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Optimization of Electrical Energy Generation Systems in the Mini-grids of Southern Algeria

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Abstract:

The objective of this paper is to review the electrification modes associated with the Great Algerian South Networks (GSN). The study focuses on the conceptualization of the GSN through the dimensioning of mini-grids. Given the remoteness and difficulties of fuel supply, a series of reforms have been undertaken to promote the energy transition and ensure the development of these regions through the realization of hybrid systems in order to reduce the dependence on fossil fuel sources by ensuring energy savings.

Key words: Electricity, hybridization, Great Algerian South Networks, energy transition, renewable energy.

JEL Classification Codes: Q42; Q48; R34

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Introduction

The production of electricity in the Great South Networks (GSN) of Algeria is ensured by diesel power plants and by gas turbines running on natural gas and some on diesel. Since they cannot be connected to the national interconnected grid due to their remoteness, covering the demand for electrical energy from these networks is very costly and increases drastically with the distance and isolation of these regions. The constrained access to conventional electricity attests to the interest in integrating renewable energies, which could constitute an opportunity to lower the cost of locally produced electricity.

The hybridization of conventional power plants by the permanent resource of the sun contributes enormously to the reduction of fossil fuel consumption and therefore ensure an inter-generational economy of resources. On that note, what are the prospects for the development of renewable energies in the networks of the Great South of Algeria? The ever-increasing demand for electricity in the GSN has led the Algerian authorities to consider new approaches to supply the population with electricity in a more reliable and economical manner.

The optimization objective is to minimize the system cost and to determine the optimal sizing of the hybrid system according to its unit energy cost (per KW). The electricity cost of diesel generator based power plants in southern Algeria is relatively very high due to their low efficiency, high maintenance and operating costs and many other difficulties in supplying these arid areas (Khelif & al, 2012, p. 1).

The study is structured in three sections, the first is dedicated to a literature review on the different electricity networks in Algeria and the mini-grids of the GSN. In the second section a description of the modes of electrification in the Great South is drawn up to deal in the third with the prospects for the development of renewable energy and the deployment of hybrid systems in the mini-grids of the GSN.

1. Generalities of Great Algerian South Networks

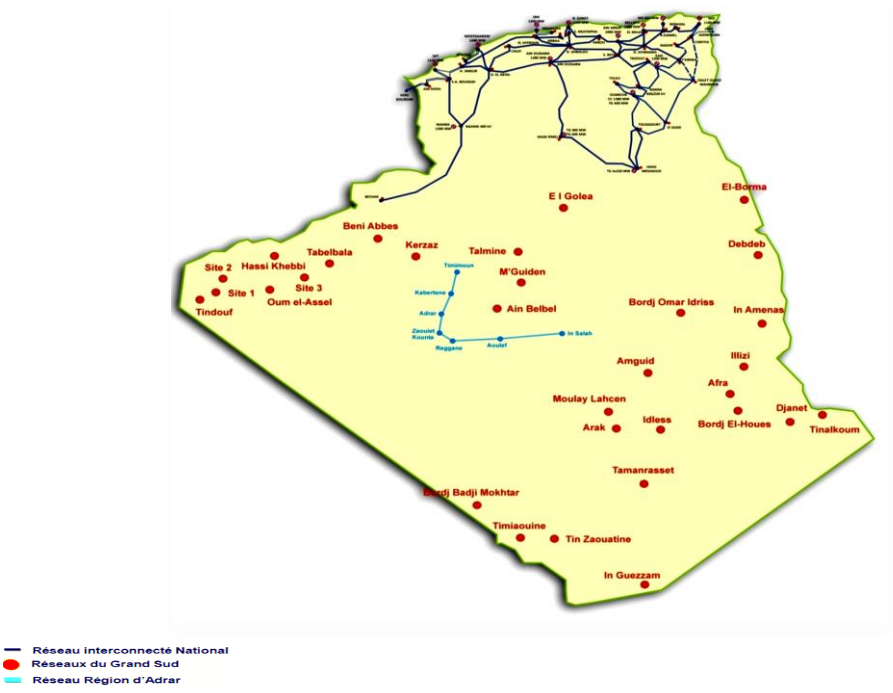
Responding to the economic and social development of Algeria and the surge in electricity consumption has required the realization of important means of electricity production. These last ones not being always near the zones of users, it was necessary

obviously, to ensure the connections between the ones and the others, and for that to realize lines, sections of lines, connected between them in installations called stations, the whole constituting the energy networks (Figure N° 1).

1.1.Overview of existing electricity networks in Algeria

In Algeria, the electricity distribution networks are differentiated (Dahmani S. , 2022, p. 67), according to the power received, the quantities of energy transited, the dimensions of the lines and the equipment of the stations, and obviously the functions they fulfill; they are then distinguished by their service voltages, are distributed geographically and include: The National Interconnected Network, NIN by abbreviation, The Pole of Adrar, called PIAT (Pole In-Salah, Adrar, Timimoune), and the Networks of the Great South which supply full time the scattered localities of the Great Algerian South with a maximum distribution voltage of 30 KV (communicated by SKTM, 2022).

Figure N° 1. The main electricity networks in Algeria



Source: *(SKTM, 2018, p. 7)*

The electricity networks are made up of energy infrastructures allowing the routing of electricity from production plants to consumers. The networks in the South are small-scale networks that are not electrically synchronized with the large interconnected

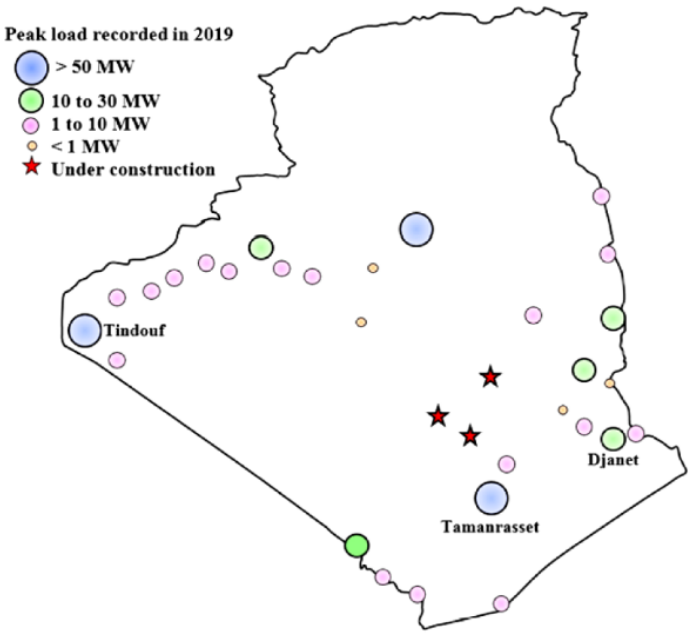
network, with the exception of the Adrar network, which consists of a regional network with a nominal voltage of up to 220 KV.

1.2. The Great Algerian South Networks mini-grids

Unlike the national interconnected grid and the PIAT, these mini-grids are characterized by low power generation capacities and small, consistent transmission and distribution infrastructures that can cover the demand for electrical energy. These independent grid systems are also called off-grid systems.

The mini-grids of the GSN, also called Southern Isolated Systems have a peak load of between 10 kW and 10 MW or less than 50 MW (Figure N° 2) where electricity is generated and supplied to the limited number of isolated consumers in the 33 GSN. They generally operate below the 30 kV voltage level or more generally at or below the locality distribution voltage level (SKTM 2022).

Figure N° 2. The major mini-grids in the south of Algeria by the end of 2019



Source : (Khirennas & al, 2020, p. 7)

Mini-grids are a viable and cost-effective configuration for electrifying remote and dispersed communities in the South. Electricity generation units in the GSNs are powered by diesel, and in some localities by natural gas. This facilitates the deployment of hybrid

systems in mini-grids due to their low capital cost per kilowatt capacity and high reliability, even in these harsh environments.

2. The electrification system in the Great Algerian South Networks

The agglomeration system of southern Algeria is quite particular in relation to its physical and climatic characteristics. It is sparsely populated and the electricity load in its localities fluctuates over the course of a day, the seasons and the year (communicated by SKTM, 2022).

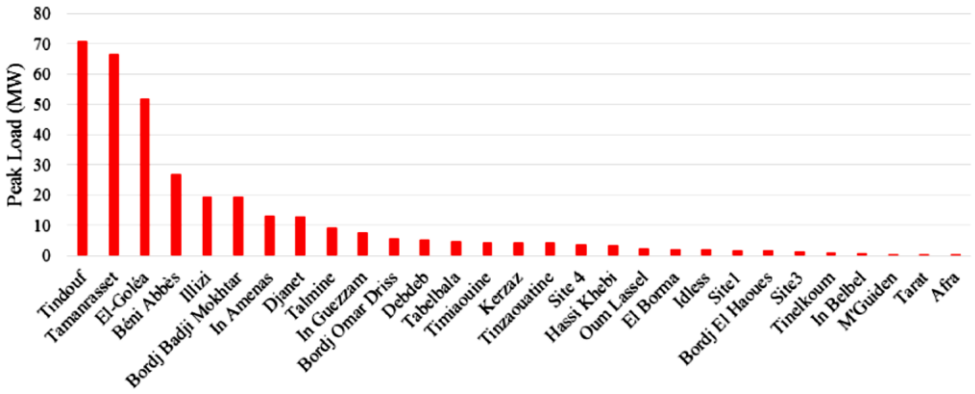
To meet the peak load, the power generation sites must be continuously supplied, and this supply constitutes the spinning reserve. Generally speaking, spinning reserve is the potential power that the system can provide in a very short period of time to maintain the supply-demand balance in case of forecast errors or sudden changes in load demand.

2.1.Electricity Demand in the Great Algerian South Networks

The Greater South Systems are independent systems and used to meet locally generated demand. According to their demand profile, the localities in the South of Algeria are mostly qualified as non-industrialized areas where customers are mainly households, public buildings and small businesses. Moreover, the annual peak loads occurring during the daytime of the summer season are much higher than the average loads.

The continuous evolution of the consumption in a locality of the GSN is presented as a load curve (Figure N° 3). The latter traces the whole of the powers measured in average value over a given duration (10 minutes for example) during a defined time interval.

Figure N° 3. Peak load reached in 2019 in each of the GSN mini-grids

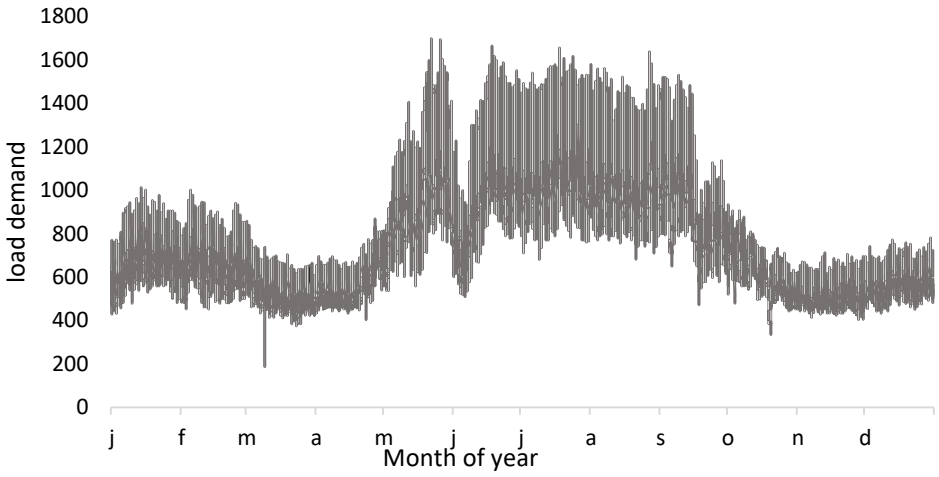


Source: communicated by SKTM, 2022

The peak loads reached during 2019 in the mini-grids of the GSN are between 1 MW and 30 MW except for the mini-grids of Ain Belbel, M'guiden, Tarat and Afra where the peak loads were less than 1 MW. In the localities of Tindouf, Tamanrasset and El-Goléa these respective values exceeded 50 MW.

The total hourly active power supplied for the whole of the year 2020 by one locality of the GSN (Bordj Omar Idris), representing the load demand of the community from the data provided by SKTM is illustrated in Figure 4.

Figure N° 4. Hourly load profile of a locality of the GSN (Bordj Omar Idris)



Source: communicated by SKTM, 2022

The peak demand of the locality of Bordj Omar Idris in 2020 is reached on May 22 at 13h. It is estimated at 1 694 KW. The minimum demand is only 188 KW while the annual average is 948 KW. The difference between the peak and the annual average load demand, also observed for all the mini-grids in the Great South of Algeria, confirms the

quasi-industrialized character of these localities with ventilation and air-conditioning units as the most electricity-consuming item, mainly in the summer season.

However, with the non-harmonized increase in demand in the GSN, the conventional power plants in operation are no longer sufficient to meet the peak load and it is necessary to install a new one each time. Conversely, during a load drop, the generators may not be suitable for the required operating range. However, in order not to damage the diesel generators, certain constraints limit their production possibilities (Katiraei & Abbey, 2007, p. 2).

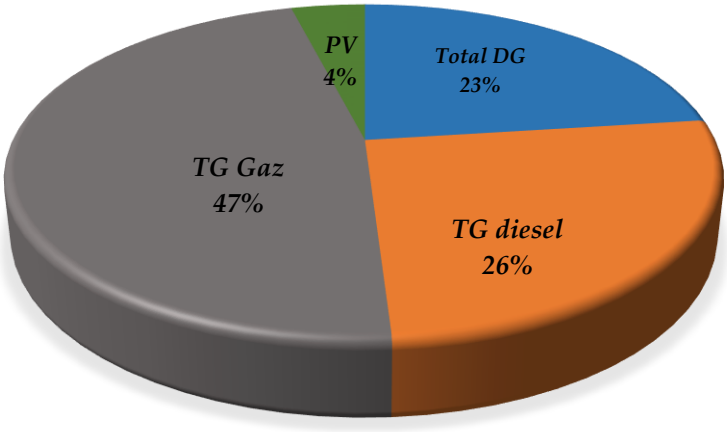
2.2.The Electricity Generation Fleet in the GSN

Electricity generated in the mini-grids, with the exception of recently installed photovoltaic capacity, is provided by local fossil fuel-based power plants consisting of diesel (DG) and/or gas turbine (GT) units. In some localities and due to anomalies, gas turbines are running on diesel instead of natural gas because the fuel is not available.

The total installed capacity in all the mini-grids of the Great South of Algeria is estimated at the beginning of 2022 at 977 MW; of which more than half (58%) operates on diesel, 38% on gas. The part of the photovoltaic source is constituted by 4% of the capacity, in other words, the 37 MWp, among others, those of Tamanrasset, Tindouf, Djanet, Timiaouine and Bordj Badji Mokhtar added to the power generation systems.
About 4% of the installed capacity in 2022 is represented by photovoltaic energy, a significantly low percentage especially since large fossil fuel based capacities are added each year to meet the constant growth in electricity demand in the Great South of Algeria.

The 2021 electricity generation balance sheet shows that diesel accounts for 49% of the total electricity delivered, natural gas contributes 47%, while 4% comes from installed photovoltaic capacity (Figure N° 5). In the same year, the cumulative electricity generated in the GSN is estimated at 1,402.37 GWh. Approximately 687.16 GWh is generated from diesel fuel and 649.11 GWh from natural gas. Only 56.1 GWh are produced by photovoltaic.

Figure N° 5. Distribution of total electricity generation from mini-grids by source and technology at the end of 2021



Source: communicated by SKTM, 2022

Conventional power plants, particularly DG-based units, are more favorable for supplying full-time power to remote localities in Algeria's Great South because of several advantages, such as their simplicity of design and the short time required for start-up. However, due to the high operating and maintenance costs of a fuel plant and its inability to meet an overload for a long period of time, diesel fuel must be regularly trucked hundreds of kilometers, on degraded roads in some cases, from the nearest supply center and stored with sufficient autonomy to ensure the continuous supply of the populations

3. Energy mix and hybrid mini-grid systems in the GSN

The key objective of the national program for the promotion of renewable energies and energy efficiency launched by the Algerian government is the exploitation of the solar potential and the diversification of the sources of electricity production in the mini-grids of the Great South as well as in the two other grids.

The experience of integrating photovoltaic systems in the production of electricity in the mini-grids of the GSN has resulted in PV-diesel hybrid systems at the MW scale in the localities of Tamanrasset, Tindouf and Djanet as the first projects realized.

3.1.The solar renewable potential in Algeria's Great South and the national RE development program

In North Africa, there is a huge reservoir of solar energy, particularly important in the southern region of Algeria. The energy received daily on a horizontal surface of 1 m^2 is about 5 kWh over most of the country and 7.26 in the Great South, or nearly 1700 kWh/m^2/year in the north and 2,625 kWh/m^2/year in the south (Bouraiou & al, 2019, p. 15).

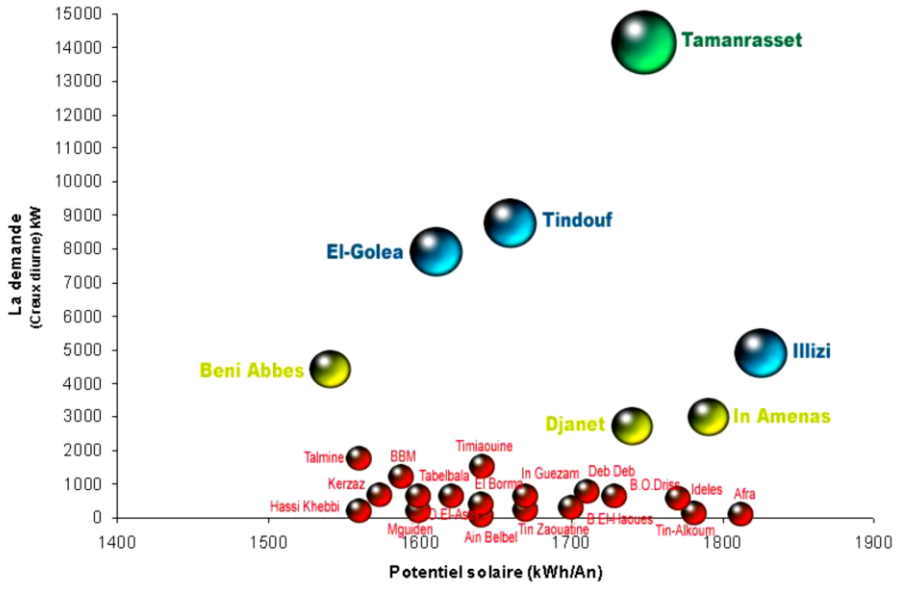
The potential of other renewables is more modest, including hydroelectricity and wind power when wind speeds vary between 2 and 6 m/s only. The potential of biomass, which includes the recycling of human, urban and agricultural waste, is estimated at 1.33 Mtoe/year. Geothermal energy has a more favorable outlook with 200 hot springs listed (Abada & Bouharkat, 2018, p. 2).

During its passage through the atmosphere, solar radiation is scattered, absorbed and reflected by particles or due to human activity and the different types of clouds that form depending on the season of the year. Therefore, the overall solar radiation received on a horizontal plane can be divided into two components (direct and diffuse) (CDER, 2019, p. 8)

A satellite evaluation, carried out by PVGIS, a software developed and updated by the European Commission and which records the degrees of sunshine and radiation throughout the world showed that for the year 2020, the average horizontal freezable irradiation of Algeria was 194.38 kWh/m^2, the largest potential of the entire Mediterranean basin.

The solar potential is almost available in the south of Algeria, especially in the localities of the southeast region, such as Illizi and Afra, which record very high temperatures (Figure N° 6). The very hot temperatures in the mini-grids mean that the cooling systems (refrigerators and air conditioners) operate at full time, which contributes to the increase in electricity demand.

Figure N° 6. Ranking of GSN Sites according to solar potential



Source: (Sonelgaz, 2016, p. 7)

The national program dedicated to the development and promotion of renewable energy and energy efficiency in Algeria, was adopted by the Government in February 2011. It aimed to achieve energy self-sufficiency through the installation of electricity generation capacity from renewable energy. The program aims to achieve 40% of electricity generation capacity from renewable sources by 2030. Quantitatively, the goal was to ensure 22,000 MW of renewable electricity generation capacity, of which 10,000 MW would be dedicated for export (Benhamida, 2015, p. 43).

Algeria considers solar energy as an opportunity and a lever for economic development and in particular a tool for the establishment of industries that create wealth and jobs (Bouraiou & al, 2019, p. 20). The energy policy pursued by the authorities supports the rapid and continuous growth of non-fossil renewable energy in electricity production, which would reach an overall share of 27% by 2030.

An estimate of the evolution of the installed capacity is presented by the Ministry of Energy and Mines (MEM). This evaluation is based on a global annual consumption of 150 TWh/year (CEREFE, 2020, p. 46).

The first version of the national program dedicated to the development and promotion of renewable energy and energy efficiency, published in 2011, was updated in 2015. It is expected that the main source of renewable energy will be photovoltaic energy, followed by wind energy. The contribution of both will increase significantly, especially in the second stage of the program (2020-2030). By 2030, these two sources will account for 84% of all energy generated with renewable energy sources (Díaz-Cuevas & al, 2021, p. 2). In its current version. This program has been motivated mainly by the notable changes in the world as to the costs of investment and pro-generation of electricity based on the various renewable resources. Concentrated solar thermal (CSP) which was initially adopted to generate 7,200 MW of solar electricity, more than 2.5 times the share of solar photovoltaic (2,800 MWp). However, if in 2011 the costs of producing electricity based on these two technologies were roughly the same (0.35$/KWh), those relating to solar photovoltaic have subsequently fallen sharply to less than 0.15$/KWh in 2015, while those of CSP have changed little and have remained well above 0.25$/KWh (CEREFE, 2020, p. 50).

Consequently, the share of CSP has been revised downward (2,000 MW instead of 7,200 MW) while postponing its effective development beyond 2021, while that of solar photovoltaic has been multiplied by about 5 (13,575 MW instead of 2,800 MW), that is to say 62% of the total of 22,000 MW planned for 2030.

SKTM, for its part, is committed to the EnR-Diesel hybridization program in Algeria's Great South. The photovoltaic power plants of the GSN are intended for the hybridization of existing diesel and GT power plants. The latter, with a total installed capacity of 50 MWp, will save 14 million $/year and 20,600 tons of diesel (Dahmani & al, 2022, p. 7).

3.2. The prospect of renewable energy development in the GSN and the hybridization of conventional power plants

The isolated and scattered localities of the Great south of Algeria are supplied with electricity by power generation systems that have long been made up of multi-unit diesel generator plants and gas turbines, and this until 2015, the year in which three

photovoltaic plants were commissioned in Tamanrasset, Tindouf and Djanet. These photovoltaic power plants whose respective installed capacities are 13 MWp, 9 MWp and 3 MWp are part of the 343 MWp project, which is an extract of the first phase of deployment of the national renewable energy program (Figure N° 7). SKTM has placed contracts for the realization of 23 photovoltaic plants in the different regions of the country, carried out between 2015 and 2017 (SKTM, 2016).

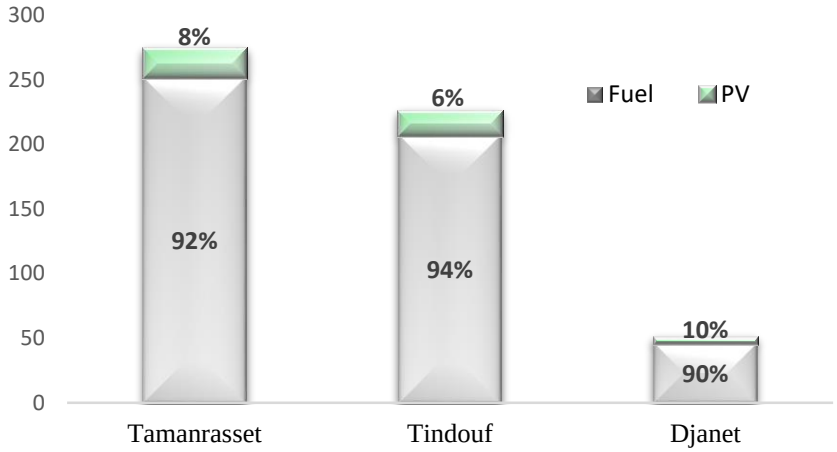
The hybridization of mini-grids in the Great south of Algeria are successfully operating in parallel with existing fossil fuel power plants. These hybrid systems are characterized by PV-diesel/gas systems with no storage and low PV penetration (Khirennas & al, 2021, p. 3). They dictate the voltage and frequency of the mini-grid and the PV inverters self-synchronize with them and inject as much PV power as available unless their output is voluntarily reduced.

The first power plant commissioned is that of Djanet, on February 19, 2015. With a power of 03MWp, this plant is the first in its category, it is located in the region of Tidjentouret, at the entrance of Djanet in the wilaya of Illizi and covers an area of 5 hectares.

The solar power plant of Tamanrasset is located on an area of 26 hectares. It has 4 092 photovoltaic panels. The public investment allocated to the realization of this project is estimated at 2.6 billion DZD (nearly 19 M EUR).

The solar power plant in Tindouf has allowed, since it's commissioning in January 2016, the strengthening of the general electricity production in the wilaya, which has increased to more than 75 megawatts while meeting the local demand for electricity. With a production capacity of 9 megawatts, it is located in the region of Merkale (Tindouf locality), and allowed the drafting of production costs of the main power plant of Tindouf, operating on diesel and consuming some 6,000 liters / day of fuel oil (diesel).

Figure N° 7. The share of PV in the electricity produced by hybrid systems



Source: SKTM, 2021

In 2019, about 3% of the installed capacity is represented by photovoltaic energy. The average annual photovoltaic production of the hybrid mini-grids of Tamanrasset, Tindouf and Djanet for the year 2019 are 8%, 6% and 10% respectively. Their specific annual energy yields are respectively 1668 kWh/kWp, 1532 kWh/kWp and 1736 kWh/kWp. Values that confirm the enormous solar potential of the localities of the Great South of Algeria. In addition, during the year 2019, about 7,149 m^3 of diesel and 7,542,615 m^3 of gas are saved thanks to the operation of the photovoltaic plant of Tamanrasset. Even more, 5,400 m^3 of diesel were saved in Tindouf. As for Djanet, the amount of fossil saved is 2 462 m^3 of diesel and 1 335 513 m^3 of natural gas.

During the third quarter of 2021, two other PV power plants of 2 MWp and 10 MWp were installed in the localities of Timiaouine and Bordj Badji Mokhtar. These plants are in addition to the 8.4 MW and 61 MW capacities of existing fossil plants. The total capacity of renewable energies is estimated at the beginning of 2022 at 37 MWp.

Conclusion

The enormous potential for solar PV in Algeria's GSN mini-grids and the dispersed population density present significant opportunities for PV integration to reduce the overall fossil fuel bill of the power sector and improve the socioeconomic welfare of the

people. However, the mini-grids in Algeria's Great South currently share only a small share of the national electricity generation capacity.

The hybridization of the power generation systems of the GSN mini-grids is a successful experience in terms of results obtained, mainly the quantities of diesel and gas saved. This analysis has prompted decision makers in Algeria to pursue the adoption of the hybrid power system approach within mini-grids, either for new construction or renovation projects, for a more sustainable and cost-effective electricity supply.

On the other hand, the low level of penetration of solar PV in hybrid systems reveals the effect of reduced PV generation in these localities.

In this sense, and in order to take advantage of the huge solar energy potential available in Algeria, a new optimized techno-economic design approach that jointly considers the sizing of the additional PV capacity and the overall system operation planning is essentially feasible. This methodology allows to reach much higher optimal PV penetration levels without compromising the reliability and stability of the hybrid system to be installed.

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