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Power Transmission Losses: Kajaki to Kandahar Breshna Kot

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Abstract

In this comprehensive study, we investigated the significant voltage drop observed in the 110 kV high-voltage transmission line connecting the Kajaki Hydroelectric Power Plant to the Kandahar Brishna Kot substation, spanning 171 km. The drop is mainly due to the line's extended length and its resistive and reactive characteristics. Using both quantitative and qualitative methods, supported by ETAP software and data from Da Afghanistan Breshna Sherkat (DABS), the analysis revealed that the voltage drop exceeds the International Electrotechnical Commission (IEC) standards, resulting in significant power losses. To mitigate this issue, the study recommends upgrading the voltage level from 110 kV to 220 kV. This enhancement would reduce current, minimize resistive losses, and improve efficiency by increasing the conductor's cross-sectional area and reorganizing the transmission route with standard components. Implementing these measures is projected to significantly decrease power losses and enhance the overall reliability and performance of the regional power transmission system.

Keywords: HV Transmission Line Losses; Voltage Drop; Power Loss; Upgrade the Voltage Level; Upgrade the Cross-Section Area

ضایعات لین انتقالی: ازکجکی به برشنا کوت کندهار

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چکیده

در این مطالعه، ما به‌طور دقیق کاهش ولتاژ قابل توجه را درلین انتقالی ولتاژ بلند 110 کیلوولت که متوصل‌کننده نیروگاه برق آبی کجکی و سب استیشن قندهار برشنا کوت به طول 171 کیلومتر مشاهده شده، مورد بررسی قرارداده ایم. این کاهش عمدتاً به دلیل طول زیاد لین و ویژگی‌های مقاومت فعال و غیر فعال است. با استفاده از روش‌های کمی و کیفی و پشتیبانی نرم افزار ETAP داده‌های شرکت ده افغانستان برشنا شرکت، تجزیه و تحلیل گردید. یافته‌ها نشان داد که کاهش ولتاژ از استندرد های کمسیون بین المللی الکتروتکنیک (IEC) فراتر بوده و منجر به ضایعات قابل توجه انرژی می‌شود. برای رفع این مشکل، ارتقا سطح ولتاژ از ۱۱۰ کیلوولت به ۲۲۰ کیلوولت پیشنهاد می‌گردد. این ارتقا جریان را کاهش می‌دهد و ضایعات مقاومت را به حد اقل و با افزایش سطح مقطع هادی و سازماندهی مجدد لین انتقالی با عناصر استندرد، کارایی را بهبود می‌بخشد. با اجرایی شدن این اقدامات می‌توان به‌طور قابل ملاحظه ضایعات انرژی راکاهش داده و قابلیت اطمینان و عملکرد کلی سیستم انتقال انرژی در منطقه را بهبود بخشید.

واژه‌های کلیدی: ضایعات در لین انتقالی ولتاژ بالا؛ کاهش ولتاژ؛ ضایعات انرژی؛ افزایش سطح ولتاژ و مقطع لین

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Introduction

Afghanistan's current energy supply comprises 77 percent imported power, 21 percent hydropower, and 2 percent diesel-generated power. The North East Power System (NEAPS) is the largest network in the country, encompassing Mazar-e Sharif and Kudzu in the north and Kabul in the south. The South East Power System (SEEPS) serves the Helmand and Kandahar Provinces. The Afghanistan power system is divided into four distinct networks (DABS, 2023).

1. The North East Power System (NEAPS) comprises a grid that connects seventeen load centers with Uzbekistan and Tajikistan (HVTL 220 kV, 110 kV, 35 kV).
2. Southeast Power System (SEPS), consisting of Kandahar, etc., linking the Kajaki Hydrometric Power Plant (110 kV).
3. Herat system, linking the Herat zone with the Islamic Republic of Iran and Turkmenistan (HVTL 132 kV, 110 kV).
4. Turkmenistan system, linking Herat and the north regions (110 kV).

Presently, the sector is governed by the Ministry of Energy and Water (MEW). Da Afghanistan Breshna Sherkat (DABS) is a government corporation that manages, maintains, monitors and enhances the operation and maintenance of generation stations, transmission systems, power substations, junctions, transformer stations, and the interconnected lines to provide power, ensuring availability, reliability, and quality. It also aims to enhance customer billing and collections, foster better leadership, and coordinate better with donors in the sector.

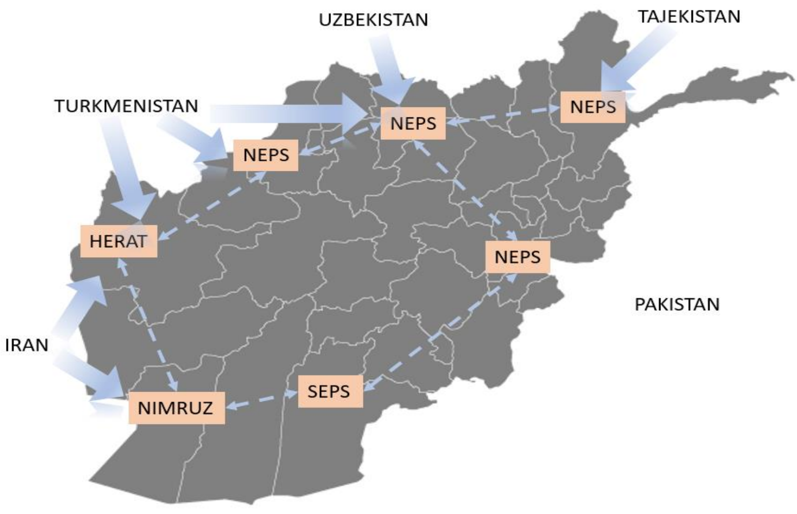

Figure 1: Afghanistan Power System Network (source: DABS)

The main parts of an electrical power system are power generation, transmission, and distribution. Delivering sufficient and lossless power to the users will be a challenge for electricity providers (Al-Hiani et al., 2021; Singh, 2018). Economic and environmental factors cause power generation to be located away from loads or consumers, and regulatory constraints on the expansion of the transmission network lead to a reduction in power stability, which can increase outages and blackouts (Kumar, 2007). Various approaches have been investigated and implemented to address the problem of loss minimization in the past. However, these approaches differ in terms of the selection of loss minimization tools, problem formulation, the different methods employed, and the solutions achieved (Living et al., 2023).

In power systems, two main types of losses are typically considered: technical and non-technical losses. Technical losses occur due to the flow of current through conductors and magnetic losses in transformers, both of which generate heat within the system. Non-technical losses, on the other hand, are related to human activities. The primary causes include electricity theft (to reduce or avoid electricity bills), inaccurate meter readings (due to false readings), unauthorized connections, and nonpayment of bills (Mehta, 2008).

Power losses in a network increase the burden on system components, potentially shortening their lifespan as the losses are dissipated in the form of heat (Pavičić et al., 2021). Additionally, higher losses necessitate increased power generation (Mehta, 2008). As population growth occurs—whether nationally, provincially, or regionally—power demand also rises. This can lead to voltage instability, blackouts, and greater losses, especially in long-distance transmission systems (Wonodi et al., 2023). Therefore, minimizing transmission losses is crucial for ensuring efficient performance. This requires the use of equipment and materials capable of managing both technical and non-technical losses.

The International Electrotechnical Commission (IEC), through its standard IEC 60038, specifies that the acceptable voltage drop in high-voltage (HV) transmission lines should range between 2% and 3% of the nominal voltage. Similarly, the Institute of Electrical and Electronics Engineers (IEEE) in the United States recommends that voltage drops in transmission lines should typically not exceed 5%, especially in long-distance transmission systems.

Key factors influencing voltage drop in a transmission line:

1. Span (Length of the Line): The longer the transmission line, the higher its resistance and reactance. This increased impedance leads to greater voltage drops over distance.
2. Transmission Line Impedance: The inherent electrical characteristics of the transmission line, namely resistance (R), inductive reactance (X_L), and capacitive reactance (X_C), significantly affect the magnitude of voltage drop.
3. Load Conditions: Variations in load demand, including sudden increases or unbalanced loading, can cause fluctuations in current flow, resulting in corresponding variations in voltage drop.

This study focuses on the power losses in the existing 185 mm^2 ACSR (Aluminum Conductor Steel Reinforced) transmission line running between the Kajaki Hydropower Plant (HPP) and the Kandahar Breshna Kot substation. The line spans approximately 171 kilometers and experiences a significant voltage drop, which adversely affects overall power transmission efficiency.

Additionally, a second transmission line is planned along the same route, referred to as the second circuit, which utilizes a single 134.87 mm^2 ACSR conductor. However, this line remains inactive, as its construction has not yet been completed, and it has not been energized. The transmission line under study is supplied by Kajaki Hydropower Plant I (HPP-I) and Kajaki Hydropower Plant II (HPP-II), with rated capacities of approximately 51.1 MW and 100 MW, respectively. Both plants generate power at a voltage level of 13.8 kV. At Kajaki HPP-I, the generated voltage is stepped up from 13.8 kV to 110 kV using three single-phase transformers rated at 15 MVA, 20 MVA, and 25 MVA. Meanwhile, Kajaki HPP-II steps up the generated voltage from 13.8 kV to 220 kV using three 42 MVA three-phase transformers. Since the subject transmission line operates at 110 kV, a 125 MVA three-phase autotransformer is employed to step down the voltage from 220 kV to 110 kV at Kajaki HPP-II (DABS, 2023; Rahimi, 2023).

Along the 171 km route of this transmission line, there are five connection points or substations, namely:

1. SANGIN North Substation
2. DORAHI Substation
3. MAIWAND Substation
4. PASHMOL Substation
5. KANDAHAR Substation

These are illustrated in detail in Figure 2 in the findings section.

The Kajaki District is located in southern Afghanistan, within Helmand Province. The Kajaki Dam, situated on the Helmand River, was constructed in 1953. The dam stands 94 meters high and spans 273 meters in length.

The following issues have been reported with the 110 kV transmission line connecting the Kajaki Hydropower Plants (HPPs) to the Kandahar Breshna Kot substation:

1. Structural Issues: Concerns related to the physical integrity and design of the transmission line structures.
2. Missing Shield Wire: The absence of shield wire across most sections of the line reduces protection against lightning strikes.
3. Lack of Transposition: No transposition was implemented along the line, which may negatively affect voltage balance and overall transmission line performance.
4. Voltage Losses: Significant voltage drops occur due to the 171 km length of the transmission line.
5. Suboptimal Voltage Level: The selected transmission voltage may not be optimal for efficient power delivery over such a long distance.

Based on these issues, the following research questions are proposed:

1. How much power will be lost in the existing power system?
2. How can we minimize the transmission network losses?
3. Is it feasible to use double conductors per phase to reduce losses in the transmission line?

Several studies and reviews have been conducted in the same research area, highlighting methods for reducing power losses and improving transmission efficiency, which are summarized below.

Transmission line losses are a crucial topic and issue in power systems research. Several methods and techniques have been employed to mitigate these losses, and one of these modern approaches is flexible alternating current transmission systems (FACTS). In this paper, one of the most important types of this technology, the unified power flow controller (UPFC), was used to reduce losses in the Iraqi national grid (ING) 400 kV. This paper presents an efficient method for minimizing losses in transmission lines within the ING system (400 kV, 46-bus approach). A particle swarm optimization (PSO)-based optimum proportional-integral (PI) controller with UPFC was proposed to obtain the optimal location of UPFC and optimum parameters of the PI controller to achieve the objective function of the research. MATLAB coded the algorithm. The Newton-Raphson method was employed to perform load flow analysis. The results showed that the best place for UPFC is buses (14-17) named BGE4 (Baghdad)-AMN4 (Baghdad), and the total active power and reactive power losses decreased from 727.4593 to 579.3874 MW and from 5155.9 to 3971.1 MVAR, respectively and also led to voltage regulation (Hussein et al., 2023).

The study examines power loss in high-voltage transmission lines, with a focus on minimizing corona losses resulting from air ionization around conductors at elevated voltages. By comparing Ohmic and corona losses, the research introduces bundled conductors as an effective technique for reducing corona discharge. A nonlinear multivariable model of total power loss is developed and optimized using an unconstrained method based on the Hessian matrix. Results show that corona loss decreases significantly with an increased number of bundled conductors (from 2 to 4 strands) and greater spacing between them. Optimal loss minimization occurs when the operating voltage approaches the critical disruptive voltage and the current is at a minimum. MATLAB simulations confirm an exponential reduction in corona loss and a declining voltage gradient with increased bundling and spacing, validating the approach for enhancing transmission efficiency (Omeje, 2020).

To mitigate against the loss of electrical power in transformers within the 330 kV transmission system in Nigeria using the Fuzzy logic technique. The objectives included utilizing Newton-Raphson's technique to perform a load flow analysis to determine line losses, bus voltages, and load angles and to use a Fuzzy Inference System to determine the points suitable for capacitor placement to reduce reactive power losses on the process and increase voltage profile, thereby improving the power system's stability and efficiency. Using the MATLAB toolbox, Newton-Raphson's power flow software was run to yield *p.u* nodal voltages ranging from 0.8890 to 1.0564, total real power line losses (0.09438 *p.u*), and total reactive power line losses. The power loss index is assessed and normalized in the range [0, 1] using power loss reduction. These indices, along with the magnitude of the *p.u* nodal voltage, were fed into the Fuzzy Inference System to produce the Capacitor Suitability Index (CSI). The obtained CSIs vary from additional to 0.897. Capacitor sizes of 50MVar, 85MVar, and 60MVar are introduced on the buses. Voltage profile improved by 3.74%, 3.27%, and 3.33% individually, while absolute genuine power loss in the framework was reduced by 17.55%, and all-out receptive influence injection to the system diminished by 8.70% separately. The installation of capacitors at strategic locations within a transmission framework enabled the achievement of a more stable network, reliable service delivery, and a record of minimal technical losses (Woke, 2023).

Minimizing electric power losses in transmission lines is crucial for enhancing grid efficiency, particularly during periods of peak demand. This study evaluates the effectiveness of a modified analytical model for minimizing power losses in Uganda's 132 kV and 220 kV transmission networks. Traditional models, which incorporate Ohmic and Corona losses, were found to be inadequate for optimization using gradient-based methods due to their inability to yield global minima. A modified loss model was developed by introducing a third, dimensionally consistent term that combines Ohmic and Corona losses. Optimal variables were derived using first- and second-order derivatives and optimality was confirmed through analysis of the Hessian matrix determinant. The modified model demonstrated superior performance compared to the unmodified model, reducing power losses from 0.406 to 0.391 kW/km/phase on the 220 kV Bujagali–Kawanda line and from 0.452 to 0.446 kW/km/phase on the 132 kV Masaka West–Mbarara North line. The results confirm that the modified model significantly enhances power loss minimization and can be applied to similar transmission networks beyond Uganda (Living et al. l, 2023).

This study presents the application of a Static Synchronous Series Compensator (SSSC) to enhance the steady-state stability and power transfer capability of Oman's 400 kV transmission grid. With the growing demand for electricity and the need for long-distance transmission from remote generation sites, the grid is increasingly susceptible to voltage instability and limited power transfer under heavy loading conditions. A section of the Oman Main Interconnected System (MIS) was modeled and analyzed using Newton-Raphson Power Flow and Continuation Power Flow methods in PSAT. The weakest bus in the network was identified, and the SSSC was strategically placed on several lines feeding this bus to evaluate performance improvements. The results demonstrated significant enhancements in bus voltage profiles, reductions in both real and reactive power losses, and an increase in the maximum power transfer limit (λ_max) from 2.3948 to 2.4153. The optimal location for SSSC installation was found to be between buses 3 and 5. This study confirms the effectiveness of the SSSC in strengthening grid stability and improving transmission efficiency under steady-state conditions (Al-Hinai et al., 2021).

As evidenced in the reviewed literature, various approaches, such as the implementation of FACTS devices, the use of bundle conductors, and the application of capacitor compensators, have been successfully employed to reduce power losses in transmission systems. However, considering the existing infrastructure, particularly the current transmission line configuration and the transformer specifications in the generation system, increasing the transmission voltage level emerges as a more effective and practical solution. Higher voltage levels reduce current for the same power transfer, thereby minimizing I^2R losses over long distances and significantly enhancing the efficiency and reliability of the transmission network.

Methods and Materials

As the identified problems and associated concerns confirm, the subject transmission line is experiencing a significant voltage drop and power loss, necessitating a thorough analysis to determine the root causes and propose practical solutions. To address this issue, a combination of quantitative and qualitative research methods was employed for data collection, while descriptive and analytical methodologies were used to assess the performance of the transmission line.

To analyze and evaluate the research subject, the required information was obtained through interviews, questionnaires, and data recording from sources such as Da Afghanistan Breshna Sherkat and the Ministry of Energy and Water in the following two steps.

Data Collection

Focused on gathering essential information regarding the Kajaki Hydropower Plants (HPPs), associated substations, the current operational status of the 110 kV transmission line, and the rated capacities of all network nodes. Most of the primary data were obtained from the

Afghanistan South East Power System single-line diagram provided by the Afghanistan Energy Information Center (AEIC). Additionally, several meetings and technical discussions were held with AEIC personnel at the Ministry of Energy and Water (MEW) to obtain a detailed understanding of the transmission route and its configurations.

To support the analysis of transmission losses and performance evaluation, secondary data were collected from various departments within Da Afghanistan Breshna Sherkat (DABS) and the Ministry of Energy and Water (MEW). This included real-time operational data from the sending end (Kajaki HPPs) to the receiving end (Kandahar Breshna Kot substation). Given the lack of a continuous shield wire on the transmission line, flash density for the relevant regions was also examined. Based on data from VAISALA Weather's Global Lightning Density Map, the flash density was reported as 0.4 events/km^2/year for Helmand province and 0.5 events/km^2/year for Kandahar province.

For the calculation of geometric and electrical parameters, two types of transmission line configurations were identified: horizontal and triangular. These configurations were essential in determining conductor spacing and impedance characteristics, which directly influence the voltage drop and power losses along the line.

To conduct the load flow analysis using the ETAP software, essential electrical and structural parameters of the network were carefully considered and incorporated into the simulation model. These parameters included the phase sequence, section lengths, conductor cross-sectional area, substation capacities, generation capacities, generation voltage levels, transformer ratings, and the voltage levels of all buses. This comprehensive dataset ensured an accurate representation of the system, enabling reliable analysis of voltage profiles, power flows, and system losses throughout the 110 kV transmission network.

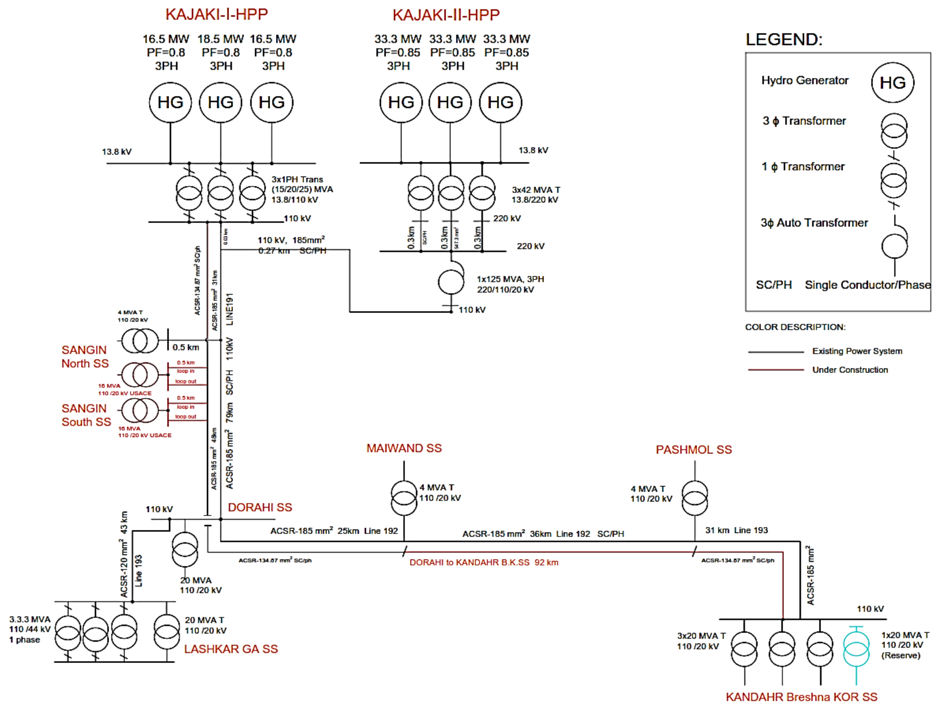

Figure 2: The single-line diagram of the Kajaki HPPs and Kandahar Breshna Kot SS transmission line

ETAP Analysis

The Electrical Transient Analyzer Program (ETAP), combined with the Newton-Raphson power flow method, was utilized to analyze the voltage profile and power flow characteristics of the 110 kV transmission line under three distinct load conditions: 100%, 70%, and 50% of the rated load. The objective was to evaluate power generation versus system loading, voltage levels at critical buses, power flow through transmission branches, and overall voltage drops across the network.

The analysis showed that both active and reactive power losses varied with the load level:

1. At 100% load, the system recorded losses of 14.364 MW (active) and 33.329 Mvar (reactive).
2. At 70% load, losses were reduced to 8.447 MW (active) and 17.167 Mvar (reactive).

3. At 50% load, the observed losses were 4.905 MW (active) and 7.338 Mvar (reactive).

Voltage levels at the receiving end (Kandahar Breshna Kot substation) were significantly affected by the loading level:

1. At 100% load, the voltage dropped to 84.2 kV, indicating a loss of over 25 kV from the nominal 110 kV.
2. At 70% load, the receiving end voltage improved to 91.76 kV, with a voltage drop of approximately 18 kV.
3. At 50% load, the voltage further improved to 96.6 kV, corresponding to a loss of about 13.4 kV.

These results confirm that the long transmission distance and current loading conditions are contributing to significant voltage drops and power losses, which degrade the system's overall efficiency. Similar loss patterns were observed across the main branches of the transmission network, reinforcing the need for technical interventions to improve performance.

Results

Transmission Line Length Impact on Losses: The subject transmission line spans 171 km, which significantly affects system losses. Unfortunately, the line lacks organization in certain sections, has not been adequately transposed, and lacks a shield wire for the entire route. These factors can impact transmission line performance and efficiency.

Load-Dependent Losses: According to the Newton-Raphson method, system losses vary with the load. When the load is reduced by seventy or fifty percent, the system losses decrease by almost half. This finding highlights the importance of load management.

Overload Concerns: The existing transmission line experiences overload, particularly between the Kajaki Hydro power plants and the Sangin North substation, as well as between the Sangin North substation and the Dorahi substation, at 100% and 70% rated load flow. Addressing this overload is crucial for maintaining system stability.

Voltage Level Challenges: The transmission line operates at 110 kV, which is insufficient for transmitting power over the entire 171 km length. As a result, current increases and voltage drops occur due to resistive and reactance parameters. These issues impact power quality, reliability, and stability for end-users.

Discussion

The ETAP load flow analysis identified significant power losses with a 110 kV transmission line spanning 171 km and verified the overloading status mentioned below.

At 100% rated load

1. Kajaki CP to Sangin North SS (Line #191 / 1x185 mm^2): 140.3% loading;
2. Sangin North SS to Dorahi SS (Line #191 / 1x185 mm^2): 135.5% loading;

The downstream segments showed relatively lower but still notable loading levels:

3. Dorahi SS to Maiwand SS (Line#192/1x185 mm^2), 84.6% loading;
4. Maiwand SS to Pashmol SS (Line#192/1x185 mm^2), 80% loading.
5. Pashmol SS to Kandahar SS (Line#193/1x185 mm^2), 75.3% loading;

At 70% rated load

1. Kajaki CP to Sangin North SS (Line#191/1x185 mm^2), 116.6% loading;
2. Sangin North SS to Dorahi SS (Line#191/1x185 mm^2), 114.3% loading;
3. Dorahi SS to Maiwand SS (Line#192/1x185 mm^2), 65.4% loading;
4. Maiwand SS to Pashmol SS (Line#192/1x185 mm^2), 62.1% loading;.
5. Pashmol SS to Kandahar SS (Line#193/1x185 mm^2), 58.7% loading.

At 50% rated load

The system operated within safer limits:

1. Kajaki CP to Sangin North SS (Line#191/1x185 mm^2), 90% loading;
2. Sangin North SS to Dorahi SS (Line#191/1x185 mm^2), 87.8% loading;
3. Dorahi SS to Maiwand SS (Line#192/1x185 mm^2), 50.2% loading;
4. Maiwand SS to Pashmol SS (Line#192/1x185 mm^2), 47.9% loading;
5. Pashmol SS to Kandahar SS (Line#193/1x185 mm^2), 45.5% loading;

These findings demonstrate that even under reduced loading conditions, the first two segments of the line remain overloaded, indicating severe capacity limitations that require urgent attention.

Meanwhile, there is no proper voltage selection based on the distance and the total power to be transmitted, no use of transposition, disappearance of shield wire in most sections of the transmission line, and issues with the transmission line structure.

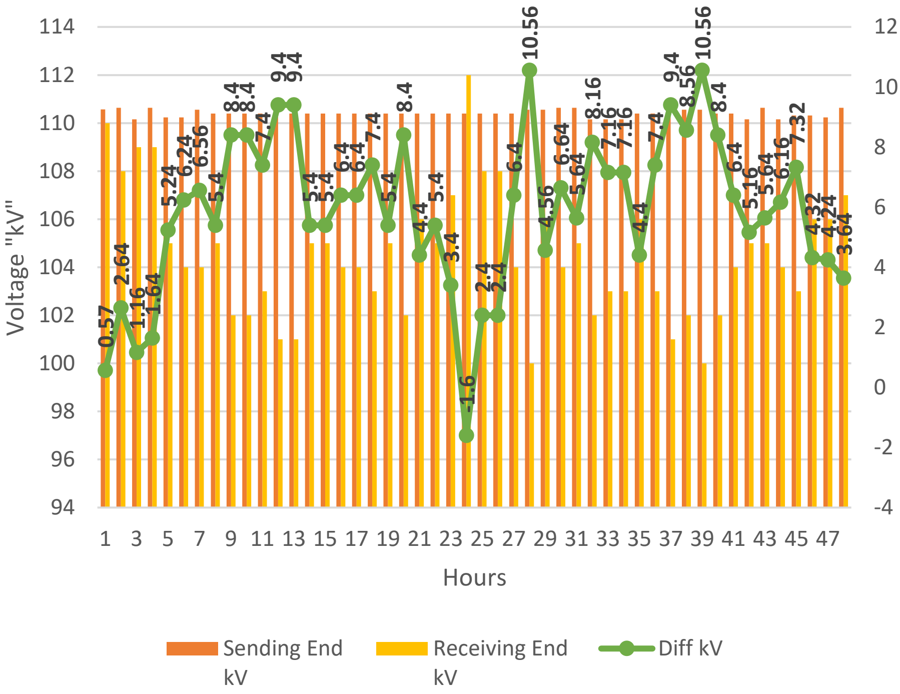

Figure 3: The sending and receiving end voltage profile (source: DABS)

The DABS-related department data, which was recorded for 48 hours about the sending end voltage and the receiving end voltage, clearly define the instability and variation of voltage with the subject transmission line, showing that the voltage losses are about 10.56 kV (with almost 31% rated load, 99.44 kV) at the receiving end by considering the 110 kV sending end voltage. By considering the contribution of transformers and bus losses, the analyzed study satisfies the case.

As previously raised, power and voltage losses at 100% and 70% loads are very high. To address this, load management can be performed by increasing the voltage level or the conductor cross-sectional area, which can significantly reduce these losses. The use of a bundle conductor is not recommended for this specific transmission line due to its existing structural limitations, such as inadequate tower design, lack of shield wire, and poor phase transposition. With growing demand and the increasing importance of analysis, the rising number of consumers, and improved lifestyles, electricity demand is on the rise. To provide reliable, stable, and high-quality power, analyzing the power transmission system and reducing losses becomes essential.

Conclusion

As per the findings and analysis of the 110 kV transmission line between the Kajaki Hydro powerplants and the Kandahar Breshna Kot sub-station at the endpoint through ETAP software, the power or voltage losses are more due to the high length of the subjected transmission line and even few sections of transmission line show overloading so it is important and considerable to focus on solutions for reliable and good power quality serving to consumers.

Additionally, the subject transmission condition does not meet the standard requirement for 110 kV or 220 kV transmission line structure (IS 800:2007) and (IS 802, P1/S1). Used different types of support structures like towers or poles (lattice, concrete, iron), different cross-arms (made locally), no shield wire, no standard foundation for supports, and no transposition to reduce power losses, so all pre-organizations were required to organize the complete route starting from Kajaki hydropower plants to Kandahar Breshna Kot sub-station.

In the same way, to assess the voltage level of the subject transmission line as per the recommended criteria for voltage level selection within the design of a transmission line system.

$$V_{LL} = 5.5 \times \sqrt{\left(0.62 \times 171 + \frac{151.5 \times 10^3}{100}\right)} = 221.44 \text{ kV}$$

According to the voltage level selection for the subject transmission line, the 110 kV voltage level was not recommended for the transmission line design due to the assigned length, and the power will be transmitted at a lower voltage level. Therefore, the nearest standard voltage level is 220 kV is acceptable. The effectiveness of the 220kV voltage level selection on pure voltage drop is shown in Fig. 4 as each branch starting from Kajaki HPPs to the first substation and so on, named A-B, B-C, C-D, D-E, and E-F, where the branch voltage drops shown in three different load categories (100%, 70%, 50%) will vary as its span respectively.

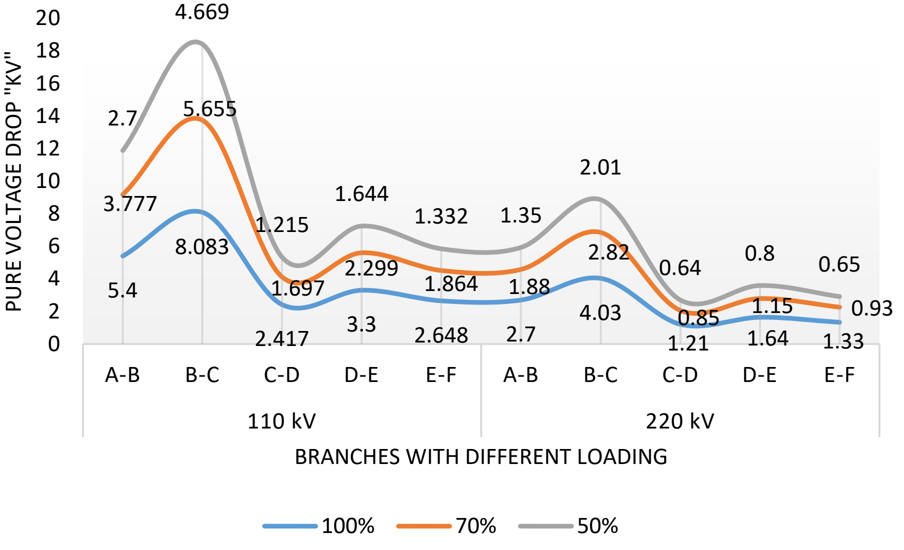

Figure 4: Voltage profile comparison with the 110 kV and 220 kV (Voltage level reduction indicator in case of voltage of 220 kV)

Recommendation

In light of the findings from the load flow analysis and system performance evaluation, it is evident that the transmission line between Kajaki Hydropower Plant and Kandahar Breshna Kot Substation is experiencing significant technical losses and reliability challenges. To address these issues effectively, the following recommendations are proposed:

1. Upgrade the Voltage Level to 220 kV: Transition the current 110 kV system to 220 kV to significantly reduce line current, lower resistive (I^2R) losses, improve voltage regulation, and increase overall power transfer capability.
2. Enhance Conductor Capacity and Routing: Increase the cross-sectional area of the conductors and reorganize the transmission line route using

standard transmission elements to support the higher voltage and improve thermal performance.

3. Replace Support Structures: Replace or upgrade existing support structures with standardized lattice towers to ensure mechanical stability, facilitate easier maintenance, and align with international transmission standards.
4. Install Shield Wires: Add overhead ground (shield) wires along the complete transmission line to provide adequate lightning protection and improve resilience against transient faults.
5. Implement Line Transposition: Apply phase transposition at one-third intervals along the transmission route to balance line impedance, reduce voltage unbalance, and minimize mutual inductive coupling between phases.

Further research on the topic of cost-benefit or economic indicators is recommended based on the provided recommendations.

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Author Contributions

Qais Ahmad Rahimi Conceptualization, data collection, methodology, analysis, visualization, and writing, Mohammad Shafi Sharifi Review and editing, supervision.

Conflict of Interest: The authors declare no conflict of interest.

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