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220KV HV Transmission Line from Deir Ammar to Deir Nbouh in Northern Lebanon

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Abstract. This paper provides a thorough analysis of the design, construction, and addition of a crucial 220-kV high-voltage transmission line that connects Deir-Ammar and Deir-Nbouh stations in northern Lebanon. The line effectively transports electricity over 11.1 kilometers, highlighting its essential function in the electrical grid. To guarantee reliability, dependability, and safety, the design takes environmental, landscape, and electrical load issues into account. High-strength materials and specialized equipment are used and proposed. In the end, the transmission line greatly improves electrical connectivity, supporting high-quality materials and environmentally sensitive design that increase grid stability, reliability, and energy accessibility. This infrastructure investment supports long-term energy needs and socioeconomic development in interconnected regions, benefits people, and businesses, and guarantees a consistent power supply. Results obtained through simulation closely align with the manual calculations and site visit measurements.

Key words. Transmission lines, sag, horizontal tension, power flow.

1.Introduction

In today's cultures, electric power transmission is essential for transferring massive quantities of electrical energy from sources of power supply to high-demand locations. But Lebanon's power grid infrastructure has flaws and inefficiencies that have made it difficult for the nation to effectively supply the nation's growing energy needs.

Lebanon has an unstable and insufficient electricity grid due to political meddling, fuel reliance, insufficient investment, and infrastructure problems. These issues have severely impacted the daily lives of its citizens and impeded economic growth. They have resulted in frequent blackouts, high operating expenses, and restricted access to electricity.

The deployment of 220kV High-Voltage (HV) transmission lines with integration of worldwide standards presents itself as a feasible remedy to some of these problems and Lebanon's growing energy requirements. This project calls for an all-encompassing strategy that includes careful design considerations, reliability improvements, cost-effectiveness, and safety precautions. These include environmental impact evaluations. This paper aims to investigate the design intricacies of HV transmission line design, with a focus on the effects of route selection on cost, reliability, and the environment. It carefully examines the results, restrictions, security issues, benefits and drawbacks of high-voltage systems. For a thorough understanding of these systems, the next parts explore certain aspects of HV transmission line configurations, thorough design techniques, sag and tension concerns, and simulation design and results.

This study's main goal is to conduct a thorough analysis of the 220-kV transmission line's significance, construction, and design. The study will assess influence on operational efficiency, environmental concerns, and grid reliability. Moreover, it aims to investigate fault situations, power flow regulation, sag and tension calculations, and safety assessments using MATLAB simulations and data collection methods. The goal is to offer knowledge and research that advances Lebanon's electrical grid, meets energy demands, and guarantees the security and dependability of the transmission line in the linked Deir-Ammar and Deir-Nbouh districts.

2. Sag and Horizontal Tension

The importance of sag predictions for overhead power line conductors is categorized into two segments. First, given the inherent danger caused by closeness to live power lines, protecting the safety of persons and their surroundings is critical. The second aspect focuses on the conductors themselves, stress the need of sag calculations in order to avoid the possibility of high mechanical stresses that might cause irreversible damage or fracture. The necessity of sag calculations is to prevent the potential of severe mechanical stresses that could lead to breakage or permanent damage. Power line sag calculations are often only done in the early stages of design [1], [2]. In order to find the sags between towers several parameters and steps should be done. This includes specifying the cable type and appropriate parameters, use the catenary equation, and locating the exact coordinate of the towers.

Several auxiliary variables are required to solve the catenary's state equation. These include steepness, medium span length, and $\sigma_{\text{horizontal}}$, which represents the horizontal component of the conductor's mechanical stress.

These variables can be defined in the following ways:

The steepness is determined according to (1):

$$S = \sum_{i=1}^{N_{tw}} \frac{chord^3}{span^3}, \quad (1)$$

where: span is the horizontal distance between two towers and N is the number of towers.

The medium span is determined according to (2):

$$\text{Chord} = \sqrt{\text{span}^2 + (\text{h}_{j-1} - \text{h}_j)^2}\ , \quad (2)$$

where: h_{j-1}, h_j are the heights of the catenary's two ending points.

The horizontal mechanical tension is found using (3):

$$\sigma_{\text{horizontal}} = \frac{\text{span}}{\text{chord}} * (\sigma_{\max} - Y_z * \frac{1}{2}|h_{j-1} - h_j| + b_z)\ , \quad (3)$$

where $\sigma_{\max}$ and Y_z are standard values.

For each span, these parameters must be determined. After that, we may determine the mechanical tension of the conductor's mean value σ_k.

The state equation will be solved to find σ_k at this point because the auxiliary variables are initialized. The following is a possible formulation for the catenary's state equation:

$$\frac{E_{mod}\gamma^2 span_m^2}{24\sigma_k^2} - \sigma_k = \frac{E_{mod}\gamma_z^2 span_m^2}{24\sigma_k^2} - \sigma_{kz} + E_{mod}\alpha\left(T_{conductor} - T_z\right) \quad (4)$$

The mechanical tension of the conductors σ_k is now been computed. In each span, 1000 points are used to compute the conductor sag [2].

Several simulations are done at different temperatures and for different types of conductors.

The following will show simulation results for an ALMELEC 570mm2 conductor that is used in Lebanon along a transmission line of 11.1-kilometer, specifically at 50 degrees Celsius.

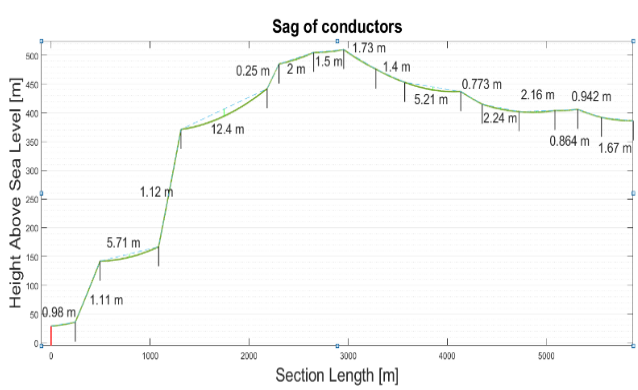

Fig. 1. Tower altitude and sag of ALMELEC conductor at 50 degrees from Starting point towards tower 19.

Fig. 1 shows the towers altitude and the sag between the starting point at Deir-Ammar station and 6 Km) towards Deir Nbouh station(tower 19), while Fig. 2 shows the towers altitude and the sag between 6 Km and the destination at Deir Nbouh Station.

It is shown in Fig. 1 that a notable sag is observed between tower 5 and 6, measuring 12.4 m. Similarly, a sag between tower 11 and 12, measuring 5.27 m is noted.

In addition, sag measuring 7.23 m is shown in Fig. 2 between tower 21 and 22. However, all other remaining sag fall below the 3 meters threshold.

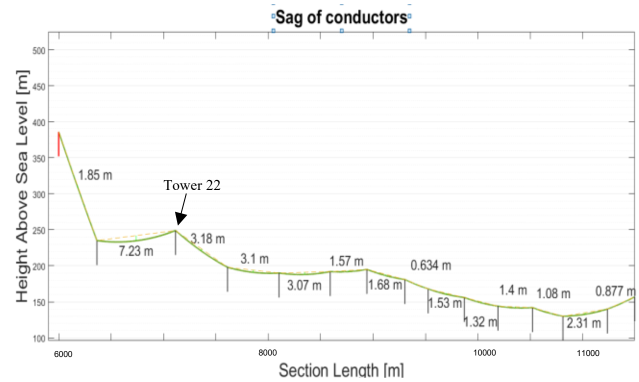

Fig. 2. Tower altitude and sag of ALMELEC conductor at 50 degrees from tower 20 to destination.

3. Data Collection and Analysis

A. Route Selection

Finding the transmission line's most feasible route requires a comprehensive analysis that takes engineering, maintenance, and environmental factors into account. Making judgments that are in line with sustainability and technical viability requires an integrated approach. It demands a careful evaluation of all feasible choices to make sure the selected path not only satisfies engineering specifications but also considers environmental considerations. Moreover, it is critical to have a thorough awareness of the constraints specified by existing rules and regulations when choosing transmission line routes that consider ecological considerations. This guarantees adherence to environmental regulations and promotes conscientious decision-making that reduces detrimental effects on the ecosystem.

Even though it takes more time than on-site visits, Google Maps is still a recommended strategy for proper tower positioning. This method offers a useful way to identify each tower's exact location along the transmission line route. Fig. 3 displays a google map showing the address for each tower location. Later, site visits to the Deir Ammar and Deir Nbouh (northern Lebanon) stations were carried out to obtain further data concerning the trajectory of the line, the points at which it intersects with settlements and the tower addresses. In densely populated regions such as the Deir Nbouh area, where many high-voltage transmission lines coexist, this on-ground data collection effort was especially important.

After the tower addresses were acquired, the data was sent to the GIS facility at the University of Balamand. In this case, the data were meticulously analyzed, including the tower's elevation. This approach was instrumental in precisely identifying the essential 32 towers crucial for this study, encompassing a substantial stretch of 11.1 kilometers. The collected data, augmented by elevation information enables the determination of sags in the power lines.

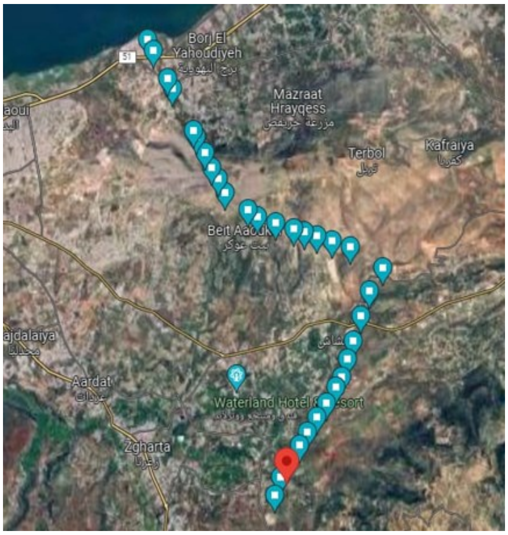

Fig. 3. Google Map showing the address for each individual tower location.

B. Safety Assessment

The map produced by the GIS center in the first part of the line shows that most of the towers are positioned strategically to take use of Terbol Mountain's terrain. Because the line is elevated and does not endanger the surrounding area, the placement of these towers shows that there is not an inherent risk created by the sag in this portion. Many homes are located below or near the transmission line. Considering this situation, it is imperative to carry out a detailed analysis of every property along this section to determine whether every home is inside a safe zone and whether there are any potential concerns associated with being close to the power line. As part of this inquiry, the power line's structural stability, the distances between it and the homes, and the potential for electromagnetic field (EMF) exposure should all be thoroughly investigated and assessed. Such an assessment is required to determine whether the dwellings are securely away from the power line and whether there are any potential dangers or hazards associated to their close vicinity.

According to the findings, all sags are more than 20 meters above the ground, and the distances between homes and power lines, measured from the lowest point of the line, are safely above the recommended safety standards [4], [9].

A safe distance is considered to be at least 20 meters between a house's ground level and the power line to reduce the possibility of any issues arising from electromagnetic fields (EMFs), electrical discharge, or other safety hazards [4], [9], [10].

4. Methodology

This study's simulation component is crucial and forms a cornerstone of the research's framework. In this regard, two painstakingly completed MATLAB simulation are quite important. In the first simulation, crucial problems in a high-voltage (HV) transmission line are analyzed using a pi-circuit model having 0% shunt admittance [7]. With a primary focus on conducting a methodical fault study, this study aims to especially target the transmission line segment that connects the Deir Ammar and Deir Nbouh stations in North Lebanon.

A. Fault Analysis

Fig. 4 provides a clear and thorough representation of a three-phase fault system. It displays a single-line diagram representing a three-phase fault system. The system under consideration functions at the conventional power frequency of 60 Hz and has a significant voltage capability of 220 kV.

This system simulation is important because it gives a clear and comprehensive representation of the three-phase fault system by visually encapsulating its complexities. It contributes to the study's overall comprehensiveness by acting as a vital point of reference for fault scenario analysis and a greater understanding of the system's response under different conditions. The electrical infrastructure from Deir Ammar station to Akkar stations comprises several key components. At Deir Ammar station, there is a synchronous machine of the swing generator type, rated at 60 MVA and 15KV. This is followed by a three-phase transformer, two-winding, with a rating of 60 MVA and a voltage ratio of 15/220 KV. Preceding and succeeding Bus 1, there are three-phase breakers, CB1 and CB2, respectively.

A three-phase pi-section line spanning 11.1 km connects Deir Ammar to Deir Nbouh with 0% shunt admittance. In the event of a single or three-phase fault occurring along this line, a three-phase fault is simulated. At Deir Nbouh station, a three-phase breaker, CB3, is situated before a three-phase transformer, two winding, with a rating of 60 MVA and a voltage ratio of 220/66 KV.

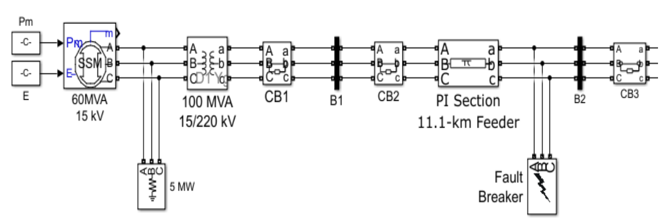

Fig. 4. Single-line diagram representing a three-phase fault system.

B. Line-to-Ground Fault Applied on Phase A

The fault breaker is specifically designed to react to a line-to-ground failure that arises during phase A.

When examining the behavior and responses of the system under fault conditions, the graph and wave pattern seen on the scope in Fig. 5 are essential. This waveform can provide important information regarding the fault's effects, the system's response, and the effectiveness of the preventive measures in place. A line-to-ground fault scenario happens at one cycle, which causes the fault current to increase to 1.4 kA (depicted as the fault maximum current in Fig. 5). A critical evaluation is performed during the fault phase to determine the most energy the line can withstand in megajoules (MJ) before reaching a critical threshold.

When the line reaches five cycles, the protective mechanism kicks in, and protection relays swiftly open breakers CB1 and CB2.
At the first zero crossing, which occurs after the breakers respond, the fault current eventually decreases to negligible levels (6 cycles). From that point on, the voltage varies while staying about around 220 kV.

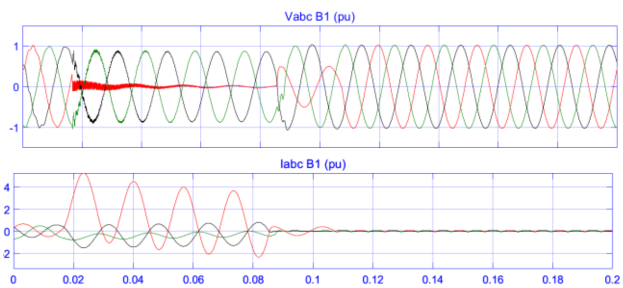

Fig. 5. Results for Line-to-Ground Fault at phase A on bus B1.

C. Three-Phase-to-Ground Fault Applied

The circuit breaker for faults is appropriately set up to identify and respond to a Three-Phase-to-Ground fault as shown in Fig. 6.

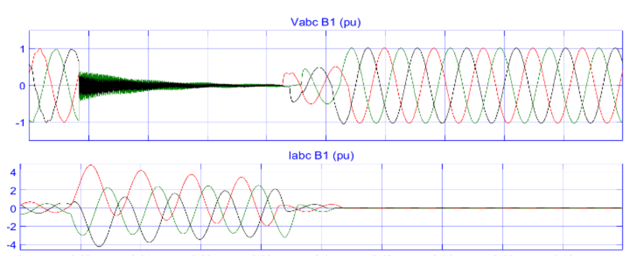

Fig. 6. Results for Three-Phase-to-Ground Fault on bus B1.

It is important to understand that, in contrast to a line-to-ground fault scenario, energy dissipation accelerates more quickly when a fault develops. In Fig. 6, in just five cycles after the defect is initiated, the energy released, measured in megajoules (MJ), exceeds the threshold. This sharp increase in energy dissipation indicates that fault-related pressures and stresses are building up inside the system very quickly. Interestingly, this collapse of the energy barrier happens one cycle before the line breakers open, highlighting how quickly the system responds to fault circumstances. The fault current then gradually decreases until it eventually reaches insignificant levels, indicating a critical moment in the fault response. This accurate detection of the fault current decrease happens at the first zero crossing that happens after the breaker operates, which usually happens after six cycles. As a result, the voltage of the system fluctuates during this time but stays constant at roughly 220 kV. This thorough observation and analysis throw light on the fast energy dissipation, the timing of breaker operations, and the voltage fluctuations that take place during fault scenarios, all of which are important insights into how the system will behave in the case of a failure. Gaining an understanding of these dynamics is essential to improving the system's fault tolerance and guaranteeing that it will consistently provide a steady power supply even under demanding circumstances.

D. Power Flow Control

Specifically, the second simulation experiment using the Bundle-Controlled Line Impedance Modulator (LIM) addressed load variations between 90 and 140 MVA. The goal of the simulation experiment was to precisely mimic the dynamic load circumstances within the system. This range is important because it captures the operating strains that a high-voltage transmission line would experience in the actual world. Because of the LIM's sophisticated architecture, these stress fluctuations can be precisely replicated, guaranteeing that the simulation closely resembles the real load circumstances. The capacity of the model to dynamically adjust to shifting loads is essential for comprehending how the system behaves in various operating conditions. This knowledge is crucial for projecting the system's behavior and supporting the formulation of plans for increased system efficiency and dependability. A more detailed understanding of the system's resilience and operating capabilities might be obtained by going into further depth about the LIM's validation procedure against real-world data and the implications of the simulation results [5].

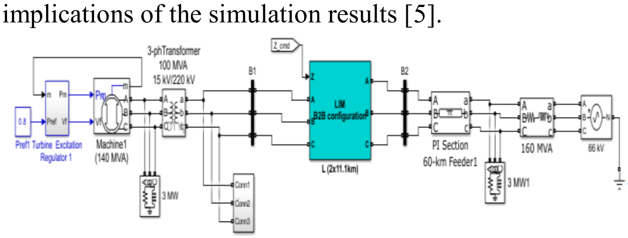

Fig. 7. Power flow control utilizing a LIM.

Fig. 7 illustrates the electrical configuration that runs from the Deir Ammar station to the Akkar stations. It is made up of essential parts that are vital to the transmission system. It starts with a synchronous machine at Deir Ammar that has a large 140 MVA rating and runs at 15 KV. Next, a two-winding, three-phase transformer with a voltage ratio of 15/220 KV and a rating of 140 MVA is used, which is also very amazing.
One significant addition that denotes the development and improvement of the transmission infrastructure is the creation of a new link that originates from the Deir Ammar end. Other parts are the CB1 and CB2 three-phase breakers, which are arranged before and after Bus 1. To maintain the operational integrity of the system, these circuit breakers are essential.
An 11.1-kilometer three-phase pi-section line connects Deir Ammar with Deir Nbouh and serves as an essential power transmission conduit. A two-winding, three-phase transformer with a large rating of 100 MVA and a voltage ratio of 220/66 KV is the main attraction of the Deir Nbouh station. The CB3, a three-phase breaker, comes next and plays a crucial part in controlling the system's power flow.
The reach of the transmission network is further increased with an 11.1-kilometer, three-phase pi-section line that connects Deir Nbouh to the Albared station. In particular,

the Line Impedance Modulator (LIM) used in this section has 0% shunt admittance and is intended to use just 7 conductors in its 2 PI component.
This complete configuration is an example of a strong and well-thought-out transmission system, efficiently distributing electricity among multiple stations and adding to the stability and dependability of the electrical grid. High-capacity transformers, breakers, and cutting-edge technology like the LIM are used to demonstrate the region's dedication to providing reliable and efficient power to Akkar.

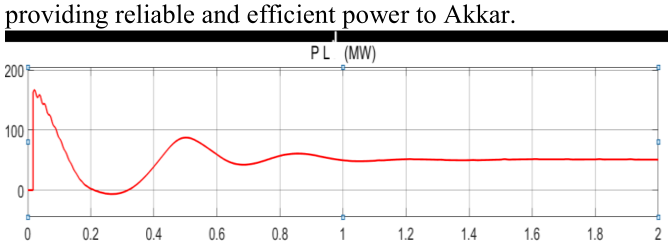

Fig. 8. Active power at bus B1.

The active power evolution at bus B1 is dynamically shown visually in Fig. 8, which provides information about its temporal nature. At first, the active power generation begins at a starting point that is comparatively high, approximately 150 megawatts (MW). Then, though, it experiences a sharp and abrupt decrease that lasts for less than a second before stabilizing at a steady 53.68 MW. This quick modification demonstrates the system's responsiveness and efficiency by highlighting its capacity to adjust to shifting load situations.
On the other hand, Fig. 9 provides an in-depth examination of the complex power dynamics at bus B1 by a methodical analysis of power measurements over a designated time. The measured active power at this location precisely converges to 56.22 megawatts (MW), and the reactive power is 3.5 MVAR. This exceptional stability highlights the system's capacity to sustain an equilibrium condition in the active power transmission, indicating its operational resilience during that time frame.

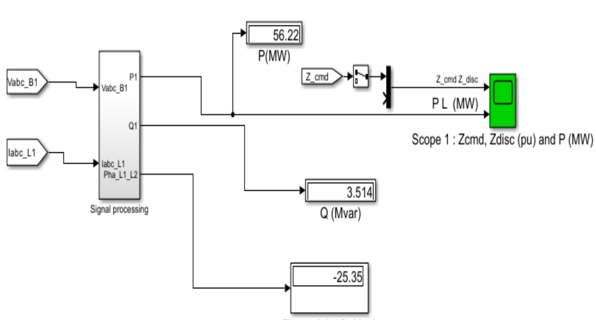

Fig. 9. Active and Reactive power at bus B1.

Furthermore, Fig. 9 provides an important parameter: the reactive power measurement for bus B1, which is expressed as 3.51 megavolt-amperes reactive (MVAR). This statistic is highly valuable for assessing the power characteristics of the system, especially regarding its ability to maintain power quality and adapt to changing load situations. The data facilitates a thorough examination of the system's operational behaviour, hence supporting the evaluation of its dependability and appropriateness in fulfilling power demand specifications.

E. Power Flow Comparison

In this section, a thorough comparison of the computed values, simulated results, and measurements from the Deir Ammar station control room will be shown and compared. The calculations and simulation results are obtained taking in consideration all real data and values obtained from Electricity du Liban (EDL) and from Deir Ammar station including the station's HV transmission line. It is impossible to make intelligible and direct comparisons without this essential historical or current data.
Minimum distance between one phase and the next is around 2.2 m, but it is roughly 5.2 m in lateral phases [8]. The geometric mean distance (GMD) and geometric mean radius (GMR) are then determined using (5):

$$GMD = \sqrt[3]{D_{12} * D_{13} * D_{23}} \quad (5)$$

$$GMR = \sqrt{D * d}, \quad (6)$$

Where:
GMR is the geometric mean radius (m),
GMD is the geometric mean distance (m),
d is the bundle's conductors' distance from one another in meters, and
D is the space in meters between the phases.
The values of the transmission line's inductance are calculated using the *GMR* and *GMD* as following:

$$L = 2*10^{-7}\ln\left(\frac{GMD}{e^{-\frac{1}{4}}*GMR}\right) \quad (7)$$

On lengthy transmission lines, Vs is obtained as follows:

$$\begin{bmatrix} V_s \\ V_r \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix}, \quad (8)$$

Where:
Vr is the voltage rated for lines,
Is is the sending end current, and
Ir is the receiving end current.
It is simple to determine the ABCD values for the short line by formulating a KVL and KCL equation as

$$V_s = V_r + ZI_r$$
$$Ir = Is, \quad (9)$$

or in matrix method

$$\begin{bmatrix} V_s \\ V_r \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_r \\ I_r \end{bmatrix} \quad (10)$$

The actual power sent (Deir – Ammar Station) to the receiving end (Deir – Nbouh Station) is found to be:

$$P_s = \sqrt{3} * 220 * 146.9\cos(0.241 - 0) = 55.9\text{ MW} \quad (11)$$

$$P_r = \sqrt{3} * 209 * 146.9\cos(0.241 - 0) = 53.1\text{ MW} \quad (12)$$

$$Qs = \sqrt{S^2 - P^2{}_s} = 3.45\text{ MVAR} \quad (13)$$

$$Qr = \sqrt{S^2 - P^2{}_r} = 17.78\text{ MVAR} \quad (14)$$

Table 1: Power Analysis

	ActivePower (MW)	ReactivePower (MVAR)	Current (A)
Manual Calculating Power	55.9	3.45	146.9
Site Visit Power	53.53	16.9	146.1
Simulation Result Power at B1	56.22	3.5	141

Table 1 shows a power analysis and a comparison between the theoretical, simulated and measured results obtained.
The current and active power shows close values between calculated, simulated and measured values. Reactive power shows some differences. According to the study's premise, the line receives power from three generators, each of which has a significant capacity of 210 MVA, at different times depending on the load that is in effect. This assumption is the basis for the significant differences in reactive power that are shown when contrasting the theoretical values obtained from manual computations and simulation results with the empirical data obtained from the site visit. These variations highlight the intricate and dynamic character of power distribution systems, where a variety of factors, such as demand unpredictability, system losses, and operational limits, frequently cause theoretical models and real field circumstances to vary. Comprehending these variations is essential to improving the simulation models and making sure they more faithfully replicate operational behaviors and circumstances in the actual world.

4. Conclusion

The planning, building, and historical significance of a crucial 220-kV high-voltage transmission line that connects Deir-Ammar and Deir-Nbouh in northern Lebanon are all thoroughly examined in this study. It attests to the crucial significance that electrical power transmission plays in modern civilization. The primary focus of the study is on environmental factors, safety precautions, and the complex architecture of the transmission line. These topics are carefully examined through fault analysis, sag predictions, power flow control assessments, and extensive MATLAB simulations.
The transmission line is designed to safely maintain distances from residential areas, ensuring the communities' well-being, which is one important finding from this research. Furthermore, it demonstrates the ability to sustain a consistent power flow in the face of varying loads, ensuring a dependable power source. The study also emphasizes how well the transmission line controls fault scenarios and protects against power supply disruptions.
Upon comparison, it is evident that the results obtained through simulation closely align with the manual calculations and site visit measurements. This close correspondence validates the design and indicates the accuracy of the simulation model.
This study promotes the creation of a more durable and sustainable electricity grid infrastructure in Lebanon on a larger scale. It highlights how important this transmission line is to improving grid stability, promoting energy accessibility, and spurring socioeconomic growth in the area. In-depth examination of these aspects provides insightful information on the complex world of high-voltage transmission lines and their crucial role in powering modern societies.
For future work, it is proposed to analyze the impact of random scattering [11] on signal integrity and power loss in high-voltage transmission lines. Random scattering in power transmission lines can arise from various sources, such as material inhomogeneity, environmental factors, and geometric irregularities. These scatterings affect the transmission of electrical signals, potentially leading to signal degradation, power loss, and decreased efficiency in the power grid.

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