

Feasibility Study of Solar Photovoltaic Integration on Distribution Networks

Case Study: Djanet's Isolated Distribution Network, Algeria

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Abstract

Grid connected photovoltaic (PV) have rapidly increased in Algeria over the past years. This rapid increase will lead to the impact of these systems on customer power quality. This paper depicts work undertaken to explore PV system integration from a network utility point of view. Additionally utility strategies to minimize the negative impacts are explored. This was done by analysis of network and PV data from selected case study areas as well as producing models based on data. The results have indicated that short-circuit current levels are too low to cause significant power quality issues, however load flow and harmonic issues have been identified. Simulated increases in PV penetration suggest negative growing adverse integration effects including voltage rise and current swing issues. All simulation results are made by the version of Cymdist software V.7.1 (from Cyme International Inc.).

1. Introduction

Compared to transmission and distribution networks, distribution networks are slightly instrumented. Due to their design and their mode of operation, it is not necessary to have many points of measurement in order to guarantee a voltage within the permissible limits at all nodes of the network. Indeed, in the absence of DG (Distributed Generation), knowledge of the average evolution of loads over time and the topology of the network is sufficient for the SDC (Electricity Distribution Company) to predict what will be the voltage drop. The direction of power flow, from the source station to the consumption, and the radial structure of the network can perform a good approximation of the voltage. It decreases progressively as the distance to the source station increases (Fig. 8).

In addition, upstream studies carried out before the construction of the network make it possible to dimension the distribution networks sufficiently to meet their maximum loads. Changes in the consumption of course have an influence on the voltage of the distribution network. Moreover, currently distributed generation connected to distribution networks doesn't participate dynamically in voltage regulation.

Some previous works have examined the effect of increased penetration of renewable energy sources, mostly wind energy, on power systems (e.g., [1] and [2]). It has been argued that if a proper control strategy is used, there would be no considerable harm to system stability [3], [4].

The impact of solar PV in transmission systems has not been extensively studied; most of the technical literature concentrates on distribution system studies. Thus, the authors in [5] examine the electrical impact of solar PV penetration at the distribution level, and conclude that these plants may affect the voltage profile if they are installed in rural radial lines. In [6], a voltage control scheme is proposed to avoid voltage problems in distribution networks. The impact of small solar PV units on the operation of distribution systems is analysed in [7], [8], where it is indicated that considerable penetration of micro-generation may be accommodated safely without major modification to the system control. A correlation index is introduced in [9] to evaluate the impact of solar PV units on real power losses in distribution systems.

Article I.6 of the Algerian Grid Code "Technical specifications of connection production units into isolated networks" [10] stipulates, however, that:

The connection of the production plant in a MV distribution network is carried out at the supply line voltage and at the nearest connection point, and this, through a MV busbar.

-Each connection link comprises a circuit-breaker and a line disconnector located downstream of the production facility at the injection point to the distribution network;

-Any generation unit must have the constructive capacity for contributing to voltage regulation. By providing and absorbing reactive power. For this purpose, the generation units and their power transformers shall be designed to comply with the following rules:

-At nominal active power and nominal $\text{Cos}\phi$ of 0.8, the generation unit must be able to provide a reactive power equal to 0.75 of the nominal active power at the nominal voltage

-With nominal active power and a nominal $\text{Cos}\phi$ of 0.8, the production plant must be capable of absorbing at least a reactive power equal to -0.30 of the nominal power at nominal voltage;

-Generation units must operate within the operating range defined by the diagram $[P, U, Q]$ indefinitely at any point in the normal operating range;

-The power transformer must be equipped with a vacuum adjuster with three taps -5%, 0 and + 5%;

-The generation units must be equipped with regulators to control the reactive power at the injection point. The control system must be backed up from a reactive power regulator manual.

2. Case study description

The case study presented here concerns a MV radial distribution network of Djanet 30 kV. The entire network consists of a single source station, that of the Djanet's diesel plant, with ten diesel generators and ten step-up transformers.

This simulated network is derived from real data provided by SDC (Electricity Distribution Company / Center) – Subsidiary of SONELGAZ. The topology of simulated departures is shown in Fig. 6 (Appendix).

The maximum total load of the network is 7.2 MW, all charges are residential. This evolution corresponds to a real evolution in 24 hours, the results are presented below.

This is an impact study on the isolated distribution network of Djanet 30 kV, given the installation of a PV plant with a total power of 3 MW. In order to evaluate the impact of the connection on the distribution network, the following studies must be carried out:

- Estimation of the new voltage, power flow (kVA, kW) and currents associated with a number of important points on the network;
- Short-circuit analysis;
- Harmonic analysis.

The version of Cymdist V.7.1 (from Cyme International Inc.) was used for Load Flow, short-circuit and harmonics studies. Djanet's network is a radial network, it's supplied by a fossil source, a single diesel power plant of around 24 MW, and the substation with three departures:

- departure of Aerodrome with 128 nodes.
- departure of Ville with 112 nodes.
- departure of Kanafer with 101 nodes.

Table 1 shows the maximum daily consumption of the Djanet's town.

Table 1. Maximum daily consumption of the djanet's town

Departure	Power consumed kW in June
Aerodrome	1870.56
Ville	3325.44
Kanafer	2078.40
Total	7274.40

Table 2 shows the size of the plant's main equipments. The selection of the inverter and of its size is carried out according to the PV rated power it shall manage. The size of the inverter can be determined starting from a value from 0.8 to 0.9 for the ratio between the active power put into the network and the rated power of the PV generator. This ratio keeps into account the loss of power of the PV modules under the real operating conditions (working temperature, voltage drops on the electrical connections...) and the efficiency of the inverter [11].

Table 2. Main Equipments of the PV Power Plant

	Unit Power	Quantity	Total Power
PV panels	250 W	13440	3.36 MW
Inverters	500 kW	6	3 MW
Transformers	1250 kVA	3	/

3. Load Flow Study

The purpose of these power flow studies of the distribution network in the concerned area is to identify the need for reinforcement of networks such as lines and cables. Thermal assessments studies of components and voltage fluctuations are mainly relevant if there are times in which a PV system produces considerably more power than the corresponding load can absorb.

As long as the production of PV is less than the maximum demand of the corresponding load, PV production will only reduce line voltage drops. Only in the case where the production of a PV system begins to exceed the associated load, an increase in voltage or increase in thermal load of lines or cables can be observed.

Fig. 1 illustrates a one day comparison with a maximum photovoltaic generation in the year (08 March) with the corresponding load curve, Fig. 2 illustrates a comparison of one day with a minimum load in the year (04 December) with the corresponding photovoltaic generation.

According to Fig. 1 and Fig. 2, the worst case occurs during the middle of the day when PV generation exceeds the local consumption, which leads to a reverse power flow on the source station.

Fig. 3 shows the voltage profile of the network nodes for different scenarios. Several simulation scenarios have been made in order to obtain significant results.

After injecting a DG (3 MW of PV) into the nodes: main busbar, 132 and 140, we compared the voltage profiles of the different scenarios. The simulations confirm foremost that in the presence of DG, the level of voltage on the network is improved especially in the case of node 140 (Fig . 3).

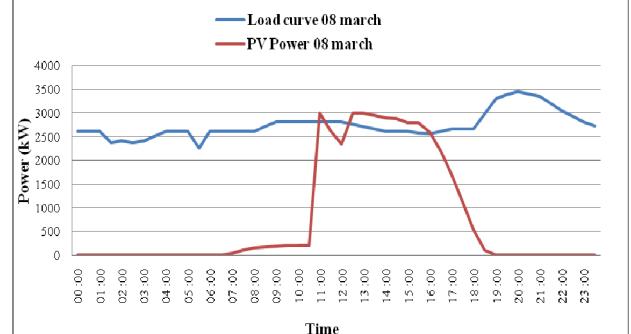


Fig. 1. Comparison between local consumption and PV generation (worse case : maximum PV)

This simple study shows that, in the absence of the DG on the Djanet's distribution network, under normal operating conditions, the current voltage profile is not defeated because the Algerian distribution networks are sufficiently sized.

The addition of the DG to the Djanet's distribution network produces a simple improvement of the voltage profile, thus Fig. 3 shows that even after the injection of the DG, the voltage profile is everywhere between the permissible limits + 5% and - 5%.

In Fig. 4, it can be seen that node 140 has the best point of injection of PV in terms of reduction of active and reactive losses.

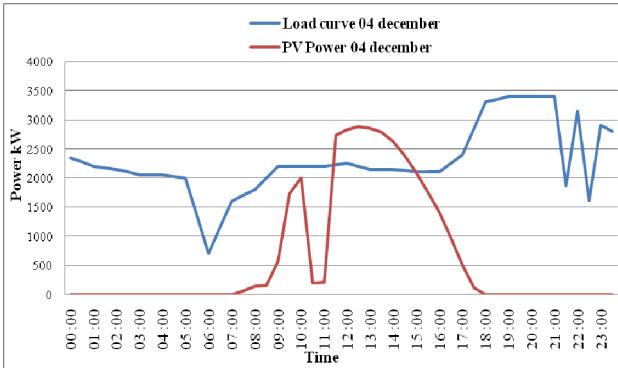


Fig. 2. Comparison between local consumption and PV generation (worse case : minimum load)

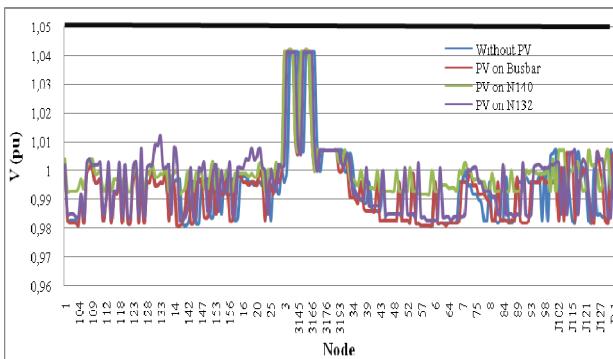


Fig. 3. Voltage profile of an extract network nodes for different scenarios

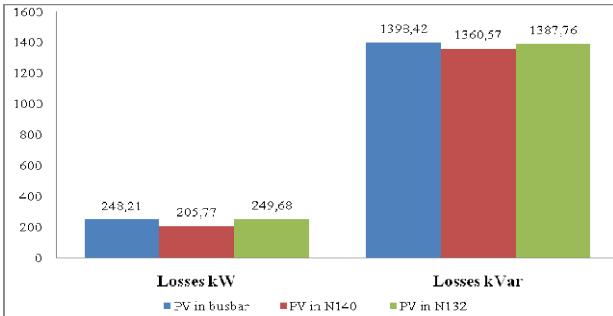


Fig. 4. Evaluation of total losses for different PV injection scenarios

3. Short-circuit study

A short-circuit is the voluntary or accidental connection of two (or more) points of an electrical circuit between which there exists a potential difference by a low resistance conductor. The following short-circuits can be distinguished on a network:
- Single phase (80% of cases), where one phase and earth or neutral are connected together.

- Biphase (15% of cases), where the two phases are connected together.
- Three-phase (5% of cases), where the three phases are connected together.
- Biphase-ground, where two phases and the ground are connected together.

This study part presents the impact of PV location on the short-circuit current contribution of the Djanet's distribution network, using the Cymdist software, this includes various types of short-circuits: Three-phase (LLL); Single phase (LG), Two-phase line (LL), and two-phase ground (LLG). A detailed comparison for the short-circuit level of the four types of short-circuit and for the four different scenarios of PV integration is shown below.

The Djanet's network is the system where short-circuit analysis is examined using the Cymdist software as a simulation tool. Four scenarios are chosen to study the impact of PV integration on the short-circuit current level of the distribution network, they are presented in Table III. In this study, the impact of change in level of solar radiation is assumed to be constant.

Table 3. Four scenarios examined

Scenario	Integration point
Scenario 1 (S1)	Without integration
Scenario 2 (S2)	3 MW of PV integrated in main busbar
Scenario 3 (S3)	3 MW of PV integrated in node 140
Scenario 4 (S4)	3 MW of PV integrated in node 132

The characteristics of the PV module used are listed in Table VI (Appendix) where I_{SC} is the short-circuit current, V_{OC} is the open circuit voltage, P_{max} is the maximum power, I_{MP} is the current for maximum power, and V_{MP} is the voltage for the maximum power.

The scenarios are varied to obtain valid and reliable results. The simulation includes an examination of the presence of four types of short-circuits (LLL, LG, LL and LLG) at three different nodes: main busbar, 140, 132.

The criterion for selecting the nodes where the short-circuit can occur is based on the distance from the source station (the diesel plant) and the concentration of the loads.

The evaluation of the simulation results is based on the comparison of the short-circuit limit values for each scenario with the short-circuit limit values in the case of the network without PV penetration.

In the case of a short-circuit on the network, the short-circuit current could theoretically be partly supplied by the PV generator, which would disrupt the detection of the short circuit by the protective devices provided on the network. This situation would arise in particular at the end of network, with high-impedance lines and a significant penetration of PV [39].

In the first place the consequences would be mainly the poor coordination of the triggering of the protective devices of the network (fuses and disconnectors).

In general, it is still considered that the PV contribution to the short-circuit current is limited by construction (choice of IGBTs) due to the small difference (10-20%) between the short-circuit current supplied by The inverter and its rated current [12]. These conclusions could be reviewed if the inverters were equipped in the future with additional functions such as mains voltage support [13].

Given the geometric location and the level of solar radiation as hypotheses, the simulation results of the short-circuit current analysis by examining the four types of short-circuits for the four different scenarios are presented in Table 4.

Table 4. Simulation results of short-circuit currents in kA

Short-circuit location	Triphase short-circuit (LLL) en kA			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Main busbar	1.58	1.63	1.63	1.63
Node 140	1.15	1.18	1.2	1.18
Node 132	1.21	1.24	1.24	1.26
Line to ground short-circuit (LG) in kA				
Scenario 1	Scenario 2	Scenario 3	Scenario 4	
	2.2	2.24	2.24	2.24
Main busbar	1.63	1.65	1.67	1.66
Node 140	1.71	1.74	1.74	1.75
Biphasic short-circuit (LL) in kA				
Scenario 1	Scenario 2	Scenario 3	Scenario 4	
	1.36	1.39	1.39	1.39
Main busbar	0.99	1.01	1.02	1.01
Node 140	1.05	1.06	1.06	1.07
Biphasic to ground short-circuit(LLG) in kA				
Scenario 1	Scenario 2	Scenario 3	Scenario 4	
	2.28	2.36	2.36	2.36
Main busbar	1.69	1.74	1.77	1.74
Node 140	1.76	1.81	1.82	1.84

The appearance of the biphasic-ground short-circuit (LLG) represents the highest impact on the short-circuit level in the four different scenarios applied, followed by the single-phase ground short-circuit (LG). Conversely, the two-phase short-circuit (LL) represents the lowest impact compared to the other three types of short-circuits tested. Also, we note that there is a slightly small change in the results of the short-circuit current values for scenarios 2, 3 and 4 (with PV) compared with scenario 1 (without PV).

Table 4 illustrate comparisons between the short-circuit currents taking into account the location of the PV and the type of short-circuit.

According to Table 4, it could be noticed that if there is a short-circuit incident in the main busbar, the short-circuit current is almost 1.4 compared to short-circuit current of nodes 132 and 140 for all types of short-circuits and the different scenarios examined. In scenarios 3 and 4, the short-circuit current has the highest values during a short-circuit at node 140 and 132 respectively (the nodes farthest from the source station at the end of the network) where PV plant is located in the same node with short-circuit. So in these scenarios the PV contribution is relatively large compared to scenario 1.

4. Harmonic study

The objective of the harmonic analysis is to examine the effects of harmonic currents on the grid and to circumscribe them within acceptable limits as specified by IEEE Standard 519-1992.

In accordance with the Algerian grid code [10] there are two requirements concerning harmonics:

- Harmonic distortion of the current must not exceed THD_I of 5%.
- Harmonic distortion of the voltage must not exceed a THD_V of 5% at the connection point of any user.

Table 5. Evaluation of THD_V and THD_I harmonics after PV integration

Harmonic	PV Integration in node:					
	Main busbar		132		140	
	THD _V %	THD _I %	THD _V %	THD _I %	THD _V %	THD _I %
	0.05	0.06	0.05	0.38	0.05	0.38

From Table 5, we note that the values of THD_I and THD_V doesn't exceed, in no case, the allowed limit of 5% because the harmonics are mitigated by the transformer connected in PV systems.

Fig. 5 shows the curve of impedance as a function of frequency, this curve has been plotted to study the effects of current harmonics produced on the system's resonance. Also, the figure shows that the probability of a resonance occurrence in the network is very low due to the high ratio R/X of radial systems.

Thus, it can be seen that inverters inject current harmonics into the network, but this is not the case with regard to voltage harmonics.

In addition, the level of current harmonics suggests that harmonics of the inverter are added (assuming harmonics of the inverter are limited to the levels set out in the standards), it is therefore possible to envisage higher penetrations inducing higher harmonic values [14].

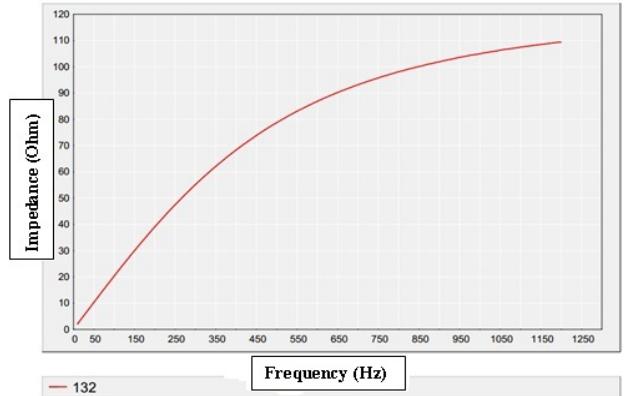


Fig. 5. Impedance vs frequency curve

From the above results of this part, it is found that there is no strong correlation between current harmonics and voltage harmonics. The main concern of current harmonics is that they lead to an increase in losses in the network.

5. Conclusion

This work was devoted to the PV plant integration, with a total power of 3 MW, into the Djanet's isolated distribution network. In this paper, we've studied different forms of PV integration impact on the Djanet's distribution network, more PV penetration increases, the impact is significant.

The injected energy by PV plant for a few days has exceeded the load requirements of the distribution network which causes overloads in the lines and consequently an increase in losses.

As a result, the problem of exceeding the PV energy injected into the isolated distribution network makes the installation of a storage battery local a mandatory solution in order to improve

the performance of the network on the one hand, and to maximize this form of sustainable energy on the other hand.

However, the results of short-circuit current have a small difference in values by comparing scenarios with PV and without PV. This concludes that PV penetration has no significant impact on the short-circuit level of the studied distribution network, even by varying location of PV and in particular near the source station.

Harmonic levels are acceptable and they're within limits as specified by IEEE Standard 519-1992.

Analysis of case study areas indicates that current PV system penetration levels are not high enough to significantly infringe on supply utility quality of supply standards.

However, such a simulation is often difficult because of the large size of distribution network.

6. Appendix

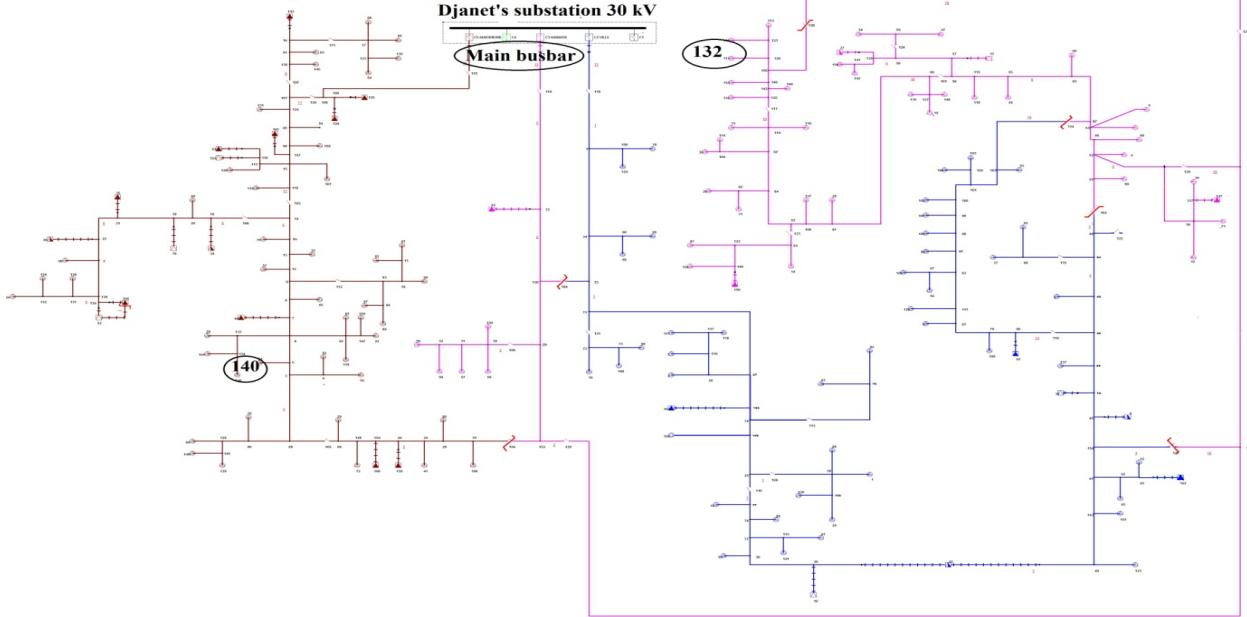


Fig. 6. General single line diagram of Djanet's distribution network.

7. References

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