Optimal Power Flow Solutions Incorporating Stochastic Solar Power withthe Application Grey Wolf Optimize

N. Taleb*, B. Bentouati, S. Chettih
LMSF laboratory, Amar Telidji University Laghouat, Algeria
*Corresponding author; Email: na.taleb@lagh-univ.dz

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ABSTRACT

The present paper aims to validate an electrical network study in consisting of conventional fossil fuel generators with the integration of intermittent generation technologies based on renewable energy resources like wind power or solar photovoltaic (PV) are the stochastic power output. By using an optimal power flow (OPF) problem different frameworks are developed for solving that represent various operating requirements, such as minimization of production fuel cost, and preserving generation emission at the lowest levels... etc. The OPF analysis aims to find the optimal solution and is very important for power system operation with satisfying operational constraints, planning and energy management. However, the intermittent combination of solar exacerbates the complexity of the problem. Within the framework of these criteria, this paper is an overview of the application Grey Wolf Optimizer (GWO) algorithm which solves the OPF problem with renewable energy. The algorithm thus combined and constructed gives optimum results satisfying all network constraints. Give an explanation for findings are based thus need to be with the optimum to effectuate of network constraints.

I. Introduction

The main task of OPF is to determine the best or the most secure operating point control variables for certain objective functions while satisfying the system equality and inequality constraints. Various objective functions related to the electric power system can be optimized such as: total generation cost, etc. Recently, intelligence optimization methods are based on different concepts such as (evolutionary, human, natural) inspired algorithms, and artificial neural networks [1, 2].To reach of wind or, solar PV farms are owned by private operators, (grid/independent) system operator (ISO) signs an agreement of purchasing scheduled power from these private operators. While abovementioned references dealt with only thermal generators, a system consisting of thermal and wind power generators has been studied in pursuit of minimum generation costing the literature. In recent years, different metaheuristic algorithms have been developed. To overcome the deficiencies of the classical methods, some of these algorithms by successfully implemented for solution OPF problems. In the above literature: The authors in have moth swarm algorithm (MSA). In [3, 4], the authors have proposed a backtracking search optimization algorithm (BSA). In [5], the authors have proposed a differential evolution algorithm (DEA). In [6], the authors have proposed a water evaporation method (WEM) .The authors in [7], have modified sine-cosine algorithm (MSCA). The authors in [8], have hybridization between two optimizers called differential evolution .In [9], the authors have proposed a harmony search algorithm (DE-HS). In [10], the authors have a stochastic model of wind generation. The authors in [11], have included DFIG model of wind turbine. The authors in [12], have proposed dynamic economic dispatch (DED) model with penetration of large scale wind power considering risk reserve constraints. Penetration of RESs in the distribution system can achieve many economical, technical and environmental benefits. In [13-15], the authors have proposed the RES-based DGs were integrated to reduce the power losses in the distribution systems as a technical benefit. The authors in

[16,17], have PV and wind sources are used for achieving environmental, technical and economic benefits by reducing the distribution system emissions, power losses and energy production costs. In this regard, the RES uncertainty due to the variation of solar radiation, temperature and wind speed can cause power and voltage fluctuation problems and this lead the system buses voltages to exceed their allowable limits. In [18, 19], the authors have an optimisation algorithm based on sensitivity analysis was presented for regulating the voltage of the distribution system by managing the reactive and active power of the DGs. The economic dispatch (ED) is willing to achieve the economic schedule of power generators output to supply the total system demand putting in mind operational constraints. Power generation from fossil fuels faces a lot of environmental problems and poor energy efficiency. While abovementioned references dealt with only thermal generators, a system consisting of thermal and wind power generators has been studied in pursuit of minimum generation costing the literature. The authors in [20;30] have proposed best guided artificial bee colony (GABC) was applied .For study of a system to improve OPF results that had been recorded in earlier publications with wind and solar these thermal power generators was solved . The contribution of both work of using the Grey Wolf Optimizer (GWO).

This article is organised as follows:

In the first section, the OPF formulation is presented in brief. Then, section 2 modelling of uncertainty in solar power output is presented and model including applicable constraint pertaining to OPF problem. Next, section 3 the results after solving different cases of OPF problem using Grey Wolf Optimizer GWO algorithm. In section 4, discusses case studies and simulation results .Finally, some conclusions are given.

II. Problem Formulation

The OPF is mathematically represented as:

$$\text{Min } f_i = (x,u) \quad (1)$$

$$\text{Subject to: } \begin{array}{l} g_i(x,u) = 0 \\ h_k(x,u) \le 0 \end{array} \quad (2)$$

In a multi-objective problem to minimize the problem, can be defined as follows:

$$\text{Min/Max: } F(\vec{X}) = \{ f_1(\vec{x}), f_2(\vec{x}), \ldots, f_0(\vec{x}) \} \quad (3)$$

$$\text{Subject to: } \begin{array}{ll} g_i(\vec{x}) \ge 0 & i = 1,2,\ldots,q \\ h_i(\vec{x}) = 0 & i = 1,2,\ldots,r \\ L_i(\vec{x}) \le x_i \le U_i & i = 1,2,\ldots,k \end{array} \quad (4)$$

II.1. Constraints

The transmission system has several constraints which can be categorized as follows [3]:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} V_j \left[G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right] = 0 \quad \forall i \in NB \quad (5)$$

The inequality constrains can be classified as follows:

$$P_{TGi}^{\min} \le P_{TGi} \le P_{TGi}^{\max} \quad i = 1,\ldots,N_{TG} \quad (6)$$

$$P_{PV,k}^{\min} \le P_{PV,k} \le P_{PV,k}^{\max} \quad k = 1,\ldots,N_{SG} \quad (7)$$

II.2. Mathematical Models

II.2.1 Modeling of cost the thermal power generators equipment

The relationship between fuel cost and thermal generated power follows a quadratic relationship and the objective function is expressed by some researchers [4, 5]:

$$C_{TG}\left(P_{TG}\right)=\sum_{i=1}^{N_{TG}}\left(a_i+b_iP_{G_i}+c_iP_{G_i}^2\right)+ \quad (8)$$
$$\left|d_i\times\sin\left(e_i\times\left(P_{TG_i}^{\min}-P_{TG_i}\right)\right)\right|$$

Where, $C_{TG}\left(P_{TG}\right)$, a_i , b_i and c_i are the cost coefficient of the i^{-th}thermal generator total number of thermal generators is N_{TG} , $d_i$and e_i are the cost coefficients related to the valve-point [7] loading and $P_{TG_i}^{min}$is the minimum power the i^{-th} thermal unit generates when in operation.

II.2.2 Emission and carbon tax

Emission in tonnes per hour we obtain the following equation [8]:

$$E=\sum_{i=1}^{NG}10^{-2}\left(\alpha_i+\beta_iP_{G_i}+\gamma_iP_{G_i}^2\right)+\xi_i\exp\left(\lambda_iP_{G_i}\right) \quad (9)$$

The cost of emission (in \$/h) is represented as:

$$C_E=C_{tax}E \quad (10)$$

There are many cost components are calculated using:

$$C_{new}=C_{Total}+C_{tax}E \quad (11)$$

II.2.3 Modeling Direct cost of solar PV

The direct cost function of their solar PV, in terms of scheduled power is following [21;26] as:

$$C_{PV,k}\left(P_{PV,k}\right)=h_{PV}P_{PV,k} \quad (12)$$

Where, h_{PV} , are the direct cost coefficient of these energy sources.

II.2.4 Solar Photovoltaic Power Model

The probability of solar irradiance (G) following lognormal PDF with mean μ and standard deviation σ is described as follows [21,28]as:

$$f_G\left(G\right)=\frac{1}{G\sigma\sqrt{2\pi}}\exp\left\{\frac{-\left(\ln x-\mu^2\right)}{2\sigma^2}\right\}\ for G\succ 0 \quad (13)$$

Lognormal distribution is defined as:

$$M_{\lg n}=\exp\left(\mu\right)+\frac{\sigma^2}{2} \quad (14)$$

Figure1.Indicates frequency distribution and lognormal fitting of solar irradiance after running Monte Carlo simulation with a sample size of 8000.The output power of solar PV as a function of solar irradiance (G) is given by[25,26]:

$$P_S\left(G\right)=\begin{cases}P_{Sr}\left(\dfrac{G^2}{G_{std}}\right) & for 0\prec G\prec R_c\\ P_{Sr}\left(\dfrac{G}{G_{std}}\right) & for G\geq R_c\end{cases} \quad (15)$$

Where, G_{std}represents the solar irradiance and $R_c$represents the certain[29]. The rated output powerP_{Sr} , for solar PV unit.

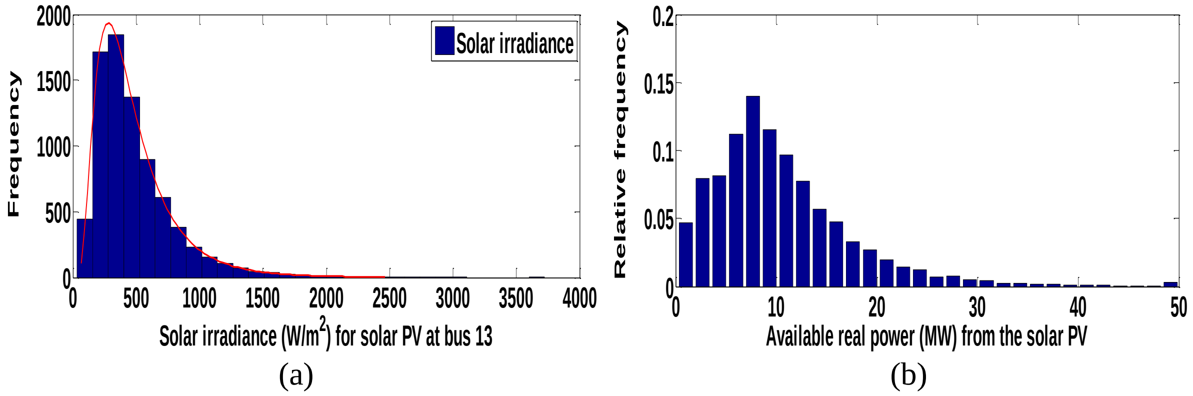

Figure 1.Solar irradiance distribution (a), and real power distribution of solar PV (b)

III.2.2 Algorithms

A new meta-heuristic called Grey Wolf Optimizer (GWO) inspired by grey wolves (Canis lupus). The GWO algorithm mimics the leadership hierarchy and hunting mechanism of grey wolves in nature [22]. The modification in the GWO involved inserting another best solution into the population of the wolves. Also, the average of the distance of the best wolves was taken into consideration instead of taking the separate distances of the best wolves. Proved that GWO can show high performance not only on unconstrained problems but also on constrained problems. This modification had a good effect, on OPF for minimizing fuel cost and the above algorithm GWO is implemented to the OPF problem.In order to mathematically model the social class of wolves when designing GWO, the most appropriate solution is considered alpha (α) wolves. Therefore, the second and third best solutions are called beta (β) and delta (δ) wolves, respectively. The remaining candidate solutions are assumed to be omega (ω) wolves.

In the GWO algorithm, the search (optimization) is guided by α, β, and δ. The ω wolves follow the three wolves in search of the global optimal value.

When $|A| \geq 1$diverge away from the prey shown in Figure 3(b).

When $|\bar{A}| \leq$ suitable position ready to attack on the pre for target archive shown in Figure3(a).

In addition to social leadership, the following equations have been proposed to simulate the siege of grey wolves during hunting [22]:

$$\vec{D} = \left|\vec{C}\vec{X}_p(t) - \overline{X(t)}\right| \quad (16)$$

$$\vec{X}(t+1) = \vec{X}_P(t) - \vec{A}\vec{D} \quad (17)$$

Where‘t’ indicates the current iteration, $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_P$ is the position vector of the prey, and $\vec{X}$ indicates the position vector of a grey wolf.

$$\vec{A} = 2\vec{a}\vec{r}_1 - \vec{a} \quad (18)$$

$$\vec{C} = 2\vec{r}_2 \quad (19)$$

Where elements of ‘a’linearly decrease from 2 to 0 over the course of iterations and r_1, $r_2$are random vectors in [0, 1].During the optimization process, the following formula is run continuously for each search agent to simulate the search and locate the promising areas in the search space [22]:

$$\vec{D}_\alpha = \left|\vec{C}\vec{X}_\alpha - \vec{X}\right|, \vec{D}_\beta = \left|\vec{C}\vec{X}_\beta - \vec{X}\right|, \vec{D}_\delta = \left|\vec{C}\vec{X}_\delta - \vec{X}\right| \quad (20)$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1\vec{D}_\alpha, \vec{X}_2 = \vec{X}_\beta - \vec{A}_2\vec{D}_\beta, \vec{X}_3 = \vec{X}_\delta - \vec{A}_3\vec{D}_\delta \quad (21)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \qquad (22)$$

III. Basic working of GWO algorithm:

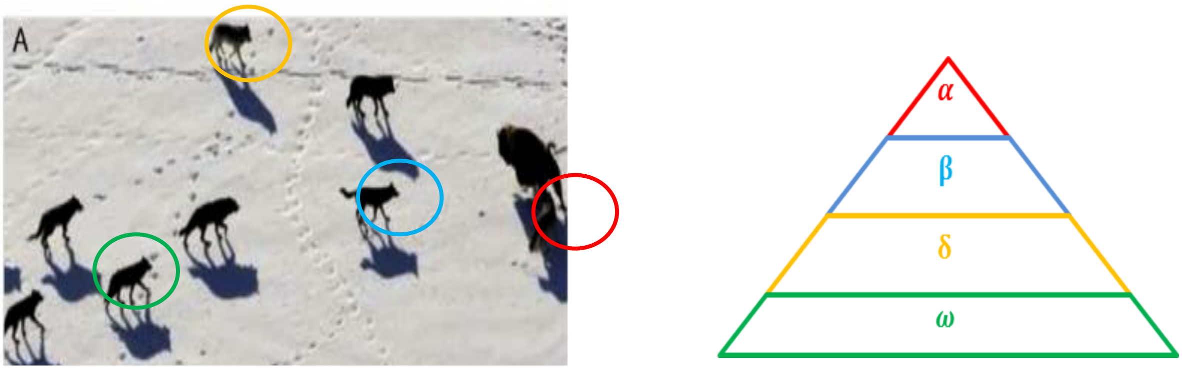

Figure2. The social hierarchy for GWO algorithm [22]

Figure 3. Attacking prey versus searching for prey [22]

- **Stage1:**

The first is to initialize the population of grey wolves, so the solution for the random generation of the grey wolf and prey is generated and their position vectors are represented in the matrix for easy understanding, and then according to the objective function.

- **Stage2:**

The final position will be in a random position within the circle, which is defined by the alpha, beta, and delta positions in the search space, so determining the value of the next position of the wolf determines any location between its current position and the prey position. Figure3. (a).Shows that |A| < 1 will force wolves to attack prey. Therefore, it is veryimportant to update the position to the optimal location towards the prey position that avoids local stagnation during optimization.

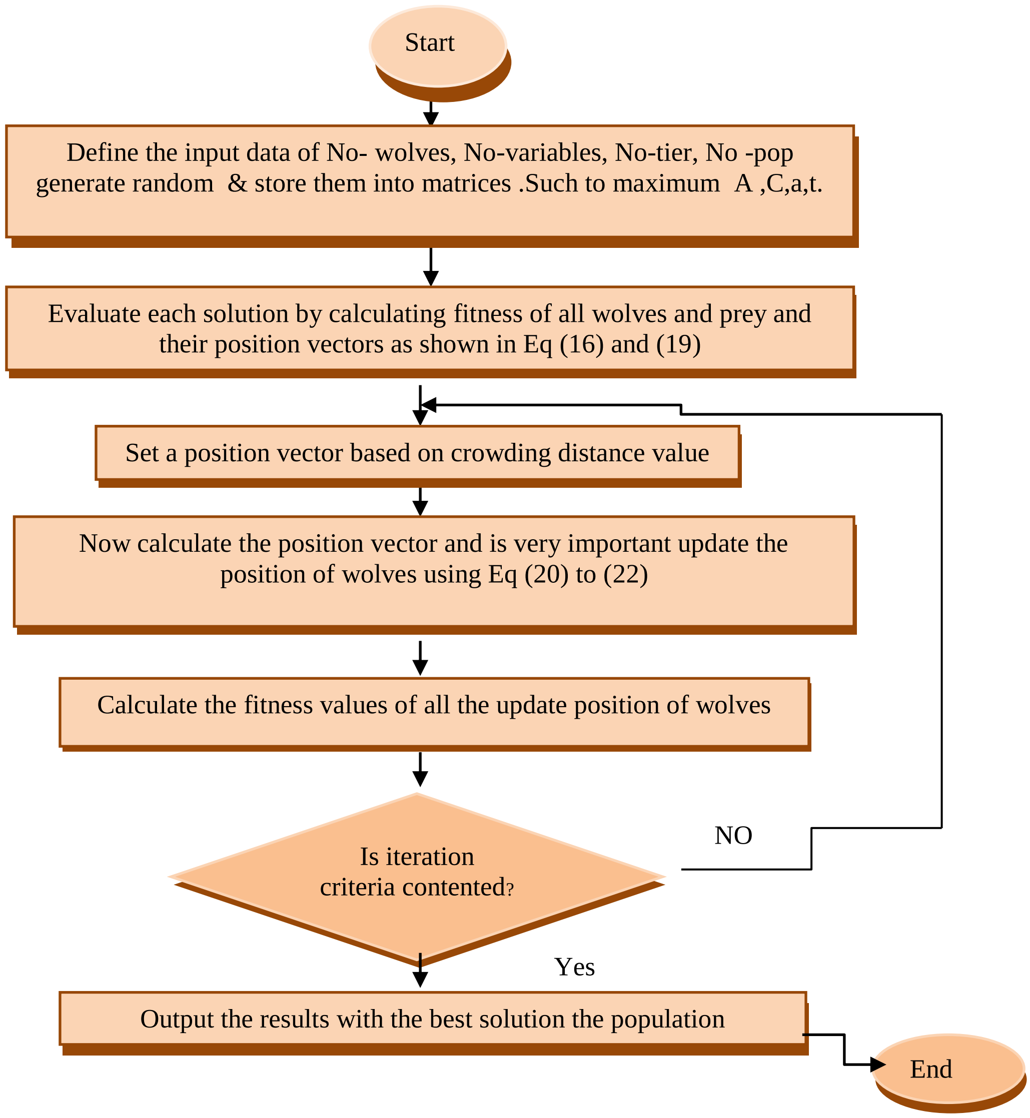

Figure 4.The flowchart of GWO

- **Stage3:**

The proposed social is to preserve the best solutions available so far during the iteration. This is due to the targeted search to find the best solution globally, while the search is the best solution to find global best. For this reason, have been as the GWO is used for OPF problem incorporated with renewable energy sources. It is clearly the GWO the performed better of FPA and SHADE-SF is recently proposed are taken from [23 and 21], in regards of the total generation cost minimization.

IV. Simulation and Results

- **IEEE-30 bus test system**
- **modified IEEE-30 bus test system**

The second aspects have been applied two case studies have been carried out for the applicable IEEE-30 bus system. The case studies using the proposed algorithm are listed and explained in this section. The studies will look at the cost of wind and solar power as the respective planned.
In each optimization case study, a complete algorithm operation performs up to 200 iterations. Run 10 times in each case, where by which you find the best value for the target function and record the corresponding control variable settings

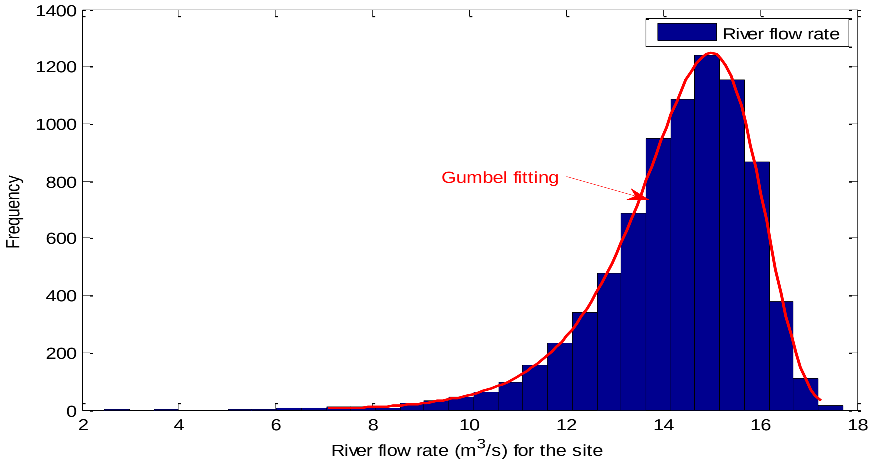

Figure5. Distribution of river flow rate

The first aspect has been applied to solve test systems of OPF problem.

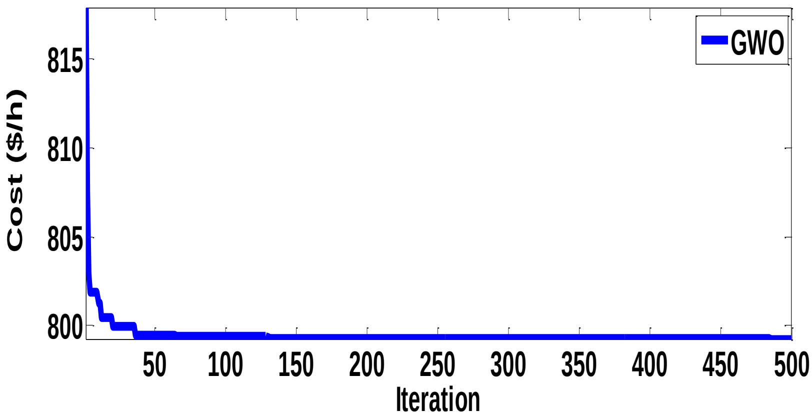

Figure6.Convergent curves of Case (1)

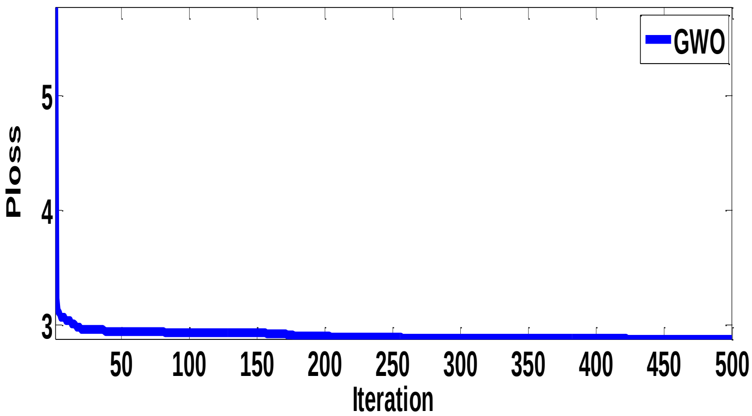

Figure7.Convergent curves of Case (2)

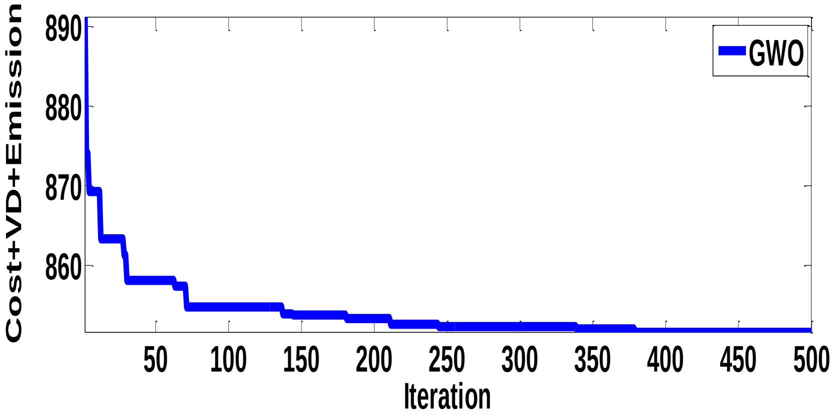

Figure8.Convergent curves of Case (6)

Table1.Optimal parameters using for optimization case studies: IEEE 30-bus system

Control Variables	Case1	Case2	Case6	Parameters	Case6	Case1	Case2
P_{TG1}	134.90791	139.83185	162.0467	Q_{TG1}	4,34142	146.8032	-50
P_{TG2}	28.30269	54.0634	51,4217	Q_{TG2}	3,9763	-18.3721	60
P_{TG3}	43.81736	52.1863	21,9641	Q_{TG3}	3,07186	-15	40
P_{ws1}	10	10.9303	28,8760	Q_{ws1}	0,466003	35	35
P_{ws2}	36.56929	17.5743	15,7946	Q_{ws2}	5	3.583786	-20
P_{PV}	35.41221	15.0978	12,3731	Q_{PV}	4,73973	24.99923	25
V_1	1.1	1.1	1,03514	**Totalcost ($/h)**	5	**781.7807**	810.3799
V_2	0.95	1.09033	1,00888	**VD (p.u)**	4,26312	1.00153	0.98611
V_5	1.1	1.07127	1,00534	**Ploss (MW)**	0,482728	5.6095	6.2840
V_8	1.1	1.07228	1,01068	**Qloss (MVAr)**	0,966765	-12.4609	8.1653
V_{11}	1.1	1.1	0,955012	**Eimission (t/h)**	0,900	1.76213	0.90346
V_{13}	1.1	1.09289	1,05687	**Lmax**	1,07502	0.1390	0.1385

- **Case 1:Minimization of generation cost**

The power generation plan is optimized for all thermal and renewable energy generators to minimize the total power generation costs offered. The cost factor and PDF parameters are given in Table 1 and Table 2 respectively. Figure9.Shows the convergence of the GWO algorithm. We can see that the best cost is accomplished in the 100 iterations.The minimum cost of generating electricity that can be achieved using the power generation plan listed in the table is **781.7807 $ / h**.

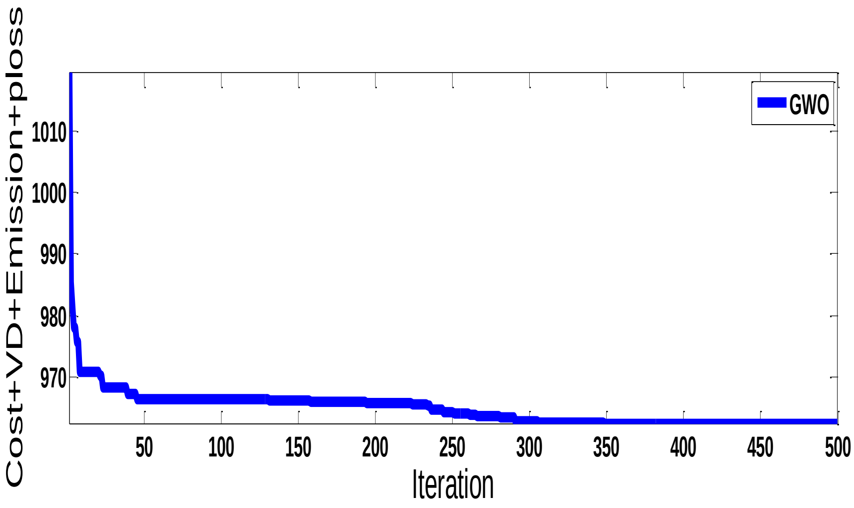

Figure9.Convergent curves of Case 9

Table 2.The Optimal of wind power and solar PV in PDF parameters plants

Wind power generating plants						**Solar PV plant**		
Windfarm #		No.of turbines	Rated power, P_{wr}(MW)	Weibull PDF parameters	Weibullmean, M_{wbl}	Rated power, P_{sr}(MW)	Lognormal PDF parameters	Lognormalmean, $\boldsymbol{M_{lgn}}$
1	Bus 5	25	75	C=9 k=2	ϑ=7.976 m/s	50 (bus13)	$\mu = 6$ $\sigma = 0.6$	G=483 W/$\boldsymbol{m^2}$
2	Bus11	20	60	C=10 k=2	ϑ=8.862 m/s			

- **Case 2:Minimization of generation cost with carbon tax**

The study minimizes total power generation costs, including a carbon tax on emissions from conventional coal-fired power plants, to be minimized. The carbon tax rate C tax is supposed to be 20 $ / t. The penetration of these sources is prospective to augmentation due to the composition of the carbon tax. The optimal power generation schedule, generator reactive power, total power generation costs (including carbon taxes) and other calculated parameters are presented in Table 1. It can be seen that in case 2 of the carbon tax, wind and solar energy penetration is higher than case 1 with no emission penalties. It is clear that the extent to which the optimal renewable energy generation scheme is increased depends on emissions and carbon tax rates

Table3.Compression of obtained results

	Case 1	Case2
GWO	**781.7807**	**810.3799**
SHADE-SF	782.503	810.346

For this reason, have been as the GWO is used for OPF problem incorporated with renewable energy sources. It is clearly the GWO the performed better of SHADE-SF is recently proposed are taken from [21], in regards of the total generation cost minimization.

V. Conclusions

In present study, the GWO algorithm has been implemented to solve the problem of optimal power flow (OPF) OPF with stochastic solar power in the network. The intermittent combination of solar and the complexity of the problem with different probability density functions are with Weibull PDF, lognormal PDF, and Gumbel PDF, respectively of IEEE 30-bus system anticipated. The integration of the GWO algorithm on the different sources (wind and solar power network) shows a good result for cost minimization and demonstrates that the algorithm could be useful and successfully applied for the study cost production. According to the simulation results, the GWO algorithm shows a good minimization of the generation cost compared to the SHADE-SF and FPA algorithms. In addition, this paper has investigated an enhanced and effective version of minimized total generation cost in the system. The future works will involve the following:

· Investigate new procedures for scheduling the RERs using variable river flow, storage in the form of batteries or pumped hydro in the networks systems with large number of buses standard systems.

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