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Proceeding Paper

Solving Optimal Power Flow Problem in Power Systems using Mountain Gazelle Algorithm †

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Abstract: The optimal power flow (OPF) is one of the fundamental mathematical tools currently used to operate power systems with the technical limits of the transmission power system. To determine OPF, a highly non-linear complex problem, it is essential to research power system planning and control. This study presents a practical and trustworthy optimization approach for the OPF problem in electrical transmission power systems. Many intelligence optimization algorithms and methods have recently been developed to solve the OPF, particularly the non-linear complex optimization problems. In this paper, a novel meta-heuristic algorithm called the mountain gazelle optimizer (MGO) is suggested for solving the OPF problem. The suggested algorithm applies the improved three single objective functions to the MGO algorithm for the best OPF issue control variable settings. Three objective functions that reflect the minimization of generating fuel cost, the minimizing of active power loss, and the minimizing of voltages deviations have been used to investigate and test the proposed algorithm on the standard IEEE 30-bus test system. The simulation results demonstrate the efficiency of the proposed MGO algorithm, the fuel costs are reduced by 11.407 %, power losses are considerably decreased by 51.016 % and enhancing voltage profile is significantly reduced by 91.501 %. Furthermore, the outcomes produced by the proposed algorithm have also been contrasted with outcomes produced by applying other comparable optimization algorithms published in recent years. The optimal results are encouraging and demonstrate the resilience and efficacy of the suggested strategy.

Keywords: optimal power flow; transmission power system; generating fuel cost; active power loss; voltage deviation; mountain gazelle optimizer.

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1. Introduction

The traditional power flow (PF) analysis will determine an electric power system's steady-state operation. This entails calculating the magnitude and angle of each voltage at each node in the electrical transmission system [1]. The active and reactive optimum power flow (OPF) in the components of the transmission power systems is calculated. By making the best modifications to the power systems control variables while meeting a variety of equality and inequality requirements, the OPF issue may be solved. Generally, the OPF solution's optimisation objectives include power loss, fuel cost and bus voltage profiles [2]. Science and engineering are involved in the investigation of global optimisation. Global optimisation issues may be used to develop many real-world optimisation applications [3].

Effective and reliable optimisation techniques are required to tackle global optimisation issues effectively. Complicated global optimisation issues are challenging to solve using conventional techniques [4]. The OPF, particularly the non-linear complicated optimisation issues, have recently been solved by many intelligent optimisation algorithms and methods including, but not limited to, moth swarm optimiser (MSO) [5], manta ray foraging optimiser (MRFO) [6], stud krill herd (SKH) [7], modified grasshopper optimisation algorithm (MGOA) [8], lightning attachment procedure optimisation (LAPO) [9], and tunicate swarm optimisation (TSO) [10]. Applied the improved artificial bee colony optimisation (IABC) [11], improved gravitational search algorithm (IGSA) [12], improved electromagnetism-like mechanism (IEM) [13], coyote optimisation algorithm (COA) [14], adaptive teaching–learning-based optimisation (ATLBO) [15], improved moth-flame optimisation (IMFO) [16], and used adaptive constraint differential evolution (ACDE) [17].

Authors used a new salp swarm algorithm (SSA) [18], social spider optimisation (SSO) [19], modified sine-cosine algorithm (MSCA) [20], enhanced most valuable player algorithm (EMVPA) [21], improved Archimedes optimisation algorithm (IAOA) [22], adaptive partitioning flower pollination algorithm (APFPA) [23], moth swarm algorithm (MSA) [24], and enhanced moth swarm algorithm (EMSA) [25]. Also, researchers applied the tunicate swarm algorithm (TSA) [26], grey wolf optimiser (GWO) [27], Jaya optimisation algorithm (JOA) [28], and improved colliding bodies optimisation (ICBO) [29]. These techniques and algorithms are based on the complex behaviours of living things to create diverse local and global search strategies, giving academics a more comprehensive range of algorithms to address optimisation issues in various objective functions.

The OPF problem in power systems is formulated and solved in this study using three single-objective functions, known as the mountain gazelle optimiser (MGO) algorithm. This is then evaluated in the standard IEEE 30-bus transmission power system.

2. Problem Formulation

The OPF, as previously said, is a power flow problem that determines the best control variable settings for a particular load setting by optimizing an objective function.

2.1 Equality constraints

The next equations are a representation of the OPF problem equality constraints:

$$P_{G,i} - P_{D,i} - V_i \sum_{j=1}^{NB} V_j \left[G_{ij} cos\left(\theta_{ij}\right) + B_{ij} sin\left(\theta_{ij}\right)\right] = 0 \quad (1)$$

$$Q_{G,i} - Q_{D,i} - V_i \sum_{j=1}^{NB} V_j \left[G_{ij} sin\left(\theta_{ij}\right) + B_{ij} cos\left(\theta_{ij}\right)\right] = 0 \quad (2)$$

2.2 Inequality constraints

The OPF inequality limitations reflect the restrictions placed on physical devices as well as the restrictions put in place to ensure system security:

a) Power generator constraints

$$V_{G,j}^{min} \le V_{G,i} \le V_{G,i}^{max} \quad i = 1, \ldots., NG \quad (3)$$

$$P_{G,i}^{min} \le P_{G,i} \le P_{G,i}^{max} \quad i = 1, \ldots., NG \quad (4)$$

$$Q_{G,i}^{min} \le Q_{G,i} \le Q_{G,i}^{max} \quad i = 1, \ldots., NG \quad (5)$$

b) Power transformer constraints

$$T_i^{min} \leq T_i \leq T_i^{max} \quad i = 1, \dots, NT \tag{6}$$

c) Shunt compensator constraints

$$Q_{C,i}^{min} \leq Q_{C,i} \leq Q_{C,i}^{max} \quad i = 1, \dots, NC \tag{7}$$

d) Security constraints

$$V_{L,i}^{min} \leq V_{L,i} \leq V_{L,i}^{max} \quad i = 1, \dots, NL \tag{8}$$

$$S_{L,i} \leq S_{L,i}^{max} \quad i = 1, \dots, Nl \tag{9}$$

2.3. Objectif Functions

The first objective function examined in this work is to minimize the cost of the generating fuel (Cost), which is given by the following equation:

$$OF_{Cost} = min \sum_{i=1}^{NG} a_i + b_i P_{G,i} + c_i P_{G,i}^2 \tag{10}$$

The minimisation of the total active power losses (APL) in the transmission system is the second objective function, and it may be written as follows:

$$OF_{APL} = min \sum_{i=1}^{NL} G_{ij} \left[V_i^2 + V_j^2 - 2V_i . V_j cos(\theta_{ij})\right] = 0 \tag{11}$$

The total bus voltage deviation (VD) minimisation process' third objective function. In order to maximize the voltage profile, the load bus voltage variation from 1.0 p.u, which is provided by:

$$OF_{VD} = min \sum_{i=1}^{NL} |V_L - 1| \tag{12}$$

3. Application

The suggested MGO algorithm has been tested on the typical IEEE 30-bus test transmission system depicted in Figure 1 in order to demonstrate its efficacy. This system has composed of 30 buses and 41 branches. Therefore, this system has 24 design variables. The test transmission system selected for this study includes the following characteristics: six power generators, nine shunt compensation, and four tap-changing power transformers.

In this test system, three main cases (objective function) are considered as follows: OPF by considering minimisation fuel cost (Case 1), OPF by considering minimisation active power loss (Case 2), and OPF by considering minimisation voltage deviation (Case 3). Table 1 represents the optimal control settings obtained by the applied GMO algorithm for various case studies in this paper. The simulation results demonstrate the proposed MGO algorithm's efficiency: fuel costs are reduced by 11.407 %, power losses are decreased by 51.016 %, and enhancing voltage profile is significantly reduced by 91.501 %.

Figure 2 represents the optimal parameters for the active power injected and the bus voltage of the generator. The values of active power injected by the generator and the bus voltage in the test system are acceptable within the lower and upper limits.

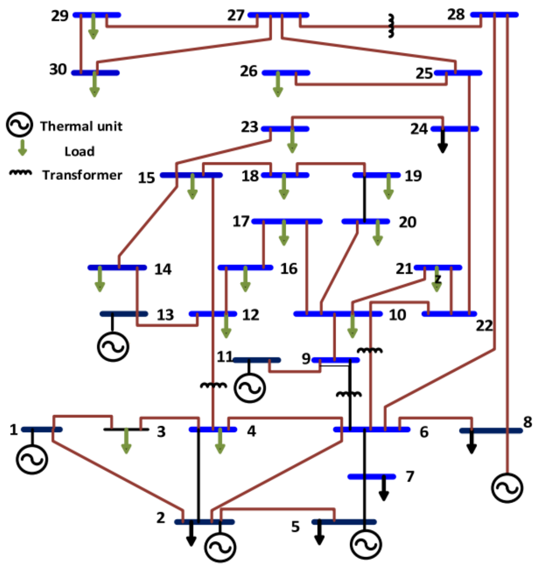
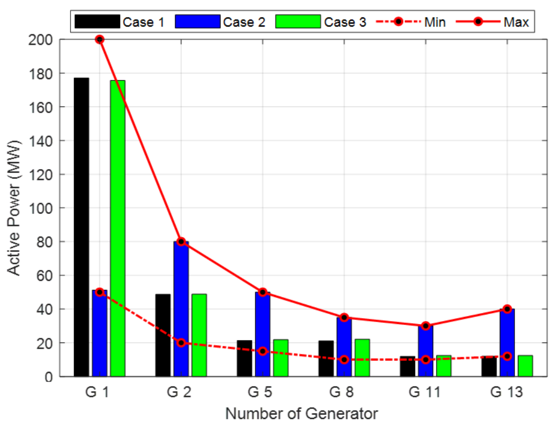


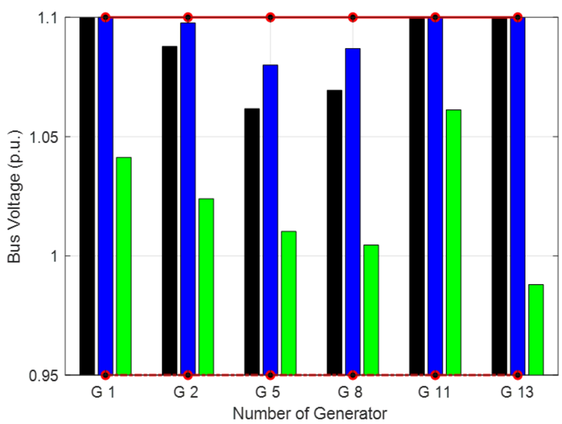
Figure 1. Single line diagram of IEEE 30-bus test system.

Table 1. Optimal control settings for the applied OPF cases.

Variables	Initial Case	Case 1	Case 2	Case 3
$P_{G.1}$ (MW)	99.2220	177.0569	51.2508	175.5896
$P_{G.2}$ (MW)	80.0000	48.6920	79.9999	48.7895
$P_{G.5}$ (MW)	50.0000	21.3006	49.9999	21.8117
$P_{G.8}$ (MW)	20.0000	21.0849	35.0000	22.0798
$P_{G.11}$ (MW)	20.0000	11.8890	30.000	12.4188
$P_{G.13}$ (MW)	20.0000	12.0000	39.9999	12.3840
$V_{G.1}$ (p.u.)	1.0500	1.0999	1.1000	1.0413
$V_{G.2}$ (p.u.)	1.0400	1.0878	1.0976	1.0239
$V_{G.5}$ (p.u.)	1.0100	1.0617	1.0800	1.0102
$V_{G.8}$ (p.u.)	1.0100	1.0694	1.0869	1.0045
$V_{G.11}$ (p.u.)	1.0500	1.0999	1.1000	1.0612
$V_{G.13}$ (p.u.)	1.0500	1.0999	1.0999	0.9879
Cost ($/h)	901.9500	**799.0679**	999.7273	803.3069
P_{Loss} (MW)	5.8225	8.6244	**2.8521**	9.7722
VD (p.u.)	1.1496	1.8576	2.0572	**0.0977**



(**a**)



(**b**)

Figure 2. Optimal parameters: (**a**). power injected by the generator; (**b**). Bus voltage of the generator.

Table 2 represented compares the simulation results from the applied MGO algorithm to those from other methods and algorithms recently described in the literature for the three case studies. For the case studies in this paper, the proposed MGO algorithm successfully applied various strategies documented in the literature used in this investigation. The computational results of the MGO algorithm are highly comparable with those obtained by applying other comparable optimisation methods and techniques.

It is clear from the optimal results that the MGO gave a better reduction of the fuel cost active loss and voltage deviation for all cases over other algorithms and methods used in the comparison.

Table 2. Comparison of optimal results with existing literature.

Case 1			Case 2			Case 3		
Ref.	**Optimisation algorithms**	**Cost ($/h)**	**Ref.**	**Optimisation algorithms**	**P_{Loss} (MW)**	**Ref.**	**Optimisation algorithms**	**VD (p.u.)**
[5]	MSO	801.5710	[14]	COA	3.0952	[23]	APFPA	0.1095
[6]	MRFO	801.3908	[15]	ATLBO	3.0906	[24]	MSA	0.1084
[7]	SKH	800.5141	[16]	IMFO	3.0905	[25]	EMSA	0.1073
[8]	MGOA	800.4744	[17]	ACDE	3.0840	[13]	IEM	0.1063
[9]	LAPO	800.0078	[18]	SSA	2.9620	[26]	TSA	0.1060
[10]	TSO	799.6041	[19]	SSO	2.9454	[27]	GWO	0.1037
[11]	IABC	799.3210	[20]	MSCA	2.9334	[28]	JOA	0.1031
[12]	IGSA	799.2817	[21]	EMVPA	2.8659	[20]	MSCA	0.1030
[13]	IEM	799.1116	[22]	IAOA	2.8590	[29]	ICBO	0.1014
Applied MGO		**799.0679**	Applied MGO		**2.8521**	Applied MGO		**0.0977**

4. Conclusions

In this study, an improvement of the mountain gazelle optimiser algorithm, called MGO, has been applied to solve the problem of OPF. This article covers using a suitable constraint handling strategy in various single-objective functions for the optimum power flow issue and its efficacy. The most important thing is to satisfy system restrictions, and effective constraint-handling techniques are helpful in this regard. The transmission power system must be operated within predetermined boundaries for system security and dependability. Compared to existing complicated algorithms and methods for discovering the OPF solution under the same restrictions, the exhibited numerical simulations employing the suggested MGO approach have established its excellent performance, effectiveness, and resilience. The MGO may be used in future research to address various optimisation issues in electricity transmission networks, including the best placement for renewable energy sources and the most effective placement of FACTS devices.

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