with a high concentration of intermittent energy sources [25]. Traditional power plants are strategically located in areas with strong demand, resulting in their proximity to high-capacity transmission lines. Renewable energy power facilities have the potential to be strategically located in various places based on the currently available wind and solar conditions. Due to this rationale, these power plants are frequently integrated with the network's vulnerable parts. Therefore, one of the most crucial requirements for grid integration is to conduct a power flow analysis of renewable resources.

3.3 Grid security

Power grid security pertains to the capacity of a power system to withstand and overcome any probable system contingencies, ensuring uninterrupted supply to customers [26]. A particular type of reliability criterion utilized in the operation and planning of power systems is referred to as the N-1 contingency. In accordance with the N-1 contingency criteria, a power system ought to maintain safe and dependable operation in the event that an unforeseen failure of a critical component, such as a transmission line, occurs. Therefore, it is imperative to conduct steady-state and transient analyses of the network while integrating renewable resources.

3.4 Grid stability

Power system stability is an important part of any power system. More study needs to be done to come up with the best ways to keep the stability of the power system from going down as the number of inverter-connected intermittent generators grows. Although power generation derived from RES experiences growth, there is a corresponding increase in the installed power converter capacity. The growth of RES capacity might result in adverse effects on the grid connectivity of RES, particularly during instances of faults or disturbances. Consequently, in the event of a malfunction occurring in the grid power system, the Point of Common Coupling (PCC) will be activated, causing the RES to disconnect from the grid and operate independently over a significant geographical area [27]. The aforementioned faults have significant consequences for the voltage and frequency of the grid, compromising its safe, stable, and reliable functioning [27]. The power system's frequency remains at the designated nominal value solely when there is a balance between the active power generated and the active power demanded. The ability of a power system to maintain a constant frequency during regular operation and the ability to return the frequency to its nominal level in the event of a system contingency resulting in a significant load and generating an imbalance are known as frequency stability. Inertia is a consequence of the kinetic energy that is stored in the rotor of the rotating machinery that comprises the power system. Demand generation imbalances are regulated in frequency by the power system's inertia. Large-scale synchronous generators are typically utilized in the conventional process of producing electrical energy; hence, these generators have a significant moment of inertia. When faults or disruptions occur in networks with high inertia moments, the kinetic energy stored in the rotors of the generators quickly responds, helping to maintain the system's steady state. The ROCOF is linked to the level of inertia inside the system. Inertia plays a role in decelerating the initial frequency deviation, a phenomenon referred to as the inertial frequency response [28]. Due to the static nature and lack of rotational energy (i.e., negligible inertia) of power electronic inverters that connect renewable energy sources to the power grid, high penetration levels of inverter-connected generation decrease the inertia of the power grid. As a result, frequency regulation is most challenging during periods when the power network is connected to a limited number of synchronous generators, intermittent generation outputs are high, and the overall power system has low inertia [29]. In order to qualify as stable with regard to voltage stability, a system must possess the capability to sustain constant voltages across all of its buses within the designated operating range, irrespective of occurrences of abnormal or normal operation [30]. The system should possess the capability to simultaneously regulate voltage and power in response to abrupt variations in system loading. Dynamic studies are commonly used to analyze voltage instability, although steady-state studies are often utilized for deterministic load systems to calculate the gap between the operating point and the P-V curve knee point for voltage stability margins [31]. Furthermore, it is imperative for every power system to uphold a steady state in order to ensure that the generators of the system remain in synchronization even when slight fluctuations in system demand occur.

3.5 Grid strength

System impedance, which includes generators, transformers, transmission lines, and loads, and the collective inertia provided by all rotating machinery inside the system, are two fundamental characteristics that define the strength of a power system [32]. A system with low system inertia and high system impedance is evidence of a weak system, which consequently leads to a decreased capacity to sustain stable frequency and stabilize voltage fluctuations. Generators that are connected to the grid by inverters that follow the grid do not add to the strength of the system;

rather, their cumulative effect is to weaken it. The analysis of power system strength at interconnection points with inverters connected to generation is commonly conducted using SCR methodologies. In this context, a power system with a short-circuit ratio below 3 is generally regarded as weak [33]. Short circuit ratios greater than 3 indicate that a power grid is sufficiently strong to limit fluctuations in frequency and voltage after an event has occurred [33].

3.6 Harmonics

The integration of renewable energy into the system may lead to the rise of harmonic problems. Power electronic converters are commonly employed by wind turbines and solar inverters to convert their generated electricity into a suitable format for integration into the electrical grid. These converters can create harmonics that distort the electrical waveform. Harmonics are the whole number of multiples of the fundamental frequency, such as 50 or 60 Hz, that exist within the electrical system. The presence of harmonics in substantial quantities can give rise to several concerns, such as greater power losses in systems, disruption of sensitive electronic devices, and deterioration of power quality.

3.7 Reactive power support

It is necessary to maintain a constant voltage within a small range in a power system to ensure safety and protect utility and consumer equipment that is designed to function at specified voltage levels. Wind farms are now obligated to participate in system voltage management, just like traditional power plants, due to recent modifications in national grid regulations. In order to meet the utility's requirements, the device must have the capability to either produce or consume reactive power, which will then affect the voltage level at the POI and the surrounding area. Under typical conditions, the POI voltage can be raised by feeding reactive power into the grid or lowered by drawing reactive power out of it. Supporting the network during voltage changes and helping to balance the grid's reactive power needs are two reasons why wind farms need reactive power capabilities.

CHAPTER 4

GRID OVERVIEW

4.1 Overview of Azerbaijan power grid

Throughout its history, Azerbaijan has relied on traditional fossil fuels to fulfill its energy needs. This is despite the fact that the country possesses an abundance of oil and gas resources. Azerbaijan's abundant energy resources enable it to export electricity to neighboring countries, thereby enhancing regional energy stability. Azerbaijan's power grid infrastructure has undergone consistent enhancements to accommodate the growing energy requirements. This comprises the construction of new power plants, improving existing facilities, and expanding transmission and distribution networks. However, in light of growing international concerns about global warming and the requirement to expand energy supplies, Azerbaijan has realized the inherent possibilities of green energy and has begun an effort to incorporate it into its current power infrastructure. This is in response to the fact that global warming is a growing concern on a global scale. The entire capacity of Azerbaijan's power generation is 7227 MW [34]. Within this capability, hydroelectric facilities account for 1158 MW, wind, solar, and other renewable resources account for 135 MW, and power plants running on natural gas account for the remaining capacity [34]. The technological potential of renewable energy sources in Azerbaijan's onshore areas is estimated to be 135 GW, while the offshore areas have a potential of 157 GW [35]. It is predicted that renewable energy sources have a total economic potential of 27 GW, with wind energy contributing 3,000 MW, solar energy contributing 23,000 MW, biofuel contributing 380 MW, and mountain rivers contributing 520 MW [35]. Attempts have been undertaken to update the power grid infrastructure, enhance energy efficiency, and include renewable energy sources into the grid. This encompasses efforts for developing solar and wind energy initiatives. The Azerbaijani government initiated two significant renewable projects in order to effectively harness the considerable energy resources at hand. This study will primarily examine the integration of 240 MW of wind energy into the power system of Azerbaijan, encompassing a thorough analysis of the process. Studies should encompass not only the electrical performance of the connection, but also an examination of alternative connections, the ability to integrate at the connection point, the capacity of local network substations to handle the generated energy, and the adherence of the connection and plant to the operational standards mandated by the system operator. The extraction of wind energy must be both feasible and safe, while also adhering to the operational standards of the network throughout the facility's lifespan.

4.2 Overview of 240 MW wind power plant

Two wind farms with a total capacity of 240 megawatts will be included in the project, which will be located in the Absheron and Khizi regions of the country. The two wind farms will be built in Azerbaijan, around 28 and 45 kilometers north of Baku. They will connect to the electricity grid via the substations Pirekeshkul and Khizi. The substations will use four transformers—two 35 MVA in Pirekeshkul and two 100 MVA in Khizi—to transform the power from the windfarms' 33 kV circuits to the 220 kV level. Three new 220 kV overhead transmission lines connect these two substations to one another and to the grid substations of Gobu and Yashma (originating in Pirekeshkul and Khizi, respectively). The combined generating capacity of the two plants, Pirekeshkul, with 12 generators totaling 62.4 MW, and Khizi, with 35 generators totaling 182 MW, will be 244.4 MW. Each wind turbine is connected to a transformer that converts the generated voltage from 900 V to 33 kV. These transformers are then linked to common 33 kV buses. In Khizi, there are two transformers rated at 100 MVA, and in Prekishkul, there are two 35

MVA transformer connected to these buses. A general single-line diagram for both Wind Power Plant is shown in Figure 4.1.

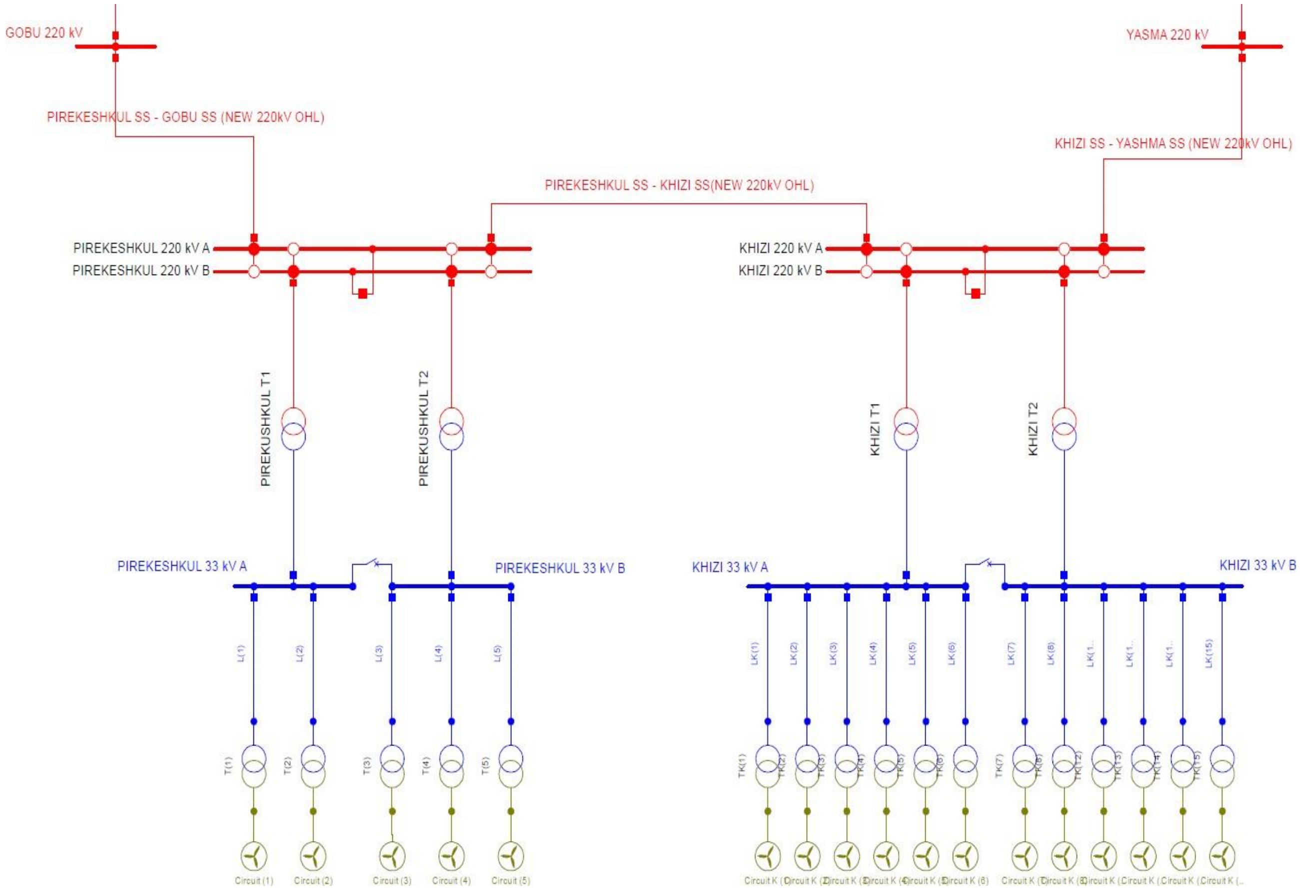


Figure 4.1 Simplified single line diagram of wind farms.

Note that the turbines (depicted in yellow) are just illustrative; in actuality, a daisy chain configuration can include up to three connected turbines per circuit.

4.3 Parameters of 240 MW wind power plant

The following tables outline the equipment parameters used in windfarm modeling:

Table 4.1 Generator parameters

Type	Pmax (MW)	Pmin (MW)	Qmax (MVAr)	Qmin (MVAr)	MBase (MVA)	Vout	PF	Number
Goldwind GW165-5.2	5.2	0	+2.51	-2.51	5.86	900	0.9	47

Table 4.2 MV transformer parameters

Rated Power (MVA)	Primary winding(kV)	Secondary winding(kV)	Reactance X (%)	Vector group	Number
5.8	33	0.9	8	Dyn11	47

Table 4.3 HV transformer parameters

Sub station	Rated Power (MVA)-ONAN/ ONAF	Primary winding (kV)	Secondary winding (kV)	Reactance X(%)	X/R Ratio	Vector Group	Number of Transformer Taps	Additional Voltage per Tap	Transformer Neutral Tap Position
Khizi	80/100	33	220	12.5	45	Ynd11	21	1.25%	11
Pirekeshkul	28/35	33	220	12.5	45	Ynd11	21	1.25%	11

Table 4.4 OHL parameters

HV OHL	Z (Ω)	R (Ω)	X (Ω)	B(mS)	Rate(MVA)
Yashma-Khizi	12.431	1.8	12.3	81.3	350
Gobu-Pirekeshkul	14.502	2.1	14.35	69.6	350
Pirekeshkul-Khizi	10.359	1.5	10.25	97.5	350

Table 4.5 MV cable parameters

MV Cable	R (Ω/km)	X (Ω/km)	B (mS/km)	R0 (Ω/km)	X0 (Ω/km)	B0 (mS/km)
3x1x95 mm2	0.40	0.20	77.00	0.56	2.25	70.06
3x1x240 mm2	0.15	0.19	96.00	0.32	2.26	96.80
3x1x400 mm2	0.09	0.17	121.00	0.26	2.24	121.00
3x1x630 mm2	0.06	0.15	140.00	0.24	2.23	140.50

CHAPTER 5

METHODOLOGY

5.1 Research strategy

This chapter will provide a full description of the research that will be conducted. This covers the purpose of the study as well as its approach and strategy. The research strategy adopted here will be quantitative, with the goal of providing numerical explanations for observed events. Azerenergy provided the maximum, average, and minimum demand levels for the country in 2022, which were used in this study across all of the methods described below. The annual minimum, average, and maximum demand levels for the whole country are 4033 MW, 3485 MW, and 1867 MW, correspondingly. This study utilizes technical network analysis to examine system restrictions, including transmission line congestion, operational voltage levels, and compliance with reactive power, in relation to the connection of generation to the power system at the POI. The 240 MW injection will have an impact not just on the connected substations but also on the functioning of the zonal transmission network. Due to time constraints, only connected substations were the focus. All analyses shall be conducted utilizing the PSS/E software, which simulates power systems.

5.2 Power flow analysis

Initially, a study of power flow will be conducted to evaluate the medium and maximum operational conditions of the grid. Subsequently, the voltages and power flows at the substations where the wind power plants connect will be examined and analyzed. It is critical to solve the set of non-linear equations in power flow analysis. In power flow analysis, the Gauss-Seidel method, an iterative numerical technique, is widely used to solve nonlinear systems of equations. The formulas for voltage, active power, and reactive power in the Gauss-Seidel method are given as follows:

$$V_i^{[k+1]} = \frac{\dfrac{P_i^{[sch]} - jQ_i^{[sch]}}{V_i^{*[k]}} - \sum\limits_{j=1, j\neq i}^{n} Y_{ij} V_j^{[k]}}{Y_{ii}} \qquad (5.1)$$

$$P_i^{[k+1]} = \Re\left\{ V_i^{*[k]} \left[V_i^{[k]} Y_{ii} + \sum_{\substack{j=1 \\ j\neq i}}^{n} Y_{ij} V_j^{[k]} \right] \right\} \qquad (5.2)$$

$$Q_i^{[k+1]} = -\Im\left\{ V_i^{*[k]} \left[V_i^{[k]} Y_{ii} + \sum_{\substack{j=1 \\ j\neq i}}^{n} Y_{ij} V_j^{[k]} \right] \right\} \qquad (5.3)$$

P_i^{sch} -is net real power

Q_i^{sch} -is net reactive power

Y- is common bus admittance matrix

P_i^{sch} and Q_i^{sch} have positive values for generator buses and negative values for load buses.

In order to determine the voltages, active power, and reactive power for any specific bus, it is necessary to compute the Y admittance matrix. A simplified diagram is necessary to facilitate comprehension, encompassing both the power plant and the substations that connect them to the grid. Additionally, it simplifies the computation of the Y admittance matrix. The diagram illustrates the identification of three buses, namely bus number 1 denoted as Khizi, bus number 2 as Pirekeshkul, and bus number 3 as common grid bus. Given our knowledge of the impedance of every transmission line, it is straightforward to convert it to admittance.

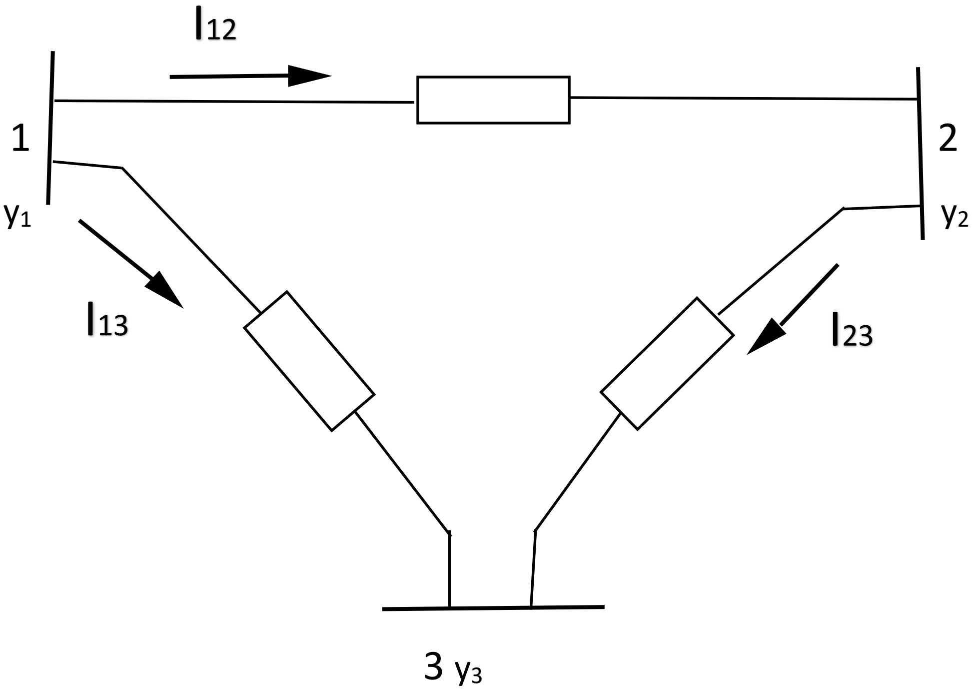


Figure 5.1 Admittance diagram

From this it needs to be find admittance matrix. The KCL equation will be applied to determine the admittance matrix.

$$I_1 = y_{12}(V_1 - V_2) + y_{13}(V_1 - V_3)$$

$$I_2 = -y_{12}(V_1 - V_2) + y_{23}(V_1 - V_3) \qquad (5.4)$$

$$I_3 = -y_{13}(V_1 - V_3) - y_{23}(V_2 - V_3)$$

By applying Ohm's laws, we obtained:

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} y_{12} + y_{13} & -y12 & -y_{13} \\ -y_{12} & y_{12} + y_{23} & -y_{23} \\ -y_{13} & -y_{23} & y_{13} + y_{23} \end{bmatrix} * \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \tag{5.5}$$

$$Y_{bus} = \begin{bmatrix} y_{12} + y_{13} & -y_{12} & -y_{13} \\ -y_{12} & y_{12} + y_{23} & -y_{23} \\ -y_{13} & -y_{23} & y_{13} + y_{23} \end{bmatrix} \tag{5.6}$$

Once the bus admittance matrix has been obtained, it is necessary to convert these values to per-unit (p.u.) values, along with other grid elements. The actual and reactive power of load buses are known. The estimation of voltage magnitude and phase angle is necessary. This estimation is commonly referred to as a "flat start" approach. The initial condition for the nominal voltage magnitude is assumed to be 1 p.u. with a phase angle of 0 degrees. The Gauss-Seidel method iteratively updates the voltage magnitudes and phase angles until convergence criteria are satisfied. During each iteration, the power flow equations are used to update the voltage magnitudes and phase angles for each bus. These revised values are then iteratively employed. The evaluation of convergence involves the examination of alterations in bus voltages over consecutive iterations, and this assessment persists until the observed changes reach a predetermined tolerance level. The obtained magnitudes and phase angles of the bus voltages represent the steady-state solution for the power system.

5.3 System strength analysis

Evaluation of system strength is a critical aspect of the WPP integration process, and this strength is frequently assessed using the SCR. In cases where the wind farm is located far from load centers, the grid near the wind farm will be weak, implying that the minimum short-circuit MVA is low; that is, a fault on the grid far from the wind farm interconnection point does not significantly increase the short-circuit current at the wind farm interconnection point. Because the short-circuit current is not noticeably larger during the fault, the switchgear will have a more difficult time detecting the problem, and the wind farm will remain connected to the grid, posing a safety risk. This analysis will primarily examine the occurrence of a 3-phase failure at the minimum load level of the network. This choice is based on the fact that, at the minimum load level, the network exhibits significantly reduced system inertia and increased impedance. The calculation of wind power plant SCR is determined by dividing the short circuit power at the fault location by the rated power of the wind power plant. To effectively conduct both studies, it is imperative to initially create the equivalent impedance circuit. Figure 3 shows that the impedance between Khizi and the grid is represented by the Z1 value, the impedance between Khizi and Pirekeskhul is represented by the Z3 value, and the impedance between Pirekeskul and the grid is represented by the Z2 value.

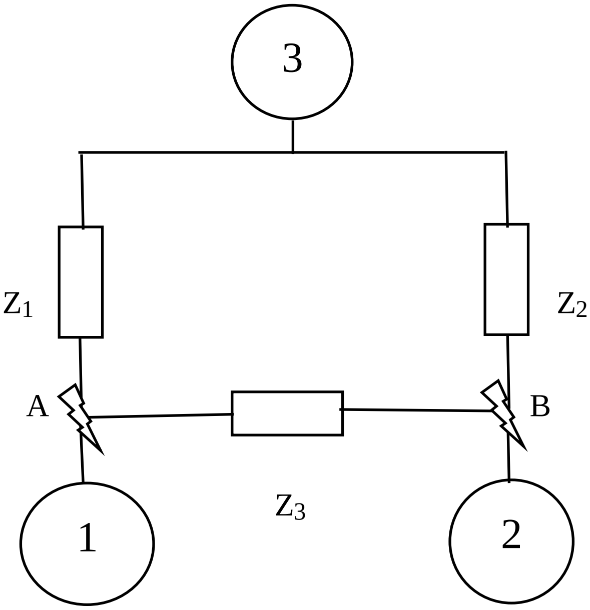


Figure 5.2 Equivalent impedance diagram.

In order to proceed with this study, it is important to compute the total impedance by taking into consideration the precise position of the fault. The determination of the total impedance with respect to points A and B occurs following to the application of impedance combination rules.

$$Z_{T-A} = \frac{(Z_2 + Z_3) * Z_1}{Z_2 + Z_3 + Z_1}, \; Z_{T-B} = \frac{(Z_1 + Z_3) * Z_2}{Z_1 + Z_3 + Z_2} \qquad (5.7)$$

The equation used for calculating short circuit current is as follows:

$$I_{sc} = \frac{V}{Z_T} \qquad (5.8)$$

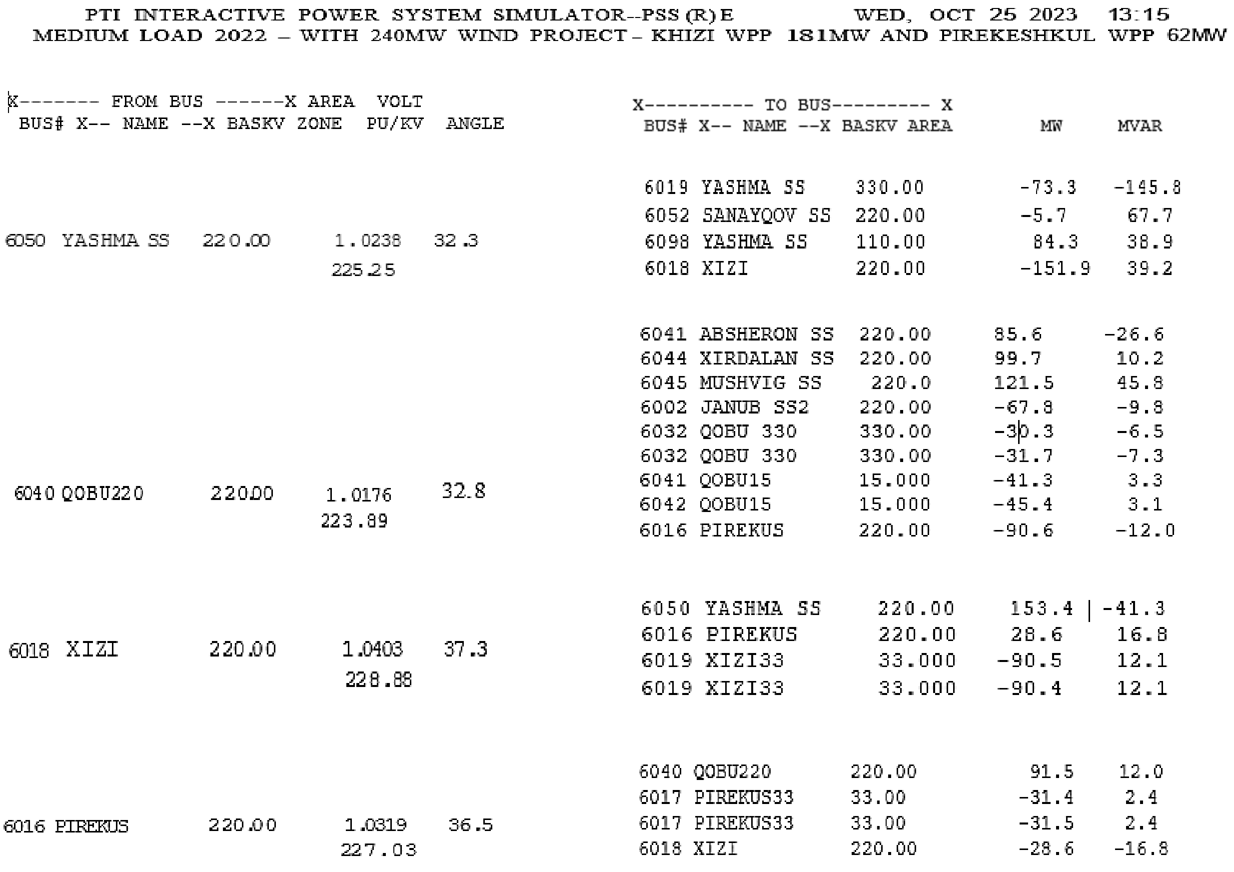
The SC MVA value is determined by multiplying the voltage value with the 3-phase fault current derived based on the minimum level of the network.

CHAPTER 6

SIMULATION RESULTS

The following result obtained from the power flow study, which simulates the grid's medium load conditions:

Table 6.1 Power flow simulation results



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     PTI  INTERACTIVE  POWER  SYSTEM  SIMULATOR--PSS(R)E           WED,  OCT  25 2023   13:15
  MEDIUM  LOAD  2022  –  WITH  240MW  WIND  PROJECT – KHIZI  WPP  181MW  AND  PIREKESHKUL  WPP  62MW

X------- FROM BUS ------X AREA  VOLT                          X---------- TO BUS--------- X
 BUS# X-- NAME --X BASKV ZONE  PU/KV  ANGLE                     BUS# X-- NAME --X BASKV AREA        MW     MVAR

                                                              6019 YASHMA SS    330.00        -73.3   -145.8
                                                              6052 SANAYQOV SS  220.00        -5.7     67.7
6050  YASHMA SS   220.00      1.0238   32.3                   6098 YASHMA SS    110.00         84.3    38.9
                              225.25                          6018 XIZI         220.00        -151.9   39.2

                                                              6041 ABSHERON SS  220.00     85.6      -26.6
                                                              6044 XIRDALAN SS  220.00     99.7       10.2
                                                              6045 MUSHVIG SS    220.0     121.5      45.8
                                                              6002 JANUB SS2    220.00     -67.8      -9.8
                                                              6032 QOBU 330     330.00     -30.3      -6.5
                                                              6032 QOBU 330     330.00     -31.7      -7.3
                                                              6041 QOBU15       15.000     -41.3       3.3
 6040 QOBU220       220.00    1.0176    32.8                  6042 QOBU15       15.000     -45.4       3.1
                             223.89                           6016 PIREKUS      220.00     -90.6      -12.0

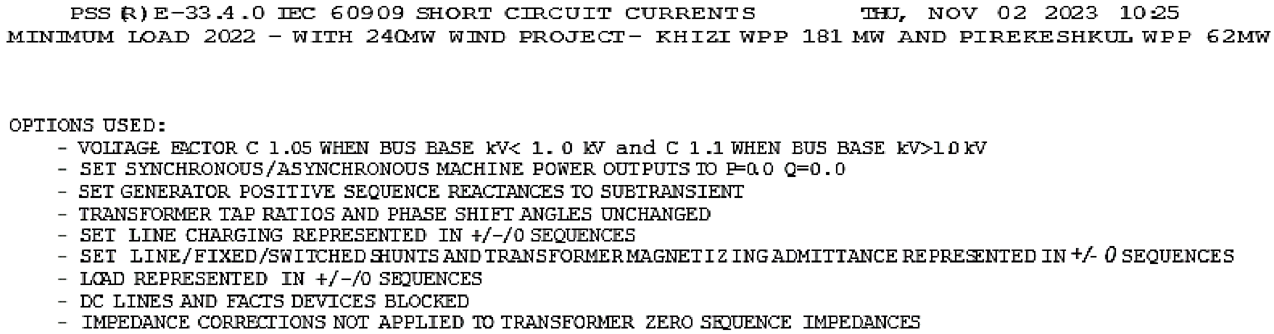
                                                              6050 YASHMA SS     220.00     153.4 | -41.3
6018  XIZI          220.00     1.0403   37.3                  6016 PIREKUS       220.00     28.6     16.8
                                228.88                        6019 XIZI33        33.000    -90.5     12.1
                                                              6019 XIZI33        33.000    -90.4     12.1

                                                              6040 QOBU220      220.00          91.5    12.0
                                                              6017 PIREKUS33    33.00          -31.4    2.4
6016 PIREKUS        220.00      1.0319   36.5                 6017 PIREKUS33    33.00          -31.5    2.4
                                227.03                        6018 XIZI         220.00         -28.6   -16.8
```

Each bus in this simulation model was allocated a unique bus number, which is displayed in the initial column of the aforementioned results. The second column displays the nominal voltage value of this busbar. The next two columns display the voltage values of each busbar in the network, expressed in kilovolts (kV) and per unit (p.u.) values, together with the angle between current and voltage, measured in degrees. These values are obtained after the integration of the wind power plants into the network. The following two columns display the busbar numbers and rated voltage of all connections in the substations where the busbars listed in the first column are located. The final two columns display the active and reactive power values of the substations that the wind power plants are connected. Values that are negative in the final column indicate the flow of power that is supplied to that busbar, while values that are positive indicate the flow of power that is supplied from that busbar. Based on these data, it is evident that both WPP provides are fully utilizing their maximum capacity to contribute to the grid. In order to enhance comprehensibility, the values of the points at which both WPPs are connected to the network are displayed. The voltage values in the Azerbaijan Power Grid currently adhere to the ГОСТ 57382-2017 standard. In order to guarantee the secure operation of the network, it is necessary for the voltage to be within the range of 0.9 to 1.1 p.u, as specified by ГОСТ 57382-2017. The collected data indicate that the voltage values in both substations fall within the permissible range. No voltage regulation equipment needs to be added to the substations because the voltage levels are within the acceptable range.

Present values resulting from a 3-phase short circuit in the busbars of Khizi and Pirekeskul substations are provided.

Table 6.2 Short circuit simulation results



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     PSS(R)E-33.4.0 IEC 60909 SHORT CIRCUIT CURRENTS        THU, NOV 02 2023 10:25
MINIMUM LOAD 2022 - WITH 240MW WIND PROJECT- KHIZI WPP 181 MW AND PIREKESHKUL WPP 62MW


OPTIONS USED:
    - VOLTAGE FACTOR C 1.05 WHEN BUS BASE kV< 1.0 kV and C 1.1 WHEN BUS BASE kV>1.0 kV
    - SET SYNCHRONOUS/ASYNCHRONOUS MACHINE POWER OUTPUTS TO P=0.0 Q=0.0
    - SET GENERATOR POSITIVE SEQUENCE REACTANCES TO SUBTRANSIENT
    - TRANSFORMER TAP RATIOS AND PHASE SHIFT ANGLES UNCHANGED
    - SET LINE CHARGING REPRESENTED IN +/-/0 SEQUENCES
    - SET LINE/FIXED/SWITCHED SHUNTS AND TRANSFORMER MAGNETIZING ADMITTANCE REPRESENTED IN +/- 0 SEQUENCES
    - LOAD REPRESENTED IN +/-/0 SEQUENCES
    - DC LINES AND FACTS DEVICES BLOCKED
    - IMPEDANCE CORRECTIONS NOT APPLIED TO TRANSFORMER ZERO SEQUENCE IMPEDANCES
```

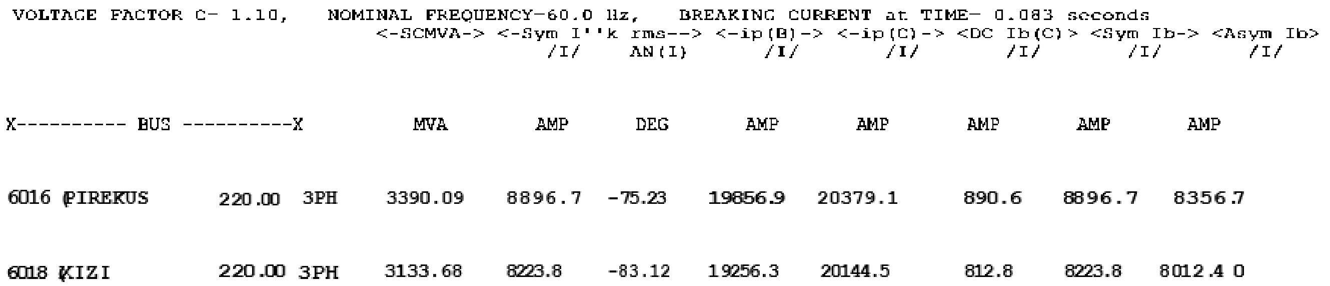

```
VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=60.0 Hz,    BREAKING CURRENT at TIME= 0.083 seconds
                          <-SCMVA-> <-Sym I''k rms--> <-ip(B)-> <-ip(C)-> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                         /I/     AN(I)       /I/        /I/        /I/        /I/        /I/

X---------- BUS ----------X          MVA        AMP      DEG        AMP        AMP        AMP        AMP        AMP

6016 [PIREKUS        220.00  3PH    3390.09    8896.7   -75.23    19856.9    20379.1      890.6     8896.7    8356.7

6018 [KIZI           220.00 3PH     3133.68    8223.8   -83.12    19256.3    20144.5      812.8     8223.8    8012.4 0
```

The study of this short circuit was conducted in accordance with the IEC 60909 standard. The simulation model allocated a distinct bus number to each bus, which was presented in the first column of the results. The corresponding nominal voltage value was displayed in the second column. SCMVA displays the magnitude of power at the location of a short circuit. The symbol I"k represents the root mean square (RMS) value of the symmetric short circuit current, which is the specific current we are investigating. The initial RMS symmetrical short circuit current is the magnitude of the AC symmetrical component of a short circuit current that applies at the time of the short circuit if the impedance remains at zero. This next value represents the angle obtained between voltage and current. The terms ip(B) and ip(C) represent the maximum short-circuit current as defined by IEC 60909 sections b and c, respectively. The term Ib(DC) refers to the direct current component of an asymmetrical breaking current. The DC component is equivalent to the magnitude of the immediate AC current at the initiation of the fault, but with opposite polarity. Ib (Sym) and Ib (Asym) indicate the symmetrical and asymmetrical short-circuit breaking currents, respectively.By dividing the rated power of Pirekeskul and Kızı power plants by the SCMVA value we obtained, the SCR value for each power plant will be 1.6% and 5.4%, respectively. As stated before, a system that has an SCR value that is lower than three is considered to be weak. The obtained value indicated that the Pirekeskul side of the network exhibited a lack of strength. This presents a risk to the grid, particularly in the event of grid failures, as it becomes impossible to achieve the desired current values necessary for the relays to function properly. The voltage and SCR value at this point can be adjusted using power electronics devices, including the SVC (Static VAR Compensator) and STATCOM (Static Synchronous Compensator).

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

The integration of renewable energy sources, namely wind power, into current power grids represents a major achievement in the pursuit of sustainable energy frameworks on a worldwide scale. In the face of increasing energy needs and growing environmental apprehensions stemming from dependence on fossil fuels, the shift towards renewable sources presents itself as a hopeful remedy. The purpose of this thesis was to investigate the incorporation of a wind power facility with a capacity of 240 MW into the power system of Azerbaijan, with a particular emphasis on two wind farms located in the Absheron and Khizi districts. During the extensive study, quantitative approaches were utilized to assess the influence on the electrical grid. These methodologies included the analysis of load flow and system strength. A number of significant discoveries have surfaced as a result of this study. The impact of wind energy injection on connected substation operations and the regional transmission network as a whole is clearly visible. The examination of power flow has provided insights into the state of operations, whereas an assessment of system strength, specifically the SCR, has identified possible vulnerabilities, underscoring the importance of precise thinking in the planning and operation of power grids. Grid stability and security have been emphasized as crucial factors in the context of renewable energy integration. The findings of the analysis indicate that wind power plants make a significant contribution to the electrical grid. However, specific regions of the network, including the Pirekeshkul side, demonstrate vulnerabilities that expose them to potential hazards in the event of grid malfunctions. The necessity for a resilient power grid infrastructure that can accommodate intermittent renewable energy sources while maintaining stability and safety becomes immediately apparent. The performance of transients and general short circuits. The current studies in this thesis were not feasible as a result of time limitations and inadequate data. Furthermore, this analysis was not conducted intentionally, as the 240 MW power plant will constitute the initial substantial power plant in the power system of Azerbaijan, thereby having a negligible influence on the total ROCOF value of the network. To summarize, the incorporation of renewable energy sources, particularly wind power, requires a thorough comprehension of grid intricacies and difficulties. This study offers significant insights into the complexities of incorporating a 240 MW wind power facility into Azerbaijan's electrical system, emphasizing the significance of grid planning, system reinforcement, and strategic actions to ensure a dependable, secure, and resilient energy future.

7.2 Future work

The issues emphasized in this thesis regarding power systems and the incorporation of renewable energy sources require a comprehensive examination of multiple crucial sectors. To effectively manage spinning reserves in systems with significant intermittent generation, it is necessary to develop sophisticated prediction models and algorithms for reserve management. These models should aim to maximize reserve requirements while considering the inherent uncertainties related to renewable energy sources. To tackle transmission congestion mandates, it is necessary to conduct thorough investigations into improving transmission lines or examining alternate grid architectures. It is important to carefully consider the positioning of renewable energy sources while also prioritizing the durability and dependability of the transmission infrastructure. Improving voltage regulation and grid stability requires an increased amount of reactive power supply from sources such as wind farms. Future research should prioritize the development of efficient control systems that can effectively balance reactive power requirements. These selected regions act as central focuses for additional research, matching with the clarified challenges and providing possible opportunities for innovation and advancement in power systems. This study direction emphasizes the incorporation of renewable energy sources and can be easily customized, expanded, or modified to correspond with individual research goals and the changing dynamics of the field.

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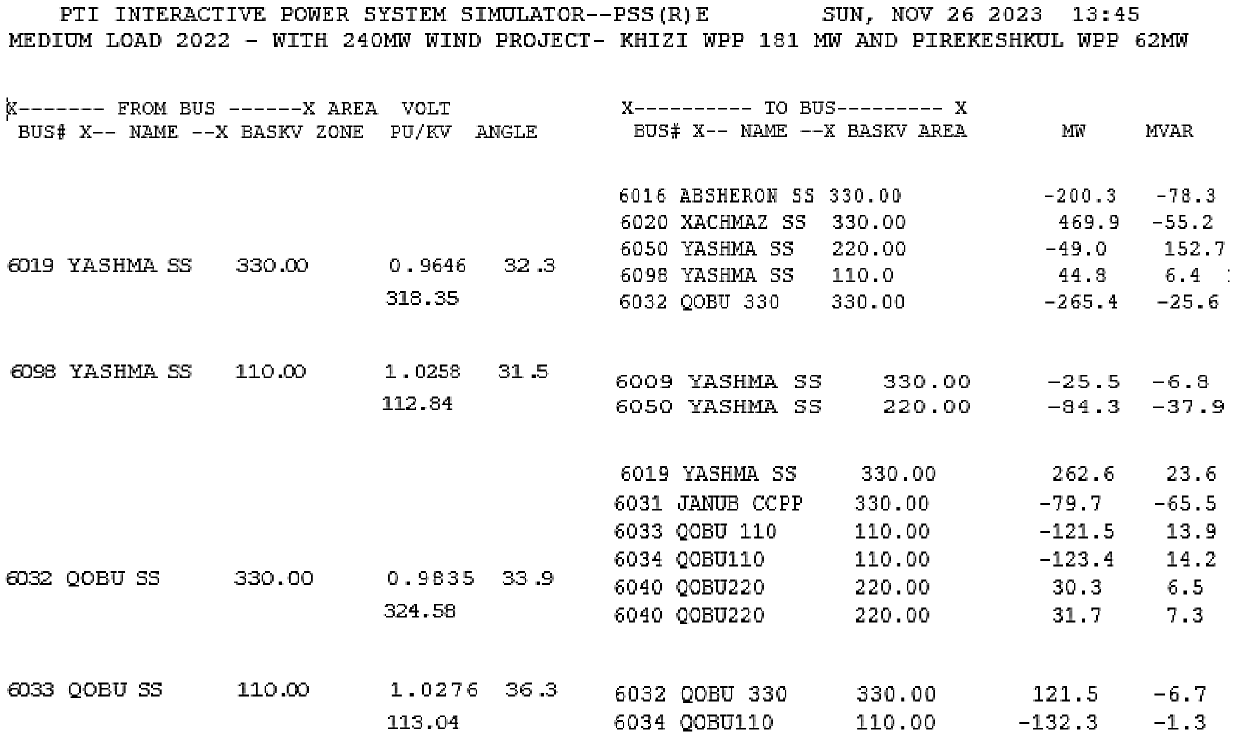
APPENDIX

A1. Overall results



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MEDIUM LOAD 2022 - WITH 240MW WIND PROJECT- KHIZI WPP 181 MW AND PIREKESHKUL WPP 62MW

X------- FROM BUS ------X AREA  VOLT            X---------- TO BUS--------- X
 BUS# X-- NAME --X BASKV ZONE  PU/KV  ANGLE      BUS# X-- NAME --X BASKV AREA       MW     MVAR

                                                6016 ABSHERON SS 330.00          -200.3   -78.3
                                                6020 XACHMAZ SS  330.00           469.9   -55.2
                                                6050 YASHMA SS   220.00           -49.0   152.7
6019 YASHMA SS    330.00       0.9646   32.3    6098 YASHMA SS   110.0             44.8     6.4
                               318.35           6032 QOBU 330    330.00          -265.4   -25.6

6098 YASHMA SS    110.00       1.0258   31.5    6009 YASHMA SS     330.00         -25.5    -6.8
                               112.84           6050 YASHMA SS     220.00         -84.3   -37.9

                                                6019 YASHMA SS     330.00          262.6    23.6
                                                6031 JANUB CCPP    330.00          -79.7   -65.5
                                                6033 QOBU 110      110.00         -121.5    13.9
                                                6034 QOBU110       110.00         -123.4    14.2
6032 QOBU SS      330.00       0.9835   33.9    6040 QOBU220       220.00           30.3     6.5
                               324.58           6040 QOBU220       220.00           31.7     7.3

6033 QOBU SS      110.00       1.0276   36.3    6032 QOBU 330      330.00          121.5    -6.7
                               113.04           6034 QOBU110       110.00         -132.3    -1.3
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