

Energy Efficiency and System Resilience in the El-Bayadh Electrical Grid: Insights from NR, ANR, and FD Methods

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Abstract: This study investigates the performance of the El-Bayadh electrical network through the application of various numerical methods and identification techniques to analyze power flow, voltage regulation, and system stability. The research employs the Newton-Raphson (NR), Accelerated Newton-Raphson (ANR), and Fast Decoupled (FD) load flow methods to evaluate the voltage profiles, power losses, and gains within a 30-bus network under different load conditions. The study reveals critical insights, including the identification of the origin of active power losses, significant voltage fluctuations at several buses, and the impact of load growth on the network's stability margin. Notably, the NR method showed the most favorable results, minimizing power losses to 3.46 MW. Furthermore, the analysis of temperature and solar data highlights the relevance of environmental factors in the grid's operation, with an average temperature of 14.98°C for the day of study and sun path data aligning with global patterns. The study also indicates that certain nodes in the network are at risk of overvoltage under prolonged load growth, emphasizing the necessity of implementing corrective measures, including voltage regulation adjustments. The findings underscore the importance of proactive technological investments and strategic planning to ensure the long-term reliability and efficiency of the network. Future studies should focus on refining voltage regulation methods and exploring additional solutions to mitigate overvoltage risks.

Keywords: power grid, optimal power flow, Adaptive Newton-Raphson, Power flow, active power losses, overvoltage, grid reliability.

1. INTRODUCTION

Modern power networks are undergoing rapid evolution, driven by increased energy demand and the integration of advanced technologies. These advancements aim to address the dynamic needs of a growing population and the shift toward cleaner, renewable energy sources [1, 2]. However, this evolution introduces complexities that challenge traditional power system management. Among the most pressing issues are errors in power distribution modeling, particularly within distribution networks [3-6]. These errors can lead to serious operational instabilities, characterized by heightened energy losses, degradation of voltage profiles, and frequency variations [7, 8]. The ramifications are far-reaching, affecting the reliability of service delivery and causing significant economic and social disruptions [9, 10].

As power networks expand and diversify, they demand innovative solutions to maintain stability and operational efficiency [5].

These challenges are especially pronounced in regions with unique geographical and energy profiles, such as El-Bayadh (BYD) in Algeria. This area exemplifies the growing complexity of modern networks due to its significant potential for renewable energy development and the associated integration challenges.

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1.1. Geographical and Renewable Energy Context of El-Bayadh

El-Bayadh, located in southwestern Algeria, is a region marked by diverse topography and climatic conditions conducive to renewable energy exploitation (Figure 1.1). Its favorable wind speeds and solar irradiance present a robust foundation for deploying wind and photovoltaic energy systems. However, integrating these renewable resources into the existing grid necessitates careful planning to avoid imbalances that could exacerbate the network's inherent operational constraints.

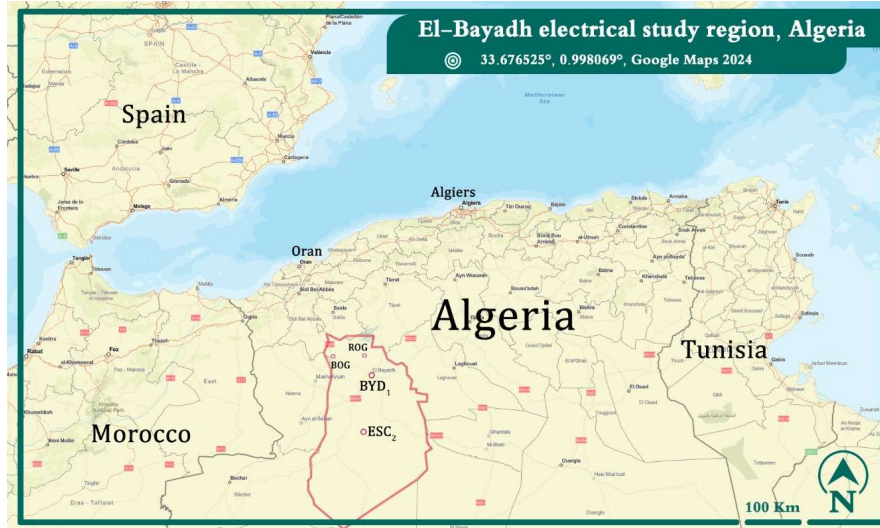


Fig. 1.1. Geographical location of El-Bayadh (BYD), Algeria

The region's distribution network is primarily radial in configuration, as shown in Fig. 1.2. This topology, common in medium-voltage systems, poses distinct operational challenges, including voltage regulation and power loss mitigation.

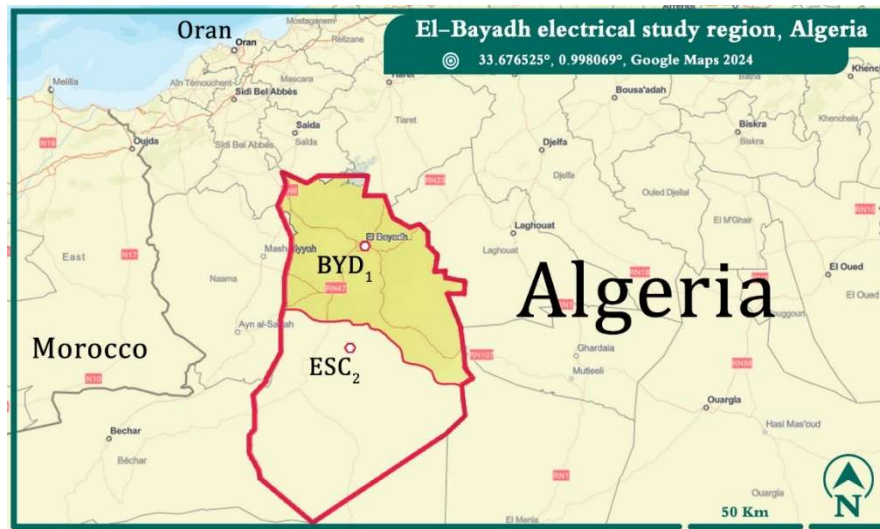


Fig. 1.1. The first area of the distribution network of El-Bayadh (BYD), Algeria

El-Bayadh's renewable energy potential is impressive:

- **Wind Resources:** The average wind speed at 50 meters is 6.78 m/s, making it an ideal location for wind farm installations (Figure 1.3).
- **Photovoltaic Resources:** The average annual solar energy capacity is 1807.8 kWh/kWp, reinforcing the feasibility of solar power projects (Figure 1.4).

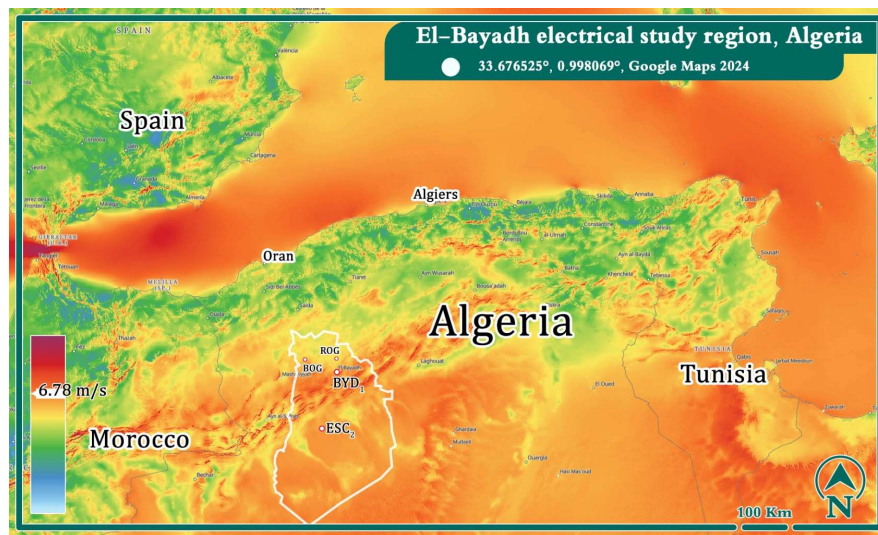


Fig. 1.2. Wind energy potential: Average wind speed at 50m in the first area of El Bayadh

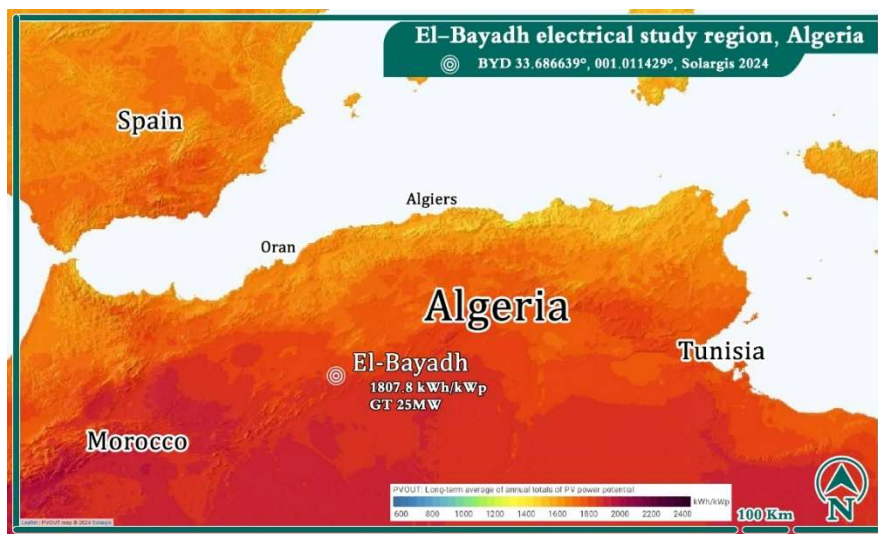


Fig. 1.3. Photovoltaic potential in the El Bayadh region: 1807.8 kWh/kWp

1.2. Challenges in Distribution Network Management

The modeling and management of distribution grids and the electrical circuit are vital for ensuring reliable, efficient energy delivery [10-12]. Distribution networks differ fundamentally from transmission networks in several ways:

1. **Topology:** Radial layouts predominate, leading to single paths for power flow and higher vulnerability to disruptions.
2. **Voltage Levels:** Operating at lower voltages than transmission networks introduces greater sensitivity to load variations and faults.
3. **Load Diversity:** The wide range of consumer types and demands necessitates adaptable management strategies.

The incorporation of renewable energy sources such as photovoltaic panels and small-scale wind turbines introduces bidirectional energy flows, which invalidate traditional unidirectional power flow approaches. Additionally, the emergence of microgrids and control energy storage systems and increases operational complexity, requiring dynamic models that account for variability and flexibility [13-18]. Economic and environmental considerations further necessitate the adoption of advanced technologies, including optimization algorithms, neural networks, and IoT solutions, to address the challenges of modern distribution network management [19-23].

1.2.1. Critical Issues in Radial Networks

Radial distribution networks, while simple in design, are particularly susceptible to specific operational problems [22-28]:

- **Voltage Drops:** Load increases at critical nodes can cause significant voltage reductions, adversely affecting power quality.
- **Active Power Losses:** Energy lost due to resistance in transmission lines reduces overall efficiency.
- **Voltage Collapse Risk:** Insufficient reactive power support and high load demands can lead to systemic voltage instability.

These challenges become increasingly severe with growing loads, further reducing safety margins and leading to gradual network performance degradation.

1.3. Study Focus: El-Bayadh's 30 kV Distribution Network

The study of the El-Bayadh (BYD) distribution network, a 30kV medium-voltage system comprising 30 nodes radially connected to a main substation, aims to analyze and enhance the network's performance. The primary objectives identified for this investigation are as follows:

1. **Voltage Violation Identification:** Detecting nodes with significant deviations from acceptable voltage levels.
2. **Active Loss Minimization:** Reducing power losses to improve the overall efficiency of the network.
3. **Capacity Optimization:** Proposing solutions to better balance load distribution while maintaining safe operational margins.

To achieve these objectives, the study employs three well-established numerical computation methods renowned for their accuracy and efficiency in power flow analysis:

- **Newton-Raphson (NR)**
- **Adaptive Newton-Raphson (ANR)**
- **Fast Decoupled (FD)**

These methods enable detailed power flow assessments and the exploration of corrective measures to stabilize the network.

2. MATERIALS AND MATHEMATICAL FORMULATION

The optimal management of electrical networks relies on maintaining a delicate balance between supply and demand while respecting technical and economic constraints. Power Flow (PF) analysis plays a central role in this process by providing critical insights into system variables such as voltage levels, power injections, and energy losses [27-29]. These analyses enable informed decision-making and proactive measures to address potential network challenges. Radial networks, in particular, pose unique difficulties due to their inherent load variability: high loads can result in significant voltage drops, while low loads may induce overvoltage scenarios [30, 31]. These fluctuations affect stability margins, increase active power losses, and disrupt synchronization in distributed generation systems. This underscores the necessity of robust modeling and management strategies.

Modern computational tools have revolutionized the field of power system studies. These tools enable the efficient resolution of complex nonlinear equations and large-scale matrix systems, accelerating simulations and improving accuracy and reliability [32, 33]. In this study, advanced computational tools were integral to analyzing various configurations of the El-Bayadh (BYD) network and identifying effective strategies to enhance its performance.

The study follows a structured approach to address the stability and efficiency challenges of the BYD distribution network:

1. Data Collection and Analysis

- Comprehensive data on network characteristics, load profiles, and generation capacities were gathered and analyzed to identify critical constraints influencing performance.

2. Modeling and Simulation

- The network components were modeled using **Newton-Raphson (NR)**, **Adaptive Newton-Raphson (ANR)**, and **Fast Decoupled (FD)** methods. These simulations facilitated:
 - Identification of voltage deviations,
 - Evaluation of active power losses,
 - Comprehensive assessment of overall network performance.

3. Solution Identification

- Specific attention was given to:
 - Recognizing critical power distributions and marginal voltage levels,
 - Proposing and implementing reactive power compensation mechanisms.

This systematic methodology ensures the identification of practical issues and the formulation of actionable recommendations for improving the reliability and efficiency of the BYD distribution network.

2.1. Static and Dynamic Modeling

Load models provide the foundation for understanding and analyzing network behavior. **Static load models** offer a simplified representation by focusing on temporal characteristics, such as constant voltage, power, or impedance. These models are often sufficient for baseline studies but may not capture the full complexity of real-world load dynamics.

In scenarios requiring more precise analysis, **dynamic load models**; such as frequency, dependent load models, become essential. These models account for load responses to frequency variations, enabling a more accurate assessment of load interactions and their impacts on system performance. This level of detail is crucial for ensuring the grid's reliability, stability, and operational efficiency [29]. The **ZIP model** is commonly used to represent both static and dynamic load behavior. Its general form is given as:

$$\begin{cases} S_i(t) = P_i(t) + j Q_i(t) \\ P_i(t) = P_{i0} \left[a_p \left(\frac{V_i}{V_0} \right)^2 + b_p \left(\frac{V_i}{V_0} \right) + c_p \right] [1 - k_{pf} \Delta f] \\ Q_i(t) = Q_{i0} \left[a_q \left(\frac{V_i}{V_0} \right)^2 + b_q \left(\frac{V_i}{V_0} \right) + c_q \right] [1 - k_{qf} \Delta f] \end{cases} \quad (1)$$

In these equations:

- P and Q the active and reactive powers of the load for the operating voltage V ,
- P_0 and Q_0 the active and reactive powers of the load for the nominal voltage V_0 ,
- a_p, b_p, c_p, a_q, b_q , and c_q are the coefficients of the ZIP model,
- k_{pf} is the sensitivity parameter of the active power,
- k_{qf} is the sensitivity parameter of the reactive power,
- Δf represents the frequency deviation in P.u.

The Figure 2.1 illustrates the fundamental components of a power system at bus i interacting with bus j . It includes:

- **Production:** Energy generation sources connected to bus i , contributing the apparent S_{Gi} , active P_{Gi} and reactive Q_{Gi} powers in the electrical grid.
- **Transmission:** The model transmission lines facilitating power flow between buses i and j , with associated impedance $Z_{ij}/2$ and susceptance $Y_{ij}/2$.
- **Load:** Consumption points at bus j , characterized by apparent S_{Load_j} , active P_{Load_j} and reactive Q_{Load_j} powers demands.

This diagram provides a foundational understanding of power flow dynamics, highlighting the interconnectedness of generation, transmission, and load within a distribution network.

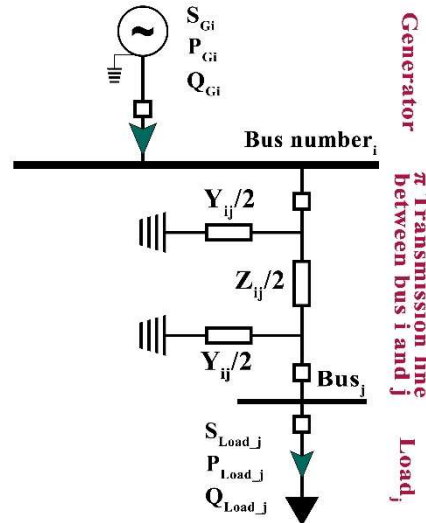


Fig. 2.1. Modeling of a Bus i with Production, Transmission, and Load at Bus j

The Single-Line diagram serves as a reference for the network's structure, enabling the analysis of power flow, loss minimization, and voltage regulation strategies. The Figure 2.2 presents a single-line diagram of the distribution network in the first zone of the El-Bayadh (BYD) region. Key features include:

- **Radial Topology:** Depiction of medium-voltage connections from the main substation to various distribution nodes.
- **Network Components:** Visual representation of transformers, distribution lines, and connected loads.
- **Operational Constraints:** Identification of critical nodes experiencing voltage drops or high active power losses during peak load periods.

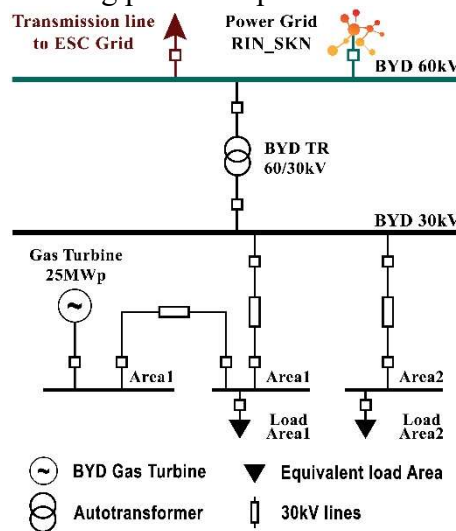


Fig. 2.2. Single-Line Diagram of the Distribution Network for the First Area of El-Bayadh.

2.2. Mathematical Formulation

The primary objective is to determine the complex nodal voltages, from which all other variables, such as power flow in lines (P , Q , and S), currents, and losses can be derived. Mathematically, this problem reduces to a set of nonlinear equations where the real and imaginary components of the nodal voltages are the variables. The number of equations corresponds to twice the number of nodes, and the nonlinearity of the system is primarily quadratic in nature. Gradient techniques and relaxation methods remain the primary

approaches for solving these nonlinear systems. Table 2.1., summarizes the input data and the objectives of power flow calculations.

Table 2.1. Input Sections and Objectives of Power Flow Calculations

Input Sections	Objectives
Energy information (production, sources)	Voltage levels and drops
Network information (transformers, protections)	Conductor and transformer load factors
Measurement data (peak current, voltage levels)	Backup power analysis
Calculation parameters	Optimization of normally open points in the network
Voltage variation profiles and load growth	Economic operation of the network and investment planning Transmission and transformation capacity assessment, cost evaluation of outages

2.2.1. Power Flow Analysis

Power flow analysis provides operators and planners with critical information, including line loads, bus voltages, generated power, and losses. This information highlights constraints and helps identify areas where limits are exceeded. Modern computational tools make power flow calculations feasible for networks of virtually any size.

Each *bus i* is characterized by six variables: V_i , δ_i , P_{Gi} , Q_{Gi} , P_{Li} and Q_{Li} . For a system with n nodes, this results in $6n$ variables. To ensure the system is solvable, $2n$ unknowns and $4n$ known parameters must be defined.

- **Non-generating Nodes**

- for nodes without generation, $P_{Gi} = Q_{Gi} = 0$, and V_i and δ_i are unknown.

- **Generating Nodes**

- for generating nodes, the following relationships apply:

$$S_i^* = P_{Gi} - jQ_{Gi} = V_i^* \cdot I_i \quad (2)$$

$$I_i = \sum_{m=1}^n Y_{im} V_m \quad (3)$$

$$S_i^* = V_i^* \cdot \left(\sum_{m=1}^n Y_{im} V_m \right) \quad (4)$$

The active and reactive power injected at a node are defined as:

$$P_i = \left(\sum_{m=1}^n Y_{im} V_m V_i \right) \cdot \cos(\delta_m - \delta_i + \theta_{im}) \quad (5)$$

$$Q_i = \left(\sum_{m=1}^n Y_{im} V_m V_i \right) \cdot \sin(\delta_m - \delta_i + \theta_{im}) \quad (6)$$

- **Power Flow in Transmission Lines**

Once the iterative voltage solution is complete, line flows can be calculated. The current between nodes i and k is:

$$I_{ik} = (V_i - V_k) \cdot Y_{ik} + V_i \cdot \left(\frac{Y'_{ik}}{2} \right) \quad (7)$$

Where:

Y_{ik} : Line admittance

Y'_{ik} : Shunt admittance

The active and reactive power flow is given by:

$$S_{ik}^* = P_{ik} - jQ_{ik} = V_{ik}^* \cdot (V_i - V_k) \cdot Y_{ik} + V_i \cdot \left(\frac{Y'_{ik}}{2} \right) \quad (8)$$

- **Losses and Constraints**

- System losses are represented as:

$$S_{ri} = \left(\sum_{i=0}^n S_{Gi} \right) - \left(\sum_{i=0}^n S_{Li} \right) \quad (9)$$

$$P_{ri} = \left(\sum_{i=0}^n P_{Gi} \right) - \left(\sum_{i=0}^n P_{Li} \right) \quad (10)$$

$$Q_{ri} = \left(\sum_{i=0}^n Q_{Gi} \right) - \left(\sum_{i=0}^n Q_{Li} \right) \quad (11)$$

Where S_r represents total network losses.

• Constraints

The table 2.2.1 present the constraints with formulation mathematical

Table 1.2.1. Constraints with formulation mathematical

Constraints	Mathematical modulation
Generation and Load Balance:	$\sum_{i=1}^N P_{Gi} - (\sum_{i=1}^N P_{Li} + P_{ri}) = 0$ $\sum_{i=1}^N Q_{Gi} - (\sum_{i=1}^N Q_{Li} + Q_{ri}) = 0$
Generation Limits:	$P_{Gi}^{min} \leq P_i \leq P_{Gi}^{max}$ $Q_{Gi}^{min} \leq Q_i \leq Q_{Gi}^{max}$
Voltage Constraints:	$V_i^{min} \leq V_i \leq V_i^{max}$
Angle Constraints:	$\theta_{ij}^{min} \leq (\theta_i - \theta_j) \leq \theta_i^{max}$

These constraints ensure that the system operates safely, avoiding damage, instability, or insecurity. Figure 2.2.1. outlines the process of evaluating power flow results, which are applied in investment planning and operational.

The lower and upper limits for the four voltage levels are shown in table 2.2.2.

Table 2.2.2. Marginal and critical voltage limits for voltage levels

Nominal Voltage	Critical voltages situation	
	Lower [P.u.]	Upper [P.u.]
All busses	0.9	1.1

The figure 2.2.1. illustrates the step-by-step process for evaluating power flow results, highlighting the sequence of data input, computation, and analysis phases. It is a critical tool for understanding the integration of power flow computations into system planning, including the identification of constraints, optimization of network operations, and assessment of reliability and efficiency.

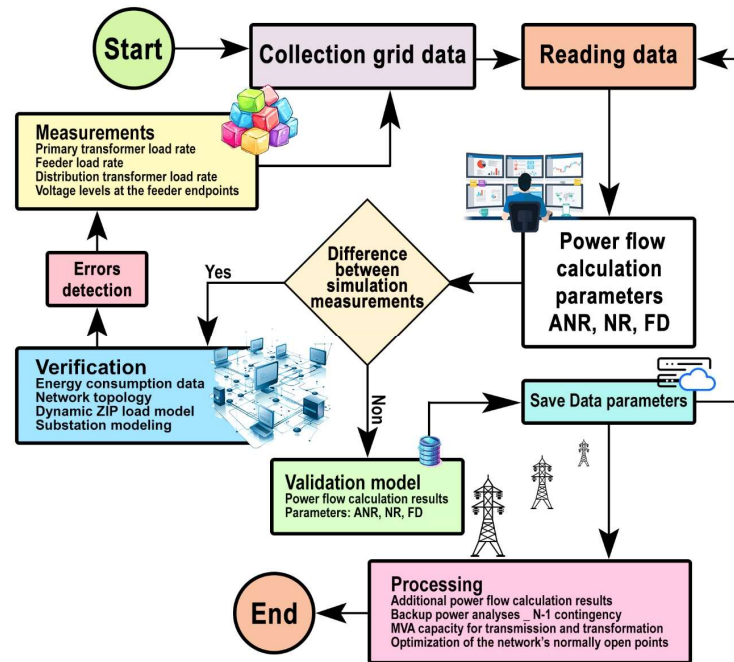


Fig. 2.2.1. Flowchart of Power Flow Result Evaluation Process

The Newton-Raphson (NR) method is widely used for solving nonlinear power flow problems due to its efficiency and fast convergence. Below is a detailed explanation of the mathematical process:

To solve a nonlinear equation $f(x) = 0$, the Newton-Raphson method relies on successive approximations of the solution x . If Δx^0 is the correction applied to the initial value x^0 , the solution is expressed as:

$$x = x^0 + \Delta x^0 \quad (12)$$

After linearization, the equation $f(x) = 0$ becomes:

$$f(x^0) + f'(x^0)\Delta x^0 = 0 \quad (13)$$

Equation (13) has the solution:

$$\Delta x^0 = -\frac{f(x^0)}{f'(x^0)}$$

The updated solution is then: $x^1 = x^0 + \Delta x^0 = x^0 - \frac{f(x^0)}{f'(x^0)}$

The general iterative form is: $x^{k+1} = x^k - \frac{f(x^k)}{f'(x^k)}$

• Convergence Criteria

The iterations stop when the following conditions are satisfied:

$$|\Delta x^k| < \varepsilon_1 \text{ and } |f(x^k)| < \varepsilon_2$$

Where ε_1 & ε_2 are small positive numbers representing the desired accuracy.

• Extension to Systems of Nonlinear Equations

For a system of n nonlinear equations:

$$\left. \begin{aligned} f_1(x_1, x_2, \dots, x_n) &= 0 \\ f_2(x_1, x_2, \dots, x_n) &= 0 \\ &\vdots \\ f_n(x_1, x_2, \dots, x_n) &= 0 \end{aligned} \right\} \quad (14)$$

The method is extended to calculate corrections $\Delta x_1^0, \Delta x_2^0, \dots, \Delta x_n^0$. Using the Taylor expansion and neglecting higher-order terms, the system can be written in matrix form as:

$$F(x^k) = -J^k \Delta x^k \quad (15)$$

Where:

- F is the vector of functions $[f_1, f_2, \dots, f_n]^T$,
- J is the Jacobian matrix containing partial derivatives:

$$J = \begin{bmatrix} \left. \frac{\partial f_1}{\partial x_1} \right|_{x_1^0} & \left. \frac{\partial f_1}{\partial x_2} \right|_{x_2^0} & \dots & \left. \frac{\partial f_1}{\partial x_n} \right|_{x_n^0} \\ \left. \frac{\partial f_2}{\partial x_1} \right|_{x_1^0} & \left. \frac{\partial f_2}{\partial x_2} \right|_{x_2^0} & \dots & \left. \frac{\partial f_2}{\partial x_n} \right|_{x_n^0} \\ \vdots & \vdots & \ddots & \vdots \\ \left. \frac{\partial f_n}{\partial x_1} \right|_{x_1^0} & \left. \frac{\partial f_n}{\partial x_2} \right|_{x_2^0} & \dots & \left. \frac{\partial f_n}{\partial x_n} \right|_{x_n^0} \end{bmatrix} \quad (16)$$

• Iterative Solution

The iterative update equations are:

$$\Delta x^{k+1} = -(J^k)^{-1} F(x^k) \quad (17)$$

$$x^{k+1} = x^k + \Delta x^k \quad (18)$$

Here, x^k represents the solution vector at iteration k , and J^k is the Jacobian matrix evaluated at x^k .

• Jacobian Matrix and Practical Considerations

The Jacobian matrix J is a key component, and its accurate computation is critical for the method's success. The NR method converges quadratically near the solution if the initial guess is sufficiently close and the Jacobian is non-singular. Via iterating until the

convergence criteria are met, the NR method effectively solves nonlinear power flow problems in electrical systems.

3. RESULTS AND DISCUSSION (BYD GRID)

3.1. One-hours Evolution Peak Loadshape

In Figure 3.1., we presents the variation in power demand (in MW) over a one-hour period for the BYD electrical network. The loadshape curve highlights fluctuations in energy consumption, accent critical patterns such as peak and off-peak demand periods, essential for accurate power flow modeling and network analysis.

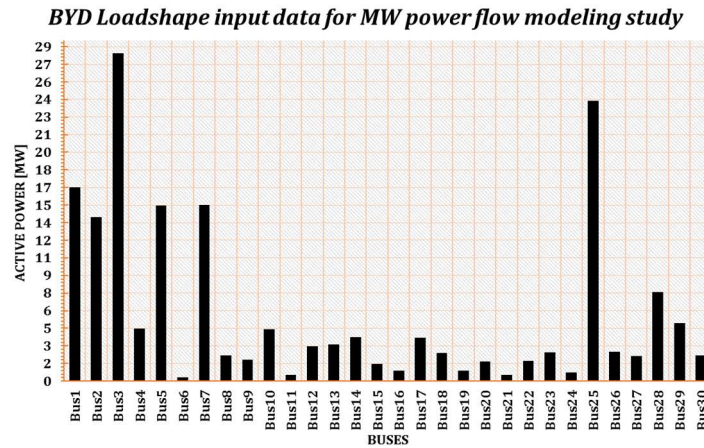


Fig. 3.1. One-hour BYD Loadshape data for MW power flow-modeling study

3.2. BYD Average Temperature

In Figure 3.2., we illustrates the hourly variation in average temperature throughout the study day for the BYD region. The temperature profile is integral to understanding its influence on power demand and network performance, offering insights into potential correlations between climatic conditions and energy consumption patterns.

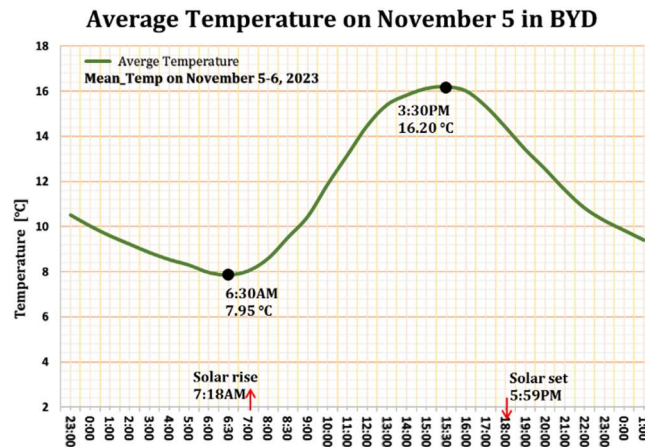


Fig. 3.2. BYD Average temperature over the study day

3.3. BYD Trajectory of the Sun

The figure 3.3., depicts the horizon and the trajectory of the sun across the sky in the BYD region. It provides essential information on solar angles, which is critical for evaluating solar energy potential and optimizing the orientation of photovoltaic installations and solar trackers in the area.

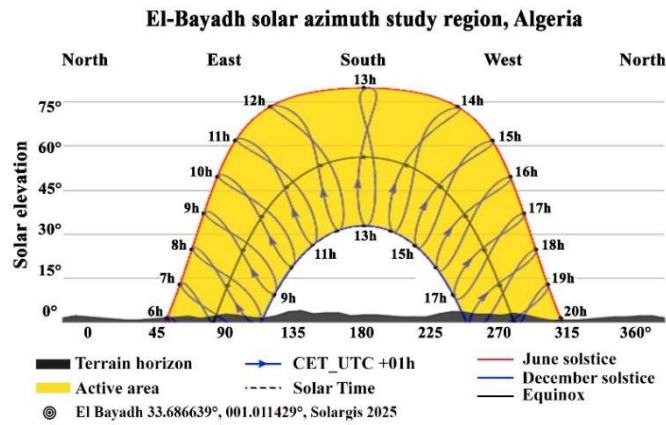


Fig. 3.3. Horizon and sun path diagram in the El Bayadh region

3.4. BYD Voltages Profiles

The figure 3.4.1., depicts the variations in voltage levels across the network over a one-hour period, calculated using the Newton-Raphson (NR) load flow method. It highlights voltage stability and violation at different nodes, providing insight into the network's performance under varying load conditions.

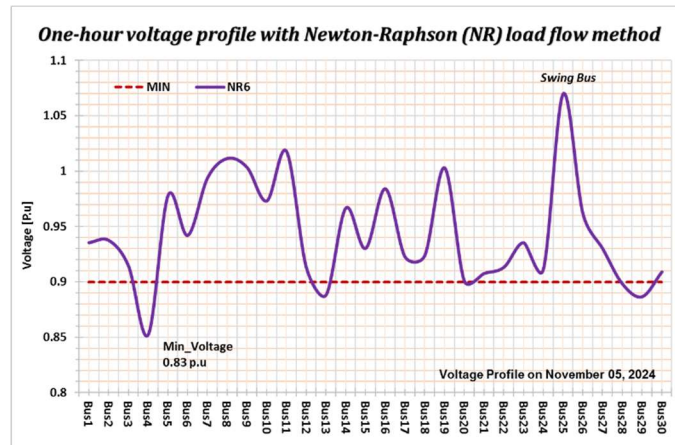


Fig. 3.4.1. One-hour voltage profile with Newton-Raphson (NR) load flow method

This figure 3.4.2., illustrates the voltage variations within the network over a one-hour period, determined using the Adaptive Newton-Raphson (ANR) load flow method. It demonstrates the method's effectiveness in maintaining voltage stability, violation and its adaptability to dynamic load conditions within a short time frame.

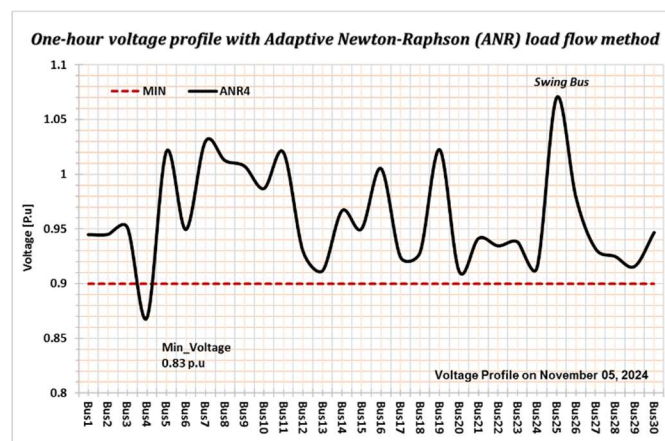


Fig. 3.4.2. One-hour voltage profile with Adaptive Newton-Raphson (ANR) load flow method

This figure 3.4.3., presents the voltage profile over a one-hour period as computed using the Fast Decoupled (FD) load flow method. It highlights the method's efficiency in providing rapid and reliable voltage stability and violation analysis under dynamic load conditions.

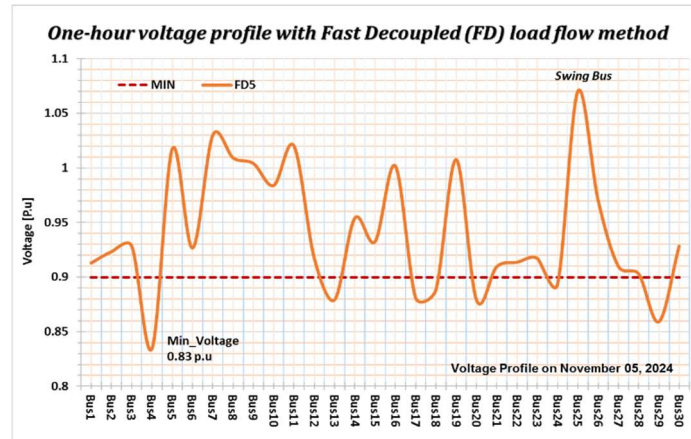


Fig. 3.4.3. One-hour voltage profile with Fast Decoupled (FD) load flow method

Figure 3.4.4., illustrates a comparative analysis of voltage profiles over a one-hour period, computed using the Newton-Raphson (NR), Accelerated Newton-Raphson (ANR), and Fast Decoupled (FD) load flow methods. It displays the performance differences among these methods in terms of voltage stability and computational efficiency.

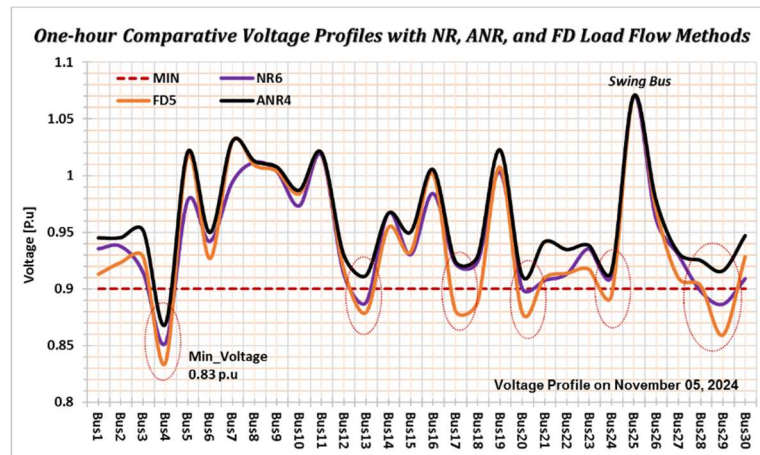


Fig. 3.4.4. One-hour Comparative Voltage Profiles with NR, ANR, and FD Load Flow Methods

3.5. BYD Gain and Losses

The figure 3.5.1. shows the active power gain and loss over a one-hour period in the BYD grid area, calculated using the Newton-Raphson (NR) load flow method. The chart highlights the distribution of power gain and loss, providing insights into the network's operational behavior and efficiency.

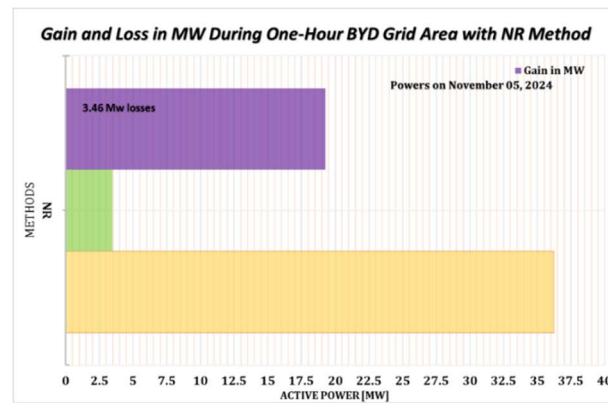


Fig. 3.5.1. Gain and Loss in MW during One-Hour BYD Grid Area with NR Method

Figure 3.5.2., this figure presents the active power gain and loss over a one-hour period in the BYD grid area, using the Accelerated Newton-Raphson (ANR) load flow method. It allows a comparison with the NR method in terms of accuracy and speed of convergence.

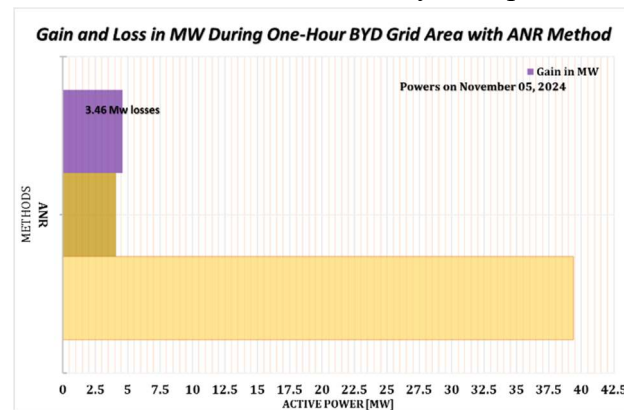


Fig. 3.5.2. Gain and Loss in MW during One-Hour BYD Grid Area with ANR Method

Figure 3.5.3., this figure illustrates the active power gain and loss during a one-hour period in the BYD grid area, calculated using the Fast Decoupled (FD) load flow method. It provides an alternative approach for analyzing the grid's performance and power distribution.

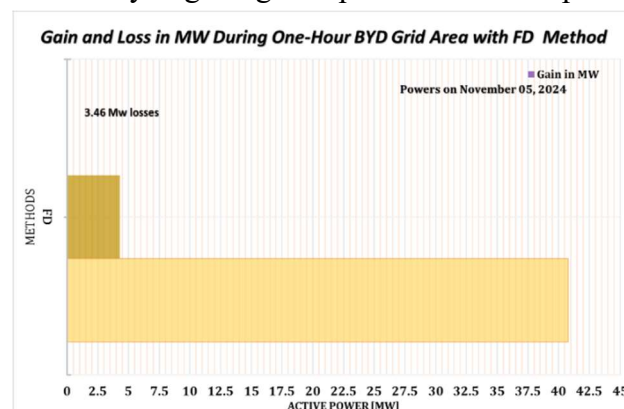


Fig. 3.5.3. Gain and Loss in MW during One-Hour BYD Grid Area with FD Method

Figure 3.5.4., Comparative Gain and Loss in MW during One-Hour in BYD Grid Area with NR, ANR, and FD Methods: This figure compares the active power gain and loss over one hour in the BYD grid area, using the NR, ANR, and FD load flow methods. It enables the evaluation of each method's effectiveness in capturing power gains and losses, helping to determine the best-suited approach for power flow analysis.

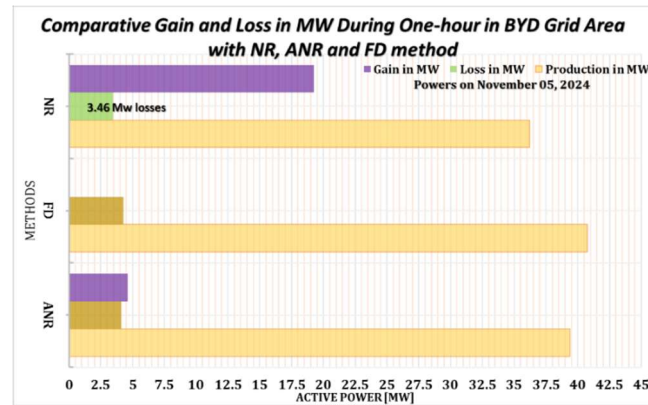


Fig. 3.5.4. Comparative Gain and Loss in MW during One-Hour in BYD Grid Area with NR, ANR, and FD Methods

The results indicate that the numerical methods and identification procedures used were effective, providing valuable insights. Notably, identifying the origins of active power losses and accurately detecting bus voltage variations (from minor to significant fluctuations) are essential for improving energy efficiency. Furthermore, the improvements in the network's stability margin under various load levels highlight the system's increased resilience.

Figure 3.1., presents the load measurements for a 30-bus electrical network over one hour of operation. The maximum load is identified at bus 3 with a value of 27.92 MW, while the minimum consumption is measured at bus 6 with a value of 0.30 MW.

Figure 3.2., shows the average temperature curve measured for the day of November 5, 2024, with an average value of 14.98 °C.

Figure 3.3., depicts the sun path for the BYD study region, where it is observed that the measurements align well with global values for June and December sun paths.

In Figures 3.4.1, 2.4.2, 3.4.3, and 3.4.4, the calculated voltages across the 30 buses in the system are presented for the three methods. Voltage violations are observed at buses 4, 13, 17, 24, and 29, indicating the need for voltage regulation adjustments. This correction approach will be addressed in future studies.

For Figures 3.5.1, 3.5.2, 3.5.3, and 3.5.4, the distribution of generated power and losses across the system is calculated. The NR method demonstrates the lowest power loss, with a minimal loss of 3.46 MW.

Additionally, the analysis revealed that, with continued load growth, certain nodes in the El-Bayadh electrical network could be at risk of overvoltage. Based on these findings, it is evident that strategic investments in technology and proactive planning are required to mitigate these risks and ensure the network's future reliability.

4. CONCLUSION

This study demonstrated the effectiveness of numerical methods and identification techniques in evaluating the performance of an electrical network, particularly in the context of power flow analysis. Through the application of various load flow methods, significant insights were gained, such as the identification of active power losses, voltage variations, and network stability under different load conditions. The results highlighted the resilience of the system, but also pointed out areas requiring improvement, especially concerning voltage regulation and the management of potential overvoltage risks in the event of continued load growth.

The analysis of load profiles, temperature data, and sun path for the study region provided valuable context for the modeling and simulation efforts. The voltage violations identified at specific buses underline the importance of corrective measures, such as voltage control adjustments, which will be addressed in future research. Additionally, the comparison of

power loss values across different methods demonstrated that the NR method offers the most efficient solution in terms of minimizing losses.

Overall, the findings emphasize the need for ongoing monitoring, technological investments, and proactive planning to ensure the long-term stability and efficiency of the electrical grid. Future studies should focus on optimizing voltage regulation techniques and exploring further solutions to mitigate overvoltage risks as part of a comprehensive strategy to enhance the performance and reliability of the El-Bayadh electrical network.

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