Power systems stability of high penetration of renewable energy generations

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Abstract. In this Paper a comprehensive analysis of the Jordanian Power Grid (JPG)'s stability under various practical scenarios, including load disturbances and the integration of Renewable Energy Sources (RES). A key focus of the study is the impact of RES on the stability of the JPG, especially during unexpected disturbances. The findings reveal a notable trend: higher RES integration tends to decrease the grid's stability under certain conditions. Additionally, the report explores the effects of interconnecting the JPG with neighboring countries, such as Egypt. This connection is shown to potentially enhance the JPG's stability, both with and without the involvement of RES. The report delves into numerous cases, providing detailed discussions and insights. The conclusions drawn emphasize the critical importance of carefully managing the proportion of RES in the JPG to maintain its stability against various disturbances. This study offers valuable recommendations for future strategies to ensure the robustness and reliability of the Jordanian Power Grid in the face of evolving energy landscapes.

Introduction

The Hashemite Kingdom of Jordan is significantly reliant on foreign energy sources, with an import ratio of approximately 92% [1] The country's energy demand is on the rise, spurred by factors such as population growth and the influx of refugees from neighboring regions. Jordan faces substantial challenges in meeting its electricity needs due to limited local fossil fuel resources, inadequate conversion capacities, and the financial constraints of its energy sector. Renewable Energy Sources (RES) have emerged as a pivotal solution for Jordan, offering a means to secure electricity supply while protecting the environment [2–4] The nation's abundant solar and wind resources make this a particularly viable option. While RES contributes to reducing emissions and enhancing supply security, they also introduce greater uncertainty and variability in the transmission and distribution of power [5 - 7]. This dynamic has been complicated by the current economic impracticality of large-scale energy storage, which exacerbates the challenge of balancing generation with real-time demand. Moreover, while Distributed Generation curtails losses associated with electricity transport and transformation, it adds complexity to the system, necessitating advanced, research-based solutions [8 - 10]

Globally, there is a growing interest in transitioning to RES, and Jordan has made significant strides in this direction. Over the past decade, approximately 3500 MW of RES has been integrated into the Jordanian Power Grid (JPG), accounting for 30% of total generation as of 2022 [8 - 10] However, this increased reliance on RES presents operational challenges for the JPG. The main objective of this research is to investigate the effects of integrating large-scale renewable energy sources on the transient behavior and sustainability of the JPG. Utilizing the Power analysis program DIGSILENT, along with current system steady-state and dynamic models, this study will focus on the impacts of RES integration on JPG's voltage profile, sustainability, and overall

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stability. The analysis will shed light on the challenges and dynamics introduced by the increased share of renewable energy within the Jordanian power landscape.

Methodology

The methodology of this study centers on evaluating the stability of the Jordanian Power Grid (JPG) with a high Renewable Energy Sources (RES) share. To achieve this, the study employs DIGSILENT power software, a tool adept at assessing electrical systems, particularly in power transmission and distribution contexts. The JPG's operational model is meticulously simulated within DIGSILENT to investigate whether the system can maintain synchronism following significant transient disturbances. The key to this study is the simulation and analysis of various challenging scenarios, such as abrupt generation loss and frequency mismatches, within the JPG model. The robustness of the system's synchronism is rigorously tested under scenarios like sudden loss of generation. These tests are conducted across different grid load conditions—specifically peak and low load periods—under high RES integration scenarios. Additionally, the stability of the system's frequency is thoroughly examined. This aspect is crucial, given that system frequency significantly influences the performance of power generating units at all voltage levels, especially during extreme imbalances.

Results and Discussions

In this section, we explore two distinct scenarios simulated for the Jordanian Power Grid (JPG) in the year 2025, under conditions of high Renewable Energy Sources (RES) integration. These simulations are aimed at assessing the impact of increased RES on the stability of the JPG.

Case 1: Peak Load Scenario in 2025

Under peak load conditions with high integration of renewable projects, the network analysis reveals a robust system. A hypothetical disturbance, such as a complete loss of power generation from all wind farms due to a wind storm, was simulated. Despite this extreme scenario, the Jordanian electrical system maintained stable performance in terms of voltage, frequency, and generator power angles and speeds. No Under Frequency Load Shedding (UFLS) was necessary as the frequency remained above the critical threshold. The National Grid summary for this category in Year 2025 in peak load situation and high renewable projects integration is shown in Table 1.

Table 1: JPG summary for case 1

National Grid summary	
Grid Demand	4670MW
Total Installed Capacity	8200MW
Wind integration	774MW
Solar integration	1710MW
Spinning Reserve	820 MW
Grid Losses	96 MW
External In feed (Egypt)	7MW (to Egypt)

In this specific case, no major problems have been detected and the Jordanian electrical system shows stable behavior in voltage, frequency and generators power angle and speed, No UFLS detected since the frequency did not reach or drop below the first stage threshold of 49.1HZ, as shown in Figs1, 2, and 3.

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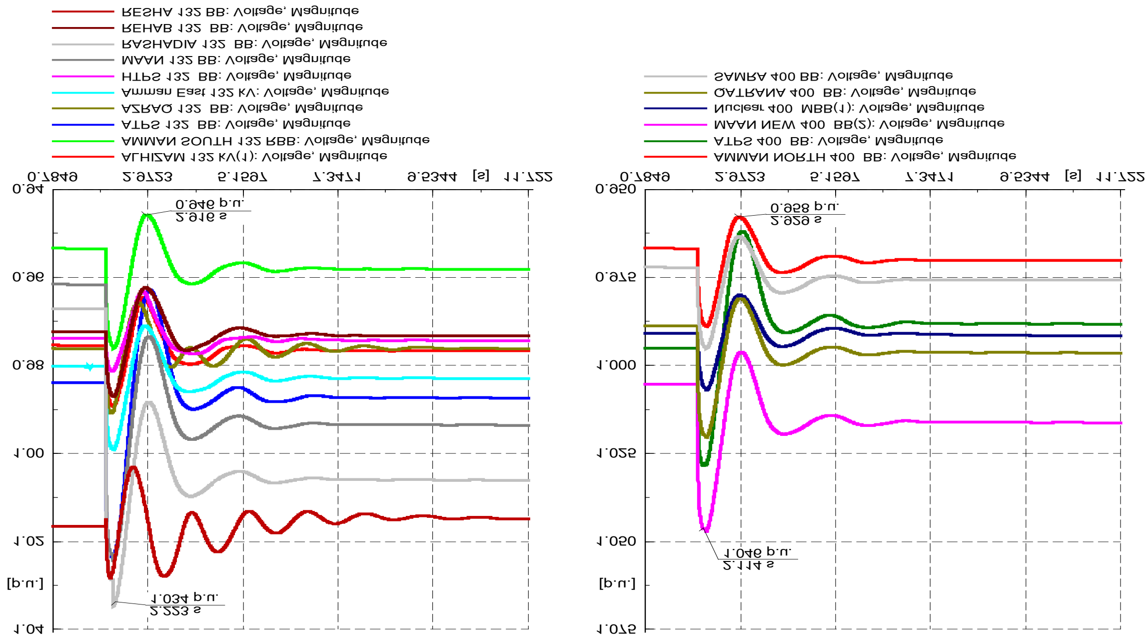

Figure 1: Voltage behavior for selected 132kV and 400kV busbars in the JPG [10]

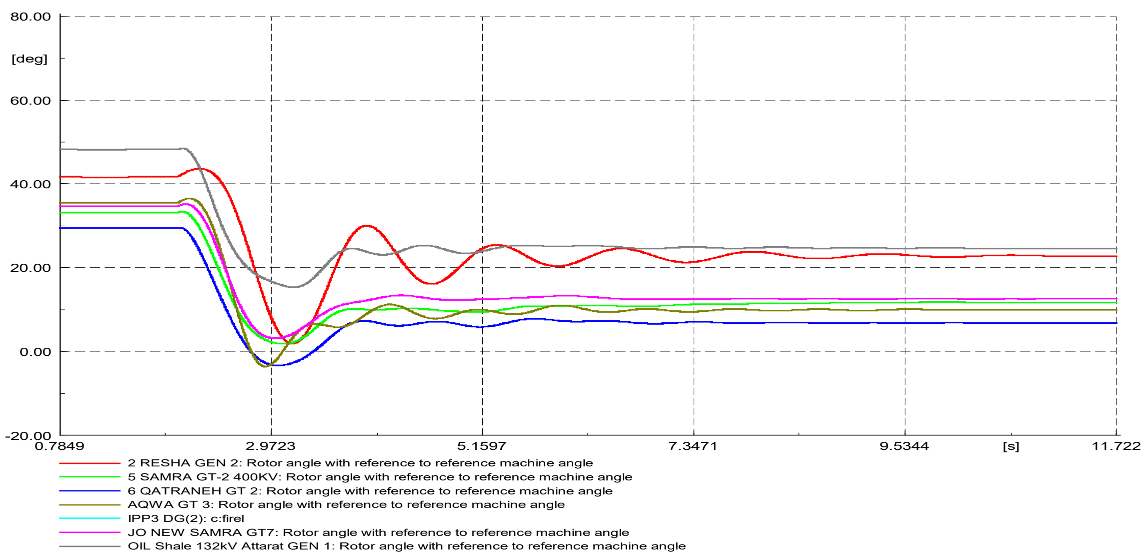

Figure 2: Power angle with reference to reference machine for several generators in the JPG

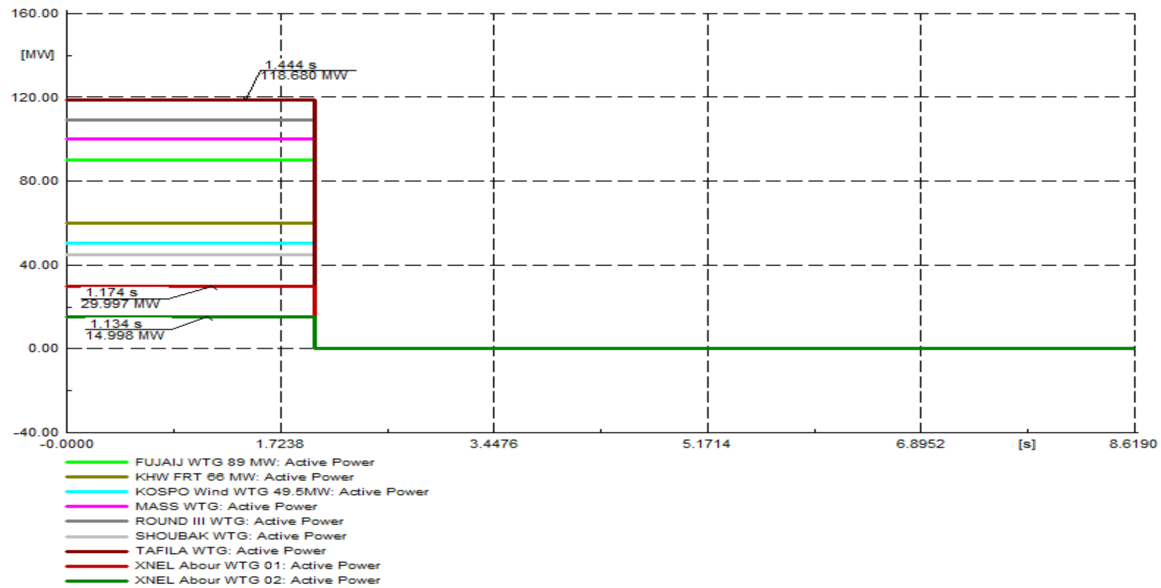

Figure 3: wind farms response after Loss of generation case [10]

Case 2: Low Load Scenario in 2025

In this scenario, the study considers a low load situation with high RES integration. The simulation predicts an increased reliance on RES, including wind and solar, alongside new primary energy resources like oil shale and nuclear power. When simulating a complete loss of power generation from all wind farms during a wind storm, it was observed that the system could handle the disturbance without major issues. The JPG summary for this category in Year 2025 low load situation and high renewable projects integration is shown in Table 2 below.

Table 2: JPG summary in 2025

National Grid summary	
Grid Demand	2100MW
Total Installed Capacity	8200MW
Wind integration	774MW
Solar integration	1710MW
Spinning Reserve	930MW
Grid Losses	91.4MW
External In feed (Egypt)	200MW (to Egypt)

In case the system forced to operate at 80% of renewable integration where only 500MW of conventional generation presented and the rest of power is covered by wind and PV, (the planning value of renewable is about 3000MW of approved projects until year 2025), the system will never converge or solve, the below errors as shown in Figure 4 will occur, where the inertia in the system is not sufficient to develop any response to the studied events [10]

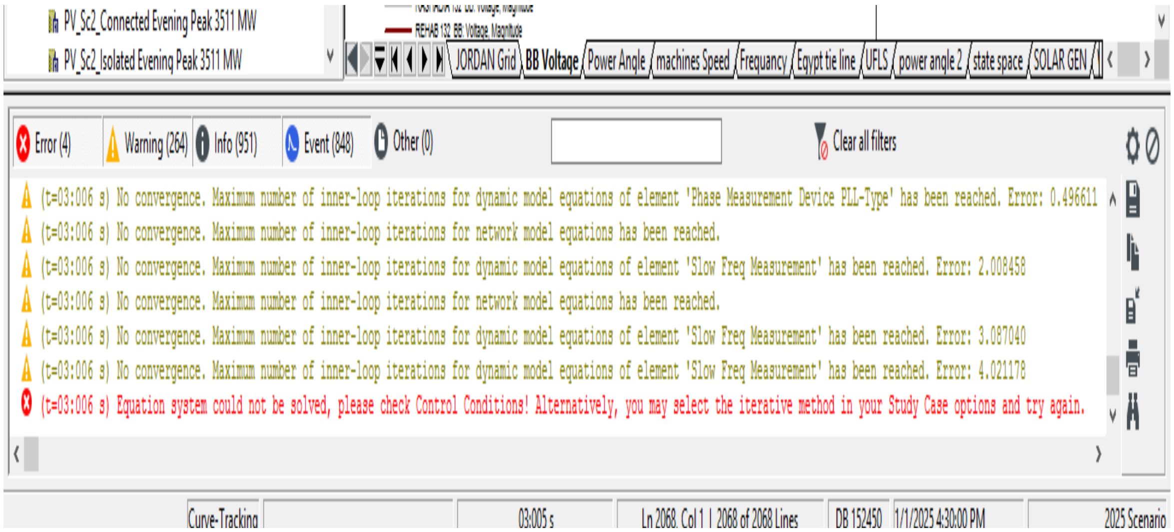

Figure 4: Error massage in Simulation of 80% RES (Wind and PV integration).

In this case the assumption is to operate several conventional generation in the system in the minimum possible power dispatch condition in order to start the initial condition for simulation and to increase system inertia, the simulation is started with 57% of RES integration by making some of wind farms in the southern area in operation condition and switching off more PV projects in the grid, then implement wind and Solar power curtailment scheme, Results of case 4 (loss of several wind farms) are shown below, in this case the system is considered stable after loss of wind event.

Here below selected monitored elements and simulation results are shown. In this specific case, no major problems have been detected and the Jordanian electrical system shows stable behavior in voltage, frequency and generators power angle and speed, No UFLS detected even the frequency drop below the fourth stage threshold of 48.4HZ but the drop duration was less than 0.2 seconds. The simulation results of this case are presented, for low spring load of 2150MW in year 2025 with maximum RES integration. The most critical contingency in the low load condition appears to be the simultaneous trip of all wind farms, particularly in the southern green corridor. This leads to a significant power deficit of 612 MW. Nevertheless, the system's resilience is primarily due to the support from interconnected systems, namely Egypt and Syria. The simulation results show that peak power transfers, particularly from the Egyptian system, could exceed protective settings, posing a risk of separation from the Egyptian grid. This highlights the importance of careful management and coordination in interconnected grid operations, especially under high RES integration scenarios.

Conclusion

The study of the Jordanian Power Grid (JPG) for 2025 underlines its robustness amidst high Renewable Energy Sources (RES) integration. While the grid-maintained stability during peak loads even with extreme disruptions like total wind power loss, challenges arose in low load conditions at 80% RES integration due to insufficient system inertia. Strategic adjustments, including a balanced mix of renewable sources and curtailment strategies, were key to stabilizing the grid. The study highlights the grid's vulnerability to simultaneous wind farm disconnections, underscoring the importance of meticulous planning, balanced energy mix, and strong interconnectivity protocols in ensuring grid resilience in a renewable-dominant future.

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