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Protection Coordination for Wind Farm Integration in the Kosovo Transmission System

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ABSTRACT
The implementation of wind power generators into transmission system presents several challenges related to protection schemes, particularly in the areas of relay protection and overcurrent protection. This paper provides an overview in the impact of connecting wind power generators to the transmission system and discusses the key considerations for designing effective relay and overcurrent protection strategies. Intensive analysis was conducted on multiple scenarios involving critical short-circuits, occurring at different nodes within the system, specifically focusing on three-phase current. The situation where the circuit breaker is disconnected after the relay protection was activated, ensuring the protection of high voltage equipment, was also examined. Without proper protection coordination, the selectivity, reliability and sensitivity of the protection system can be compromised. In this paper, a comprehensive protection coordination strategy was developed for the new substation 35/10 kV in Koznica. The use of system simulation techniques, such as employing (Electrical Transient Analyser Program (ETAP) software, can be an effective way to validate the performance and functionality of a system protection. In all simulated scenarios, the analysis identified the circuit breakers that were activated in response to short-circuit faults. This approach ensured the reliability and accuracy of the coordination scheme, thereby enhancing the overall performance and resilience of the system.

Keywords: wind farm, wind power generator, transmission system, relay protection, overcurrent protection, ETAP software.

THE MAIN TEXT

In conventional power systems, electricity generation primarily relies on traditional power plants that predominantly utilize fossil fuels as their energy source. Traditional power plants typically demonstrate substantial power output from 150 to 1000 MW. These power plants demand significant investments and entail high operating costs, often necessitating their positioning at considerable distances from the consumption centres. Rather than relying on conventional coal-based power plants, modern power systems are increasingly characterised by distributed generators (DG) primarily utilising renewable energy sources such as wind energy and solar energy to produce electricity. Generators of this type are most often located in the consumption centre, whereas their output power and energy are uncontrolled (Ymeri et al., 2022).

The main idea behind a DG is that generation is done in a small scale and can be easily placed closer to the point of consumption. Distributed generation are small electricity producers located near the consumption and load (Ymeri and Mujović, 2018).

The presence of the DG changes the power flow and load characteristics of the electrical grid. With the connection of the DG, the passive distribution network becomes active and power flow changes significantly (Vukobratović et al., 2014).

DGs include renewable and non-renewable sources for electricity generation. The renewable sources comprise PV systems, hydropower plants, wind generators, geothermal generators and biomass generators (Tamayo et al., 2015).

The implementation process of wind farms is not without its challenges. It involves several significant issues, including high construction costs, careful selection of suitable locations and capacities, as well as the on-going effort to optimise the utilisation of operational resources. The integration of wind power plants into the distribution network has a diverse range of impacts, including technical, economic, techno-economic, techno-ecological, and economic-ecological aspects (Naik et al., 2012).

The integration of wind power plants into the distribution network brings about several technical impacts, such as the reduction of power losses, enhanced voltage stability, effects on electricity quality, increased system reliability and security as well as implications for protection coordination.

The implementation of a wind generator into the transmission network can result in both beneficial and adverse effects regarding active power losses. More precisely, when the production of the wind power generator aligns proportionally with the consumption demand, the impact on power losses is relatively minimal. Wind generators contribute to supplying backup power during periods of heightened electricity demand, thus mitigating the power losses in the transmission system.

The impact of a wind generator on voltage control is contingent on the power flow within the network. The voltage increase impact is a crucial factor that restricts the integration of additional wind power generators into the transmission network. As the capacity of these units increases, it necessitates a voltage regulation analysis (Ahmad and Farman, 2013).

The connection of a substantial wind generator to an inadequately robust transmission network can give rise to substantial electricity quality issues (Kayalvizhi and Kumar, 2014). Large wind generators can inject variable amounts of power into the grid, depending on wind conditions. If the transmission network is not adequately designed to handle the fluctuating power output, it can lead to voltage fluctuations. These voltage variations can impact the quality of electricity supplied to consumers, potentially causing voltage sags or swells that may disrupt the operation of sensitive equipment. Wind generators can introduce harmonics into the electrical system due to their electronic converters and control systems. If the transmission network is not adequately designed to mitigate harmonic distortions, it can affect the overall power quality, leading to voltage distortion and interference with sensitive equipment.

Reliability issues in the electricity supply are indeed associated with permanent interruptions and wind power plants can offer potential solutions to enhance the reliability of the power system. The options provided by wind power plants to increase system reliability are: increasing total generation capacity; increasing system reserve and reducing loads on the transmission network. By implementing appropriate planning, operational strategies and grid integration techniques, wind power plants can effectively contribute to increasing the reliability of the power system, reducing the risk of permanent interruptions as well as ensuring a more secure and resilient electricity supply.

DG integration requires protection coordination that can maintain bidirectional power flows. The contribution of DG strongly depends on the type of DG and the way in which the DG unit is connected to the distribution network (Kayalvizhi and Kumar, 2014). Protection design requires good communication between DG and network designers during the design process.

The integration of wind power generators into the grid necessitates protection coordination capable of accommodating two-way power flow. Wind power generators are typically connected to the grid through power electronic converters, such as inverters. These converters facilitate the conversion of the variable output from wind turbines into a stable and synchronized power supply for the grid. Consequently, wind power generators do not contribute to increasing the short-circuit power of the system as their current generation cannot exceed their nominal value.

To protect both the wind power generator and the connected transmission line, it is adequate to implement overcurrent protection, targeting the relevant segment of the line (Ymeri and Mujović, 2017).

Proper coordination and design of protection systems, considering the unique characteristics of wind power generators, are essential to ensure the safe and reliable operation of both the plant and the interconnected grid. This coordination helps to mitigate the impact of faults and disturbances, ensuring the overall stability and resilience of the power system.

In this paper, relay protection and overcurrent protection for a real case were analysed.

Relay protection

The main objectives of power system protection are the precise identification of malfunctions or abnormal operating conditions and the prompt response without causing significant disruptions to the system operation. Protection relays play a crucial role in achieving these objectives by delivering signals to guide circuit breakers in isolating faulty areas within the system (Hussain et al., 2013).

To maintain the coordination of protection devices, it is essential to ensure selectivity among the affected equipment during various fault scenarios. This selectivity guarantees the integrity and safe operation of the system (Jazaeri et al., 2015).

To achieve the objectives of power system protection: selectivity, design, and protection coordination are crucial. A comprehensive analysis of all possible disturbances and abnormal operating conditions in the system, along with the expected protection actions, is necessary.

The protection system, which detects faults and rapidly isolates the faulty part of the system, is a vital and integral component of any power system. To ensure reliable and safe protection, the protection system must fulfil the following basic criteria:

1. Reliability: The protection system should operate effectively when a malfunction occurs, ensuring that faults are detected and appropriate actions are taken promptly.
2. Safety: The protection system should not operate under normal operating conditions to prevent unnecessary interruptions or disturbances.
3. Speed of Action: Quick response time is essential for the protection system to swiftly eliminate faults and prevent potential damage to other elements of the power system.
4. Selectivity: In the event of a fault, the protection system should isolate only the specific element or part of the power system that is faulty, while allowing the rest of the system to continue normal operation.
5. Sensitivity: Faults in the system are characterised by deviations from normal operating values in quantities such as current, voltage, and frequency. The protection system should be sensitive enough to detect and respond to these deviations.

Relay protection refers to a set of devices, including relays, measuring transformers, and switches, used to protect elements or parts of the power system, such as buses, lines, transformers, and generators. The purpose of relay protection is to ensure the reliable operation of power systems and minimise the impact of unavoidable system failures, particularly in situations involving excessive currents and overvoltage.

Overcurrent protection

The overcurrent protection relay is a type of protection relay that triggers when the load current exceeds a specified setting value. The setting value is typically set as a percentage multiplier, ranging from 50% to 200% with 25% increments, known as the Tap Setting (TS) (Korde and Bedekar, 2016). The TS of each relay is determined based on two factors: the maximum load current and the minimum fault current.

For every potential fault location, relay coordination is needed determining the arrangement and sequence of relay operations. By incorporating appropriate limits and additional time delays, the faulted section of the system can be isolated (Thangaraj et al., 2010). The coordination process focuses on optimising the Time Multiplier Setting (TMS) based on predetermined pickup current settings.

When aiming to achieve optimal relay coordination in overcurrent protection, there are various potential arrangements that can be utilised. These arrangements often involve a combination of time grading, current grading, or both. However, it is important to note that reaching the desired level of coordination requires initial guess settings that are biased towards the specific objectives.

Overcurrent protection coordination is a highly specific and constrained domain, heavily influenced by user preferences, such as time grading, current grading, and minimum operating time grading (Thangaraj et al., 2010). The main objective in coordinating overcurrent relays is to determine the Pickup Setting Multiplier (PSM) and Time Multiplier Setting (TMS) for each relay. Additionally, minimising the overall operation time for the primary relay is an important objective.

The process of coordinating overcurrent relays involves finding the optimal settings that ensure selectivity and coordination among the relays. This involves careful analysis and consideration of factors such as fault current levels, time delays, and the desired sequence of operation. The ultimate goal is to achieve a coordinated protection system that effectively detects and isolates faults while minimising the overall operation time for the primary relay.

By focusing on these objectives and utilising appropriate techniques, such as time grading, current grading, and minimum operating time grading, the coordination of overcurrent relays can be optimised. This optimisation leads to an efficient and reliable protection system that enhances the performance and safety of the power system.

In order to ensure consistent coordination of the protection system, the backup relay is designed to activate only when the primary relay fails to respond or does not take appropriate action to isolate the fault. The backup relay acts as a secondary protect for line protection, providing an additional level of protection in case of a slight failure at the primary relay.

To achieve optimal coordination between the primary relay and backup relay, several constraints need to be considered, with the primary objective being the shortest operation time. The parameters that need to be satisfied for coordination include the Pickup Setting Multiplier (PSM), Time Multiplier Setting (TMS), Objective Function (OF), and Optimum Method (OM).

For an optimal coordination strategy, particularly in radial or ring power systems, it is important to employ non-linear relay characteristics that are proportionate to the Tap Setting (TS), Pickup Setting Multiplier (PSM) and Time Multiplier Setting (TMS). These characteristics help ensure effective coordination between the primary and backup relays, enhancing the overall performance and reliability of the protection system.

By considering these parameters and utilising appropriate optimization techniques, the coordination of primary and backup relays can be optimised to provide efficient and reliable protection for the power system. This optimisation process ensures that the protection system operates quickly and accurately in isolating faults while minimising the overall operation time.

The presence of DG affects the fault currents detected by protection relays, potentially causing operational issues in the existing protection system. This can result in undetected faults and compromised selectivity of the protection scheme.

The aim of the protection coordination study is to ensure the proper coordination and sizing of all protective devices, including relays, breakers, fuses, and more, in relation to the equipment they are intended to protect.

A protective equipment coordination study offers several advantages, which include:

- Enhanced system and facility reliability;
- Improved equipment protection;
- Minimisation of costs associated with disruptions;
- Increased operational efficiency;
- Assistance in operations and prevention of unnecessary downtime;
- Identification of underrated equipment to prevent damage;
- Identification of overloaded equipment to prevent breakdowns.

Integration of the wind farm in Koznica

The cumulative capacity of wind power plants in the Kosovo power system amounts to 136.5 MW, encompassing the "Kitka" and "Selaci" facilities. In the contemporary era, the integration of renewable energy systems, notably wind farms, poses both a challenge and an imperative for nations aiming to effectively harness this resource within their energy production framework.

This article centred on a project that demonstrates the impact of connecting a wind farm to the 110/35/10 kV substation, Gjilani1, specifically emphasising its impacts for protection coordination. With an installed capacity of 51.5 MVA, the substation assumes a pivotal role as a distribution node of power flow. The wind farm consists of a total of 12 turbines, contributing to a collective power generation capacity of 45.6 MW.

This paper examined three different scenarios of short circuits: one occurring at the Artana 35 kV busbar, another at the Gjilani 35 kV busbar, and the third at the Koznica 35 kV busbar.

Figure 1 presents scenario 1, when short circuit occurred at the Artana 35 kV busbar. On the basis of the simulation conducted in the ETAP software, it is evident that the short circuit current at the Artana 35 kV busbar is 3.89 kA (Figure 2). In this case, when the short circuit is at the Artana 35 kV busbar, at first the relay 1 responds which trips circuit breaker CB15, then relays 7 and 10 which trips CB28 and CB25 circuit breakers.

Figure 3 presents scenario 2, when short circuit occurred at the Gjilani 35 kV busbar. On the basis of the simulation conducted in the ETAP software, it is evident that the short circuit current at the Gjilani 35 kV busbar is 5.35 kA. In this case, when the short circuit is at the Gjilani 35 kV busbar, at first the relay 7 responds which trips

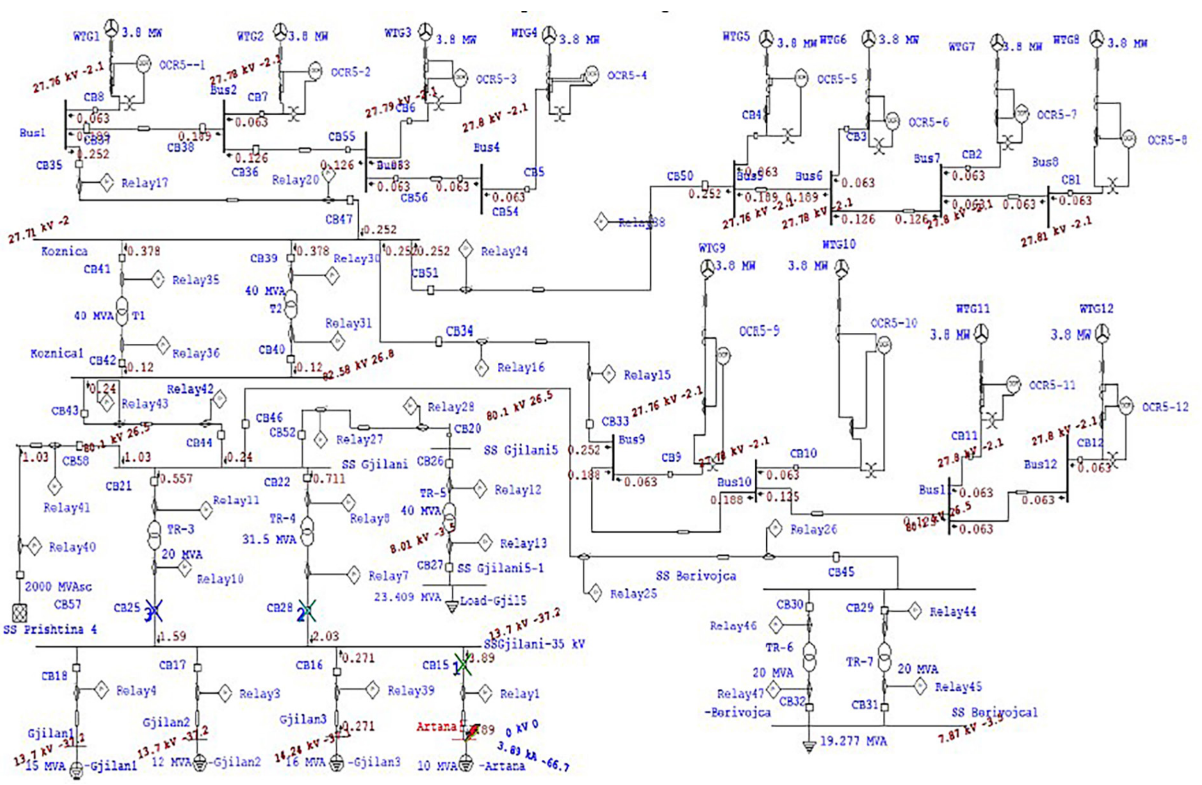

Figure 1. The situation when short circuit occurred at Artana 35 kV busbar and action of relay protection

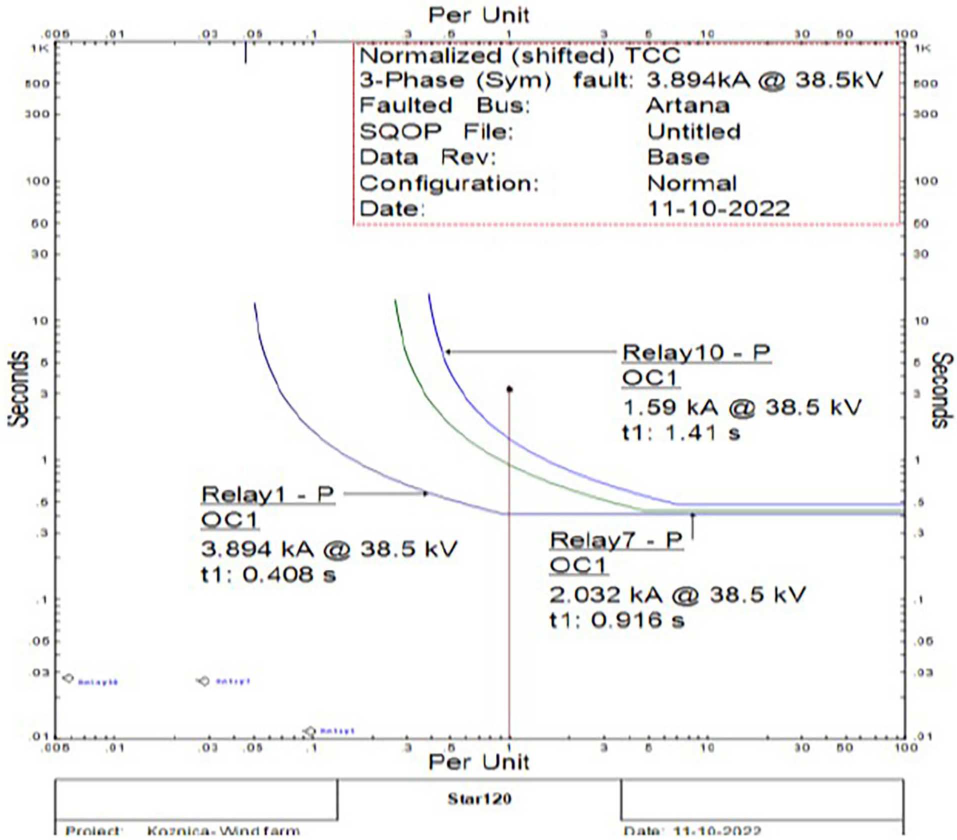

Figure 2. The coordination of protective devices in the event of a short circuit at the Artana 35 kV busbar

circuit breaker CB28, then relay 10 trips CB25 circuit breaker and finally relay 8 and 11 responds trips CB22 and CB21 circuit breakers (Figure 4).

Figure 5, presents scenario 3, when short circuit occurred at the Koznica 35 kV busbar. On the basis of the simulation conducted in the ETAP software, it is evident that the short circuit current at the Koznica 35 kV busbar is 13.158 kA (Figure 6). In this case, when the short circuit is at the Koznica 35 kV busbar, at first 35 and 30 responds which trips CB41 and CB30, then relays 20, 24 and 16 trips CB47, CB51 and CB 34 circuit breakers.

As wind generators become more prevalent in transmission networks, it becomes crucial to establish a strategy that determines the necessary level of their technical impacts.

Coordination involves the systematic utilisation of current-activated devices within the power system. Its purpose is to selectively disable a minimal number of devices in response to failures or overloads, ensuring efficient operation while maintaining reliability. The primary objective of relay coordination is to minimise equipment damage. In alignment with this goal, the main aim is to attain the necessary selectivity and speed while ensuring sensitivity and a rapid clean up time are not compromised. To ensure effective coordination of relays throughout various locations in the power system, it is essential to calculate the Protective System Margin (PSM) and Time Setting Multiplier (TSM) using the relevant data needed for relay coordination. The optimisation parameters in this process include the current setting and time multiplier setting for all relays. A thorough examination of relay coordination enables the identification of faults and subsequent isolation of the damaged section. The coordination study yields valuable data that aids in the selection of measuring transformers, determination of protective relay characteristics and settings, assessment of fuse ratings, and gathering other crucial information. This data is crucial for achieving optimal protection and selectivity in the coordination of these devices.

In this article, a unique context was chosen for a case study, where simulations were performed using the ETAP software package. The analysis focused on a part of the Gjilani region electrical network, specifically the integration of a wind farm with 45.6 MW total installed capacity. The article investigated the operational efficiency of the Gjilani 110/35/10 kV substation under three distinct short circuit scenarios. These scenarios

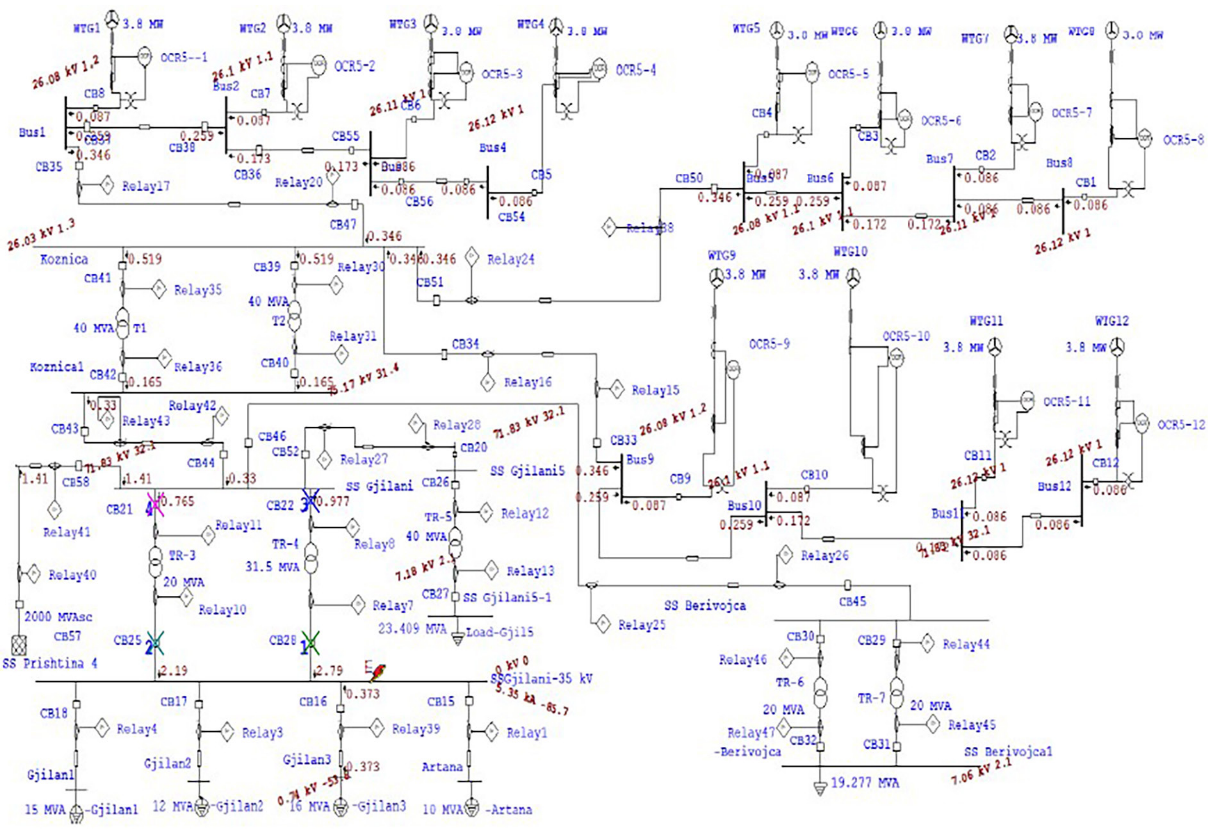

Figure 3. The situation when short circuit occurred at Gjilani 35 kV busbar and action of relay protection

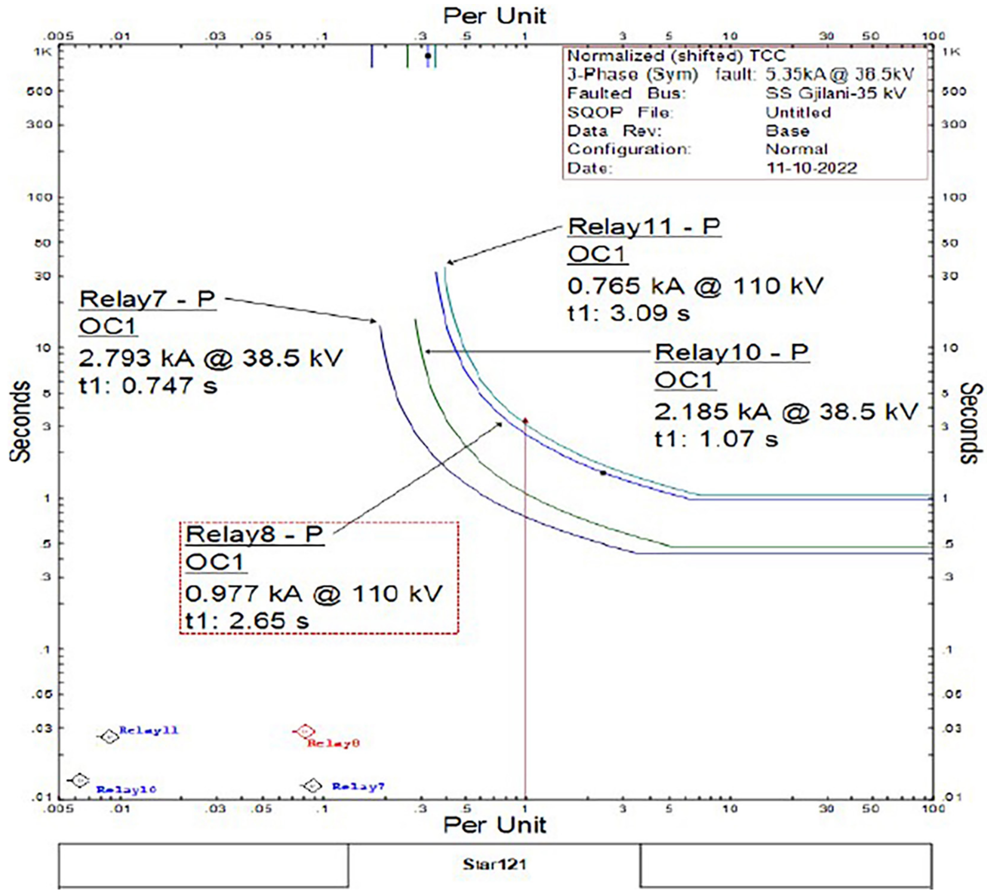

Figure 4. The coordination of protective devices in the event of a short circuit at the Gjilani 35 kV busbar

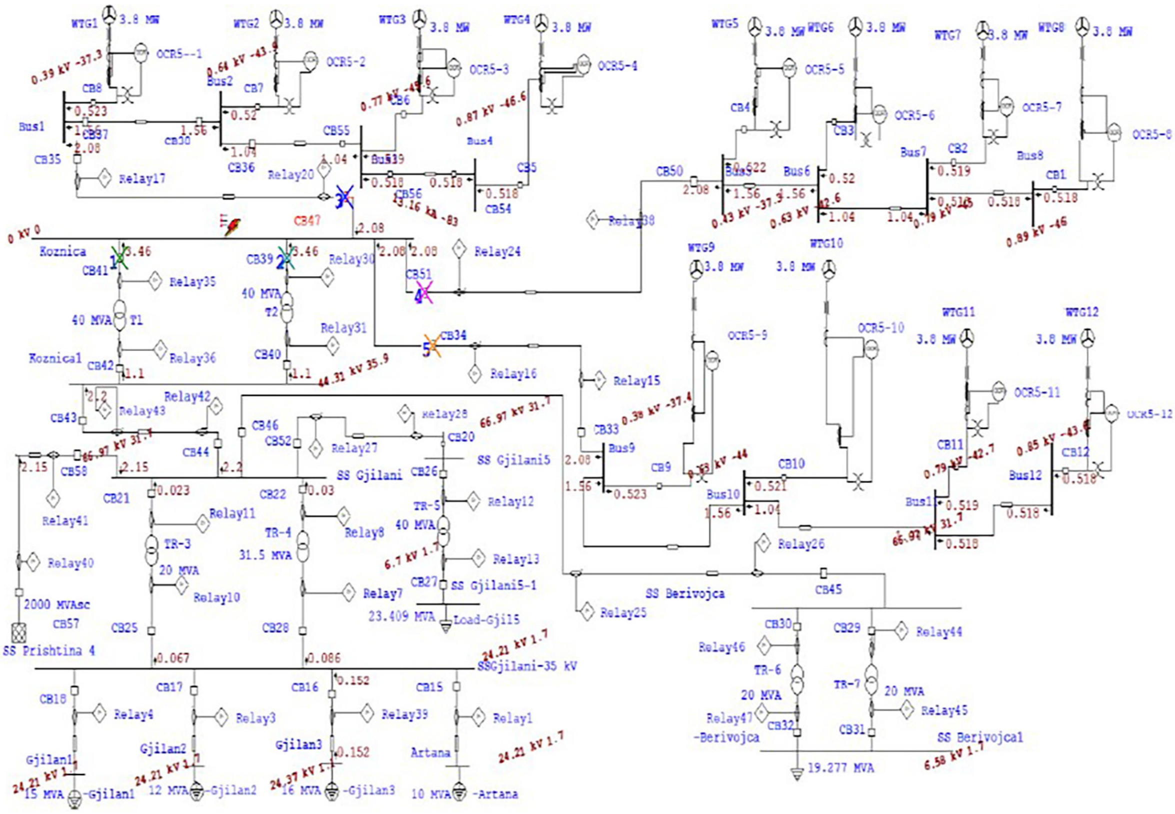

Figure 5. The situation when short circuit occurred at Koznica 35 kV busbar and action of relay protection

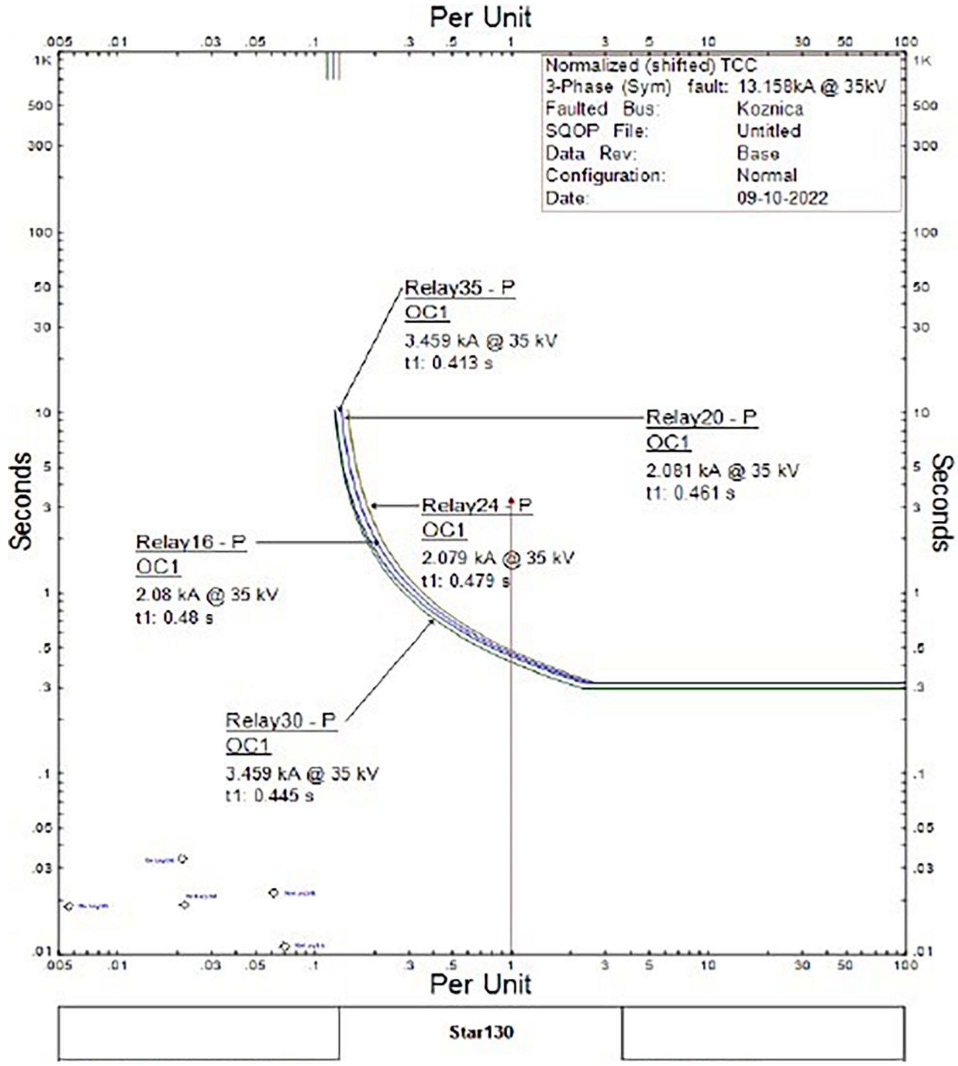

Figure 6. The coordination of protective devices in the event of a short circuit at the Koznica 35 kV busbar

involve short circuits at the Artana 35 kV busbar, the Gjilani 35 kV busbar, and the Koznica 35 kV busbar. By utilising the ETAP software simulation, the short circuit currents and corresponding circuit breakers tripping patterns were observed in each case. The analysis revealed the circuit breakers that were triggered during the occurrence of short circuits in all scenarios.

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