IMPACT ANALYSIS OF PV INTEGRATION ON POWER SYSTEM STABILITY UNDER CONTINGENCIES: CASE STUDY

SEDDIK ZEMITTE[1], MESSAOUD HAMOUDA, FATIMA ZOHRA ARAMA, ABDALLAH LAIDI

[1]University of Ahmad draia, Faculty of Science and Technology Laboratory of Sustainable Development and Computer Science (LDDI), Adrar, Algeria

DOI: 10.17973/MMSJ.2023_06_2023006

E-mail : sed.zemitte@univ-adrar.edu.dz

Today, greenhouse gas emissions and climate change stemming from the usage of fossil fuels are significant worldwide issues. Renewable energy, such as solar energy, is an environmentally friendly and non-polluting option. However, there are numerous worries regarding the possible influence of renewable energy integration on power system stability. Therefore, research is required to investigate and assess this effect. This study analyzes and investigates the impact of photovoltaic (PV) power plants installed in the kaberten region (Southwest of Algeria) on the power system's transient stability. The obtained results proved that the photovoltaic power plant positively affects the system's stability. In addition, it provides clean energy and reduces reliance on traditional sources.

KEYWORDS

Transient stability, Renewable energy integration, Photovoltaic, MATLAB/Simulink

1 INTRODUCTION

Many countries are moving towards renewable energy as an irreplaceable solution to meet their energy needs, especially since traditional energy sources from fossil fuels, such as coal, oil and natural gas, are not sustainable in addition to their negative impact on the global economy. In order to reduce gas emissions, a net zero emissions program has been developed, which consists of reducing greenhouse gas emissions as close as possible to zero. In this context, 2030 has been identified as the first step to reduce emissions by 45% and achieve net zero emissions by 2050[Anika et al., 2022].

The power system is known to be complex and non-linear due to the continuous variation of loads, production, and operating conditions. Therefore, integrating renewable energy into the grid can raise concerns about grid stability and reliability. Thus, it is necessary to study and analyze the impact of this integration on network stability. Many researchers in the literature, with different points of view, investigated the effect of solar PV as a distributed generation (DG) unit on critical clearing time (CCT) during the islanded operation of an industrial microgrid system [Khan et al., 2019]. It was found that the CCT goes up when solar PV energy is added, but only until a certain rate of penetration, after which it starts to go down. Authors in [Shah et al., 2010], address power system stability issues by studying the integration of two models of PV generation systems in an IEEE-14 bus test system. The effect of photovoltaic power generation's radiation pattern, size, and location is tested. The results show that increasing the penetration of the PV system improves the stability of the power system's oscillations. The analysis of photovoltaic plant effects on the Modified IEEE 9 bus system using Etap software was introduced by[Upadhyay et al., 2022].The study concludes with a recommendation regarding integrating RES with the conventional electrical grid by Respecting the grid code.

PV system integration can have positive or negative effects on the transient stability of the power system. This depends on the level of PV penetration, system configuration, placement of PV integration, and the type and location of the disturbance (fault or loss of generator) that the grid experiences[Tavakoli et al., 2020]. hybrid technique for Enhancement of power quality (PQ) in grid connected PV system with the Radial Basis Function Neural Network technique and Proportional Integral (PI) controller[Sujatha et al., 2018] Numerous efforts have been made to offset the technical limits of PV penetration in Regulation systems. including active power reduction, voltage regulation, and coordinated stress control. Compared to conventional techniques, the results show that the proposed method may be a promising candidate for the PQ enhancement of grid-connected PV systems in the event of grid-side disturbances. Work in[Jawad et al., 2022] presents a novel method for predicting optimal deloading percentages for PV systems in terms of frequency response parameters, employing multiple linear regression analysis for various PV penetration levels on modified IEEE 39 bus test system. The obtained results indicate the success of the proposed methodology. deloaded PV is more effective for protecting the system from undergoing load shedding. Researchers in[Siraj Khan, 2013] study the stability of the power system with the integration of photovoltaic energy. And the conclusion of the photovoltaic generator's contribution to voltage accuracy and enhanced system stability was extracted.

Algeria, like other countries, strives to increase the proportion of renewable energies in its power generation to protect its fossil fuel resources and profit from greater exports at better prices, as well as to achieve a sustainable mix that aids in managing energy crises. In this context, the Algerian government wants to produce approximately 15 gigawatts of renewable energy by 2035, utilizing photovoltaic energy, solar thermal energy, and wind energy, as well as cogeneration, biomass, and geothermal energy. According to data released by the government, Algeria's total renewable energy capacity reached 567,1 MW by the end of December 2021,Photovoltaic solar energy represents 92% of renewable energies in Algeria, 84% of which are connected to the grid[Himri et al., 2022]. According to (2020–2030) programme of the Algerian government, the main renewable energy source will be photovoltaic energy, followed by wind energy. It is planned that, by 2030, these two sources will account for 84% of all energy produced with renewable energy (RE) sources in Algeria[Díaz-Cuevas et al., 2021] . In this regard, examining the effects of integrating this generation type on the power system stability is crucial.

The main contributions of this paper are the following:

•Investigating the effect of different levels of photovoltaic energy penetration on the existing network's stability under various disturbance scenarios.

•Formation of a prospective understanding of the power system's behavior in the event of a disturbance.

The remainder of the paper deals with materials and methods, modeling, and control of the studied system under SIMULINK/SIMPOWER.in Section 2. Then, Section 3 results and discussion. Finally, a conclusion is presented in Section 4.

2 MATERIALS AND METHODS

Transient stability refers to the ability of the power system to maintain synchronism after being subjected to a severe disturbance, [Kundur et al., 2004] such as a short circuit on a transmission line, sudden outages, fault incidents, Sudden connection or disconnection of a large load … ext. Loss of transient stability can lead to catastrophic occurrences like cascading failure and/or widespread blackout. Therefore, maintaining transient stability is a crucial necessity in the operation of a power system.

in this study we applied three scenarios of disturbance to investigate and analyze the impact of integration PV-power on power system transient stability.

- case 1: sudden Loss of utility Grid
- case 2: three phase Fault in the main bus-bar
- Case 3: sudden connection of load

2.1 Design and modelling of grid-connected photovoltaic system

The photovoltaic power plant is located in southwest Algeria, in the Kaberten region (72 km north of Adrar - Algeria) With 12276 panels and a surface area of 6 hectares, it is connected to a 30 kV distribution network main busbar, this station contains three (3) photovoltaic sub-fields with an output capacity of 1 MW each, with each sub-field divided into two sections with an output capacity of 0.5 MW each. The station's panel type is YL245P-29b made by YINGLI SOLAR. Table 1 show the Panel « YL245P-29b » nameplate.

Module Type	YL245-29b
Rating Power	245 W
Rated current (Ir)	8.28 A
Open circuit voltage (Voc)	37.7 V
Short circuit current (Isc)	8.83 A
Max system voltage	1000 V
Fire resistance class	C
Application Class	A

Table 1. Nameplate of reference solar module.

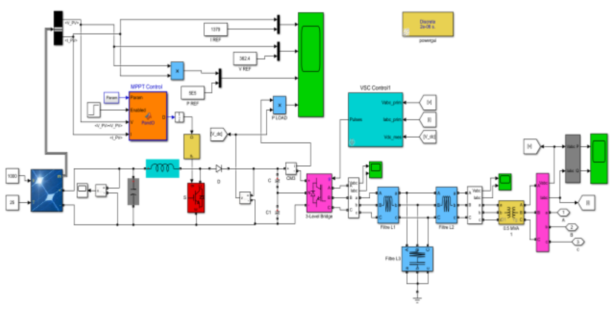

Figure 1. SIMULINK model of sub-field of PV plant in studied system

In this study, we used a ready-made PV array block from the Simulink library. The array is formed of parallel strings of modules, each consisting of modules coupled in series. The PV Array block is a five-parameter model that consists of a current source IL (light-generated current), a diode, series resistance R_s, and shunt resistance R_{sh}.

As shown in Figure 1, The Simulink model of the sub-field of the PV plant in the studied system interfaces the photovoltaic system with the utility grid. In the first stage, the output of the photovoltaic generator is connected to a boost converter. We used the perturb-and-observe (P&O) algorithm MPPT to control the boost converter and MPP tracking. The second stage is 500 kW inverters (SG1000TS-SUNGROW), which connect the sub-filed to a 1.25/0.630 MVA step-up transformer. This raises the generation voltage from 0.315 kV to 30 kV, then injects it into a 30 kV distribution network. An LCL filter is used at the output of the inverter to reduce the harmonics emitted by the inverter, which a high-frequency PWM controls.

Figures 2 and 3 show the I-V and P-V characteristics of the sub-field plant of the studied system with the YL245P-29b module under (irradiation/temperature) changes.

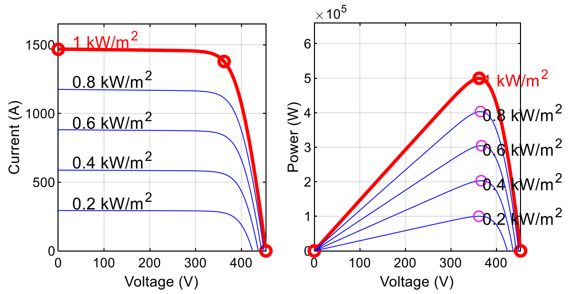

Figure 2. P-V and I-V curves under irradiation change.

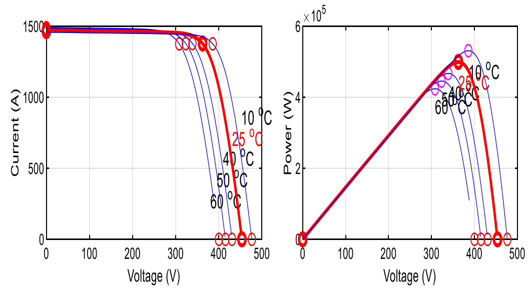

Figure 3. P-V and I-V curves under Temperature change.

We can show that an increase in temperature reduces the power generated by photovoltaic panels. When the temperature is around 25˚ , they achieve the optimal mode of operation.

2.2 VSC Inverter control

The PV inverter is a three-level bridge voltage source converter (VSC) that will provide reliable AC power from output of boost-converter, The VSC control system employs two control loops: an external control loop that regulates the DC link voltage to +/- 840 V, and an internal control loop that governs the Id and I_q grid currents (active and reactive current components). I_d current reference is the output of the external controller for DC voltage. Iq current reference is set to zero to preserve a power factor of unity. The current controller's V_d and V_q voltage outputs are transformed into three modulating signals Uabc_ref utilized by the PWM Generator.

The control system uses the Phase-locked loop (PLL) for determination of the grid voltage phase angle and frequency and its synchronization with the inverter voltage. Figure 4 provides the inverter control algorithm

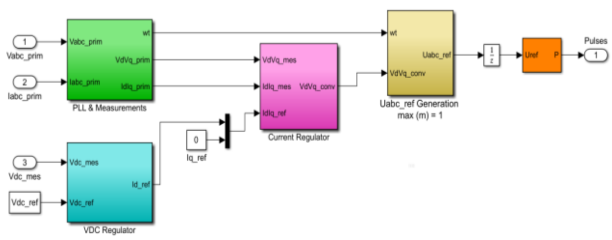

Figure 4. The VSC Control implementation in Simulink.

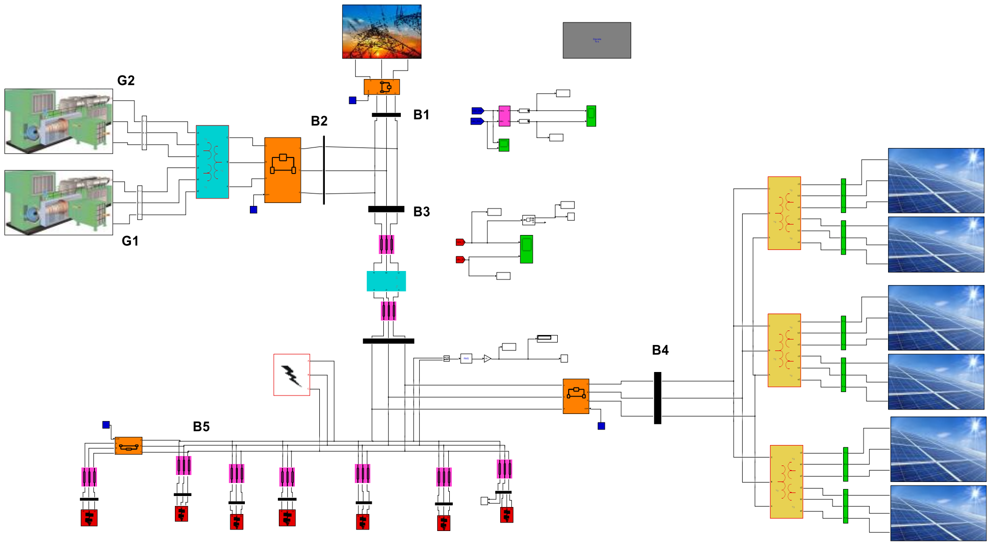

Figure 5. SIMULINK/SIMPOWER model of the studied system

3 SYSTEM CONFIGURATION

The studied power system is located in Kaberten region (72 km north of Adrar- Algeria).is a distribution network medium voltage including six (6) loads: AGRL (1.09 MVA), BNTLHA (4.20 MVA), ARAINRAS (4.46 MVA), MTRFA (2.90 MVA), OMAHUD (4.21 MVA), and TLKN (4.36 MVA), Load values were recorded on July 17, 2021. Two sources feed the network. The first is a power grid through a 220 kV transmission line, Adrar-Timimoun. The second is a conventional generation station containing two generators (G1, G2), a steam gas turbine, each with a rating of 23 MVA. In addition to a photovoltaic power plant with a capacity of 3 MW and a wind power plant with a capacity of 10 MW. In this study, we consider the wind farm in a state of rest. Figure 5 shows a description of the studied system and its components.

4 RESULTS AND DISCUSSION

4.1 Normal operation of studied system

To validate the system's design in the MATLAB/Simulink environment, the system under study was simulated under normal operating conditions, with total system load of (p=21 MW, Q=4.45MVAR), Load value real recorded on July 17, 2021. irradiation profile used for PV array [1000, 700,300,1000] w/m^2.

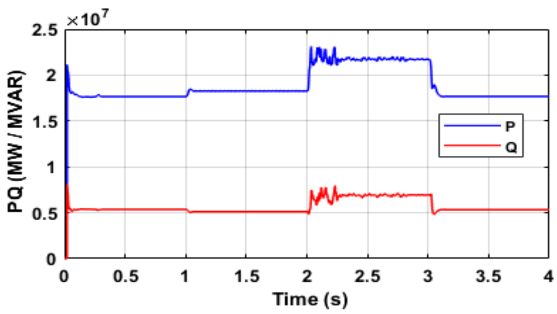

Figure 6. Generated PQ at BUS_3

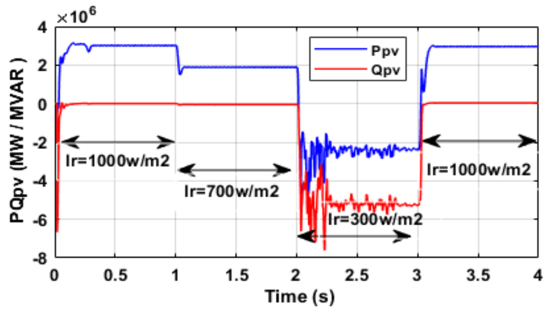

Figure 7. Generated PQ From PV plant

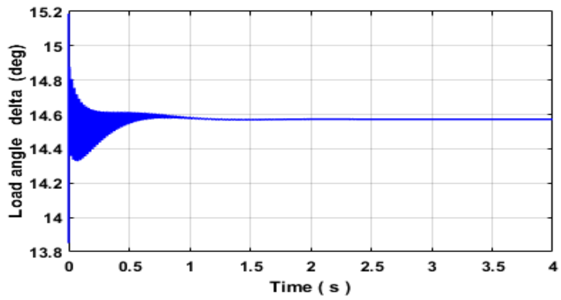

Figure 8. Load angle delta of G2

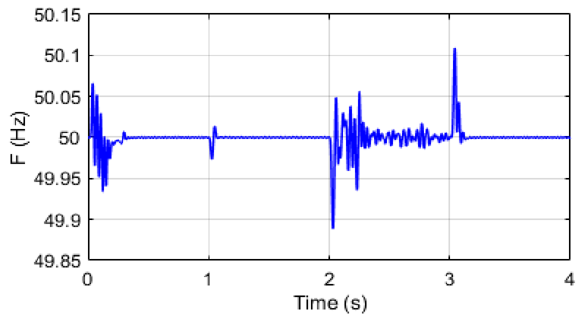

Figure 9. Frequency at BUS_5

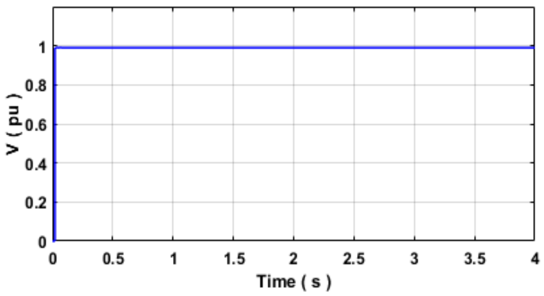

Figure 10. Voltage at BUS_5

- Figure 06 shows the active and reactive power generated at Bus 3. the generated power is consistent with the loads connected to the main bus bar and the losses in the transmission lines and transformers. The power grid injects additional power into the system when the PV power decreases (reduces irradiation).
- Figure 7 demonstrates that when I_r=1000 w/m^2, the photovoltaic power plant injects 3 MW of active power. As radiation decreases, PV power decreases. In [0 to 2 s], there is no exchange of reactive power between the PV system and the grid, proving the dependability of the control applied to the inverter. In [2 to 3 s], the radiation reduces to 300 w/m^2, and we observe that the photovoltaic power station became out of synchronisation with the grid and is absorbing active power from the grid. The protection devices isolate the station from the network in such a scenario.
- Figure 08 shows that generator 2's load angle starts with an oscillation that starts large and then decreases gradually. Because the power grid imposes itself as the network's main power source, the generator rotor speed exceeds the synchronous speed and begins to decline due to the generator's inertia. When the rotor speed equals the synchronization speed, the load angle remains constant at 14.6 degrees.
- Figure 9 indicates that synchronous generators affect system frequency during a few milliseconds transient phases at the start of the simulation. Nonetheless, it quickly stabilizes at the nominal frequency of 50 Hz. The PV production oscillates when radiation decreases, impacting the main Bus-bar frequency.
- According to Figure 10, the voltage at bus 3 is 1 PU. It is unaffected by the photovoltaic power plant's output variations because the power grid compensates for the loss of any other source from the system.

4.2 case 1: sudden Loss of utility Grid

In this scenario, we impose a sudden Loss of utility Grid, a type of disturbance that can destabilize a system. In order to carry out this scenario, the circuit breaker opens at 1.5 seconds. Figures 11, 12, and 13 shows the Load angle delta of Generator 2 and the Voltage, frequency at the network's main bus bar.

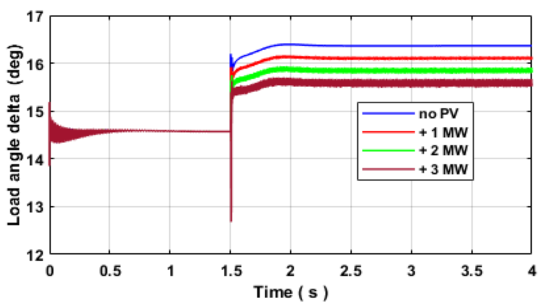

Figure 11. Load angle delta of G2

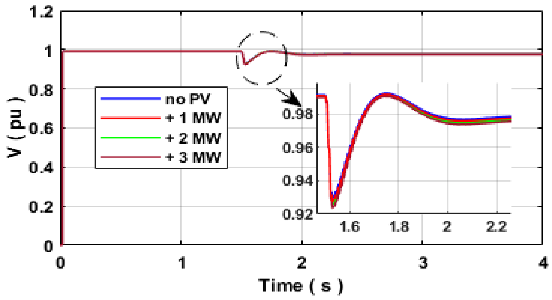

Figure 12. Voltage at BUS_5

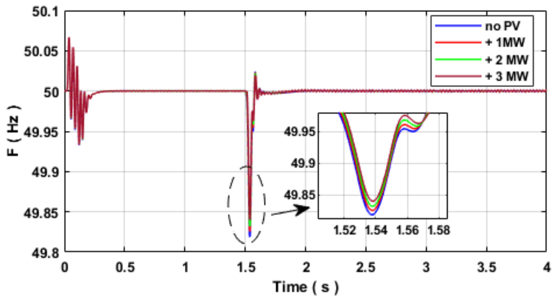

Figure 13. Frequency at BUS_5

- According to Figure 11, before the fault, the load angle of the generator two in the base case is 14.6 deg.

During a fault, it shows higher oscillations in the base case. Even after clearing the fault, it settles at values of 16.4 deg. When 1 MW PV is penetrated in the grid, the load angle settles at a lower value of 16.1 deg. In the case of 2 MW PV power shared in the grid, it drops to 15.8 deg, while in the case of 3 MW, the value of the load angle stabilizes at 15.5°. With the integration of PV into the grid, the demand on the generator decreases, resulting in a slower rotor speed and a reduced load angle, which makes the system more stable.

- As shown in Figure 12, the integration of PV power into the grid improves the voltage, as the damage is less severe in the case of integrating 3 MW.

- Figure 13 shows that the frequency decreases when the system loses the utility grid because the system has less generation due to the outage of utility grid. It is noticed that the system's response is better in the case of the integration of solar energy.

4.3 case 2: three phase Fault in the main bus-bar

In this scenario, a three-phase fault has been introduced at bus 3 at "1.5 seconds". The relative rotor angle of G2 and the voltage and frequency at the main bus bar have been monitored and plotted in the time domain for "4 seconds" after the fault was cleared after 5 cycles.

In the basic case, there is no penetration of PV power. We then increase solar penetration by 1 MW in each case until we reach 3 MW.

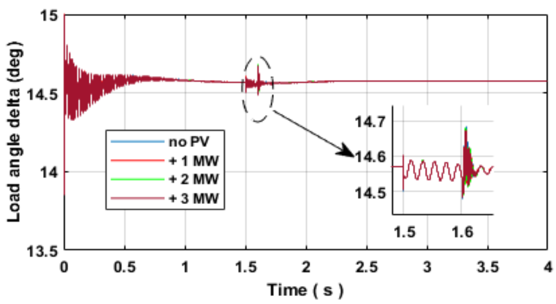

Figure 14. Load angle delta of G2

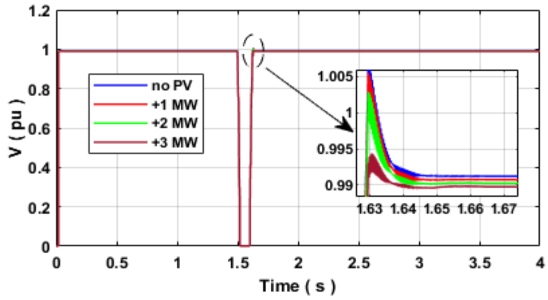

Figure 15. Voltage at BUS_5

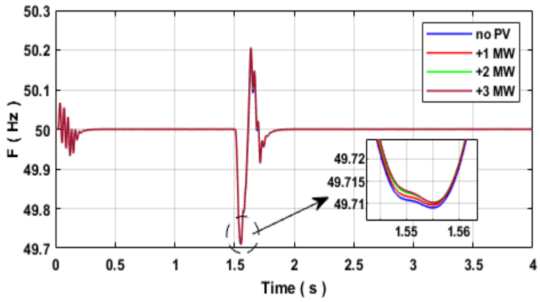

Figure 16. Frequency at BUS_5

- Figure 14 demonstrates that the PV integration contributes marginally to the improvement in system response during a fault, as the load angle is less affected during the PV integration than when no PV is installed.

- Figure 15 shows the voltage variation during a three-phase fault for (100 ms) at the main bus. We notice that the voltage drops to zero at the instant of the fault and then recovers to its steady-state value once the fault is eliminated with a higher overshoot in the basic case. The overshoot decreases as the PV penetration ratio increases.

- According to Figure 16, the frequency during a three-phase fault reduces to its lowest value when there is no PV power in the grid, but it rises when solar energy is integrated into the system.

4.4 *Case 3: sudden connection of load*

In this scenario, a sudden connection of additional significant load achieves 10 MW active power and 02 MVAR reactive power at the main bus bar in (1.5 s).

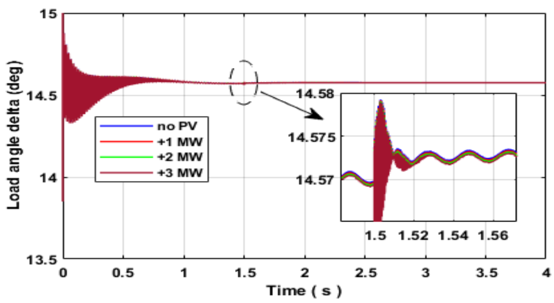

Figure 17. Load angle delta of G2

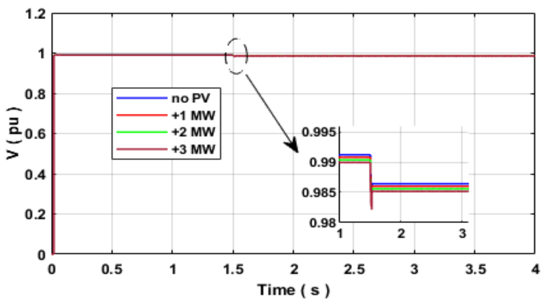

Figure 18. Voltage at BUS_5

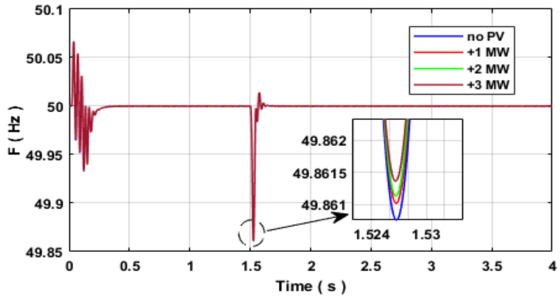

Figure 19. Frequency at BUS_5

- In the event of a sudden connection of a significant load to the grid will brak the generator's rotor (decrease frequency). As the frequency decreases, the gas turbine detects this and increases its "production" of mechanical energy to speed up the rotor and meet the demand. the main bus bar voltage drops and settles at a lower value than the original as shown in Figure 18, which leads to an increase in the load angle which decreases with the penetration of PV power, as shown in Figure 17.

5 CONCLUSION

This paper investigates the effect of grid-connected PV plants on power system transient stability. Simulation studies are carried out in MATLAB/SIMULINK/SIMPOWER to illustrate and compare the transient performance of the system under a variety of disturbances, such as - sudden loss of utility grid - three phase fault in the network main bus bar - sudden load connection. The obtained results proved that the photovoltaic power plant installed in the kaberten region (Southwest of Algeria) positively affects the power system's stability. It enhanced steady-state voltages and frequency. Furthermore, increased voltage drop during emergency scenarios. Reduce load angle and voltage instability and increase the reliability of the power system. In addition, it provides clean energy and reduces reliance on traditional sources. In future work, it is necessary to research to improve system stability using FACTs (Flexible AC Transmission System) Devices like STATCOMs, SVCs, UPFC, ... etc.

REFERENCES

[Anika et al., 2022] Anika, O. C., Nnabuife, S. G., Bello, A., Okoroafor, E. R., Kuang, B., & Villa, R. (2022). Prospects of low and zero-carbon renewable fuels in 1.5-degree net zero emission actualisation by 2050: A critical review. Carbon Capture Science & Technology, 5(August),100072.

[Khan et al., 2019]Díaz-Cuevas, P., Haddad, B., & Fernandez-Nunez, M. (2021). Energy for the future: Planning and mapping renewable energy. The case of Algeria. Sustainable Energy Technologies and Assessments, 47, 101445.

[Shah et al., 2010] Himri, Y., Rehman, S., Mostafaeipour, A., Himri, S., Mellit, A., Merzouk, M., & Merzouk, N. K. (2022). Overview of the Role of Energy Resources in Algeria's Energy Transition. Energies, 15(13).

[Jawad et al., 2022]Jawad, A., & Masood, N. Al. (2022). A systematic approach to estimate the frequency support from large-scale PV plants in a renewable integrated grid. Energy Reports, 8, 940–954.

[Khan et al., 2019] Khan, F. I., & Aziz, T. (2019). Transient Stability evaluation of a Solar PV Integrated Industrial Microgrid. Proceedings of 2019 IEEE Region 10 Symposium, TENSYMP 2019, 535–540.

[Kundur et al., 2004]Kundur, P., Paserba, J., Ajjarapu, V., Andersson, G., Bose, A., Canizares, C., Hatziargyriou, N., Hill, D., Stankovic, A., Taylor, C., Van Cursem, T., & Vittal, V. (2004). Definition and classification of power system6

stability. IEEE Transactions on Power Systems, 19(3), 1387–1401.

[Shah et al., 2010] Shah, R., Mithulananthan, N., Sode-Yome, A., & Lee, K. Y. (2010). Impact of large-scale PV penetration on power system oscillatory stability. IEEE PES General Meeting, PES 2010, 1–7.

[Siraj Khan, 2013]Siraj Khan, M. M. (2013). Stability Analysis of Power System with the Penetration of Photovoltaic Based Generation. International Journal of Energy and Power Engineering, 2(2), 84.

[Sujatha et al., 2018]Sujatha, B. G., & Anitha, G. S. (2018). Enhancement of PQ in grid connected PV system using hybrid technique. Ain Shams Engineering Journal, 9(4), 869–881.

[Tavakoli et al., 2020] Tavakoli, A., Saha, S., Arif, M. T., Haque, M. E., Mendis, N., & Oo, A. M. T. (2020). Impacts of grid integration of solar PV and electric vehicle on grid stability, power quality and energy economics: A review. IET Energy Systems Integration, 2(3), 215–225.

[Upadhyay et al., 2022] Upadhyay, T., & Jamnani, J. G. (2022). Simulation and analysis of solar photovoltaic penetration in conventional power system. Materials Today: Proceedings, 62(P13), 7281–7287.

CONTACTS:

ZEMITTE seddik
University of Ahmad draia, Faculty of Science and Technology, Laboratory of Sustainable Development and Computer Science (LDDI), Adrar, Algeria
Tel : (+213)6-66-30-66-45
E-mail : sed.zemitte@univ-adrar.edu.dz

HAMOUDA Messaoud
Tel : (+213)6-61-27-72-01
E-mail : mes.hamouda@univ-adrar.edu.dz

ARAMA Fatima Zohra
E-mail : fatimaarama@yahoo.fr

LAIDI Abdallah
Tel : (+213)6-98-07-85-62
E-mail : laidi93abdallah@gmail.com