Mesopotamian Journal of Civil Engineering
Vol.2024, **pp**. 54–59
DOI: https://doi.org/10.58496/MJCE/2024/008; ISSN: 3006-1148
https://mesopotamian.press/journals/index.php/MJCE

Research Article

Assessment of Cyber Security Risks in Electrical Engineering System of Georgia

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ARTICLE INFO

Article History
Received 21 Apr 2024
Revised: 26 Jun 2024
Accepted 19 Jul 2024
Published 20 Aug 2024

Keywords
Cybersecurity
Engineering
Sustainability
Risks
Logic Gates

ABSTRACT

Cyber security is an integral part of electrical engineering and covers various aspects such as power grid security, electrical and power equipment security, risk management, standards compliance, and incident response to prevent cyber attacks on power grids. The article examines the probable risks of the electrical system of Georgia. for this purpose a logical graphic tool is used, to identify top-down failures, which cause lower-level system failures. Fault tree analysis consists of "events" and "logic gates", which correlate accidents to determine the cause of the most adverse event. The paper analyzes the causes of possible short-circuiting, violation of the dynamic stability of the network, and harmonic distortion in the networks of the electric system of Georgia and gives recommendations for their reduction.

1. INTRODUCTION

Assessment of cybersecurity risks in electrical engineering systems requires an approach that includes technical, organizational, and human factors. By implementing defense-in-depth measures, protecting critical infrastructure, following secure design principles, and adhering to international standards, electrical engineers can enhance the resilience of electrical engineering systems. The history of international standardization began in 1906 when the International Electrotechnical Commission was established, and the establishment of the International Organization for Standardization was aimed at simplifying the process of international trade. In the international organization of standardization, Georgia is represented by the national standardization body - the National Agency of Standards, Technical Regulations and Metrology of Georgia. Membership of these organizations and the introduction of modern quality systems using international norms allows Georgia to become a full member of the international community [1].

2. CRITICAL ANALYSIS OF THE STABILITY OF THE ELECTRIC SYSTEM OF GEORGIA

2.1. The Critical Elements of the System

The electrical system of Georgia is represented by High Voltage Power Transmission-Dispatching Company. The goal of the quality policy of JSC "Georgian State Electric System" is the safe, reliable, economically justified, effective management, maintenance, and development of the electricity transmission, dispatching, and electricity market operation for the balancing and auxiliary services market segment. The requirements of the quality management system, ISO 9001:2015 Implementation, and continuous improvement increase the reliability and effectiveness of the company's services. To solve the possible risks of cyber attacks and information security challenges, the staff is being raised and the security standard ISO27001 is being implemented. The relevant profile specialists are constantly working to ensure cyber security [2].

For all electrical systems, including Georgia, it is appropriate to identify the critical elements of the system and analyze the causes of short-circuit currents, instability, and harmonic imbalance (table 1).

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TABLE I. THE CRITICAL ELEMENTS OF THE ELECTRIC SYSTEM

Critical, Characteristic Short Circuit in the Network Elements	**Violation of System Stability**	**Source of Harmonics Generated in the Network**
All generators of the electrical system	500 kV power line emergency shutdown	Akhaltsikhe 700 MW 500/400 kV High Voltage Direct Current (HVDC) plug
All system power transmission lines of the power system	Emergency shutdown of the 400 kV power transmission line connecting to Turkey	Connecting the LLC Qartli Wind Farm to the power system
---	Enguri HPP shutdown	---
---	Shutting down the 9th block of Gardabani Thermal Power Plant	---

All power converters, including HVDC converters, produce some degree of harmonic distortion on power grid systems. Also, as is known, the impact of wind power plants on the electrical network causes harmonic changes, which are manifested in distortion of voltage and current. In 2016, a wind power plant was included in the electrical network of Georgia, which has a certain influence on the generation of harmonics in the network. Harmonic filters should be installed on the terminals of such converters. Designing filters for a wide range of system harmonic impedance frequencies is a multi-criteria task considering their high cost [3]. Electricity generated from wind energy varies hourly, daily, or seasonally. Because instantaneous power generation and consumption must be balanced to maintain grid stability, this variability can cause difficulties when incorporating large amounts of wind power into the power system. Intermittency of wind power generation can increase regulation cost, and additional operating reserve and may require load shedding, storage solutions, or system interconnection with HVDC.

The operation of wind farms generates variations in the power grid. It increases reactive energy consumption, which is related to their electricity production. These variations in the grid cause voltage variations for the power system and consumers. Because the increasing development of wind farms causes voltage and current harmonics in the power system, wind energy is an uncontrolled energy source and can cause problems with voltage stability. Thus, the connection of wind farms to electric power systems affects system performance, active and reactive power load flow, nodal voltage, power losses, and overall grid stability and security.

In the power supply system, the voltage and frequency must be kept close to the nominal values because the electrical equipment is manufactured according to the given alternating current (AC) specification. Conventional power plants perform two main tasks in large-scale electric power systems: power generation and voltage control. Along with the generation of electrical energy, the quality of electrical energy must be maintained. Intermittent power supply in system networks affects power quality. The impact depends on how much the intermittent source contributes to the instantaneous load. At low penetration, wind farms can be connected to the grid as active power generators, and up to 10-15% of the penetration is absorbed into the power grids without a negative impact on power quality and without the need for additional backup power. The main problems arise during the reduction in wind speed when the wind turbines are disconnected from the grid and remain idle. When the wind speed returns to the operating range, the turbines are reconnected to the system, and therefore the sudden start of a large turbine can cause a voltage drop. Short-term variations in wind power cause voltage fluctuations in the network, which are manifested by damage to sensitive electrical devices, etc.

Connecting wind farms to the grid can cause harmonics and transient instabilities that cannot be countered by grid control systems. This has been demonstrated in connection with small-scale autonomous systems, for example, such as the electrical system of Georgia.

Electrical transmission and distribution network codes define technical requirements to ensure the security of supply. Technical requirements regulate the capabilities of wind power conversion systems through frequency control. System active power control is closely related to frequency control, and the wind farm must have frequency control capabilities to boost active power according to the frequency and active power characteristics determined by the grid operator. When a power system is subjected to a sudden increase in reactive power demand after system stability is disturbed, the additional demand must be met by the reactive power reserve provided by generators and compensators. Achieving electrical system reliability at significantly reduced voltage levels is difficult. The problem with wind turbines is that conventional power converter controllers designed for reliable operation around rated voltage levels will not perform as designed at low grid voltages that can occur during a fault. This results in a sharp increase in converter currents, which can lead to converter failure. Wind power plants are considered relatively complex generation facilities and require a multi-variant economically efficient solution.

2.2. Short Circuit in the Georgian Electrical System

A short circuit in the electrical system is the most common and dangerous accident. It occurs when the insulation of electrical circuits is damaged. Its causes can be: the falling of a tree on power lines, aging and breaking of insulators, wires breaking and falling to the ground, animals and birds getting into the insulation gap, etc. Short-circuit currents, the magnitude of which is much greater than the normal mode currents, lead to overheating of electrical equipment and the generation of large forces between current-carrying parts [4]. When designing a power plant or substation, knowledge of the actual short-circuit currents is required to enable proper selection of equipment. Thus, circuit breakers, current transformers, and switches can be damaged due to overheating or mechanical breakage. All these devices are designed for a short-circuit current of a certain magnitude, which is indicated in their passports. In addition, it should be noted that during short circuits, the voltage in the area of the network near the damage drops sharply, and the operation of self-consumption synchronous and asynchronous motors in the power plant may be interrupted, and in the case of prolonged short circuits, they may even be turned off. Thus, on the one hand, electrical equipment must be selected in such a way that it can withstand the maximum short-circuit currents, on the other hand, the time of short-circuit currents must be limited. The latter is provided by relay protections of electrical stations and substations [5]. Thus, the calculation of short circuit currents is of particular importance for the correct design of power stations and substations. Figure 1 shows the fault tree of high-voltage power lines and related infrastructure.

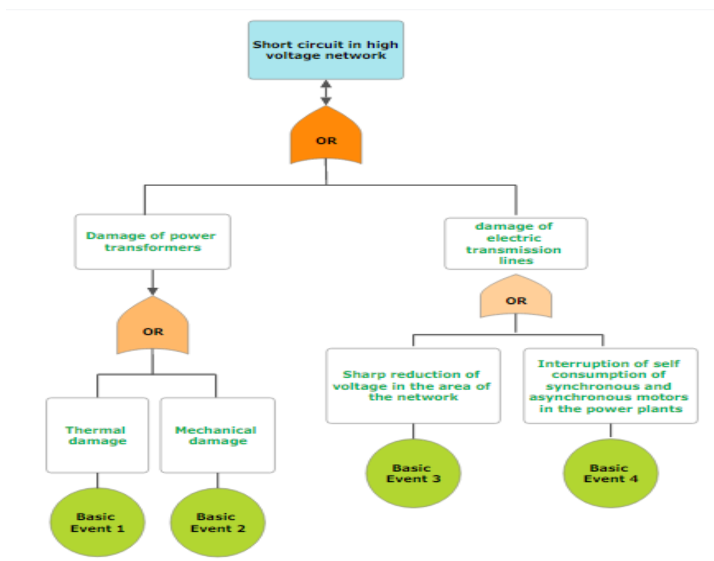

Fig .1. Fault tree of high voltage power line

2.3. Violation of Dynamic Stability of Georgian Power System

Dynamic stability studies the behavior of a power system and the ability to maintain synchronous operation of generators under finite magnitude disturbances, namely, emergency shutdowns of power lines or generators [6].

- The system must maintain the stability of internal lines in the 500 kV and 220 kV network

with basic protections in case of emergency shutdown;

- Wind power plants should not cause a significant negative impact on the stability of the system, in particular, they should remain operational during short-circuits and not consume reactive current.

Analysis of dynamic stability is important for the energy system of Georgia since the transit from west to east is carried out by one 500 kV and several parallel 220 kV power lines. Georgia's power system is designed as part of a unified power system, the loss of its largest generators or powerful units, as well as the loss of 500 kV generators, can cause significant concerns in Georgia's power system. Therefore, when planning the network, it is necessary to study the influence of such concerns on the stability of the system, To avoid the development of emergencies, violation of the integrity of the system, or its complete shutdown. Figure 2 shows the tree of injuries developed in case of violation of dynamic stability.

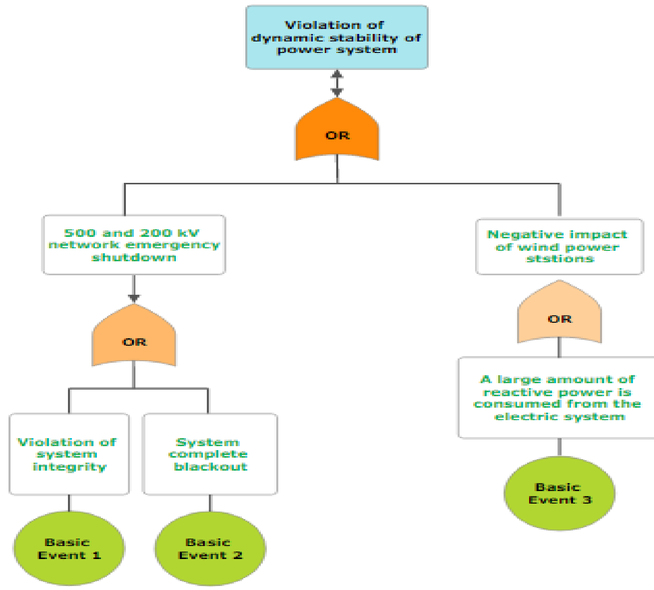

Fig .2. Violation of dynamic stability of power system

2.4. Harmonic Distortion in Georgian Power System

Distortion of the sinusoidal voltage occurs in the power transmission network due to the characteristics of non-linear consumers and electrical devices. This, in turn, causes the generation of high-order harmonics in the electrical network. Harmonics create several problems in an electrical system [7]. In particular, they cause unwanted high-frequency currents in consumers, deteriorate manufactured products, increase losses in electrical equipment, cause large delays in telecommunications, increase errors in measurement and recording circuits, and in many cases even cause false activation of relay protection. Thus, the generation of harmonics worsens the operating parameters of the system, as well as reduces its reliability, deteriorates the quality of electricity, and can even cause an accident.

Power transmission is more efficient with direct current rather than alternating current, when: the synchronous connection of two systems is not feasible due to stability problems or differences between nominal frequencies. Connecting two AC power systems can be done with a DC power plug. On the side of the transmitting system, a device that converts alternating current into direct current, or a controller, is installed, and on the side of the receiving system, a device that converts direct current into alternating current, or an inverter, is installed. Important elements are:

- Distance between DC plug and DC line (cable) between converter devices;
- Length of constant current conductor.

In the case of a direct current plug, this length does not exceed 250 meters, and in the case of a direct current cable or line, it can be longer than several dozen to 2000 km. It should be noted that converters on any DC power supply must have the ability to reverse power and reverse functions, when necessary, the controller can become an inverter, and the inverter becomes a controller.

Transformers or converters are converters from alternating current to direct current (rectifier) or from direct current to alternating current (inverter). Their functions are:

- Reduction of harmonic voltages and currents in the direct current line (or electrode).

2.4.1 Harmonics Filters.

Converters generate harmonic voltages and currents on both the AC and DC sides. These harmonics can cause nearby synchronous generators and capacitors to overheat or suppress signals from telecommunications systems. Filters should be installed on both the variable and permanent sides of the converter stations.

2.4.2 Reactive Energy Sources.

Converters consume reactive energy during operation. In normal established mode, reactive power consumption is about 50% of the active transferable power. In accidents, the reactive power required can be greatly increased. Therefore, reactive power sources should be installed in the vicinity of the converters. In the case of powerful alternating current systems, such sources are capacitors. Depending on the strength of the DC input installation and associated AC systems, either synchronous compensators or static compensators can be used as reactive power sources. It should be noted that the capacitances used in the filters also ensure the supply of a certain part of the reactive power required for the converters.

2.4.3 Direct Current Lines and Electrodes.
An overhead transmission line or cable may be used as the main conductor in the DC plug and line. Their construction is very similar to alternating current lines the difference is the number of conductors and the distances between them. The ground can be used as a neutral. In this case, a large ground surface should be used to limit the current density and surface voltage gradients. If this is not possible for some reason, an additional wire can be used as the zero neutral.
2.4.4 AC Circuit Breakers.
Circuit breakers are installed on the AC side to remove short circuits occurring in the transformers and to switch off the DC input. Removal of short circuits on the DC side is faster and more efficient using converter control.
Figure 3 shows the most powerful harmonic source in the electrical system of Georgia is the Akhaltsikhi 700 MW DC substation. Georgia's 500 kV transmission system has been expanded with two new 500 kV links from Gardabani and Zestafon substations to a new 500/400/200 kV substation in the nearby town of Akhaltsikhe near the Turkish border [8]. Akhaltsikhe substation was connected to the Turkish EHV network asynchronously by substation Borchka. Two back-to-back high-voltage direct current links in Akhaltsikhe and a 400 kV overhead transmission line to the Turkish border are used [9].

Fig .3. Akhaltsikhe 700 MW and 500/400 kV High Voltage Direct Current (HVDC) plug

In the near term, it is planned to expand this substation with a 350 MW power block, while in Armenia, in the vicinity of Georgia, the construction of a 700 MW DC power substation is planned, which will be connected to the transmission network of Georgia. Figure 4 shows the fault tree caused by harmonic imbalance.

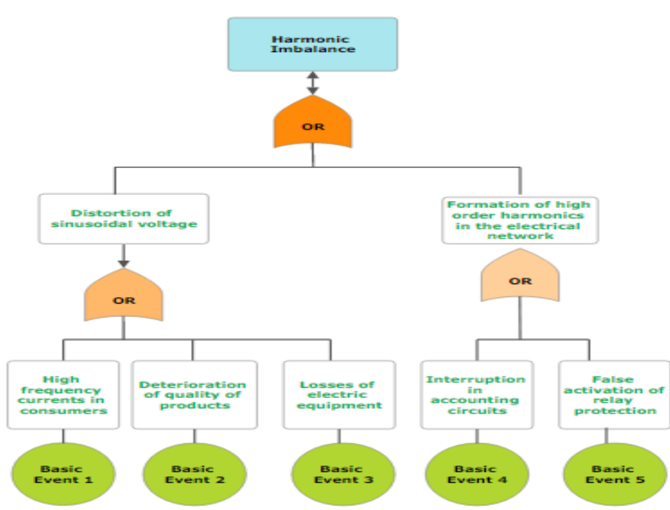

Fig .4. Fault tree caused by a harmonic imbalance in power system

3. SERVICE QUALITY IN ELECTRICITY DISTRIBUTION COMPANIES OF GEORGIA

In electricity distribution companies, there are two areas of service quality monitoring: reliability of power supply and commercial quality. Reliability is characterized by the number and duration of power outages, for the determination of which three indices are introduced: System Average Interruption Duration Index per customer (SAIDI min/customer), the average frequency of power outages per customer (SAIFI outages/customer) and ENS is the amount of unsupplied electricity that during the reporting period Not delivered to the customer due to outage (kWh). Using the above-mentioned indices, it is determined how reliably the power supply system of the distributing power company works and what is the quality of service in this field. The National Electricity Regulatory Commission of Georgia conducts monitoring for the protection of the mentioned standards in the relations with customers of Telasi Energy Distribution Joint Stock Company and Energo-Pro Georgia Joint Stock Company [10]. Comparison of SAIDI, SAIFI indicators of the quality of electricity supply with the indicators of neighboring countries clearly shows the better results of the energy distribution companies of Georgia [11].

4. CONCLUSIONS

The failure of the infrastructure of the electric power system can cause great damage to the country's economy, it can cause cascading disruption of the related systems, therefore, critical analysis and forecasting of cross-sectoral risks is important. A combination of qualitative and quantitative methods is needed to estimate the risk and vulnerability of electrical system hazards. Probable threats are identified and their corresponding foult trees are constructed. As a result of the use of Fault Tree Analysis, the quality of power supply, process reliability and safety will be improved, by collecting information, the professionalism of engineers will increase and the probability of this type of damage will be reduced in the future.

Conflicts Of Interest

The paper states that there are no personal, financial, or professional conflicts of interest.

Funding

The acknowledgments section of the paper does not mention any financial support from institutions or sponsors.

Acknowledgment

The author acknowledges the assistance and guidance received from the institution in various aspects of this study.

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