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Power Flow Optimization in Isolated Algeria power system Network Under Presence of the Renewable Energy Sources

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dedication

In the name of peace, the source of speech, and the height of humility and respect, I dedicate this humble work to those whose supplication was the secret of my success and their tenderness like a surgical balm for my mother, then my mother, then my mother, then my father, may allah bless their lives, to my brothers, sisters and their children, to the whole family (Rabah).

To each of the families (El-Kheir, Siad, Kerroum and Abid).

To everyone who taught me a letter, to all colleagues and friends, to all students To all those who are carried by my memory and who have not been carried by my memorandum

ABBREVIATIONS

Sox : sulfur oxides

NOx : Nitrogen oxides

CO2 : carbon dioxide

INA : isolated network of Adrar

FPA : flower pollination algorithm

AME : Algerian Ministry of Energy

TPG : Thermal power generation

RES : Renewable energy sources

RE : Renewable energy

CSP : Concentrated solar power

SKTM : Shariket Kahraba waTaket Moutadjadida

PV : Photovoltaïque

CSP : concentrated solar power

DNI : direct normal radiation

GHI : global horizontal radiation

CSP : The most suitable locations for

PIAT : (PôleIn Salah – Adrar – Timimoun)

RIN : Interconnected Network of the North

RIS : Interconnected Network of the South

(SPE) : La Société Algéienne de Production de l’Eléctricité

CDF : Cumulative distribution function

PDF : Probability distribution function

OPF : Optimal power flow

Résumé : This memory is devoted to the study of the effects of the integration of renewable energies in the existing isolated network in Ain Salah-Adrar-Timimoun (IAT). First, the use of wind and solar power plants was analysed. Then, we developed a new approach for the optimal distribution of energy flows, taking into account intermittent wind speeds, to do this we used an algorithm (FPA) that minimizes the total cost of fuel while respecting the environment by reducing NOx emissions. In order to effectively integrate renewable energies into electrical systems, new installation and usage requirements must be taken into account from the start of the electrical system. Based on this need, the first part of this report provided guidelines and recommendations for the installation of renewable energy plants.

Abstract : Cette mémoire est consacrée à l'étude des effets de l'intégration des énergies renouvelables dans le réseau isolé existant à Ain Salah-Adrar-Timimoun (IAT). Dans un premier temps, l'utilisation des centrales éoliennes et solaires a été analysée. Ensuite, nous avons développé une nouvelle approche pour la répartition optimale des flux d'énergie, en tenant compte des vitesses de vent intermittentes, pour ce faire nous avons utilisé un algorithme (FPA) qui réduit au maximum le coût total du carburant tout en respectant l'environnement en réduisant les NOx émissions. Afin d'intégrer efficacement les énergies renouvelables dans les systèmes électriques, de nouvelles exigences d'installation et d'utilisation doivent être prises en compte dès le début du système électrique. Sur la base de ce besoin, la première partie de ce rapport a fourni des lignes directrices et des recommandations pour l'installation de centrales d'énergie renouvelable

ملخص : هذه الذاكرة مكرسة لدراسة آثار تكامل الطاقات المتجددة في الشبكة المعزولة القائمة في عين صالح - أدرار - تيميمون .(IAT) أولاً ، تم تحليل استخدام محطات طاقة الرياح والطاقة الشمسية .بعد ذلك ، قمنا بتطوير نهج جديد للتوزيع الأمثل لتدفقات الطاقة ، مع مراعاة سرعات الرياح المتقطعة ، للقيام بذلك استخدمنا خوارزمية (FPA) تقلل التكلفة الإجمالية للوقود مع احترام البيئة عن طريق تقليل انبعاثات أكاسيد النيتروجين .من أجل دمج الطاقات المتجددة بشكل فعال في الأنظمة الكهربائية ، يجب مراعاة متطلبات التركيب والاستخدام الجديدة منذ بداية النظام الكهربائي .بناءً على هذه الحاجة ، قدم الجزء الأول من هذا التقرير إرشادات وتوصيات لتركيب محطات الطاقة المتجددة.

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Introduction générale

General Introduction

Fossil fuel power generation plays a very important base on the atmosphere pollution phenomenon because it releases many pollutants, such as sulfur oxides (SOx), Nitrogen oxides (NOx) and carbon dioxide (CO2). Systematic use of fossil fuels, eg Oil, coal and natural gas make it possible to have lower production costs but lead to The release of large quantities of polluting gases [1].

With the development of the new electricity law and the national and international incentives for the use of this energy, the penetration of renewable energy connected to the Algerian electricity grid is expected to increase significantly in the coming decades. The production of electrical energy associated with renewable energies plays a complementary role to the production of conventional energy. Therefore, renewable energy is an alternative to fossil energy in many ways. It emits no greenhouse gases and produces no waste. Population growth and strong urbanization in Algeria greatly affect energy demand and our environment, as Algeria's energy development strategy relies primarily on fossil fuels (oil and gas), which is inconsistent with international commitments in the field of sustainable environmental development. In fact, there may be limits to access to various renewable resources with some drawbacks, including high cost and extent of floor space. filled. Discontinuity in availability is the biggest hurdle, i.e. the fact that it is impossible to guarantee that power will be available at all times. In terms of costs, it is evident that renewables become more profitable with the rise in the price of oil [2-4].

This work will deal in particular with the impact of the comprehensive deployment of renewable energies and measures for the effective and maximum integration of renewable energies (especially wind and solar energy) in isolated network of Adrar (INA) (In Salah – Adrar – Timimoun). Recommendations on operating requirements and connecting renewable energies to INAs (called “Grid-code”) will be published. These rules describe the levers of integration of renewable energies that must be implemented when there are limitations resulting from production or due to the electricity network itself, and also include an assessment of the operation of wind and photovoltaic plants ... . This problem is solved with the help of flower pollination algorithm (FPA) algorithm.

The first chapter describes the development of renewable energy sectors in Algeria.
Chapter 2 Mathematical formulation of optimal power flow
Chapter 3 Study the optimal flow of energy in the presence of renewable energies

Chapter I

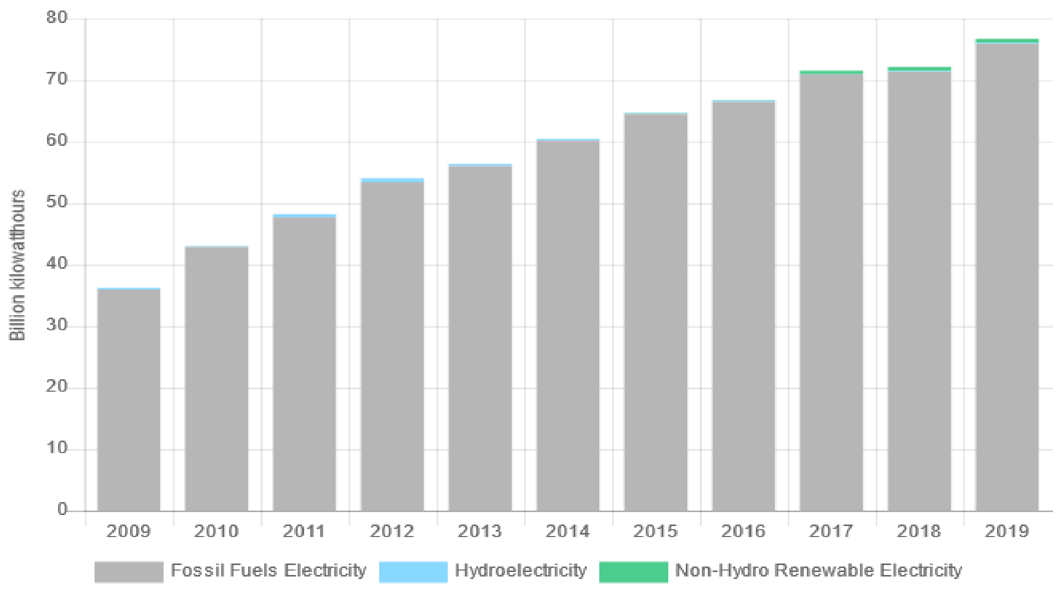
Overview of the Renewable Energy sources in Algeria

I.1 Introduction

Algeria is located in the Sunbelt, which has a high potential for solar energy. In 2011, the Algerian Ministry of Energy (AME) introduced the law No. 11-11[5], to fund and support renewable energies(RE) projects and lay the groundwork for future RE programs and sustainable development in the country. This law is seen as a new incentive to start initiatives to minimize excessive consumption of conventional energy sources linked to higher CO_2 emissions and fluctuating oil and gas prices [5]. With the annual increase in energy consumption, Algeria seeks to integrate renewable energies, such as photovoltaic energy and wind energy.

I.2 Energy Consumption and Productionin Algeria

In 2019, Algeria produced about 76.69 GWh of electricity from 76.4 TWh in 2018 and from 76.0 TWh in 2017[6], of which 98.9% was by fossil fuels, 0.2% by hydropower, and 0.9% by other non-negligible renewables. The other energy sources, such as coal or nuclear power, are not used as of now for power generation.Historically, Algeria has a high share of fossil fuels in electricity production (Fig. I.1) .



Sources : U.S. Energy Information Administration (Dec 2021) / *https://www.eia.gov/*

Figure I.1. Electricity Generation in Algeria.

As seen in Table I.1, the primary energy production rose by +7.3% to 166.2 MTOE in 2016 compared with 2015.The primary electricity production (including hydro-electricity) increased significantly by +51.1% in 2015, compared to 2016, to reach 336 GWh as a result of installation of 13 new PV projects with a total capacity of 180 MW (part of the national Renewable Energy Program)[8].The total primary energy consumption during 2006–2016 is summarized in Table I.2. It is evident from the data in Table I.2 that the total primary energy consumption in Algeria increased from 33.8 MTOE in 2006 to 55.1 MTOE in 2015[8]. However, between 2015 and 2016, it remained unchanged at 55.1 MTOE due to the stability in fuel consumption (Table I.3) [7].

Table I.1. Primary energy production in Algeria [7].

Energy Product (MTOE)	2015	2016	Evolution (%)	Share of Total Primary Energy Production (%
Natural gas	79.931	89.731	+12.3	54.0
Crude oil	54.250	56.193	+3.6	33.8
Condensate	10.885	10.449	−4.0	6.3
LPG	9.753	9.726	−0.3	5.8
Primary electricity	0.053	0.080	+51.1	0.1
Solids fuels : Wood	0.006	0.006	−3.1	
Total	154.878	166.185	+7.3	100

Table I.2. Primary energy consumption in the period 2006–2016 [7].

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total of primary energy consumption MTOE	33.8	35.6	37.7	39.9	38.9	41.3	45.1	47.8	51.6	55.1	55.1

Table I.3. Primary energy consumption by fuel between 2015 and 2016[7].

	Oil	Natural Gas	Coal	Nuclear Energy	Hydro-Electricity	Renewables	Total
2015 (MTOE)	19.5	35.5	0.1	-	Less than 0.05	Less than 0.05	55.1
2016 (MTOE)	18.9	36.0	0.1	-	Less than 0.05	0.1	55.1

The load demand increased by 7.4% from 2007 to 2017. The country's population and energy consumption profile are shown in Figure I.2. By 2030, generation is expected to rise to approximately 150 TWh, with an additional 5.2% increment each year. The promulgation of the new law N° 02/01 February 2002, corresponding to the distribution of the electricity grid and gas functioned as a steppingstone for reorganizing the sector and opening the electricity market. The outcome of this law includes significant grid expansion for electricity transmission from the year 2002 to 2015. Moreover, Algeria was is able to export more than 880 GWh of electricity in 2017 to the neighboring countries such as Tunisia and Morocco [8] [9].

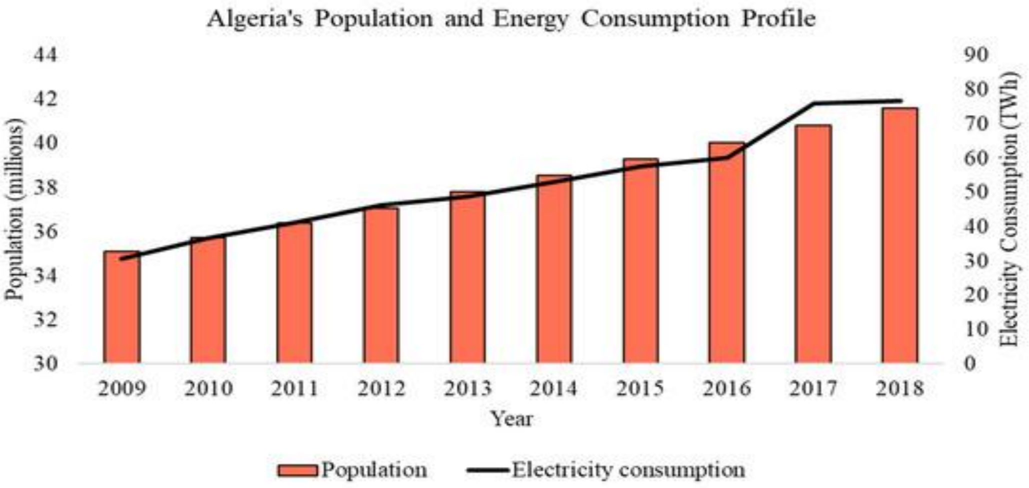


Figure I.2. Evolution of population and electricity consumption in Algeria.

The structure of the Algerian electric grid is divided into the following three systems [10,11]:

- ✓ **Interconnected Network of the North (RIN)**: It extends in the north of the country and covers Ghardaia, HassiR'Mel, Hassi Messaoud, and Béchar. It has high-voltage transmission lines (220–400 kV) that carry power from distant sources to demand centers.
- ✓ **The Pole of InSalah-Adrar-Timimoun (P.I.A.T)**: This pole constitutes an interconnected network in the south from InSalah to Adrar and Timimoun and is supplied by gasturbine-based power plants. By 2020, the P.I.A.T will be connected to the national grid (RIN) through a 400 kV line including the localities of El Golea and Beni Abbes.
- ✓ **The isolated networks of the south (RIS)**: There are 26 sites in the far south, provided power through diesel generators and gas turbines via local networks.

I.3 Development of renewablesectors in Algeria

The energy production in Algeria depends on fossil fuel sources. According to the AME, the structure of installed power by origin is dominated by the gas turbines (11,530MW), followed by the combined cycle (6080 MW), steam turbines (2306 MW), and diesel (362 MW) for the year 2018. The rest (686 MW) is shared among RES such as solar

(448 MW), hydro (228 MW), and wind (10 MW)[12], as illustrated in the graph below (Fig.I.3).Because Algeria needs to export (rather than burn) its hydrocarbon resources that support an overwhelming part of the Algerian economy, the country must now reconsider the role of renewables[13].

Algeria aims to achieve a 27% RES penetration into its existing national energy by 2035, mostly from solar power[14]. To reignite the country's energy transition, in 2021, the Algerian government made a new push to develop strategic partnerships in the field of renewable energies with multiple countries, including China, Germany, and the United States.Towards this end, Algeria launched a tender for a one-gigawatt solar energy project in 2021, comprised of building five power generation sites ranging from 50 to 300 MW each[15]. Algeria intends to be an important player in the production of electricity based RE. In terms of future RE development, the country's most abundant renewable resources are solar, wind, hydro, and biomass.Regarding solar power potential, Algeria is home to some of the world's highest solar irradiance levels, with the capacity to generate 1,850 to 2,100 kilowatts per hour and up to 3,500 hours per year in its desert regions.

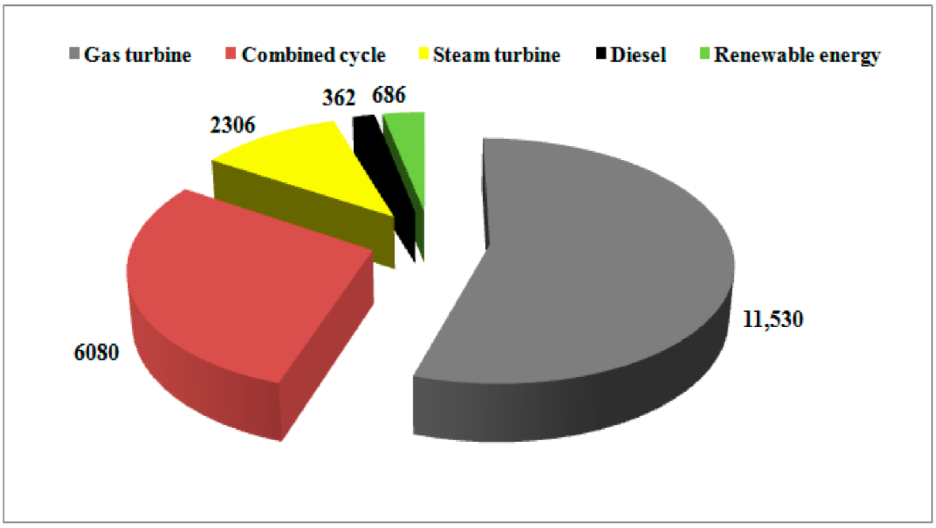


Figure I.3. The total installed capacity breakdown of Algeria until 2018.

For wind, Algeria has a 1,300-kilometer Mediterranean coastline with wind speeds of more than eight meters per second, in addition to winds coming off the surface of the Sahel in the South[12].

Table I.4. Renewable energy capacity in Algeria from 2011 to 2021 (in MW).

CAP (MW)	Hydropower	Wind power	Solar energy	Total RE
2011	228	-	25	253
2012	228	-	25	253
2013	228	-	25	253
2014	228	10	26	264
2015	228	10	74	312
2016	228	10	244	482
2017	228	10	425	663
2018	228	10	448	686
2019	228	10	448	686
2020	228	10	448	686
2021	228	10	448	686

Source: Compiled by the authors, data extracted from [11]

The renewable power in Algeria shows a steady growth (see Table I. 5). Between years 2007 and 2014, the cumulative capacity remained almost stagnant but in 2016 and 2017, respective increases of 54.5%and 37.6% are observed compared to 2015 [16].

A total of 170 MW and 181 MW of renewable power capacities were added in 2016 and 2017, respectively. However, from 2017 to 2019, the cumulative capacity again remained unaltered .Algeria has promoted the utilization of RE through a series of renewable energy conducive policies, laws, and awareness programs [17].

Algeria has a significant potential for the development of renewable energy, TableI.5 describe the RE targets in Algeria [18].

Table I.5. Renewable energy targets in Algeria.

RenewableSources	First Stage 2015–2020	Second Stage 2021–2030	Total(MW)
Photovoltaic	3000	10,575	13,575
Wind energy	1010	4000	5010
CSP	-	2000	2000
Cogeneration	150	250	400
Biomass	360	640	1000
Geothermal	05	10	15
Total (MW)	4525	17,475	22,000

The projects including RE will be finished in two phases [19, 20]. According to the contributions of the various sources listed in Table 10 above, the development of 4525 MW

RE capacity will be the primary goal of the first-stage program (2015–2020). The second-stage program (2021–2030) will be directed towards the development of electrical interconnection between the north and Sahara (Adrar).This will make it easier to install renewable energy facilities in the regions of InSalah, Adrar, Timimoun, and Béchar. By 2020, 60 solar PV and thermal, wind farms, and hybrid power systems will be operational nationwide, according to the country's policy for deploying renewable energy (Figure I.4) [20].

Figure I.4. Solar projects in the Algerian Sahara.

The Saharan regions will likely host the majority of the renewable energy projects. In fact, these areas are becoming a pioneer in Algeria for the exploitation of electricity from renewable sources. Table I.6 details the operation of 14 installed photovoltaic parks and one wind farm in the Sahara under the direction and management of Shariket Kahraba waTaket Moutadjadida (SKTM), a subsidiary of SONELGAZ.

Table I.6. Energy output and installed capacity of completed projects in Sahara [21].

Site	Region	Area Project (km^2)	Installed Capacity (MW)	Energy Output at June 2017 (GWh)	Commissioning Date
El Hadjira	Ouargla	0.6	30	9.738	2017
Oued Nechou PV	Ghardaia	0.05	1.1	4.593	2014
Tindouf	Tindouf	0.18	09	6.376	2015
Djanet	Illizi	0.06	03	10.729	2015
Tamanrasset	Tamanrasset	0.26	13	36.410	2015
Aoulef	Adrar	0.1	05	12.557	2016
ZaouiateKounta		0.12	06	15.213	2016
Reggane		0.1	05	12.221	2016
Timimoune		018	09	23.8222	2016
In Salah		0.1	05	12.328	2016
Kaberten (PV)		0.06	03	9.584	2015
Adrar		0.4	20	59.585	2015
Kaberten (windfarm)		0.33	10.2	51.579	2014

I.3.1 Renewable energies production in Algeria (includ hydraulics) by power grid

In 2020, the production of renewable energies totals an energy of 657.4 GWh representing 0.9% of national production. It is 49.6 GWh for Power Generation Company (sonelgaz) and 607.8 GWh for SKTM.

This production is down 15.4% compared to 2019 (776.6 GWh), this decrease is explained by a deterioration in production:

- Hydropower plants by 67.3%, going from 151.5 GWh in 2019 to 49.6 GWh in 2020, due to the drop in production of the Mansouria power plant by -71% caused by the repair work on the valves (this plant usually represents more than 85% of the production of hydropower plants). It should be noted that the situation of water stress that the country has been going through for a few years already has accentuated the non-use of the production of electricity from hydraulic resources.

- From the Kaberten wind power plant by 20.6%, going from 9.7 GWh in 2019 to 7.7 GWh in 2020, due to prolonged unavailability of wind turbines following technical faults.

- PV of 2.5%, going from 615.4 GWh to 600.1 GWh, due to factors related to unavailability of inverters and transformers, as well as a few other operating constraints [22].

I.3.2 Hydraulic electric energy

Both kinetic and potential energy from flowing water can be converted into mechanical energy Powered by a turbine wheel, 17% of the electricity consumed in the world today is generated from hydropower. The total flows that land on Algerian soil are important and are estimated at 65 billion cubic meters, but they are of little benefit to the country. Hydraulic electricity accounted for 265 GWh in 2003, barely 1% of total electricity production. Electricity generation from hydropower is low due to the fact that precipitation is low and unevenly distributed throughout the country. Table I.7 present the means of production of the hydraulic Park

Table I.7. Means of production of the Hydraulic Park

Power stations	Installed Power (MW)	Group Size	Date of Commissioning	Production (GWh)		Rate(%)
				2019	2020	
SOUKEL DJEMAA	8,1	1x2, 695 1x2, 695 1x2, 695	06/12/1948 23/12/1948 17/01/1949	12,1	7,3	-39,7
GHOURIET	6,4	2x2, 8 1x0, 825	1949 1949	0,8	0,3	-62,5
ERRAGUENE	14,4	1x14, 4	01/01/1962	0	1,9	-
MANSOURIAH	100,0	1x 50 1x 50	18/10/1963 15/11/1963	138,6	40,3	-70,9
Total	128,9			151,5	49,6	-67,3

I.3.3 Wind energy

The world's fastest growing energy source is wind energy, which is also one of the most often used alternative energy sources in use today. Wind speed in the area where the wind power plant is located (power curve) is the key factor influencing how much energy is produ**ce**d by wind turbines. Depending on the speed of the wind, the wind map in Figure I.5,

created by the Ministry of Electricity and Mathematics [23], shows that the southwestern region experiences high wind speed for a large part of the year as shown in Table I.8 [24] which shows the average annual wind speeds and strength in the three locations in the southern region west of Algeria.

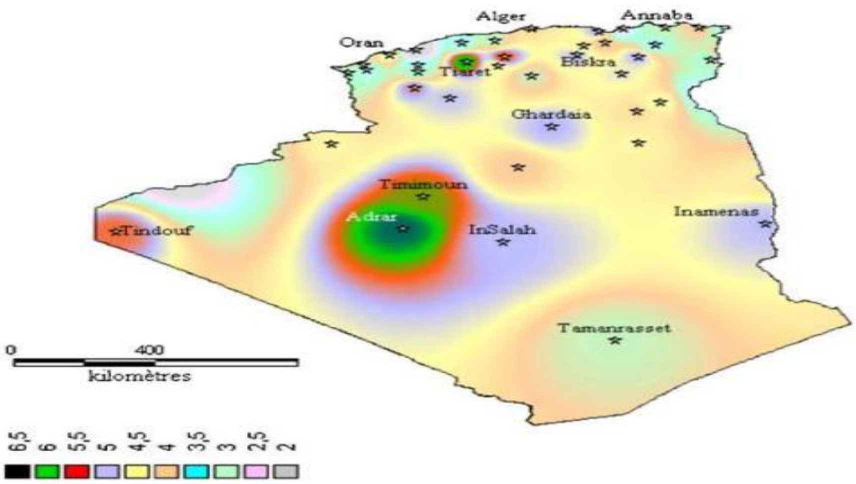


Figure I.5. Annual maps of wind speed in Algeria at 10 m high. [25]

Table I.8. The annual average wind

Velocities in the six identified places [24]

Sites	Adrar	Tindouf	Bordj Badji Mokhtar	Bechar	Tamanrassat	Djanet
Annual average speed (m/s)	6.3	5.1	4.6	4.4	3.7	3.3

Table I.9. Adrar 10.2 MW Wind Farm (…continued)

Designation	**Characteristic**
Number of wind turbines	12 (Gamesa G52 type)
Number of blades	3 / wind turbine with a length of 26 m
mast height	**55 m**
Unit power	**850 Kw**
Energy evacuation	Kabertene 220/30 kV substation
Annual energy produced	**3,42 GWh**(Vmoy: 8,5 m/s, d.air: 1,225 kg/m3)
CO2 avoided/year (*)	about 1000 tons

I.3.4 Solar energy

Algeria has one of the highest solar energy potentials in the world. estimated at 13.9 TWh/year [26]. Average annual sunshine is estimated at 2,650 hours/year in the coastal region, 3,000 hours/year in the High Plateau, and 3,500 hours/year in the desert. Corresponding annual mean of direct normal radiation (DNI) in the three above-mentioned regions It is estimated at 1700, 1900 and 2650 kWh/m^2/year, respectively (see Table 10). This could favor the development of concentrated solar power (CSP). In addition, Algeria The global horizontal radiation (GHI) ranges from 2100 kWh / m^2 / year in the North and 2400 kWh / m^2 / year in the south. Figure I.6 provides an illustration of the geomorphology The most suitable locations for CSP and PV plants according to DNI and GHI values .

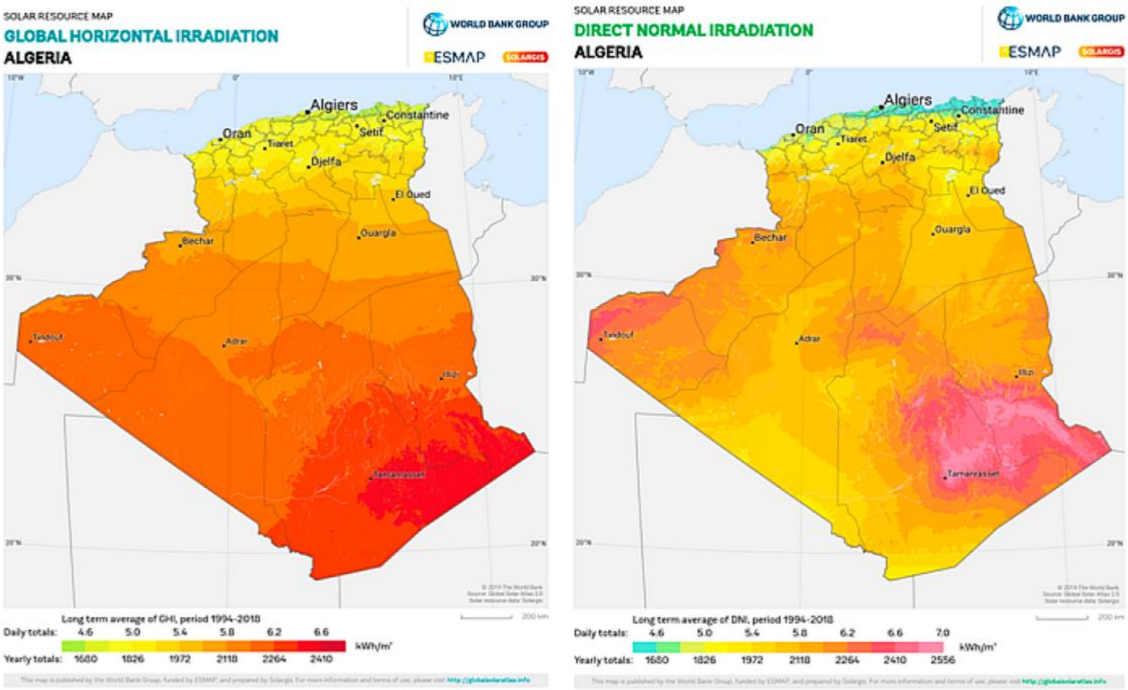


Figure I.6. Global resource potential for CSP and PV. Global resource potential for CSP and PV.

Table I.10. Solar potential in Algeria [27]

Regions	North Country		Sahara	Unit
	Coast	High Plateaus		
Area	4	10	86	%
Average sun duration	2650	3000	3500	**hours/year**
Average amnual energy received	1700	1900	2650	**kWh/m2**
Average GHI	2100	2100	2400	**kWh/m2/year**

I.4 Production means of the Renewable Park

Table I.11. Photovoltaic power plant project

Power stations	Installed Capacity (MW)	Power Output (MW)
KABERTEN WIND PIAT	10.2	10.2
ADRAR	20	8.41
KABERTEN	3	1.26
ZAOUIAT KOUNTA	6	2.52
REGGANE	5	2.10
TIMIMOUNE	9	3.78
AOULEF	5	2.10
IN SALAH	5	2.10
Total PV PIAT	63.2	32.5

I.5. Pole Insalah–Adrar–Timimoun (PIAT)

The synchronous peak recorded at PIAT is 377MW in 2020 against 359MW in 2019, growth rate of around 5.0%.

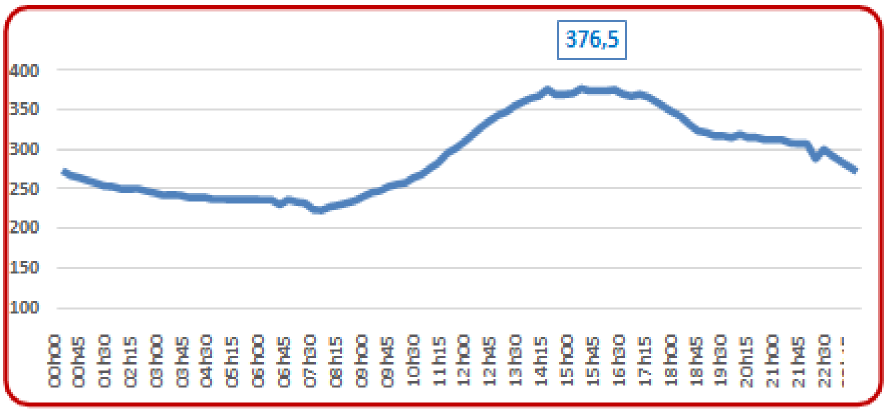


Figure I.7. PIAT power demand at 08.22.2020.

Table I.12. PIAT maximum Power Called in (MW)

2019	2020	Evolution rate (%)
359 10 august à13h45	377 22augustà15h30'	5

The installed capacity of RE in 2020 remains unchanged (483.2 MW), as follow in Table I.14.

Table I.13. Installed power (incl hydro) of RE per grid

	Unit	Grid	2019	2020	Evolution rate 20/19 (%)
SPE	Hydraulic	RIN	128,9	128,9	0%
SKTM	PV (Installed Peak Power)	RIN	266,1	266,1	0%
	PV (Installed Peak Power)	PIAT	53	53	0%
	Wind		10,2	10,2	0%
	PV (Installed Peak Power)	RIS	25	25	0%
	Total RIN		395	395	0%
	Total PIAT		63,2	63,2	0%
	Total RIS		25	25	0%
	Total RE		**483,2**	**483,2**	0%

Table I.14. Output power by RE (incl hydro) per grid

	Unit	Grid	2019	2020	Evolution rate 20/19 (%)
SPE	Hydraulic	RIN	151,5	49,6	**-67,3**
SKTM	PV (Installed Peak Power)	RIN	474,2	466,5	**-1,6**
	PV (Installed Peak Power)	PIAT	100,2	96,7	**-3,5**
	Wind		9,7	7,7	**-20,9**
	PV (Installed Peak Power)	RIS	41	36,9	**-10,0**
	Total RIN		625,7	516,1	**-17,5**
	Total PIAT		109,9	104,4	**-5,0**
	Total RIS		41	36,9	**-10,0**
	Total RE		**776,6**	**657,4**	**-15,4**

I.6 Conclusion

Energy resources are abundant in Algeria. The usage of renewable energy sources has a lot of promise, particularly for solar and wind power. Although these energy sources are only at a very rudimentary stage of development, efforts must be enhanced. Energy-specific laws should be introduced to promote the use of this clean energy source in both the public and commercial sectors and to highlight the value of energy efficiency and conservation. Due to its geographic location and significant position in the world's energy markets, renewable energies are currently one of the primary pillars of Algeria's energy policy.

Chapter II
Mathematical formulation of optimal power flow

II.1 Introduction

The economic power dispatch problem is defined as the setting of active power outputs of generation units, for the system load to be satisfied by the units under system constraints and at minimum cost [28]. In general, power generation units use coal, petroleum, and natural gas as fossil fuels. The cost of wind energy is based on calculating the cost of overestimating and underestimating the available wind energy using the Weibull distribution function of wind speed and the wind turbine power curve. The second contribution is the proposal to use the maximum energy of the wind speed to calculate the maximum power output of the WPG. This formulation has not yet been proposed in the OPF problem area.

II.2 Problem Formulation

In recent years, with the growing interest in environmental issues and the widespread integration of renewable energies, it has become more necessary than ever to consider them in the Renewable Energy Fund. Useful guides on theory and practice of OPF considering renewable energies [29,30].

The objective of economical transmission problems for electric power generation is to schedule the production of generating units dedicated to meeting the required load demand while satisfying the equality and inequality constraints of the system [31]. The objective function of the environmental economic power dispatch problem to be minimized combined with weighted sum method is as follows [32]. In this context, the multi-objective function (efficiency function) that summarizes NOx emission objectives is expressed as follows

II.3 Cost Function

$$FC = \sum_{i=1}^{TPG} (a_i + b_i P_i + c_i P_i) \tag{1}$$

Where, FC is the fuel cost function,a_i , b_i and c_i are the coefficients cost of i^{th} thermal unit, and$P_i$is the active power of generating unit.

II.4 Emission Dispatch

$$Emd = \sum \alpha_i P_i^2 + \beta_i P_i + \gamma_i \tag{2}$$

Where, α_i, β_i *and* $\gamma_i$are the coefficients cost

II.5 Power system security and operational limits

The equality constraint for the OPF problem represents the balance equation between active and reactive power and is expressed as follows, which is a typical load flow equatio

$$P_i - \sum_{k=1}^{N} |V_i V_k Y_{ik}| \csc(\theta_{ik} - \delta_i + \delta_K) = 0 \quad (3)$$

$$Q_i - \sum_{k=1}^{BN} |V_i V_k Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_K) = 0 \quad (4)$$

Where $P_i$and Q_i: the real and the reactive powers injected at bus i: N: the number of bus in the power systemY_{ik}: the element admittance matrix from the bus i to the bus kθ_{ik}: the angle of the element of the admittance matrix V_i: V_k: Y_{ik}: respectively the voltage magnitude of buses i and k, and their corresponding voltage angles are δ_K and δ_i Inequality constraints represent the operating and physical limits of each component of the power system. These constraints include limits on active and reactive power (including sag generation), line and transformer capacity limits, and all voltage bus limits:

$$P_{G.i.min} \leq P_{G.i} \leq P_{G.i.max} \quad (5)$$

$$Q_{G.i.min} \leq Q_{G.i} \leq Q_{G.i.max} \quad (6)$$

$$0 \leq P_{PV.i} \leq P_{G.i.max} \quad (7)$$

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (8)$$

$$|S_{ij}| \leq S_{ij}^{max} \quad (9)$$

In our case, WPGs do not consume or deliver reactive power

II.6 Combined economic emission dispatch (CEED)

The first term of Eq. (1) represents the total cost of the fuel and the NOx emission, approximated by two quadratic functions of PGi:

$$C_i = \omega_1 \sum_{i=1}^{TPG}(a_i + b_i P_{Gi} + c_i P_{Gi}^2) + \omega_2 h_i \sum_{i=1}^{TPG}(d_i P_{Gi}^2 + e_i P_{Gi} + f_i) \qquad (10)$$

With : a_i, b_i, and c_i:the constants of the ith TPG fuel cost .d_i, e_i, and f_i : the NOx emission coefficients. ω_1 and ω_2: the weighting factors .hthe price penalty factor .
According to Ref. [33], the price penalty factor h_i is given by:

$$h_i = \frac{Cf_i\,(P_{Gi\,.max})/P_{Gi\,.max}}{Em_i\,(P_{Gi\,.max})/P_{Gi\,.max}} \qquad (11)$$

The average cost of TPG and NOx emission is given by:

$$\frac{Cf_i(P_{Gi\,.max})}{P_{Gi.max}} = \frac{(a_i + b_i P_{Gi.max} + c_i P_{Gi.max}^2)}{P_{Gi.max}} \qquad (12)$$

$$\frac{Em_i(P_{Gi.max})}{P_{Gi.max}} = \frac{(d_i P_{Gi.max}^2 + e_i P_{Gi.max} + f_i)}{P_{Gi.max}} \qquad (13)$$

Considering the total power load (P_D) of the power system, the price penalty factorh_i is calculated following these steps:
1 Sort hi in ascending order
2 Calculate the $\sum_{i=1}^{TPG} P_{Gi.max}$ from the lowest value of PGi to the highest one until:

$$\sum_{i=1}^{TPG} P_{Gi.max} \geq P_D \qquad (14)$$

When Eq. (13) is fulfilled, the price penalty factor h corresponds toh_i of the i^{th} TPG of the last unit

II.7 Economic Dispatch with RES

In recent years, the integration of RES with thermal units in electrical power networks has attracted much attention from researchers. Even though their initial installation cost is higher, the operating costs of solar and wind production units are significantly low [34].

II.7.1 Probabilistic Modeling of Wind Energy Integration

$$P_r\left(\sum_{i=1}^{N} P_i + W \leq P_D + P_L\right) \leq P_a \qquad (15)$$

The probability that the wind speed will be v and the corresponding cumulative distribution function (CDF) [35,36] are described by Equations (15) and (16), respectively:

$$fv(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (16)$$

$$FV(v) = \int_0^v fv(\tau)\, d\tau = 1 - exp\left(-\left(\frac{v}{c}\right)^{k}\right),\ v \geq 0 \quad (17)$$

where, kandc are positive parameters called shape factor and scale factor for a given location, respectively.

II.7.2 Probabilistic Modeling of PV Cell Power

The energy produced by a photovoltaic (PV) generator is estimated based on manufacturer data as well as climate data (radiation and temperature). The output power of thePV generator can be calculated as follows [37]:

$$P_{pv} = rA\eta \quad (18)$$

Where

$$\eta = \eta_{ref}\left(1 - \gamma(T - T_{ref})\right) \quad (19)$$

where r is solar radiation, Ais total area of the PV module and $\eta$is efficiency of PV generation. On the other hand, ηvaries with the cell temperature T, where η_{ref} is reference efficiency of the PV generator, $\gamma$is the temperature coefficient of short-current, and T_{ref} is reference cell temperature. The solar radiation r can be described by a beta distribution [38,39], as follows:

$$f_r(r) = \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)}\left(\frac{r}{r_{max}}\right)^{a-1}\left(1 - \frac{r}{r_{max}}\right)^{b-1} \quad (20)$$

where

$$a = \mu\left[\frac{\mu(1-\mu)}{\sigma^2 - 1}\right] \quad (21)$$

$$b = (1-\mu)\left[\frac{\mu(1-\mu)}{\sigma^2 - 1}\right] \quad (22)$$

where$r_{max}$is maximum solar radiation. In this work, PV cell temperature predictions are assumed to be without error. Then the PDF of the PV cell power P_{PV} is described by

$$f_{PV}(P_{PV}) = \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)}\left(\frac{P_{PV}}{P_{PV}^{max}}\right)^{a-1}\left(1-\frac{P_{PV}}{P_{PV}^{max}}\right)^{b-1}\frac{1}{A\eta} \qquad (23)$$

Where P_{PV}^{max} is the maximum generated by the PV generator. Then, the expected values and the CDF of PV generation are expressed in Eq (23) and (24), respectively:

$$E(P_{PV}) = \int_{-\infty}^{+\infty} P_{PV} f_{PV}(P_{PV})\, dP_{PV} \qquad (24)$$

$$CDE(P_{PV}) = \int_{-\infty}^{P_{PV}} f_{PV}(x)dx \qquad (26)$$

As explained for wind power integration, CDF can be used to find the probability that power balance cannot be met when random PV output is added to the power grid. Therefore, overestimation and underestimation of PV output can be avoided.

II.8 flower pollination algorithm (FPA)

Flower pollination algorithm is a new nature-inspired algorithm, based on the characteristics of flowering plants. namely Flower Polination Algorithm (FPA) proposed in 2012 by Xin-She Yang [40]. Bees pollinate the flowering trees they visit, thus increasing reproduction on the same flowering tree.With limited memory and minimal learning costs, bees can know in advance that nectar will be available at the location they foraged.Therefore, bees seek to reduce the effort and cost of accessing nectar sources.Keeping in mind the main stages described above, the main steps of implementing FPA can be summarized as follows [41]:

1 Biotic cross-pollination can be considered as a process of globalpollination and pollen-carrying pollinators adopt a Levy flightmotion pattern.

2 Local pollinationsare best described by abiotic pollination-andself-pollination.

3 Pollinators such as honeybees can develop flower constancy[42], which is a reproduction probability that is proportional tothe similarity of two given flowers.

4 The interaction between local and global pollination is driven bya switch probability pa∈[0,1], slightly biased in local pollination due to physical proximity.

In Rule 1, flower pollen and spores are transported by pollinators over long distances. This concept, combined with flower constancy (Rule 3), allows expressing both as:

$$X_i^{t+1} = X_i^t + \gamma L(\lambda)(g_* - X_i^t) \tag{27}$$

Where :

X_i^t ; the pollen i of solution vector xi at iteration t.

g_*: the best solution selected among all solutions at the iteration t.

γ : a scaling factor to control the step size .

$L(\lambda)$: the parameter of the Levy- flight-based step size, given by Eq:

$$\text{Levy}(S, \lambda) = \frac{\lambda\Gamma(\lambda)\sin\pi\lambda/2}{\pi}\frac{1}{S^{1+\lambda}}, (S \gg s0 \gg 0) \tag{28}$$

the Mantegna's algorithm is used to express the Levy distribution. For local pollination, both Rules 2 and 3 are written as:

$$X_i^{t+1} = X_i^t + \varepsilon\left(X_j^t - X_k^t\right) \tag{29}$$

Where X_j^t and X_k^t are pollen from different flowers of the same plant species. This essentially mimics flower constancy in a limited neighbourhood. Mathematically,

if X_j^t *and* X_k^t from the same species or are selected from the same population of flowers, this equates a local random walk with ε extracted from a uniform distribution in the range [0, 1].

Objective function $f(x), x = (x_1 \dots \dots x_d)$

Generate the initial population of `n` flowers/pollen gametes$X_i(i = 1,2, \dots \dots n)$ with random

Solutions $f(X_i)$

Find the best solution in the initial population

Define a switch probability

While (t< $Max.Generation$) or (**stop criterion**)**do**

For i = 1:n,all n flowers in the population

if (rand> p**),**

Drawn a (d-dimensional) step vector L which obeys a Lévy distribution

Global pollination via

else

Drawn from a uniform distribution in $[0,1]$

Do local pollination via

end if

end for i

Find the current best solution

end while

print the results

end

Figure II.1. Pseudo code of FPA

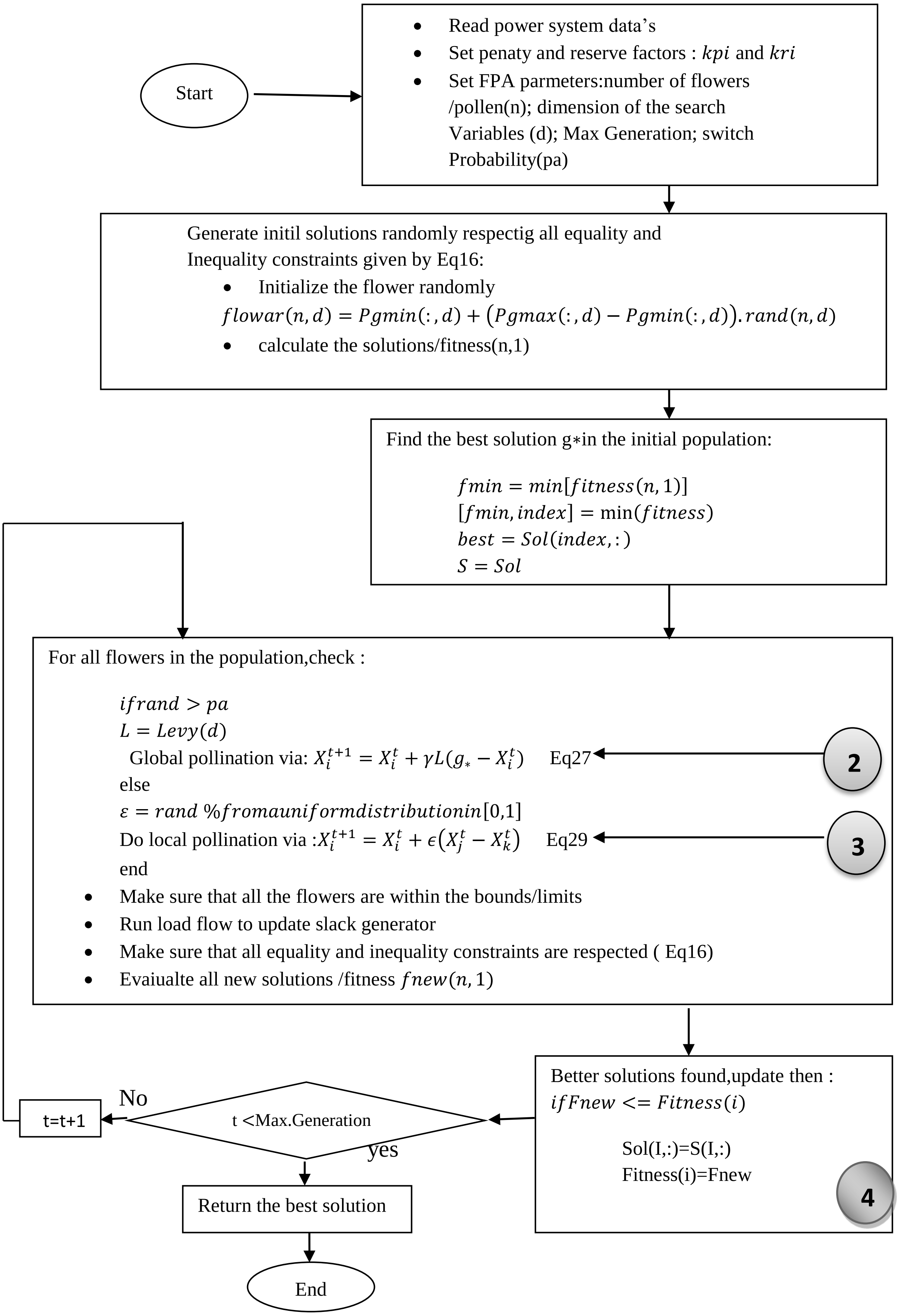


Figure II.2. Flow diagram representing the solution search methodology for FPA

II.9 Conclusion

In this chapter, the problem of allocating economic emissions can be solved more precisely by considering both fuel costs, emissions, and wind energy costs This is achieved by performing FPA to solve the OPF problem for the Adrar power system where WPG is present. The proposed algorithm is applied to simultaneously reduce fuel costs, NOx emissions and wind energy costs. In addition, the proposed model explicitly considers the maximum power of wind energy. The proposed algorithm successfully solves the OPF problem by proving its applicability and computational efficiency .

Chapter III

Study the optimal flow of energy in the presence of renewable energies

III.1 Introduction

The contribution of this study is to develop an effective approach to OPF transmission as applied to real power systems using FPA, where the primary objective of OPF is to determine the amount of effective power produced by the generating set, where the minimum value of the multi-criteria function includes is fuel costs, NOx.and uncertainty of PV resource and wind resource.

III.2 Results and discussion

The isolated network of Adrar, located in southwestern Algeria, is designed to meet local demand for electrical energy. The electrical system consists of 7 gas turbine generator sets. according to the plan By developing renewable energies, it is planned to open 1 wind farm and 7 photovoltaic power plants with a total capacity of 63.2 megawatts in this system. The wind and photovoltaic parks will supply the substations with a voltage of 30 kV / 220 kV. This system is not connected to the Algerian electricity system. The electrical diagram of the (INA) is shown in **Fig. 5.4**.

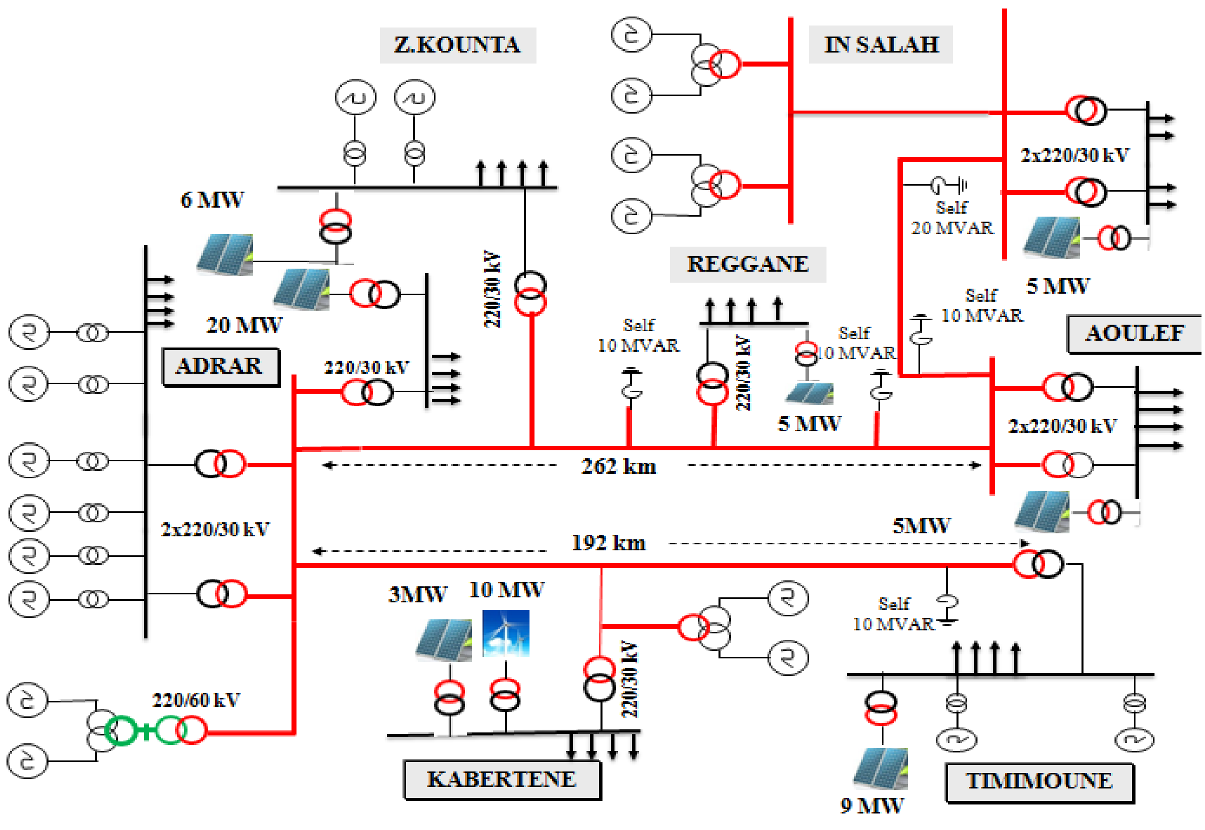


Figure III.1. electrical diagram of the isolated network of Adrar(INA)

- **Without PV**

Table III.1 active power of both TPG units and wind farms, and the cost component of the multi-objective function.

Centrale	**W1=0.8; W2=0.2**	**W1=0.5; W2=0.5**
	active power (MW)	
P1 (ADRAR1 TG)	24	24
P2 (ADRAR2 TG)	47.63	47.3
P3 (ADRAR3 TG)	13.60	13.60
P4 (TIMIMOUNE TG)	44	44
P5 (ZAOUIET kOUNTA TG)	48.85	48.85
P6 (AIN SALAH TG)	51.25	51.25
P7 (KABERTANE TG)	44	44
P8 (ADRAR EOL)	6.30	6.30
P9 (KABERTANE EOL)	6.30	6.30
P10 (TIMIMOUNE EOL)	237.27	358.7182
cost_emission (ton/hr)	237.27	358.7182
cost_fuel ($/hr)	8473.8273	8241.75258
cost_wind ($/hr)	0.1223	0.1212

```
W1=0.8; W1=0.2;
% cp=31*kp.*cpp./1000
% cr=31*kr.*crr./1000
% the Weibull PDF of WECS power output random variable in the
continous
% range takes the form below:
cost_fuel=(sum((Pgg.*Pgg).*c1)+sum(Pgg.*b1))+sum(a1)
cost_emission=sum((Pgg.*Pgg).*a2)+sum(Pgg.*b2)+sum(c2)
cost_wind=  sum(cp)+sum(cr)%+lam;
F1=EED1*cost_fuel+cost_wind+EED2* h*cost_emission
```

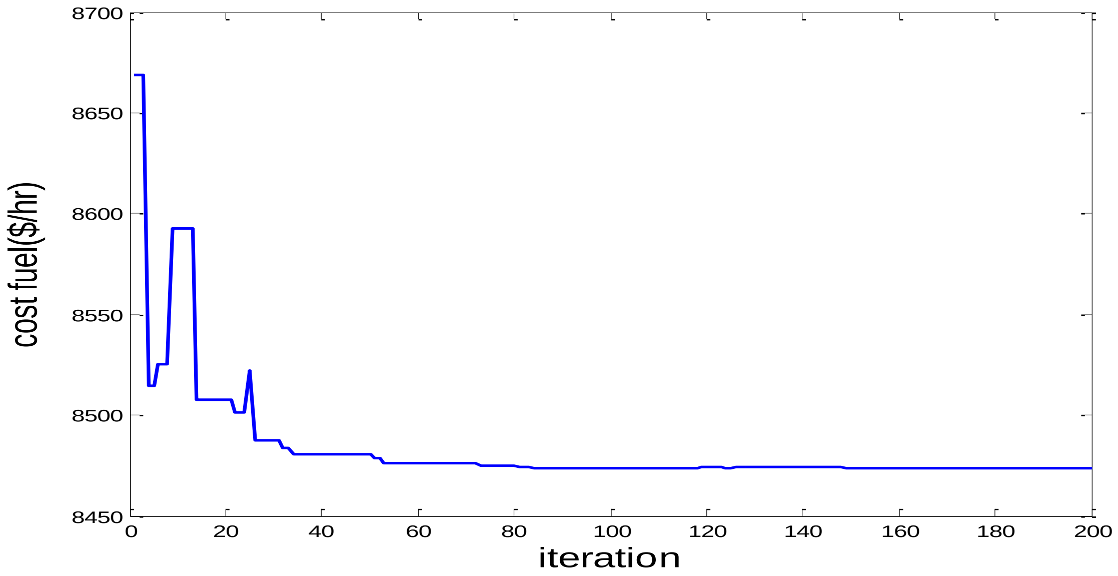


Figure III.2. Convergence curve of the fuel cost

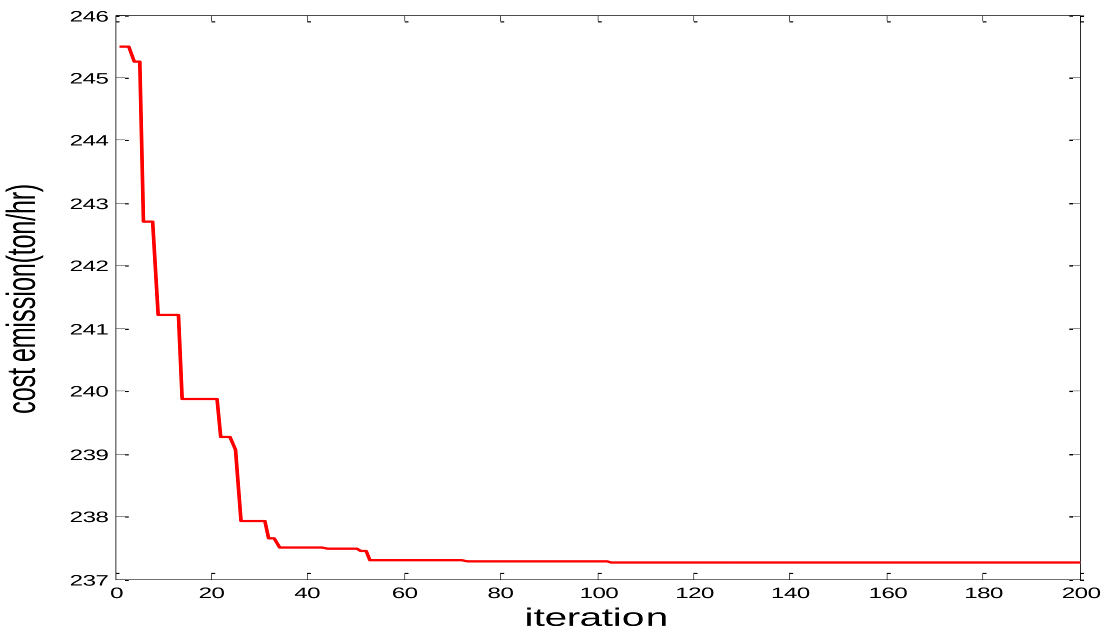


Figure III.3. Convergence curve of the emission cost

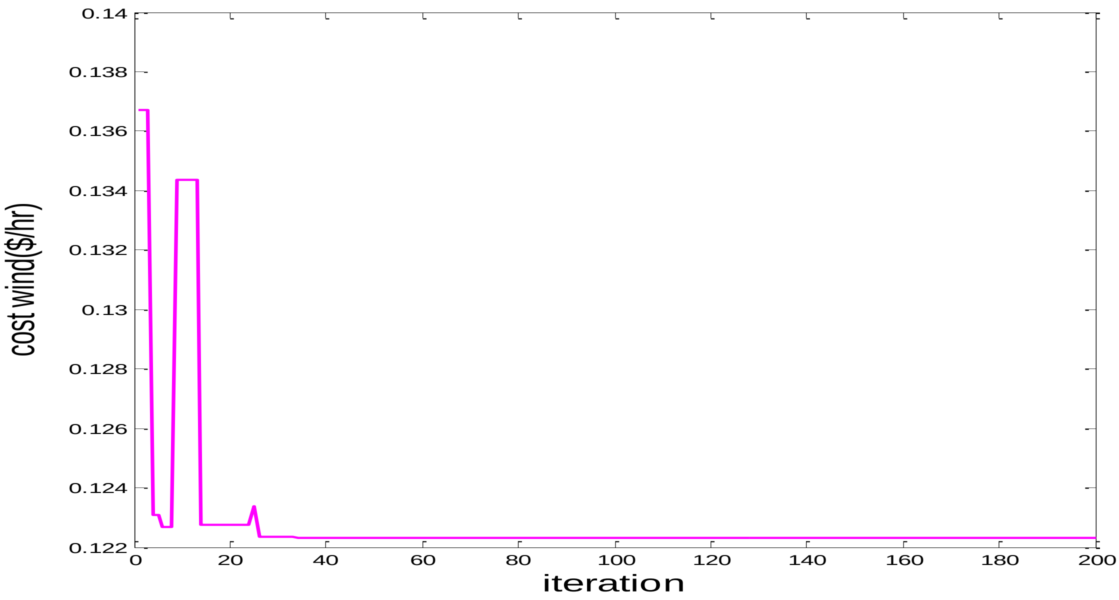


Figure III.4. Convergence curve of the wind cost

```
W1=0.5; W1=0.5;
% cp=31*kp.*cpp./1000
% cr=31*kr.*crr./1000
% the Weibull PDF of WECS power output random variable in the continous
% range takes the form below:
cost_fuel=(sum((Pgg.*Pgg).*c1)+sum(Pgg.*b1))+sum(a1)
cost_emission=sum((Pgg.*Pgg).*a2)+sum(Pgg.*b2)+sum(c2)
cost_wind=  sum(cp)+sum(cr)%+lam;
F1=EED1*cost_fuel+cost_wind+EED2* h*cost_emission
```

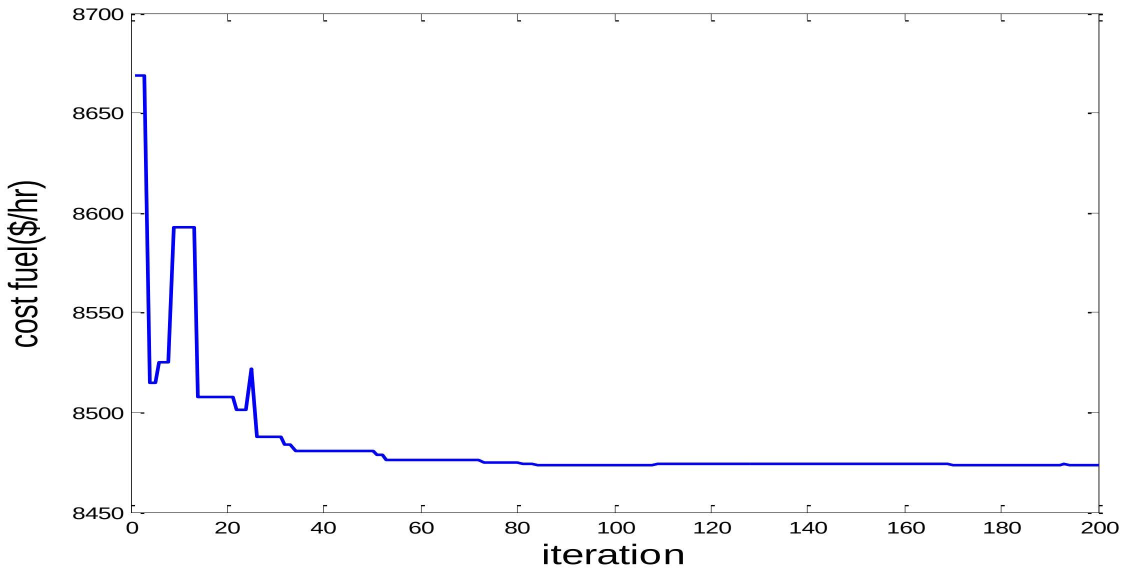


Figure III.6. Convergence curve of the fuel cost

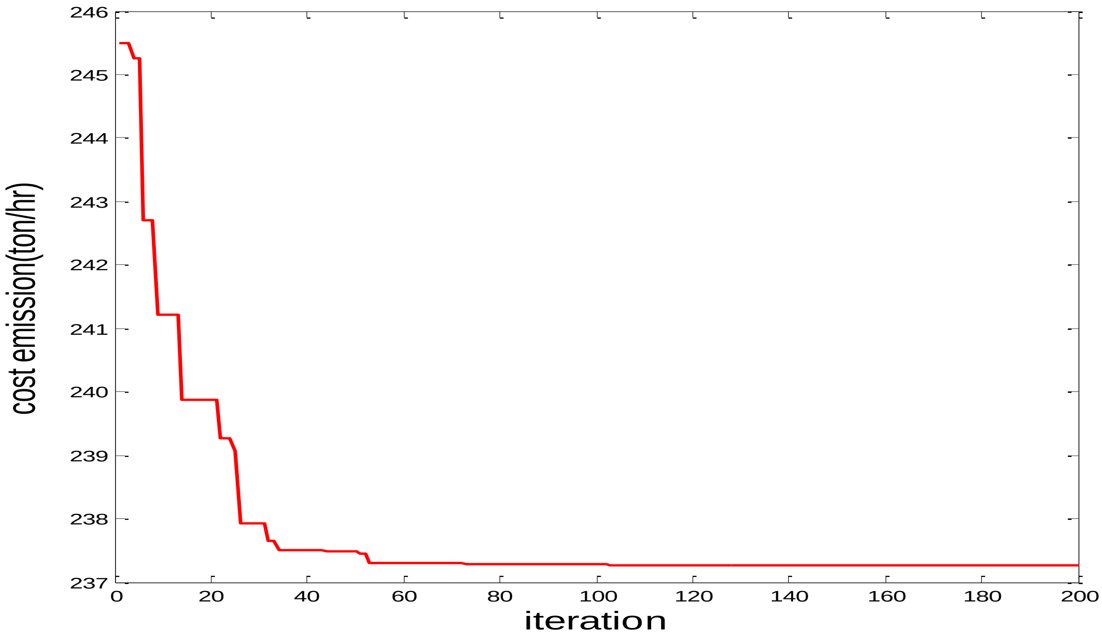


Figure III.7. Convergence curve of the emission cost

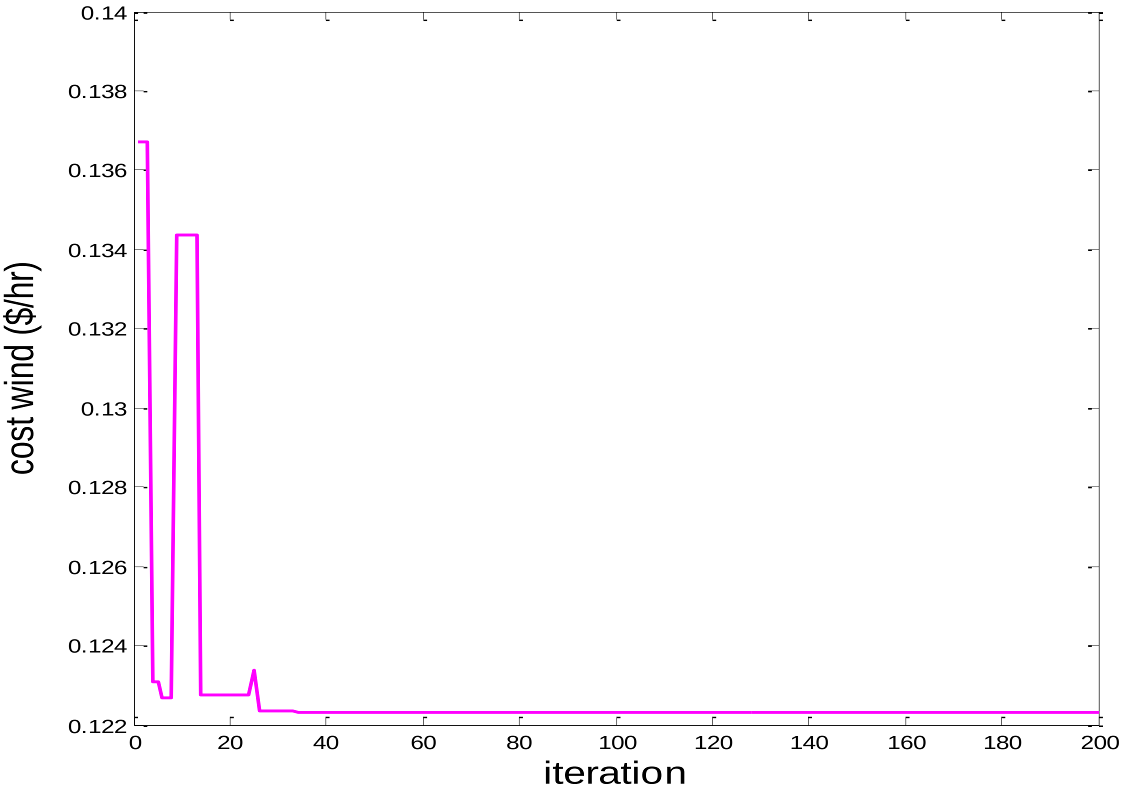


Figure III.8. Convergence curve of the wind cost

- **with (pv)**

Table III.2. active power of both TPG units and wind farms ,PV, and the cost component of the multi-objective function.

Centrale	W1=0.8; W2=0.2	W1=0.5; W2=0.5
	active power (MW)	
P1 (ADRAR 1 TG)	13.0953	13.0953
P2 (ADRAR 2 TG)	59.3607	59.3607
P3 (ADRAR 3 TG)	19.7624	19.7624
P4 (TIMIMOUNE TG1)	55.1827	55.1827
P5 (ZAOUIET KUNTA TG)	70.1701	70.1701
P6 (AIN SALAH TG1)	89.3041	89.3041
P7 (KABERTANE TG1)	37.1321	37.1321
P8 (KABERTANE EOL)	10.30	10.30
P9 (ADRAR PV)	20	20
P10 (TIMIMOUNE PV)	7.5202	7.5202
P11 (REGGANE PV)	5	5
P12 (AOULEF PV)	5	5
P13 (AIN SALAH PV)	5	5
P14 (ZAOUIET KOUNTA PV)	5.7907	5.7907
P15 (KABERTANE PV)	1.1297	1.1297
cost_emission (ton/hr)	306.2841	436.1567
cost_fuel ($/hr)	10724.0957	10524.0957
cost_wind ($/hr)	0.0404	0.0401

```
W1=0.8; W2=0.2;
% cp=31*kp.*cpp./1000
% cr=31*kr.*crr./1000
% the Weibull PDF of WECS power output random variable in the
continous
% range takes the form below:
cost_fuel=(sum((Pgg.*Pgg).*c1)+sum(Pgg.*b1))+sum(a1);
cost_emission=sum((Pgg.*Pgg).*a2)+sum(Pgg.*b2)+sum(c2);
cost_wind=  sum(cp)+sum(cr);%+lam;
F1=EED1*cost_fuel+cost_wind+EED2* h*cost_emission;
```

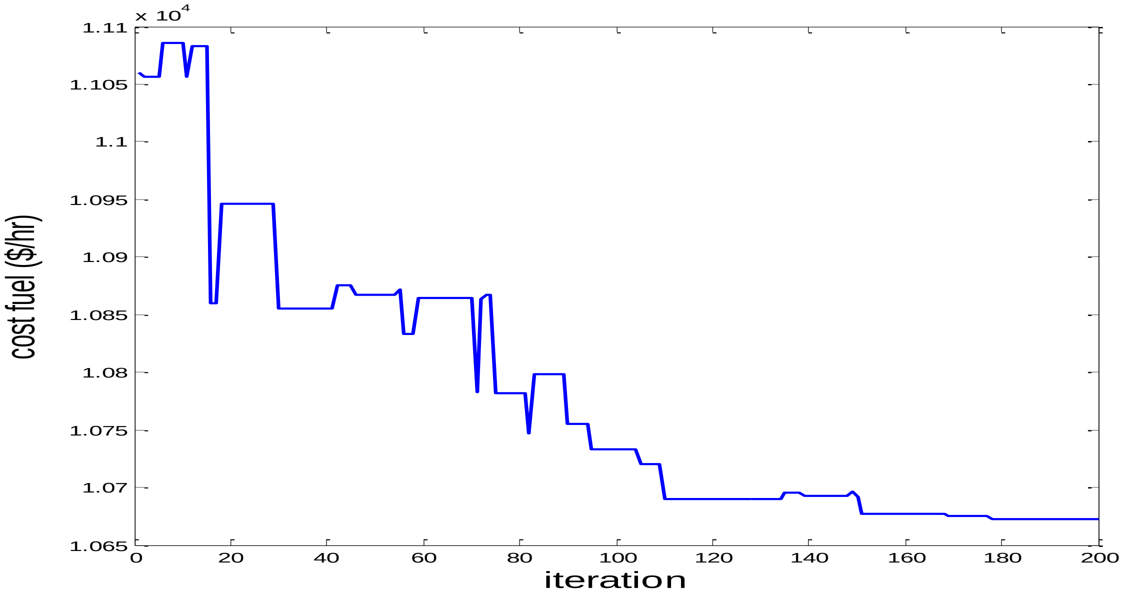


Figure III.10. Convergence curve of the fuel cost

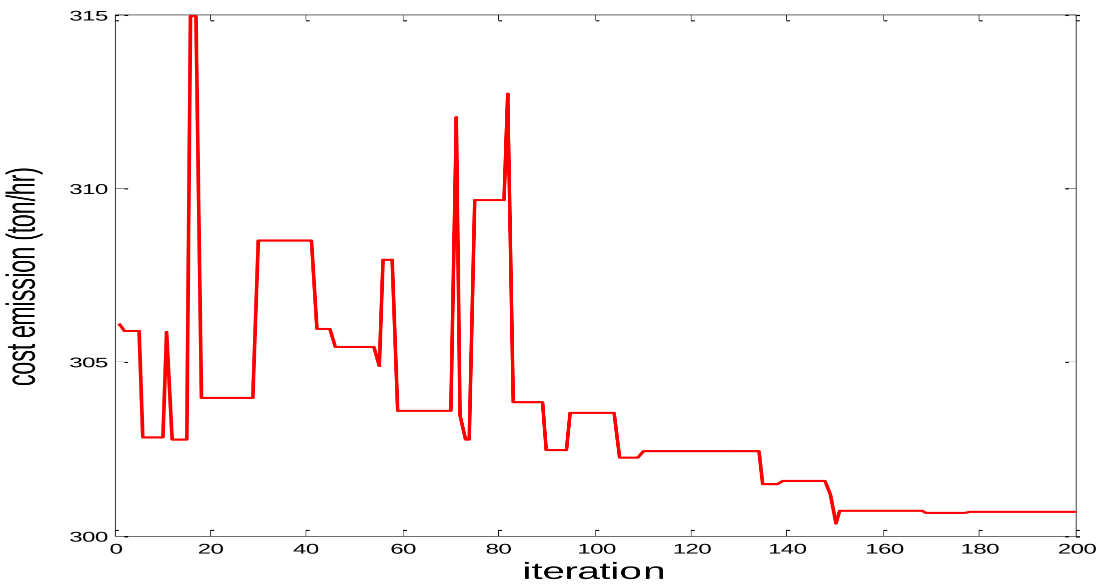


Figure III.11. Convergence curve of the emission cost

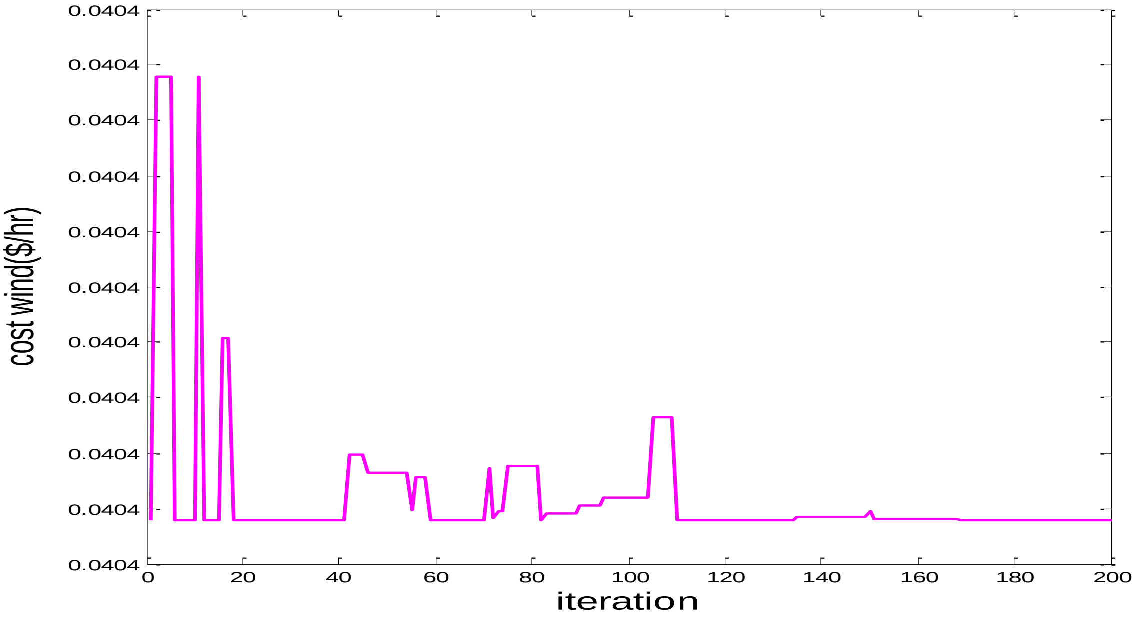


Figure III.12. Convergence curve of the wind cost

```
W1=0.5; W2=0.5;
% cp=31*kp.*cpp./1000
% cr=31*kr.*crr./1000
% the Weibull PDF of WECS power output random variable in the
continous
% range takes the form below:
cost_fuel=(sum((Pgg.*Pgg).*c1)+sum(Pgg.*b1))+sum(a1);
cost_emission=sum((Pgg.*Pgg).*a2)+sum(Pgg.*b2)+sum(c2);
cost_wind=  sum(cp)+sum(cr);%+lam;
F1=EED1*cost_fuel+cost_wind+EED2* h*cost_emission;
```

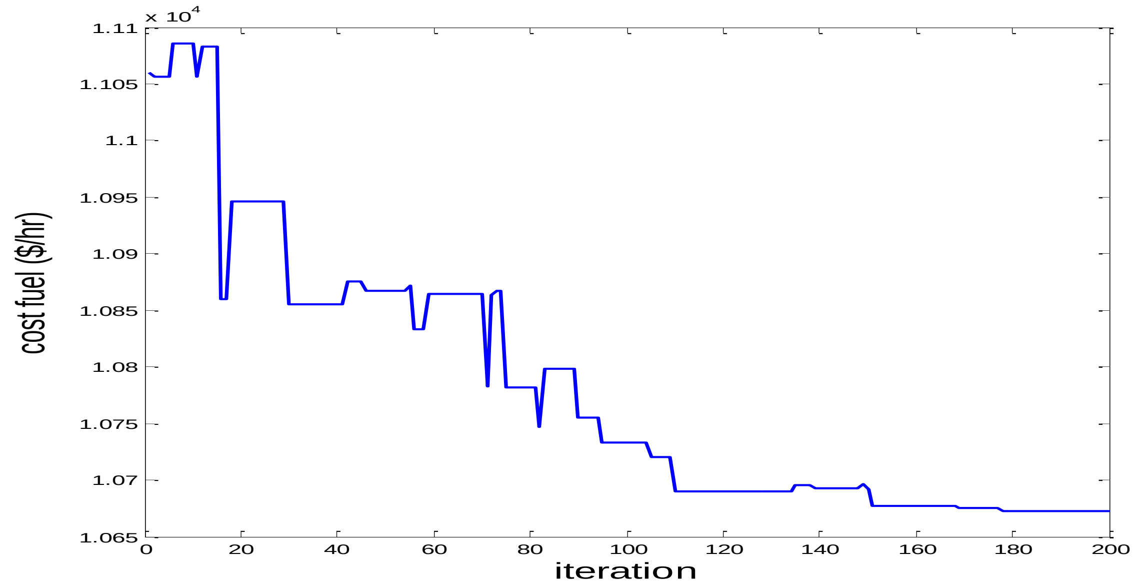


Figure III.14. Convergence curve of the fuel cost

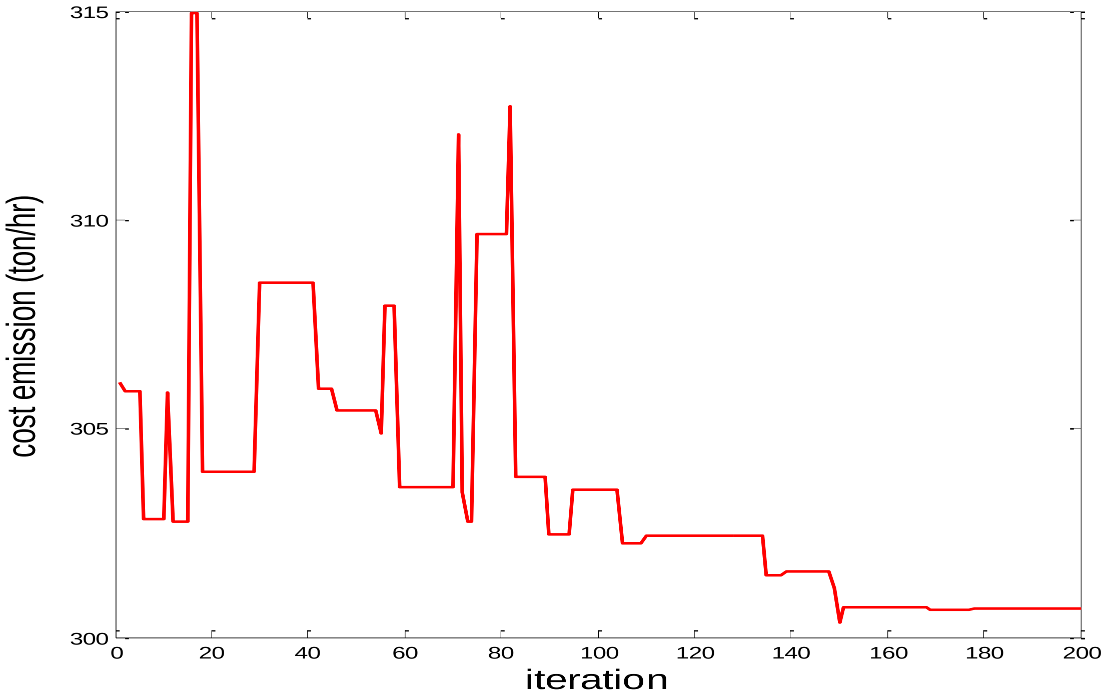


Figure III.15. Convergence curve of the emission cost

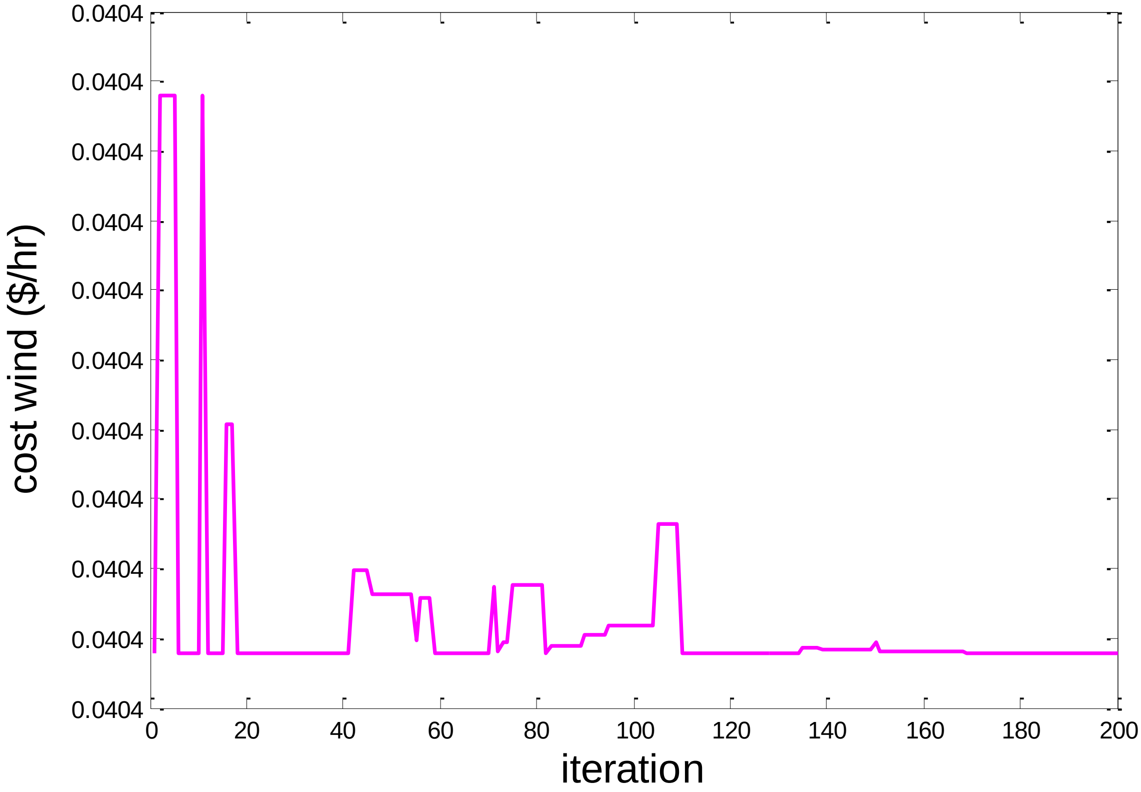


Figure III.16. Convergence curve of the wind cost

By comparing the two tables, it is clear that both the cost of fuel and emissions increased with the increase of photovoltaic plants.

We also notice that there is oscillation in the network, which increases the duration of its stability.

a study should be conducted to verify whether the existing protections must not be modified in order to maintain good discrimination. Adjustment of protections in a distribution network comprising RE requires an in-depth study due to the the complexity of the problem. This is not the subject of thisthesis.

III .3 Conclusion

From the results obtained, the following conclusions can be drawn :

The characteristic tracking volatility of each component of a multi-objective function must be taken into account to optimally qualify the EPO.

Replacing the power rating of the wind turbine with the maximum power rating as an upper limit is the most appropriate approach for modeling wind turbines.

Finally, we can extend the FPA to solve the dynamic EPO of the Algerian power system Various renewable resources can be effectively applied.

General Conclusion

General Conclusion

Algeria has launched an ambitious program to introduce renewable energy sources (NIA). The goal is to preserve fossil fuel resources, diversify electricity production and contribute to sustainable development. The integration of renewable energy production into NIA is the most promising source of energy, since the Adrar region has the highest concentration of solar and wind energy resources. The incidental nature of primary sources (wind and solar) is that they can have a negative impact on the operation of vulnerable power systems, as voltage and frequency control the integrity and stability of the power system. Because of the lack of research on the efficacy of renewables, the NIA is in for a risk reassessment: unreliable system predictions are often identified. This re-evaluation makes the system costly and unprofitable to operate. This is contrary to the original intent.

Operating costs can be reduced by calculating the costs associated with wind uncertainty, while respecting the environment by reducing emissions of harmful substances (NOx), and the goal is to find an algorithm that can solve this problem. To find an algorithm that can solve this problem with minimal computational effort and time, and in order to optimize these goals, we developed the Flower Pollination Algorithm (FPA). The disadvantage of applying this algorithm to an EPO solution is that it requires more than 2 hours and 20 minutes of computation time. This can be a major drawback in Wadi An-Nahar, as it becomes difficult to maintain a balance between production and demand.

The work carried out within the framework of this document is encouraged to be applied to the national electricity grid, taking into account reserves, different load conditions (peak and off-peak hours) and emergency situations. Much work is under way and still needs to be done to study the impact of the integration of renewable energies in the Adrar isolated grid and in the national electricity grid.

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