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Optimizing Frequency Stability in Distributed Power Grids through Advanced Power Flow Control with 25MW Photovoltaic Integration

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Abstract: This study addresses the challenges associated with integrating photovoltaic (PV) systems into the Western Algerian power grid, primarily focusing on mitigating frequency fluctuations induced by variable electrical load profiles. These fluctuations can have adverse effects on power quality and grid stability. To address this challenge, the study introduces the benefits of frequency stability analysis and Optimal Power Flow (OPF) control within distributed and adaptable power networks. The primary goal is to enhance the integration of PV systems by ensuring the dynamic stability of the network, optimizing solar energy utilization through the Maximum Power Point Tracking (MPPT) technique, and employing var compensation methods. These strategies are designed to facilitate reliable and economically viable PV integration into the power grid, particularly in the SAIDA-NAAMA region. Through the implementation of OPF control, var compensation techniques, and PV integration, this research achieves a notable reduction in power losses, ranging from 10% to 25% within a single day. Furthermore, the utilization of reactive power control, employing NAAMA's Static Var Compensator (SVC) for the transmission network, along with localized compensatory measures for the distribution network, effectively maintains voltage levels within acceptable parameters. These combined efforts provide critical support for the advancement of PV integration, the transition towards Variable Renewable Energy (VRE) sources, and the promotion of sustainable power generation practices within the region.

Keywords: static var compensator, transient stability, photovoltaic integration, MPPT, variable renewable energy, power grid, optimal power flow

1. INTRODUCTION

In the realm of electrical system operations, operators encounter notable challenges associated with maintaining voltage stability and managing frequency fluctuations, especially during periods of high load. The preservation of stable voltage and frequency levels stands as a critical pillar in guaranteeing the dependable and efficient functioning of power grids. Variations in these parameters can result in adverse consequences, such as equipment malfunctions, diminished power quality, and potential interruptions in power supply. Consequently, dispatchers bear the vital responsibility of adeptly overseeing voltage stability and frequency control to uphold the reliability of the system [15].

A pivotal factor influencing voltage stability is the conduct of nonlinear electrical loads under demanding transient conditions. Nonlinear loads exhibit intricate characteristics that can affect overall system performance. These loads have the potential to introduce harmonics, distort the voltage waveform, and exhibit dynamic behaviors that can further complicate voltage stability. An accurate understanding and representation of the behavior of these nonlinear loads assume great significance in designing control equations and devising effective operational strategies [1].

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Static load models offer a simplified portrayal of load behavior within electrical systems, primarily focusing on static temporal attributes such as fixed voltages, constant powers, and constant impedances. While these models provide a valuable foundational framework, they may fall short in capturing the full complexity and dynamic nature of actual load behavior. In scenarios where traditional static load models prove inadequate in faithfully representing load characteristics, the adoption of alternative dynamic load models becomes imperative. Dynamic load models, such as frequency-dependent load models, offer a more detailed and precise comprehension of load characteristics in electrical systems [9, 11].

By accounting for the dynamic responses of loads to fluctuations in frequency, a comprehensive assessment of load interactions and their impact on system performance can be achieved. This knowledge assumes a pivotal role in safeguarding the reliability, stability, and efficient operation of electrical grids. The general expression of the impedance Z, current I, and power P, namely ZIP model can be represented as follows:

$$\begin{cases} P = P_0\left[a_p\left(\frac{V}{V_0}\right)^2 + b_p\left(\frac{V}{V_0}\right) + c_p\right]\left[1 - k_{pf}\Delta f\right] \\ \mathrm{Q} = Q_0\left[a_q\left(\frac{V}{V_0}\right)^2 + b_q\left(\frac{V}{V_0}\right) + c_q\right]\left[1 - k_{qf}\Delta f\right] \end{cases} \tag{1}$$

In these equations:

P and Q represent the active and reactive powers of the load for the operating voltage V, P_0 and Q_0 denote 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.

Furthermore, frequency fluctuations can occur due to imbalances between the power generation and load demand in the electrical system. These fluctuations can lead to synchronization issues among devices connected to the grid, potentially causing operational challenges and compromising system stability. Dispatchers must closely monitor and regulate the system's frequency to ensure its operation within an acceptable range. Effective frequency control mechanisms and feedback systems are necessary to maintain the desired frequency levels [12, 10].

In the modelling and control equations of electrical systems, it is crucial to consider the impact of nonlinear loads and their behaviour under critical transient conditions. These models help capture the complex characteristics of various electrical devices and their interactions within the system. By incorporating these models, dispatchers can gain a deeper understanding of the system dynamics, enabling them to devise robust control strategies to mitigate voltage instability and frequency fluctuation [16, 17].

The power generation facilities need to be designed to operate under exceptional conditions for limited durations. The operating durations are specified in Table 1 below, indicating the minimum times an electricity generation unit must be able to remain connected to the grid at different frequencies deviating from the nominal value [3, 6-8].

Moreover, it is essential to recognize that frequency fluctuations can arise from disparities between power generation and load demand within the electrical system. These fluctuations have the potential to trigger synchronization issues among grid-connected devices, which, in turn, can give rise to operational challenges and jeopardize overall system stability. Dispatchers bear the responsibility of vigilant monitoring and control over the system's frequency to ensure it operates within an acceptable range [13, 18].

When it comes to modeling and establishing control equations for electrical systems, it is paramount to account for the influence of nonlinear loads and their responses under critical transient conditions. These models serve as invaluable tools for capturing the intricate characteristics of diverse electrical devices and their intricate interactions within the system.

By incorporating these models into their analyses, dispatchers can attain a more profound understanding of system dynamics, empowering them to formulate robust control strategies aimed at mitigating voltage instability and addressing frequency fluctuations [8, 2].

Furthermore, it is imperative that power generation facilities are designed to operate under exceptional conditions for specific durations.

The power generation facility's ability to remain connected and synchronized with the Electricity Transmission Network. Even during rapid frequency variations of up to 1 Hz per second, is pivotal [19, 4]. This capability ensures the generation unit's ongoing reliable operation and the provision of a stable electricity supply, even when confronted with substantial frequency fluctuations. Maintaining coupling and synchronization under such rapid variations is essential for safeguarding safety and system stability during dynamic conditions.

Frequency stability analysis plays an indispensable role in understanding and mitigating these fluctuations, thereby ensuring the optimal performance of power systems [10, 20]. It encompasses the examination of the dynamic behavior of grid frequency and the identification of factors contributing to its oscillations [14]. Through a comprehensive analysis of frequency stability, power system operators and engineers can devise effective control strategies to maintain the frequency within acceptable limits. Several factors contribute to the attainment of such an impressive effective energy production rate:

1.1. Solar Resource Availability

The ample solar energy resources within the ESC region play an instrumental role in maximizing energy production. These regions, characterized by high solar irradiation levels and minimal shading or obstructions, allow PV panels to receive abundant sunlight, resulting in heightened energy generation.

1.2. Efficient PV System Design

Efficient PV system design involves a thorough assessment of these factors to maximize energy production and ensure the long-term performance and economic viability of the PV installation. By paying careful attention to these details, the ESC PV Park can harness the full potential of solar energy resources for sustainable electricity generation.

1.3. Effective Operations and Maintenance

Routine maintenance and continuous monitoring of the PV Park are essential for ensuring optimal system performance. This includes tasks such as panel cleaning, fault inspections, and addressing technical issues promptly to minimize energy losses and maximize production [6].

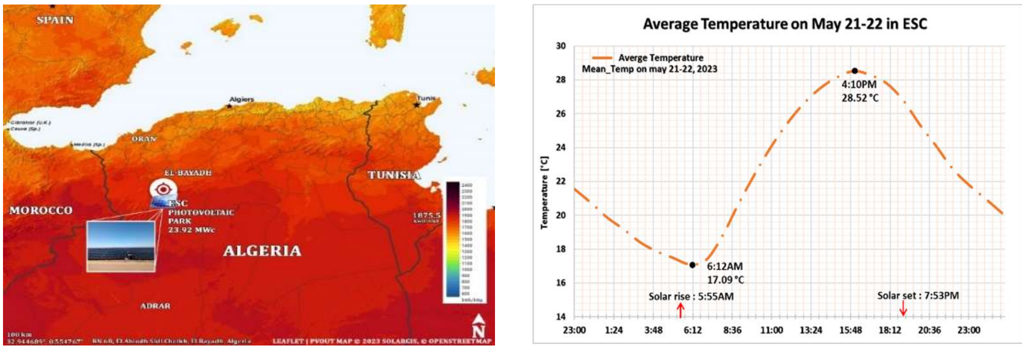
1.4. Grid Integration and Power Management

The integration of the ESC PV Park into the grid and the application of efficient power management systems are vital for optimizing its output. This may involve the use of technologies like grid-tied inverters, energy storage systems, and advanced control algorithms to regulate power flow, maintain grid stability, and minimize energy curtailment. This signifies the effective utilization of available solar resources, maximizing the PV Park's output, profitability, and contributing to greener and more sustainable energy generation.

Frequency stability analysis assumes a critical role in the successful integration of PV systems into power grids. By ensuring frequency stability, we can effectively address the challenges posed by fluctuations in renewable energy generation and promote the reliable and efficient operation of electrical grids. The subsequent sections of this paper will delve deeper into the control measures and strategies employed in frequency stability analysis, presenting their potential benefits and practical applications [7, 14].

Frequency monitoring and control are pivotal in maintaining the electrical grid within predetermined frequency ranges. The balance between power generation and demand influences grid frequency; excessive generation raises frequency, while excess demand lowers it [5, 12]. This study aims to explore the advantages of frequency stability analysis in the context of PV integration. By comprehending the factors influencing frequency variations and implementing control measures, we can enhance PV system integration, optimize performance, and reduce disruptions to the grid.

This paper centers its attention on elucidating the significance of frequency stability analysis in the context of integrating PV systems into power grids, with a specific focus on the case of western Algeria, as illustrated in Fig. 1.1(a) below. Its objective is to shed light on the challenges arising from frequency fluctuations resulting from variable electrical load profiles and underscore the criticality of preserving frequency stability to ensure reliable and efficient grid operations.



(a) (b)

Fig. 1.1. Sample figure with caption, (a) geographical photovoltaic park in the ESC region, (b) average temperature on May 21, 2023 in ESC region, Algeria

Through an in-depth exploration of these facets, this study endeavors to offer valuable insights and practical methodologies to assist dispatchers and system operators in effectively managing voltage stability, frequency control, and energy management within electrical systems. By adeptly addressing these challenges, power grids can operate with heightened reliability, ensure optimal power quality, and provide uninterrupted electricity supply to consumers.

In Fig. 1.1(b), the graphical representation exhibits a line graph with markers denoting the maximum and minimum average temperatures recorded on May 21, 2023, in El-Abiodh Sidi Cheikh (ESC) region, Algeria, at 6:12 AM, a marker positioned at 17.09°C signifies the minimum temperature, while at 4:10 PM; a marker located at 28.52°C represents the maximum temperature. This graph visually captures the temperature variations throughout the day.

Indeed, by harnessing these factors and implementing best practices in the deployment and operation of PV systems, it becomes feasible to achieve a remarkably high effective energy production rate of 64.75%.

The Fig. 1.2. illustrates daily load profiles on PQ buses, displaying typical electricity demand patterns with peak hours and lower demand periods.

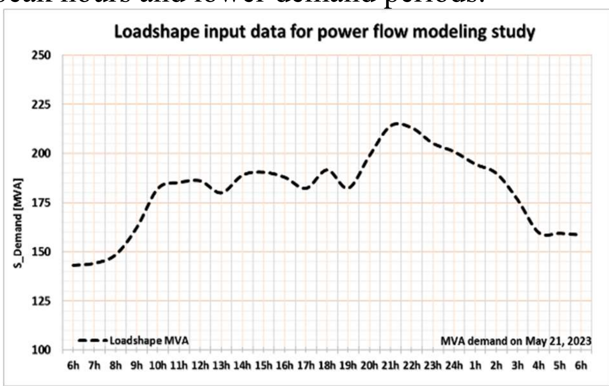


Fig. 1.2. Evolution of the daily load profile

2. MATERIALS AND MATHEMATICAL FORMULATION

The production generators in the network supply the required active and reactive powers based on the demand profile while ensuring that the generated reactive power remains within specified limits. The complex power at node i can be represented by:

$$\begin{cases} \bar{S_i} = P_i + jQ_i \\ \bar{S_i} = \left(P_{G_i} - P_{L_i} - P_{T_i}\right) + j\left(Q_{G_i} - Q_{L_i} - Q_{T_i}\right) \end{cases} \tag{2}$$

where

P_i, Q_i: active and reactive power at node i;

P_{G_i}, Q_{G_i}: generation active and reactive power at node i;

P_{L_i},Q_{L_i}: active and reactive load power at node i;

P_{T_i},Q_{T_i}: active and reactive power transmitted.

By properly managing the active and reactive power flow in the network, the production generators can ensure that the demand is met while maintaining the required voltage and power factor levels within acceptable limits. This balance between generation and consumption is crucial for operation of system.

Modelling of the powers transmitted via the transmission line by:

$$\begin{cases} \bar{S}_{ij} = |\bar{V}_i|^2.\bar{Y}_{ij}^* - \bar{V}_i.\bar{V}_j^*.\bar{Y}_{ij}^* + |\bar{V}_i|^2.\bar{Y}_{i0}^* \\ \bar{S}_{ji} = \left|\bar{V}_j\right|^2.\bar{Y}_{ij}^* - \bar{V}_j.\bar{V}_i^*.\bar{Y}_{ij}^* + \left|\bar{V}_j\right|^2.\bar{Y}_{j0}^* \end{cases} \tag{3}$$

where $\bar{S}_{ij}, \bar{S}_{ji}$ are apparent powers transited from node $i\ to\ j\ \&\ j\ to\ i$ respectively.

Active and reactive losses are involved during power transmission.

$$\begin{cases} \bar{S}_{Loss} = \sum \bar{S}_{Lossij} = \sum (\bar{S}_{ij} + \bar{S}_{ji}) \\ \bar{P}_{Loss} = R\left\{\sum \bar{S}_{Lossij}\right\} \\ \bar{Q}_{Loss} = Imag\left\{\sum \bar{S}_{Lossij}\right\} \end{cases} \tag{4}$$

where $\bar{S}_{Loss}, \bar{P}_{Loss}, \bar{Q}_{Loss}$ are total apparent, active and reactive power lost in the network.

The complex voltage and the active and reactive powers, for each PV bus and PQ bus, we have the following equation can be written as follows:

$$\begin{cases} \Delta P_i = P_{is} - P_i = 0 \\ \Delta Q_i = Q_{is} - Q_i = 0 \\ \Delta P_i = P_{is} - V_i \sum_{j=1}^{n} V_j\,(G_{ij}\cos\theta_{ij} + jB_{ij}\sin\theta_{ij}) = 0 \\ \Delta Q_i = Q_{is} - V_i \sum_{j=1}^{n} V_j\,(G_{ij}\sin\theta_{ij} - jB_{ij}\cos\theta_{ij}) = 0 \end{cases} \tag{5}$$

where $\theta_{ij} = \theta_i - \theta_j$ is the transport angle between buses i and j.

At the core of Particle Swarm Optimization (PSO) is a swarm of particles, each representing a potential solution. These particles move through the solution space in search of the best solution. They adjust their positions based on their current velocity and their memory of the best solution they've encountered so far. Additionally, they are influenced by the best solutions found by their neighbors within the swarm.

PSO is used in optimization problems, particularly in cases where the objective function is complex and lacks a simple mathematical expression. It has been applied in various fields, including engineering, economics, and machine learning. PSO's ability to explore solution spaces efficiently and its simplicity make it a popular choice for solving optimization problems.

2.1. Power grid presentation

Figure 2.1. presents the single-line diagram illustrating the topology of the SAIDA-NAAMA grid region. Within this diagram, we can observe the NAAMA power plant and the ESC photovoltaic park, serving as key generation sources. Additionally, the Static Var Compensator

is featured as a device responsible for controlling the transmission network, thereby ensuring both voltage stability and power factor regulation. The distribution network is connected to various consumer categories representing electrical loads, collectively contributing to the overall power demand.

In terms of power generation, the system comprises a 180 MW gas turbine power plant situated in the NAAMA region and a $25MWp$ photovoltaic park located in the El-Abiodh Sidi Cheikh region of Algeria. The electrical loads within the network predominantly fall into two categories: residential and industrial consumers. The transmission network operates at 220 kV, while the distribution network functions at 60 kV.

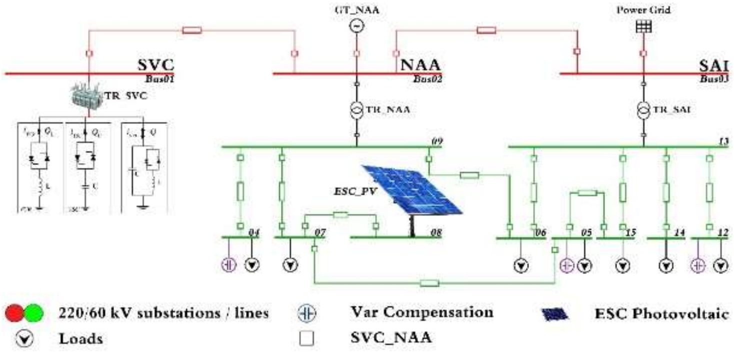


Fig. 2.1. Single-line topology diagram of the SAIDA-NAAMA grid

Under normal operating conditions, the power transit limits for transmission lines and autotransformers are conventionally set at 80% of their maximum capacity. This choice of power transit limits, below the maximum capacity, serves to establish a safety margin, ensuring that these components operate within a secure and reliable range. These limits take into account factors such as fluctuations in load demand, variations in environmental conditions, and the potential occurrence of unforeseen contingencies. This approach helps uphold the system's security and minimizes the risks associated with equipment failures or overloads.

2.2. Automatic Active power generation control

A frequency deviation step response characterizes how a power system's frequency reacts when subjected to a sudden change in power generation or load demand. When such a step change occurs, the frequency temporarily deviates from its nominal value before stabilizing again. This behavior typically follows a specific pattern as shown in Fig. 2.2. With the following steps, initial deviation and transient Response.

The duration of the transient response depends on the system's inherent inertia and the speed of the control mechanisms in place.

Figure 2.2 illustrates a block diagram of the closed-loop control system, where the frequency deviation is continuously monitored and processed by the PI (Proportional-Integral) controller. The control signal generated by the PI controller adjusts the generator set points through the governor control system. The power system model provides feedback on the actual frequency, closing the control loop. This MW Load Frequency Control (LFC) model with a PI controller ensures frequency stability by dynamically adjusting the generator outputs based on the frequency deviation, maintaining the power system within acceptable limits. For a load change of $\Delta P_L(s) = 0.2\, p.u$, if you set the integral controller gain k_I to 4, the closed-loop transfer function relating the load change to the frequency deviation $\Delta\Omega(s)$ can be determined based on the PI controller settings.

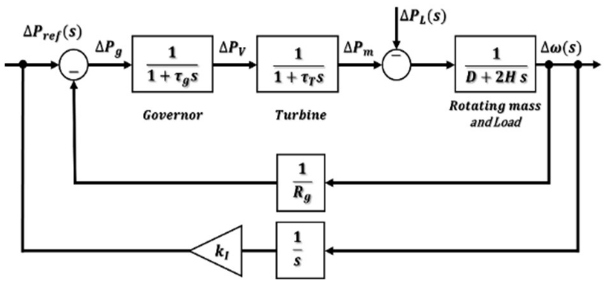


Fig. 2.2. Blocks diagram of active/load power frequency control model with PID controller

Key parameters include:
Turbine time constant $\tau_T = 0.5s$
Governor time constant $\tau_g = 0.2s$
Generator inertia constant $H = 5s$
Governor speed regulation $R_g = 0.05\ P.u$
Load change factor $D = 0.67$

The turbine is designed to generate electricity at a constant frequency of 50Hz, with a rated output of 180MW. However, a load change of 67.74MW ($\Delta P_L = 0.376\, per\ unit$) occurs. This results in a steady-state frequency deviation of 0.91Hz $\Delta f = |(-0.0182)(50)|$when a 67.74MW load change is applied.

$$\begin{cases} \dfrac{\Delta\Omega(s)}{-\Delta P_L(s)} = T(s) = \dfrac{s(1+\tau_g s)(1+\tau_T s)}{s(D+2Hs)(1+\tau_g s)(1+\tau_T s) + k_I + \dfrac{s}{R_g}} \\ T(s) = \dfrac{s^3 + 7s^2 + 10s}{50s^4 + 353.35s^3 + 523.45s^2 + 1033.5s + 200} \end{cases} \quad (6)$$

3. RESULTS AND DISCUSSION

The simulation results in this study underwent comprehensive analysis and were presented using multiple approaches, including the examination of small signal stability, dynamic voltage behaviour in the time domain, and the utilization of specific resolution algorithms.

Notably, the study employed the Fast Decoupled Load Flow (FDLF) method and the Multi-Objective Optimal Power Flow (MO-OPF) method for in-depth analysis. These analyses were conducted on the electrical network comprising the 220KV transmission system and the 60KV distribution system within the SAIDA-NAAMA region situated in western Algeria (as depicted in Fig. 2.1.). The software tools used for conducting the analysis and visualizing the results were MATLAB 2021a and ETAP 2019. These advanced software platforms provided the necessary computational capabilities to carry out the complex analysis required to evaluate the integration stability of photovoltaic systems in the region effectively.

3.1. Voltages profiles results

Fig. 3.1. demonstrates the impact of integrating the photovoltaic park in the ESC region on the dynamic voltage profile throughout the study day of May 21, 2023. It also includes the MW PV production curve.

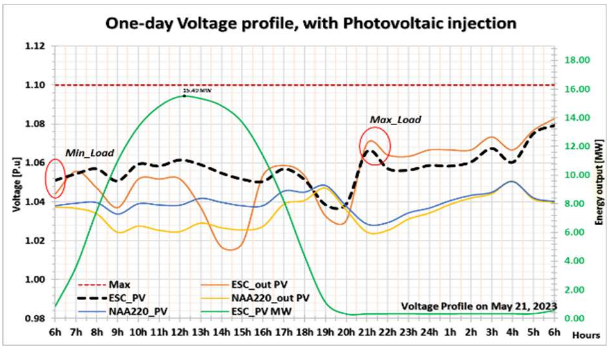


Fig. 3.1. Impact of PV integrating dynamic voltage profile in the ESC region

Fig. 3.2. displays the voltage evolution scenario during the study day for maximum loads, comparing the cases with and without reactive power compensation.

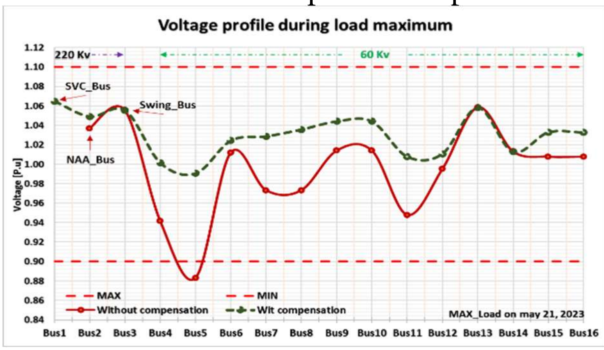


Fig. 3.2. Voltage profile during load maximum conditions in both cases: with & without compensation

Fig. 3.3. illustrates the voltage evolution scenario throughout the study day for minimum loads, comparing the cases with and without reactive power compensation (voltage sag regulation).

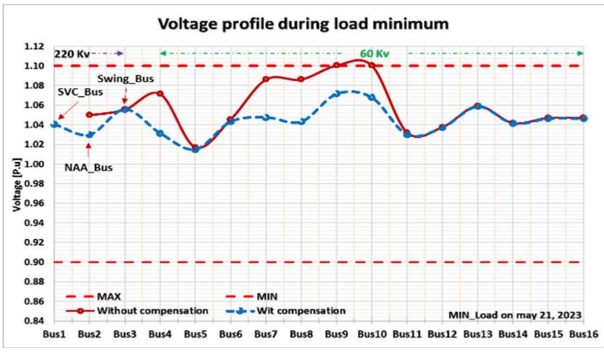


Fig. 3.3. Voltage profile during load minimum conditions in both cases: with & without compensation

3.2. Frequency control results

Fig. 3.4. depicts the frequency evolution in grid during the study day of May 21, 2023, incorporating the correction of fluctuations based on the model PI-AGC we previously proposed.

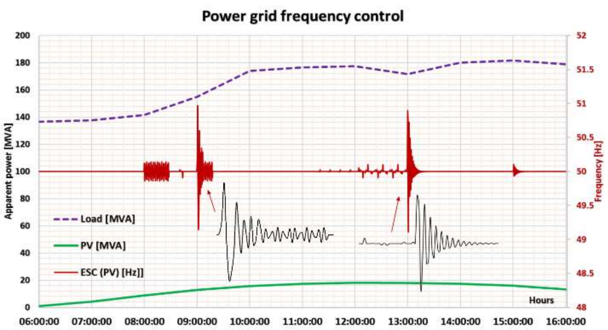


Fig. 3.4. Frequency evolution in grid with PI regulation.

3.3. Active power production control

Fig. 3.5. illustrates the evolution of active power production by the NAAMA gas turbine (GT) and the power demand from the electrical grid (PG) without photovoltaic introduction of ESC Park's.

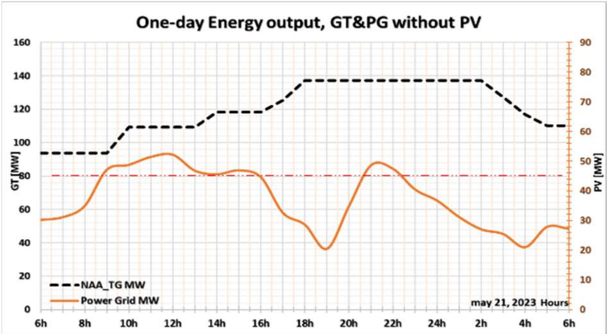


Fig. 3.5. MW Production from gas turbine and power grid without PV

Fig. 3.6. illustrates the evolution of active power production by the NAAMA gas turbine (GT) and the power demand from the electrical grid (PG) without photovoltaic introduction of ESC Park's, during a study day on May 21, 2023.

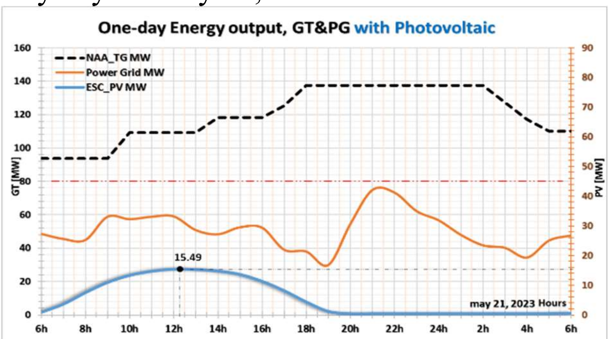


Fig. 3.6. MW Production from gas turbine and power grid with PV

The decrease in curves Fig. 3.1. and Fig. 3.6 between 10h and 18h present the power active evolution production of photovoltaic park (ESC_PV).

3.4. Total active losses evolution

Fig. 3.7. displays a comparison between the evolutions of power losses in MW, when considering the presence of photovoltaic energy with var compensation.

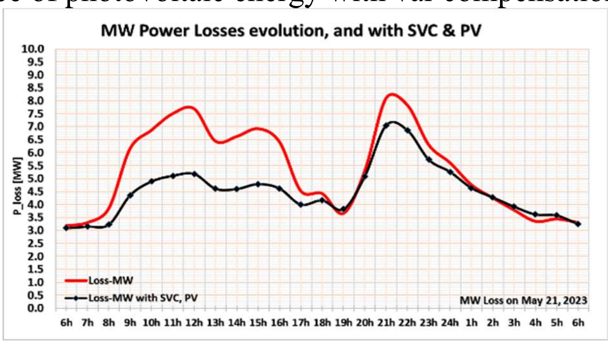


Fig. 3.7. Comparison between evolutions of MW power losses

3.5. Multi-Objective Optimization Algorithm

Fig. 3.8. presents the optimal voltages attained by employing the Multi-Objective-OPF with a optimization algorithm, namely MO-OPF.

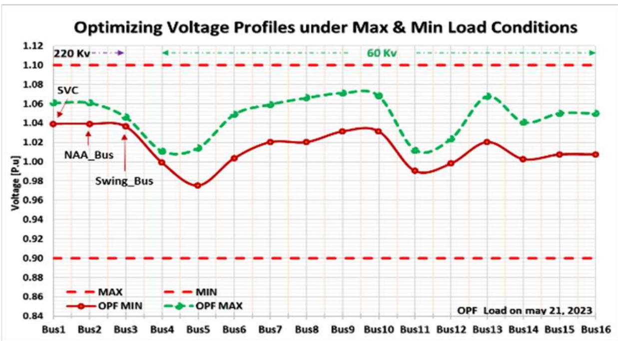


Fig. 3.8. Optimisation voltage profiles of load MAX and MIN with MOOPF methods with SVC and PF control

Table 3.1 displays the daily power losses and reduction rates for the maximum and minimum load scenarios on May 21, 2023.

Table 3.1 Daily Power Losses and Reduction Rates for May 21, 2023

Load	MW_{MAX}	$Mvar_{MAX}$	MW_{MIN}	$Mvar_{MIN}$
Power Losses Power Flow	8.369	-31.542	2.292	-14.976
Power Losses Optimal Power Flow	6.300	-31.092	2.064	-9.456
MW Reduction %	24.72%		10%	

The integration of photovoltaic energy into an electrical system has several notable impacts on various system parameters:

Active Power 3.1:

The generation of photovoltaic energy is contingent on factors such as solar radiation, weather conditions, and time of day. Consequently, the active power output from photovoltaic sources can vary. When integrated into the electrical grid, this energy contributes to the overall available active power.

Injection Bus Voltage 3.2:

Integrating photovoltaic energy can positively influence voltage levels within the electrical system. However, maximizing electrical loads can potentially lead to voltage degradation at certain buses, necessitating a thorough examination of local and global reactive power compensation.

Integration Power Factor 3.3:

The power factor, indicating the efficiency with which a load utilizes supplied energy, may experience fluctuations due to variations in solar energy production.

System Frequency 3.4:

Substantial fluctuations in solar energy production can indirectly influence the system's frequency. When photovoltaic energy production diminishes suddenly, such as during passing clouds or adverse weather conditions, an increase in grid load may lead to a minor frequency reduction. These frequency variations are typically modest and can be mitigated through grid regulation mechanisms.

The study employs an algorithm that simultaneously addresses various constraints and objectives to optimize power flow. Key objectives encompass minimizing MW and Mvar power losses, swing bus MW power, shunt Var devices, and achieving a flat voltage profile. Implementing this algorithm resulted in a notable reduction of power losses, with a 24.72% reduction observed for maximum load conditions and a 10% reduction for minimum load scenarios, all while maintaining optimal voltage adjustments.

5. CONCLUSION

This paper presents a comprehensive study that focuses on addressing the static and dynamic integration stability of photovoltaic (PV) systems in the SAIDA-NAAMA region of western Algeria. The central challenge addressed in this research pertains to the complex issue of frequency fluctuations, arising from a combination of variations in load curves and electrical production. Recognizing the critical nature of this challenge, the study introduces an innovative approach that integrates frequency stability analysis, optimal power flow control, and reactive power compensation within a flexible distributed power grid.

The primary objective of this research is to enhance the overall energy quality and stability of the PV Park located in El-Abiodh-Sidi-Cheikh (ESC) by ensuring dynamic stability across the network. This objective is achieved through the implementation of maximum power point tracking (MPPT) techniques, the maximization of solar resource utilization, and the compensation for reactive power variations. The results obtained from this study demonstrate substantial progress in improving the integration of photovoltaic systems.

By utilizing optimal power flow control in conjunction with var compensation and enhanced photovoltaic integration, the research reveals significant reductions in active power losses, with reductions of up to 24.72% observed, contingent on the specific load scenarios. Furthermore, the study addresses reactive power control through the application of NAAMA's Static Var Compensator (SVC) for the transmission network, along with localized compensations for the distribution network. This approach effectively maintains voltage levels well within acceptable thresholds.

These findings are of significant importance as they lay the foundation for the integration of photovoltaic systems by increasing the production capacity of the ESC photovoltaic station beyond its current 25MWp capacity. Moreover, the study provides insights into implementing additional PV stations throughout the region. These advancements contribute significantly to strengthening ongoing efforts toward transitioning to sustainable energy sources and the utilization of green energy. Ultimately, this research delivers invaluable knowledge to the field, offering a pathway to overcome the challenges associated with the integration of photovoltaic systems into Algeria's national interconnection network, commonly referred to as the RIN.

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APPENDIX

Table A.1, provided below, outlines these operating durations, delineating the minimum times an electricity generation unit must remain connected to the grid while experiencing variations in frequency away from the nominal value.

21. **Table A.1** Minimum frequency range and operating durations without

Frequency Range	Operating Duration
47 Hz - 47.5 Hz	10 seconds
47.5 Hz - 48 Hz	20 seconds
48 Hz - 52 Hz	Unlimited
52 Hz - 52.5 Hz	10 seconds