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The PV generation impact on the system's short-circuit power - study of the PIAT case

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Abstract. The National Society of Electricity and Gas of Algeria (SONELGAZ) is interconnecting the national power grid with the isolated power grids in the south of the country. One such grid is the Pole In Salah-Adrar-Timimoune (PIAT). It is an exceptional power grid of considerable installed renewable energy sources values. The paper investigates the short-circuit phenomenon in the PIAT. The share of the renewable sources in the PIAT fault current is studied, and the difference between fault currents with and with-no integration of renewable sources are studied in order to find out if the protection parameters need to be changed in the case of the absence of renewable sources. Also, to interconnect the PIAT with other power grids, the PIAT short-circuit power is studied at different short-circuit points in the current situation and after the planned increase in the PV installed power. It is shown that the actual installed renewable sources contribute to the fault current with less than 10 % regardless of the fault position. Increasing the installed power by 300 % would increase the short-circuit power with less than 10 %. A method is suggested to determine the power grid short-circuit power using the short-circuit admittance instead of the impedance.

Keywords: Power grid, renweable energies, PV generation, short-circuit study, fault current, renewable energy integration.

Vpliv moči obnovljivih virov na moč kratkega stika - študij primera PIAT

Danes si Nacionalno združenje za elektriko in plin v Alžiriji (SONELGAZ) prizadeva za medsebojno povezavo nacionalnega električnega omrežja z izoliranimi električnimi omrežji na jugu države. Med temi izoliranimi električnimi omrežji je PIAT (Pole In Salah-Adrar-Timimoune) eno izmed električnih omrežij, ki so vgradila obnovljive vire energije z velikimi močmi. V prispevku proučujemo pojav kratkega stika v PIAT. Obravnavamo udeležbo dejanskih obnovljivih virov v okvarnem toku PIAT in proučujemo okvarne tokove v odvisnosti od obnovljivih virov. Analizirali smo moč kratkega stika PIAT v dejanskih primerih in s povečanjem inštalirane PV-moči. Dobljeni rezultati so pokazali, da dejansko nameščeni obnovljivi viri prispevajo manj kot 10 % pri okvarnem toku ne glede na lokalizacijo okvare v PIAT in da povečanje inštalirane PV-moči za 300 % ne poveča moči kratkega stika za več kot 10 %. V prispevku smo tudi predlagali novo metodo za določanje moči kratkega stika električnega omrežja.

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1 INTRODUCTION

The electric power grids are the greatest systems developed by humans in the world: electricity is the most available energy and the easiest to use. The currently power grids in many countries have been constructed a long time ago. They mainly consist of the three-phase generators, transformers and lines to supply different categories of loads. For them to function, many control and protection systems are used to meet the power demand [1].

The Algerian power grid dominates in the north of the country (Figure 1). It is connected to some sites in the south-east of the country to extract gas and oil. Some new gas and oil sites are discovered in the last decades, inhabited are now habited and require a more sophisticated power supply. Several micrograds of a limited size have been created by SONELGAZ. At an annual increase in the demand meeting 8 % [2], the power grid needs to be reinforced by using the great potential of the renewable energies in the south of the country.

With the above target in mind, some micro-grids of the cities In salah, Adrar and Timimoune located in the south have already been interconnected to become

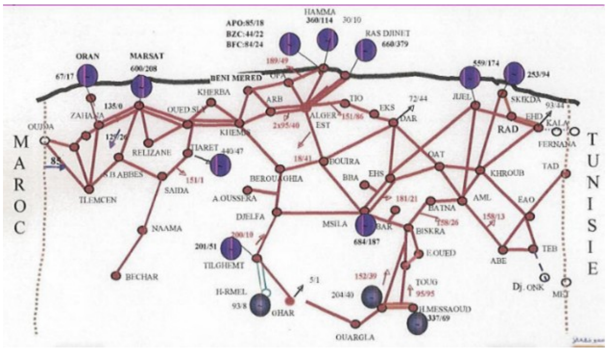

Figure 1. Algerian national power grid [2]

one grid of a radial configuration named Pole In salah-Adrar- Timimoune (PIAT) [3]. This interconnexion is 220 kV voltage, 600 km long.

Many investigations have been carried out to implement such grid which is of great importance for the country, for being the second gate (west gate) to the south side of the country, thanks to the big number of power generators based on renewable energies and connected to this power grid.

The PV systems faults taking place in this power grid have been studied: Ahmed et al. [4] study the degradation of the PhotoVoltaic (PV) panels when installed in the Saharan climate to estimate the future behavior of the PV power systems installed in PIAT. [5] study the faults likely to appear in PV power systems either on PV panels or in accessories connecting the panels to the power grid. Ziane et al. [6] have model the dust effect on PV panels and use their model in experimental work. Comparing the results shows an acceptable agreement.

Many studies have been evaluating the integration of the wind farm to the power grid. Benmedjahet & Maouedj [7] make a statistical analysis of the wind in the Adrar region, to estimate the cost of the wind generated electricity. Their results show that the generation and maintenance costs are greater than those foreseen by the project. Benseddik et al. [8] simulate the integration of a large wind power generation with the power grid to asses the PIAT transient stability. They show that the presence of the Doubly Fed Induction Generators (DFIG) improves the transient stability, but at an intermittence of the wind energy, the transient stability may worsen.

Makhloufi et al. study PIAT in many of their works to optimize its power flow. In [9] they optimize the power flow by using an hybrid algorithm between a particle swarm optimization and gravitational search algorithm. Their proposed algorithm enables a fast convergence for the cases studied in the paper. In [10], they study the PIAT dynamic behavior to propose a protection scheme to maintain the PIAT frequency within permissible limits. Their plan insures a reliable power grid operation when supplying overloads. In [11], three meta-heuristic algorithms are used to optimize the PIAT power flow; Makhloufi et al. propose to integrate two wind farms to PIAT. Chihani et al. [12] propose a better integration of the wind power generation to PIAT. A protection plan is proposed to protect PIAT against disturbances both with and without integration of the wind power generation.

On the other hand, there are many that have studied the PIAT power grid : Boussouha and Elmaouhab [13] propose a reliability block diagram method to determine reliability parameters in each PIAT node. Their results show that PIAT is quite reliable. Bergad et al. [3] study the possibility to interconnect the national Algerian power grid with PIAT. They consider the renewable energy development. Several technical problems are discussed in their paper, particularly the long distance between the two grids. Aoufi and Ameyoud [14] analyse the impact of the integration of renewable energies to PIAT on the quantity of gas used to generate electric energy. A remarkable reduction is foreseen at a random development.

There has been a variety of studies in the last years focusing on the short-circuit issues. Fu and Montross [15] study the protection against short-circuits in the DC power systems. The Z-source circuit breaker is improved by integrating a fuse to the DC power system to upgrade its protection. Pola and Azzouz [16] develop an algorithm to limit the currents at a fault occurrence, and set up a voltage source model to have the synchronverter protected. Elsamahy [17] investigates the impact of superconducting fault current limiters on the power distribution networks with a bidirectional power flow. The results show the efficiency of such component to simplify the power grid interconnection.

Realizing that there is a possibility for the PIAT power grid to integrate renewable energies to the high-voltage power grid, we decided to study the impact of such integration in general and particularly on the short-circuit occurrence. As a novelty, our paper determines the impact of the renewable energy integration on the short-circuit power of a power grid. The paper is organized as follows: Section 2 presents the PIAT components and parameters. The impact of the renewable energies on the PIAT short-circuit currents is discussed in Section 3. In Section 4, the dynamic parameters of the PIAT short-circuit power are studied. Section 5 draws conclusions of our work.

2 The PIAT parameters

The PIAT power grid is a power system situated in the south west of Algeria (see Figure 2). It contains approximately 2000 high voltage towers connecting seven nodes : Timimoune, Kabertene, Adrar, Zaouit Kounta, Regane, Aoulef and In salah.

The topology of the PIAT power grid is radial. Its supply is insured by several gas turbines distributed on

Figure 2. PIAT location on the Algerian map [12]

the nodes, seven PV arrays of different sizes and a wind power plant. A single line diagram showing the principal source dispositions and the lines connecting the nodes is displayed in Figure 3.

All the lines connecting the power grid nodes are on the 220 kV voltage level using a single cable per phase of a 570 mm^2 section, except the line between Aoulef and In salah which uses a 400 kV line configuration (two cables per phase), but operates on the same voltage level.

The PIAT 10 MW wind power plant uses DFIG and its PV arrays uses the polycrystalline silicon technology [18]. The PV array power is shown in Table 1.

The Table 2 shows loads supplied to the PIAT nodes.

Table 1. PIAT PV array capacities [18]

PV array	Capacity [MW]
Timimoune	9
Kabertene	3
Adrar	20
Z Kounta	6
Regane	5
Aoulef	5
In salah	5

Table 2. PIAT power demand meeting values [12]

The PV array	P [MW]	Q[MVAR]
Timimoune	29.18	15.8
Kabertene	13.18	7.14
Adrar	27.29	14.77
Z Kounta	30.28	16.4
Regane	27.38	14.82
Aoulef	18.56	10.05
In salah	41.42	22.43

3 THE IMPACT OF THE RENEWABLE ENERGIES ON THE PIAT SHORT-CIRCUIT OCCURENCE

In this section, the short-circuits are simulated in each PIAT node, both with and with no consideration the existence of the renewable energies.

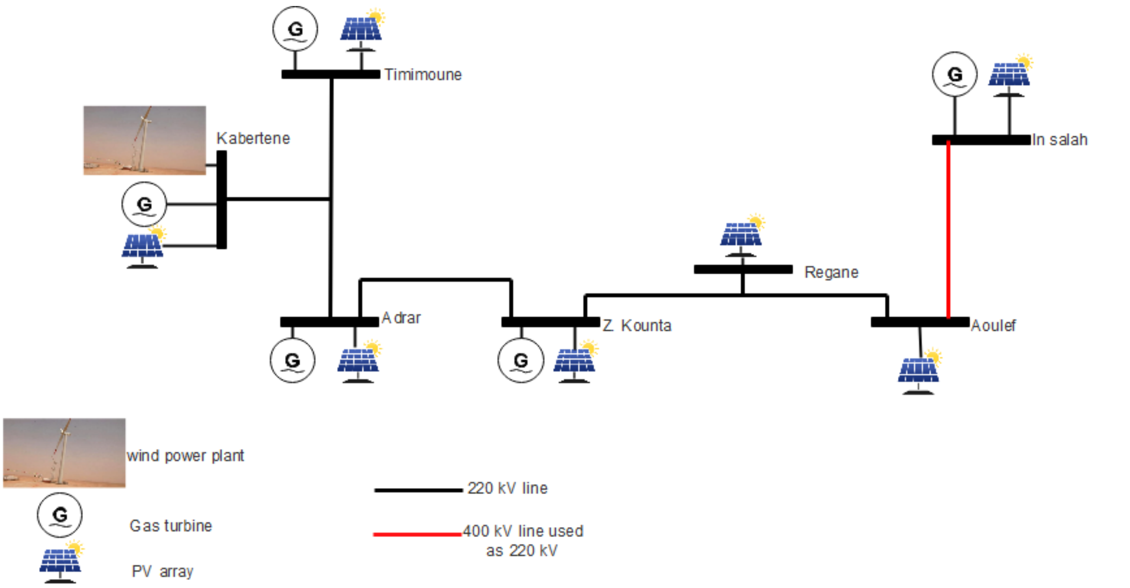

Figure 3. The PIAT single line diagram

Table 3. Short-circuit currents at the PIAT nodes and the source currents

SC location	I_{SC} (kA)	TG Tim (kA)	TG Kab (kA)	TG Ad (kA)	TG ZK (kA)	TG IS (kA)	Eol Kab (kA)	PV Tim (kA)	PV Kab (kA)	PV Ad (kA)	PV ZK (kA)	PV Reg (kA)	PV Alf (kA)	PV IS (kA)
Tim	2.95	1.64	0.37	0.29	0.36	0.16	0.026	0.035	0.01	0.058	0.016	0.013	0.012	0.012
Kab	3.45	1.02	0.70	0.55	0.01	0.31	0.049	0.03	0.012	0.068	0.018	0.014	0.014	0.012
Ad	3.73	0.75	0.52	0.82	1.01	0.46	0.036	0.028	0.011	0.079	0.02	0.016	0.014	0.013
ZK	3.89	0.47	0.33	0.51	1.65	0.75	0.023	0.025	0.009	0.067	0.024	0.018	0.016	0.014
Reg	2.88	0.29	0.20	0.32	1.03	0.89	0.014	0.022	0.008	0.059	0.02	0.02	0.017	0.015
Alf	2.52	0.17	0.11	0.18	0.59	1.35	0.008	0.022	0.007	0.054	0.017	0.016	0.02	0.016
IS	3.16	0.13	0.09	0.14	0.44	2.29	0.006	0.022	0.007	0.047	0.017	0.015	0.018	0.02

3.1 Simulation with integration of the renewable energies

The short-circuit currents (in kA) occuring at each node and the currents generated at each PIAT source (Timimoune (Tim), Kabertene (Kab), Adrar (Ad), Zaouit Kounta (ZK), Regane (Rg), Aoulef (Alf) and in salah (IS)) are given in Table 3.

For each short-circuit there are a short-circuit current, a TG current and renewable energy current.

To determine the share of the gas turbine sources and renewable sources in the short-circuit current, Table 4 presents the sum of the source currents.

Table 4. Classification of the short-circuit current origin

SC location	TG currents (kA)	Renewable sources currents (kA)
Tim	2.851	0.182
Kab	2.62	0.217
Ad	3.568	0.217
ZK	3.741	0.196
Reg	2.761	0.175
Alf	2.437	0.16
IS	3.104	0.152

Figure 4 presents the share of the gas Turbines (GT) current and of the renewable energy (REN) in the total fault current.

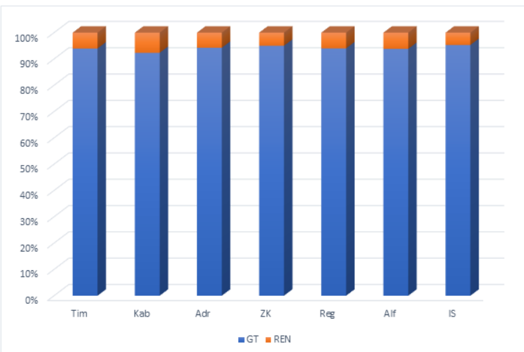

Figure 4. Participation of the Gas turbines (GT) and the renewable energies sources (REN) in the fault current at each point of the PIAT.

Judging from the above results, the conclusions is that:

- The short-circuit current depends on the position of the short-circuit in PIAT.
- Each renewable energy source generates its own current differently from the others because of the differences between the installed powers.
- The share of the current of the renewable sources is very small compared to the one generated by generators operating with gas turbines.
- The share of the fault current generated by renewable energy sources is almost the same regardless of the short-circuit position, and is less than 10 % of the total share.

3.2 Simulation with no integration of renewable energy sources

The currents occurring when simulating the short-circuit behavior with no integration of the renewable energies are shown in Table 5.

Table 5. Short-circuit current with and without integration of renewable energies

SC location	I_{SC} (kA) Without Renewable energies	I_{SC} (kA) With Renewable energies
Tim	2.898	2.957
Kab	3.333	3.456
Ad	3.613	3.735
ZK	3.799	3.893
Reg	2.82	2.88
Alf	2.481	2.521
IS	3.128	3.16

In absence of the renewable energies, a big impact is noticed on the value of the fault current. This confirms that the Gas turbines generators contribute the most on the value of the fault current. On the other hand, the absence of the PV generation has a minor impact on the PIAT fault current in the PIAT. This means that there is no need to change the PIAT protection settings during the night.

3.3 *Simulation of the PIAT short-circuits at an increased PV generation*

In the policies of several energy societies in Algeria, the installation of new PV arrays appears on the top of their priorities. The maximal power of the current PV arrays in PIAT is 53 MW. In this part, PIAT is simulated on increased PV generation: the short-circuit occurring in PIAT is simulated with similar PV arrays in any PIAT node. The simulated powers of the PV arrays are 20, 30 and 40 MW. The simulation results are given in Table 6.

Table 6. Short-circuit current with and without integration of renewable energies

SC location	I_{SC} **With actual sources (kA)**	I_{SC} **With 20 MW in each node (kA)**	I_{SC} **With 30 MW in each node (kA)**	I_{SC} **With 40 MW in each node (kA)**
Tim	2.957	3.016	3.06	3.104
Kab	3.456	3.547	3.619	3.689
Ad	3.735	3.833	3.915	3.997
ZK	3.893	4.021	4.113	4.204
Reg	2.88	2.994	3.07	3.145
Alf	2.521	2.622	2.685	2.748
IS	3.16	3.25	3.303	3.356

As seen, installation of 20 MW PV array in each node only increases slightly and differently the short-circuit current in individual nodes.

At an increase of the power of PV arrays on the level from 30 to 40 MW, the fault current increases differently. The variation in the level from 20 to 40 MW are between 0.09 (Timimoune) to 0.18 kA (Z Kounta).

4 PIAT Short-circuit power study

4.1 *From the short-circuit impedance to the short-circuit admittance*

The study of the short-circuit is not limited to protection reasons. It can be used also to determine the power grid short-circuit power (S_{SC}) using equation 1:

$$S_{SC} = \sqrt{3}\, U_N\, I_{SC} \tag{1}$$

Where U_N is the grid nominal voltage and I_{SC} is the fault current.

By determining the fault current generated by each source, the short-circuit of each GT source is given in the Table 7.

Table 7. GT sources short-circuit powers

Source	**Short-circuit power (MVA)**
Timimoune	625.686
Kabertene	269.784
Adrar	312.843
Z kounta	632.163
In salah	872.607

The total system short-circuit power is the sum of generators short-circuits, i.e. 2713.083 MVA.

Examining the former results, one can see that the sources don't generate their maximum fault with all of the short-circuits. It is only when the fault takes place at the bus connected to the source that the source generates 100 % of its short-circuit current. When the fault is far from the source, the current generated by the source decreases (see Figure 5).

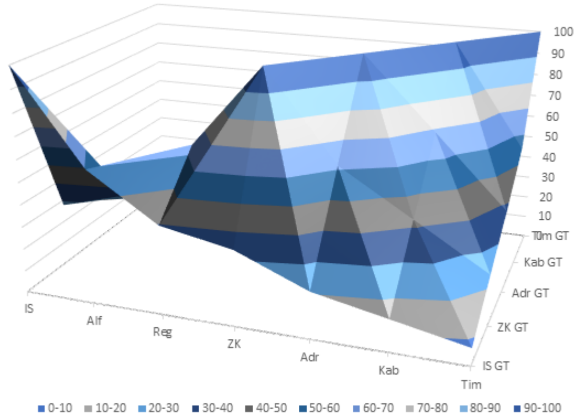

Figure 5. Share of the total source fault current in the total fault current

For example, when a short-circuit occurs at the Timimoune node, the Timimoune source participates with 100 %, Kabertene participates with 55 %, Adrar source participates with 37 %, Z kounta with 23 % and In salah with 7.8 % of its short-circuit current.At a short-circuit occurrence at the Adrar node, the Timimoune source participates with 47 % , Kabertene participates with 74 %, Adrar source participates with 100 %, Z kounta with 61 % and In salah with 20 % of its short-circuit current.

Most of the power grids literature addresses the short-circuit issue in terms of the impedance determined by the following relation [19]:

$$Z_{SC} = \frac{U_N^2}{S_{SC}} \tag{2}$$

Where short-circuit occurs in node i, the short-circuit impedance will be the impedance of the source connected to bus i in parallel to all the impedances of all the other sources in series with lines linking source i to the other nodes. Determination of the short-circuit is when there are only two or three sources in the power grid. When numerous or the power grid is complex, the short-circuit admittance should be used instead of the short-circuit impedance.

By using the admittance, the total short-circuit admittance in node i is :

$$Y_{SC} = Y_i + \sum_{j=1}^{1} \frac{Y_{ij}\ Y_j}{Y_{ij} + Y_j} \tag{3}$$

where Y_{ij} is the admittance between nodes i and j, and Y_j is the admittance of the source connected to node j.

Using the above equation simplifies the determination of the short-circuit impedance as well as the short-circuit power too.

4.2 Dynamic short-circuit power

Knowing where of the short-circuit currents occurring at different PIAT fault locations, the short-circuit power at each PIAT node is determined. Thus obtained results are smaller than the sum of all short-circuit powers of all of the sources. The dynamic relative short-circuit power for PIAT each node i is :

$$S^{*}_{SC\ i} = \frac{\sqrt{3}\ I_{SC\ i}\ U_N}{\sum S_{SC\ source}} \tag{4}$$

where $I_{SC\ i}$ is the fault current obtained for short-circuit in node i, and $\sum S_{SC\ source}$ is the sum of the short-circuit power at any source connected to PIAT.

Figure 6 shows the values of the dynamic short-circuit power along PIAT.

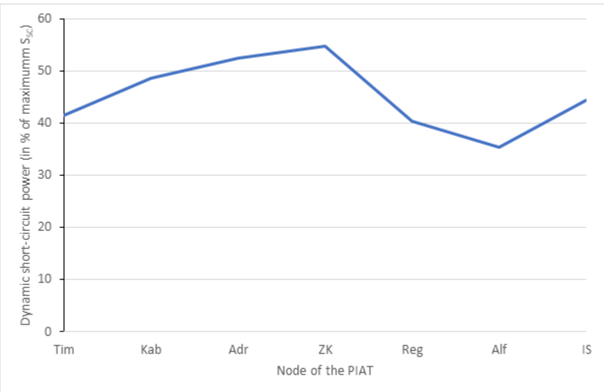

Figure 6. Dynamic relative short-circuit power along PIAT

Figure 6 shows that the total PIAT short-circuit power depends on the point of interconnection with other grids. If the Timimoune node interconnects PIAT with the Algerian power grid, the short-circuit power will be 42 %, If PIAT is interconnected with Tindouf city, over the Zaouit Kounta node, the short-circuit power will be some 54 %.

Table 8 shows the increase in the short-circuit power at each node when installing 40 MW in each PV array of the seven PIAT nodes (adding 227 MW of PV sources).

The results show that adding 227 MW of the PV power generates an increase between 5 to 9 % in the PIAT short-circuit power. So, in the case of a future interconnection, and an increase in the PV power, the variation in the PIAT short-circuit power between the day and night should be considered.

Table 8. Increase of S_{SC} of the node

Source	**Increase of S_{SC} (in %)**
Timimoune	4.971
Kabertene	6.741
Adrar	7.014
Z kounta	7.988
Regane	9.201
Aoulef	9.004
In salah	6.202

5 Conclusion

The paper studies an isolated power grid operating in Algeria. It integrates renewable energies of large power values. The focus of the study is on the short-circuits occurring in the grid.

Studying the share of the renewable energy sources in the faulty current shows that the PV arrays and the wind farm contributes in a small share to the total fault current irrespective of the fault location in the grid.

A comparison is made between the fault current in the absence of renewable sources and the one occurring upon integrating new renewable energy sources. The results show that the difference is small. This means that there is no need to change the grid protection setting in the night time (absence of the PV generation).

Simulating an increase in the grid PV generation does not considerably affect the fault current value. The study of the short-circuit power shows its variation along the grid, and its dependance on the sources powers.

To determine the short-circuit power, the use of the short-circuit admittance is proposed instead of the short-circuit impedance. It is shown that an increase in the installed PV power leads to an increase in the grid short-circuit power.

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