Hunting-Based Optimization Technique for Secured Optimal Power Flow with Lines Outages in Power System

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Abstract: - This paper aims to achieve the exact resolution of an optimal power flow (OPF) problem in an electrical network. In the OPF, the goal is to plan the production and distribution of electrical power flows to cover, at minimal fuel cost, the consumption at various points in the network. Three variants of the OPF problem are studied in this manuscript. The first one, OPF corresponds to the case where power production costs in the network are modeled with a quadratic cost. In the second variant, OPF with outages of some lines, we clarify the extent to which power flow is affected by the outages and the increasing number of overloaded lines. Finally, the last variant, secured OPF corresponds to the case where the management of production units can respect the power limit of each line by rescheduling power production units. The study focuses on congestion management in the IEEE 30 bus system by applying a model for OPF, incorporating data from both transmission lines and generators. The research proposes a Hunting Optimization Technique which is named "Multi-Objective Ant Lion Optimizer (MOALO)" to solve single and multi-objective optimization problems to find a solution for management pricing, comparing results with other research methods to show the effectiveness of the applied approach and the mathematical model representing congestion management.

Key-Words: - Optimal power flow; Fuel cost minimization; Line outage; Line overloading; Ant Lion Optimizer; secured power system.

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1 Introduction

The electrical energy is produced simultaneously with its consumption. Therefore, production must constantly adapt to consumption. The active and reactive powers of generators must be adjusted within their permissible limits to meet fluctuating electrical loads, [1], with minimal cost and sometimes with certain environmental protection while keeping power losses within limits, [2]. This is called optimal power flow, [3].

The optimal power flow problem has a long history of development. Over forty years ago, Carpentier introduced a formulation of the economic dispatch problem involving constraints on voltages and other operational constraints. In his approach (known as the injection method), he framed the economic dispatch problem as a nonlinear optimization problem and used the generalized reduced gradient technique, [4]. In 1968, an optimization problem involving classical economic dispatch was introduced and controlled by power flow equations and operational constraints, where they used the reduced gradient technique to solve the Kuhn-Tucker optimality conditions. This formulation was later named the optimal power flow (OPF) problem. Since then, it has experienced considerable growth, as evidenced by the literature. Excellent synthesis of solution methods and their applications are provided in [5] and [6].

There are many conventional optimization methods used for the optimal power flow problem, like Linear Programming (LP), [7], Interior Point Method (IPM) [8], Differential Evolution (DE) [9], and Artificial Bee Colony (ABC) [10]. For secured optimal power flow, in [11], Sunflower Optimization (SFO) algorithm was proposed for solving the problem, and in [12], Self-Organizing Hierarchical PSO with Time-Varying Acceleration Coefficients was proposed for Security Constrained Optimal Power Flow.

2 Problem Formulation

The OPF solution is used to find a network's optimum operating state while taking into account its limitations on control variables and electrical law constraints. It uses the control variables at its disposal to maximize a goal while satisfying the network's power flow equations. Depending on the situation under study, the goal function characterizes either the maximizing of power transmission or the minimization of losses.Constraints are physical laws that govern a system's behavior and the design limits of devices and operating strategies. This type of problem is usually expressed as a nonlinear static optimization problem. The objective function is represented as a nonlinear equation, and the constraints are represented by nonlinear or linear equations. The OPF problem can be formulated in the following equations, [13]:

$$(P) = \begin{cases} \max/\min f_{obj}(x) \in I \\ g_i(x) \le 0, i = 1, \ldots, p \\ h_i(x) = 0, i = 1, \ldots, q \\ x_{k\min} \le x_k \le x_{k\max} \end{cases} \tag{1}$$

2.1 Objective Function

The main goal of solving the OPF is to determine the arrangements of control and state variables of the system that optimize the value of the objective function. The choice of the objective function should be based on a better analysis of the security and economy of the power system. Generally, it is represented by a second-order nonlinear function. Some common objective functions used in OPF studies include:

- Minimum production costs.
- Minimum active transmission losses.
- Minimum reactive transmission losses.
- Maximum transmissible active powers.
- Minimum costs of injected reactive power (to determine the optimal location for installing new batteries or compensation coils).
- Minimum costs of injected active power (to determine the optimal location for installing new production units).
- Minimum of emissions, [14].

2.1.1 Equality Constraints

These constraints are translated by the physical laws governing the electrical system. In steady-state conditions, the generated power must satisfy the load demand plus the transmission losses. This energy balance is described by the power flow balance equations (Mismatch), formulated as follows, [15]:

$$P_{Gi} = P_{Di} + |\bar{V}_i| \sum_{j=1}^{n} |\bar{V}_j| \left[-G_{ij} \cos(\theta_i - \theta_i) + B_{ij} \sin(\theta_i - \theta_i) \right] \tag{2}$$

$$Q_{Gi} = Q_{Di} + |\bar{V}_i| \sum_{j=1}^{n} |\bar{V}_j| \left[G_{ij} \sin(\theta_i - \theta_j) - B_{ij} \cos(\theta_i - \theta_j) \right] \tag{3}$$

2.1.2 Inequality Constraints

The inequality constraints consist of constraints on the active powers P and reactive powers Q generated, the voltage magnitudes V and their angles θ at each PV node, and on the line currents.

$$P_{i\min} \le P_i \le P_{i\max} \tag{4}$$

$$L_{ij} \le L_{ij\max} \tag{5}$$

$$V_{n\min} \le V_n \le V_{n\max} \tag{6}$$

Where:

P_i: real power generation of generator i.

$P_{imax/min}$: maximum/minimum real power generation of generator i.

L_{ij}: power flow in line (i-j).

$L_{ijmax/min}$: maximum/minimum power flow limit in line (i-j).

$V_{n\,max/min}$: maximum/minimum voltage magnitude.

2.2 Economic Dispatch Problem

The main objective of economic dispatch is to find the active power contribution of each generation group in the electrical system so that the total production cost is minimized for any load condition. The production cost of a unit varies depending on the power provided by the unit in question, [16].

For an electro-energetic system with ng production units, the total fuel cost is equal to the sum of the elementary fuel costs of the different units, as follows:

$$\min F_T(P_G) = \sum_{i=1}^{N} F_i(P_{Gi}) \tag{7}$$

Where:

P_{Gi}: is the active power produced by the i^{th} generator.

F_t: Represents the total production cost.

$F_i(P_{Gi})$: Represents the production cost of the i^{th} generator.

The production cost function of a generator can be expressed by a quadratic form of a second-order polynomial as follows:

$$F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \tag{8}$$

where:

a_i, b_i, c_i: are the coefficients of the cost function.

2.3 Multi-Objective Ant Lion Optimizer Methodology

The Multi-Objective Ant Lion Optimizer (MOALO) was developed in 2016, [17]. This is an updated version of the Ant Lion Optimizer (ALO), which was first introduced by in 2015, [18]. A stochastic method Ant Lion Optimizer method (ALO) was developed in response to ant lion hunting behavior, [18].

The (ALO) algorithm emulates the interplay observed between lion ants and regular ants within the trap scenario. In these interaction models, ants are mandated to traverse the search space, while other ants are sanctioned to pursue and enhance their fitness using traps. Given the stochastic nature of ant movement during food foraging in nature, a random walk is selected as the modeling approach for ant locomotion, where the graphical presentation of ant lion hunting and Antlion optimization algorithm are presented in Figure 1 and Figure 2 respectively.

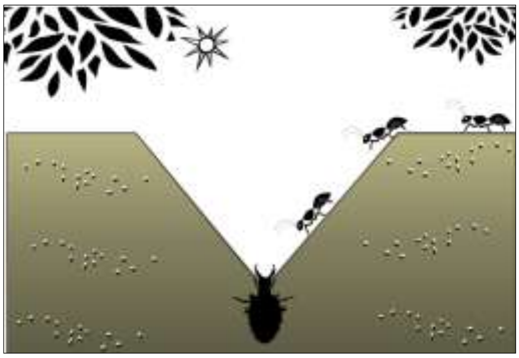

Fig. 1: Graphical presentation of ant lion hunting

The following flowchartpresents the ant lion optimization algorithm, [19]:

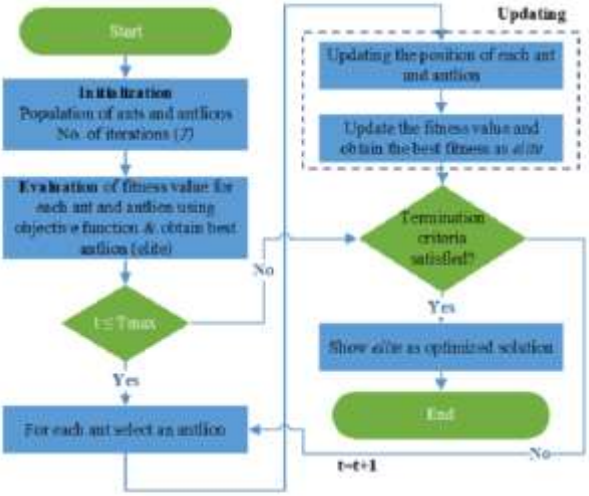

Fig. 2: Antlion optimization algorithm

3 Problem Solution

In this paper, research has tested Multi-Objective Ant Lion Optimizer for Congestion Management, so that, this approach is presented to mitigate congestion in IEEE 30 buses shown in Figure 4, which includes 41 transmission lines and 30 buses, 6 generator units, [20]. The load in each system is 283.4 MW, with a total active and reactive power of 126.2 MVar.

3.1 Case Study I:

In this case, we test the performance of our proposed method to minimize the quadratic fuel cost without an outage of lines (normal case).

Table 1 presents the effectiveness of (MOALO) by comparing it with other optimization techniques like GA, FPA, MDE, GAMS, and GWO techniques. It can be observed that MOALO can find an optimal solution for fuel cost, which equals 801.8436 $ where the electrical losses are 9.3760 MW. In Figure 3, we can see that the fuel cost convergence without an outage by using (MOALO) optimization.

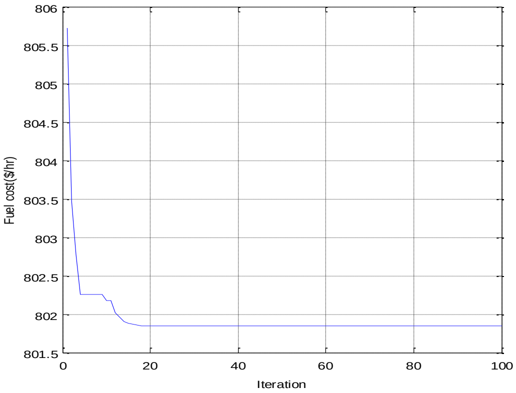

Fig. 3: Fuel cost convergence without an outage

3.2 Case Study II:

In this case, the test system is exposed to some outages on transmission lines, so, we proposed 4 scenarios to determine the impact of outages on the optimal power flow, the fuel cost, and overloading on lines.

- Scenario 1: Outage of line 1-2
- Scenario 2: Outage of line 1-3
- Scenario 3: Outage of line 2-6
- Scenario 4: Outage of line 4-6

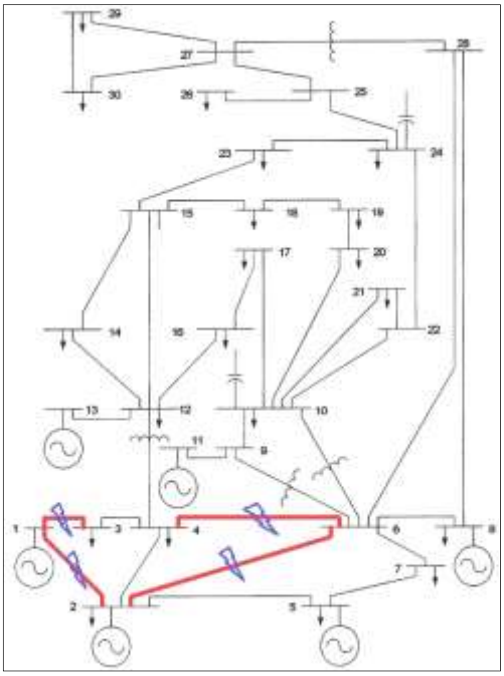

Fig. 4: Line diagram of 30 IEEE bus Systems with 4 scenarios

Table 2 and Table 3 present the optimal solution for the 4 scenarios by comparing them with two methods proposed in [22]. It can be observed that the outage on the line caused an increase in fuel cost due to a change in the electrical system. For example, in the normal case, the fuel cost was 801.8436 $, but in Scenarios 1, 2, 3, and 4 the fuel cost becomes 839.2833$, 815.1970$, 805.8811$, and 806.7213$ respectively.

Table 1.Fuel cost comparison obtained by different optimization techniques

	MOALO	GA [21]	FPA [21]	MDE [22]	Gradient method [23]	EEA [24]	GAMS [24]	GWO[25]
P1	176.7303	176.6374	176.7294	175.974	187.219	173.4593	177.1	176.1721
P2	48.8300	48.7022	48.8300	48.884	53.781	47.7363	48.8	48.0926
P3	21.4738	21.6967	21.4750	21.51	16.955	23.7692	21.4	21.1376
P4	21.6482	21.5941	21.6475	22.24	11.288	23.2234	21.5	23.3591
P5	12.0937	11.9399	12.0940	12.251	11.287	11.3724	12	11.3591
P6	12.0000	12.1910	12.0000	12.0000	13.355	2.2530	12	12.0000
Losses (MW)	9.3760	9.3613	9.3753	9.459	10.486	/	8.4137	9.1528
Fuel cost ($/h)	801.8436	801.8566	801.8436	802.376	804.853	802.060	800.0831	801.176

Table 2. Fuel cost comparison obtained by different optimization techniques (Scenario 1 and 2)

	1-2			1-3		
	MOALO	GA [22]	FPA [22]	MOALO	GA [22]	FPA [22]
P_1	151.1891	151.3525	151.1886	168.7236	168.4838	168.8781
P_2	59.2042	59.2858	59.2040	49.1312	49.4219	49.1360
P_3	24.0579	24.0334	24.0580	21.8775	21.7093	21.8775
P_4	33.9503	33.9226	33.9500	27.6647	27.5947	27.6750
P_5	16.3833	16.1131	16.3840	14.3261	14.5627	14.3140
P_6	14.8979	15.0079	14.8980	13.9215	13.8633	13.9236
Losses (MW)	16.2827	16.3153	16.2826	12.2448	12.2356	12.4042
Fuel cost ($/h)	839.2833	839.2858	839.2833	815.1970	815.21	815.1970

Table 3. Fuel cost comparison obtained by different optimization techniques (Scenario 3 and 4)

	2-6			4-6		
	MOALO	GA [22]	FPA [22]	MOALO	GA [22]	FPA [22]
P_1	173.8089	172.8813	173.7989	172.9537	172.6048	172.9495
P_2	47.6827	47.6091	47.6720	48.4095	48.4625	48.4100
P_3	21.4508	22.4618	21.4540	21.6101	21.2781	21.6115
P_4	25.0345	25.6042	25.0825	25.6087	25.4855	25.6100
P_5	13.3432	12.8147	13.3280	13.1694	13.3780	13.1700
P_6	12.2469	12.0940	12.2296	12.0000	12.1629	12.0000
Losses (MW)	10.1670	10.0650	10.1650	10.3514	9.3883	10.3510
Fuel cost ($/h)	805.8811	805.9622	805.8811	806.7213	806.7550	806.7213

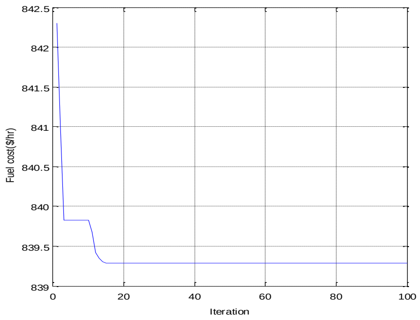

Fig. 5: Fuel cost convergence with outage of line 1-2

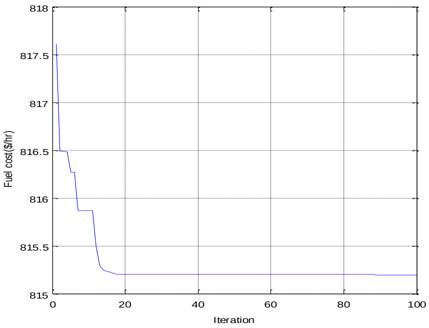

Fig. 6: Fuel cost convergence with outage of line 1-3

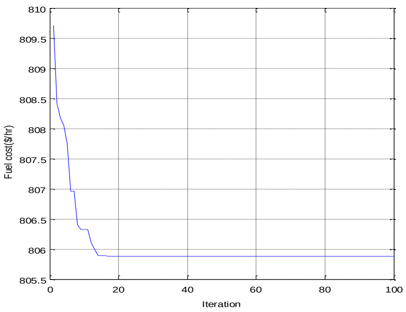

Fig. 7: Fuel cost convergence with outage of line 2-6

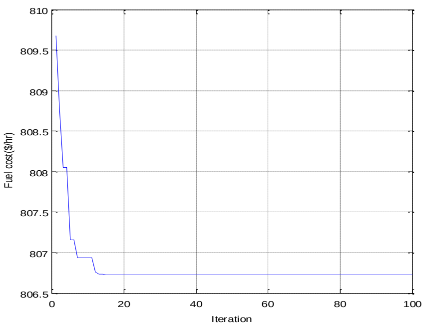

Fig. 8: Fuel cost convergence with outage of line 4-6

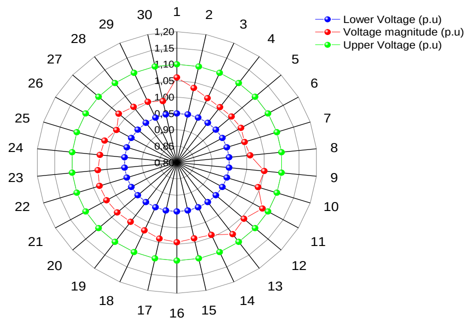

Fig. 9: Voltage magnitude in p.uwith outage of line 1-2

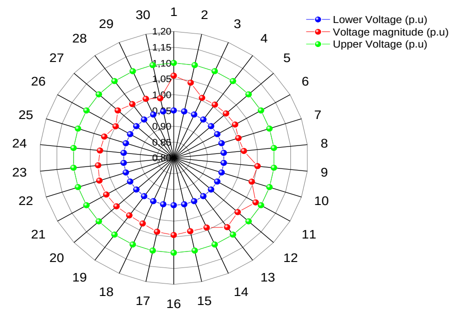

Fig. 10: Voltage magnitude in p.uwith outage of line 1-3

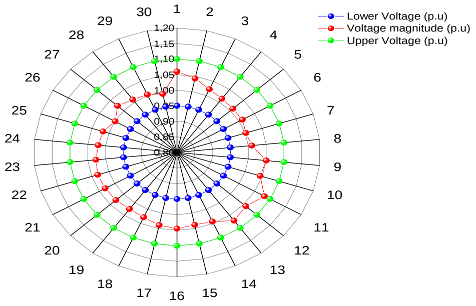

Fig. 11: Voltage magnitude in p.uwith outage of line 2-6

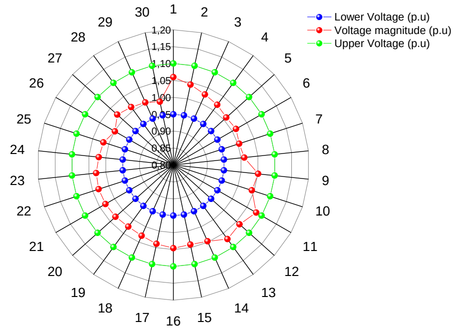

Fig. 12: Voltage magnitude in p.uwith outage of line 4-6

Table 4. Results of power flow in lines after4 scenarios

Line	Line limit (MVA)	1-2	1-3	2-6	4-6
1-2	130	0	**168.9020**	103.9468	129.1996
1-3	130	**151.2313**	0	70.0516	43.8798
2-4	65	13.3401	58.5122	53.1723	12.9914
3-4	130	**139.6031**	2.4000	65.6479	40.6727
2-5	130	44.8153	70.9142	74.8976	73.1521
2-6	65	6.0290	61.9943	0	**66.9042**
4-6	90	82.7810	17.5150	74.6626	0
5-7	70	26.2196	3.5958	0.2943	1.7699
6-7	130	50.1231	26.6147	23.2581	24.7500
6-8	32	0.2023	5.4482	7.4629	6.7088
6-9	65	14.0385	17.9911	16.8770	11.3156
6-10	32	11.2404	13.0913	12.2471	9.0575
9-11	65	16.3834	14.3173	13.2670	13.1693
9-10	65	30.4218	32.3084	30.1441	24.4849
4-12	65	32.9956	29.1921	34.5275	45.7167
12-13	65	14.8979	13.9472	12.2288	12.0000
12-14	32	8.2745	7.7788	8.1618	9.3022
12-15	32	19.6063	17.5512	19.0972	23.7977
12-16	32	8.8127	6.6094	8.2973	13.4168
14-15	16	1.9935	1.5054	1.8825	3.0038
16-17	16	5.2399	3.0626	4.7303	9.7616
15-18	16	6.8136	5.6383	6.5549	9.2974
18-19	16	3.5652	2.4034	3.3094	6.0108
19-20	32	5.9426	7.1005	6.1975	3.5110
10-20	32	8.2278	9.4055	8.4856	5.7641
10-17	32	3.7930	5.9624	4.2996	0.6797
10-21	32	16.0510	16.2871	16.0296	15.3352
10-22	32	7.7904	7.9447	7.7764	7.3228
21-22	32	1.5616	1.3275	1.5825	2.2709
15-23	16	6.3253	5.0014	5.9741	8.9333
22-24	16	6.1748	6.5617	6.1400	5.0017
23-24	16	3.0824	1.7701	2.7339	5.6564
24-25	16	0.4960	0.4274	0.1153	1.8829
25-26	16	3.5447	3.5446	3.5447	3.5447
25-27	16	3.0506	3.9754	3.4317	1.6685
28-27	65	16.3450	17.2749	16.7279	14.9583
27-29	16	6.1901	6.1898	6.1900	6.1902
27-30	16	7.0922	7.0918	7.0921	7.0923
29-30	16	3.7038	3.7037	3.7037	3.7038
8-28	32	3.7465	3.0591	2.6178	2.3083
6-28	32	12.6350	14.2565	14.1486	12.6815

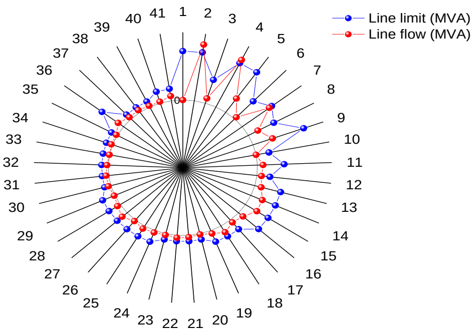

Fig. 13: Power flow in lines with outage of line 1-2

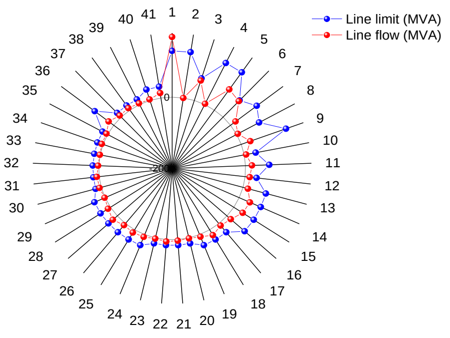

Fig. 14: Power flow in lines with outage of line 1-3

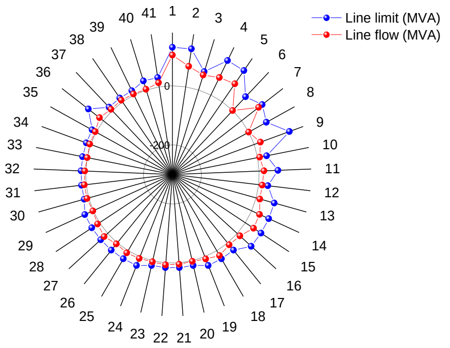

Fig. 15: Power flow in lines with outage of line 2-6

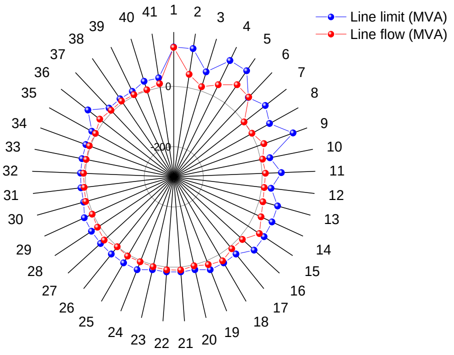

Fig. 16: Power flow in lines with outage of line 4-6

In Figure 5, Figure 6, Figure 7 and Figure 8 it can be observed the fuel cost convergence for each scenario from the four scenarios by the application of (MOALO) optimization, and in Figure 9, Figure 10, Figure 11 and Figure 12, we note that the voltage magnitude respected the lower and the upper voltage for each scenario.

In Table 4 and Figure 13, Figure 14, Figure 15 and Figure 16, the impact of line outages can be seen on the power flow of each line, and it can be observed that some of the power flow exceeds the limit of some transmission lines (overloaded lines).

Table 5.Results of line limits problem by securedOPF

line Outage	Overloaded line	Line limit (MVA)	Power flowbefore secured OPF (MVA)	Power flowafter secured OPF (MVA)	Violation(MVA)
1-2	1-3	130	151.2313	130	21.2313
	3-4	130	139.6031	52.2188	87.3843
1-3	1-2	130	168.9020	122.4327	46.4693
4-6	2-6	65	66.9042	50.9818	15.9224

Table 6. Fuel cost result after secured OPF (4 scenarios)

	1-2	1-3	4-6
P_1	129.9991	122.3032	133.5647
P_2	79.8120	69.4864	49.0689
P_3	15.5871	29.9095	26.8427
P_4	18.5757	28.1856	33.1922
P_5	23.7541	12.9890	29.0994
P_6	29.3149	29.1476	18.7686
Losses (MW)	13.6428	8.6214	7.1365
Fuel cost ($/h)	863.3217	842.6816	824.5087

The blue curve represents the limits of the transmission lines and the red curve represents the power flow on each line.In Figure 13, we notice an overload on lines (1-3) (3-4), and in Figure 14, we can notice an increase in the load on the line (1-2), while in Figure 16 the increase in load is present on the line (2-6). As for Figure 15, it can be seen that there is no crossing of the limitson each line.

In scenario 1, we can see that the three lines (1-3) and (3-4) are overloaded, and in this case, the problem will inevitably lead to damage to overloaded lines and an increase in electrical losses, from 9.3760 MW to 16.2827 MW. In scenario 3, it can be noted that there are no overloaded lines, and a small increase in fuel cost compared with the other scenarios.

3.3 Case Study III:

Due to the problem of outages on transmission lines and the issue of overloaded lines, this aspect of the study will be a solution to these two problems by managing the congestion in the network and reducing the load on some power lines. Therefore, we will attempt to reformulate the objective by taking into account the permissible power limits for each transmission line (secured OPF). The results are presented in Table 5 and Table 6. It can be observed that the secured OPF causes an increase in fuel cost due to a change in the management of the electrical system.

4 Conclusion

This paper allowed us to address the issue of optimal power flow, which is one of the most prominent problems in the field of operation of electrical networks, especially as the demand for electrical energy continues to increase with growing socio-economic needs in all societies worldwide. This paper attempted to provide a brief overview of methods that have been used to solve this problem, whether conventional methods based on analytical techniques of functions derived from power system modeling or unconventional methods mainly based on artificial intelligence techniques. It is worth noting that we focused on the case of economic dispatch, which is one of the most important problems in optimal power flow.This paper elucidated the impact of lineoutages on production costs and the increase in load on other lines, and it provided the proposed methodMulti-Objective Ant Lion Optimizer (MOALO) with mathematical solutions to solve the problem without the intervention of other devices or tools.

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