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Pelican Optimization Algorithm for Optimal Demand Response in Islanded Active Distribution Network Considering Controllable Loads

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Abstract: One of the challenging tasks in an active distribution network (AND) embedded with intermittent renewable energy sources (RES) under islanding conditions is the maintenance of frequency and voltage profiles within tolerable limits. Failing to maintain these operational requirements may lead to voltage collapse or complete blackout of the network. In order to avoid this scenario, ADNs may function with contemporary load shedding schemes but these schemes may result in an inadvertent and excessive amount of load shedding, thereby consequently causing unsatisfactory and low reliability at the consumer level. Thus, this paper used Pelican optimization algorithm (POA) approach for minimising the amount of load to be shed by determining the optimal amount of load to be shed within the consumers' specified limits. Simulations are performed on IEEE 33-bus by assuming different kinds of renewable and distribution generation (DG) units. The computational efficiency of POA is compared with literature works and its performance is also characterised based on 25-indipendent runs of each case. The results obtained by POA are observed to be superior in terms of global optima and less run time. Also, the ADN is observed as satisfactory operation with fewer distribution losses, an improved voltage profile, and enhanced stability margins by imposing optimal load controls to the consumer.

Keywords: Active distribution system, Direct load control, Islanding mode, Renewable energy, Voltage stability index, Multi-objective mouth flame optimization.

1. Introduction

A microgrid (MG) is a small power grid that can run by itself or in cooperation with other major power grids. Such MGs can be treated as active distribution networks (ADN) and are more eco-friendly with renewable energy (RE) based small-scale distribution generation (DG) units [1]. ADN can be treated as a smart grid (SG), in which an electrical grid that includes automation, communication, and information technology systems that can monitor power flows from points of generation to points of consumption and control the power flow or curtail the load to match generation in real-time or very-close to real-time. Controllable load management in a smart grid (SG) environment can provide many ancillary services to the grid, including frequency and voltage controls. Despite the fact that RE sources are better for the environment, the facts that they are intermittent and have high penetration levels have become major obstacles in the way of preserving energy balance and have also led to a variety of power quality problems in ADNs [2].

On the other hand, islanding operations might be caused by a variety of probable uncertainties within the network zone or at the upstream-grid. Also, the economic aims of utilities in a deregulated environment can occasionally trigger purposeful islanding operations. This can happen when the environment is deregulated [3]. However, it is possible that the integrated DGs will be unable to meet demand in any ADN. It is possible that this scenario will lead to load shedding in the present. Load shedding schemes are typically designed for either under frequency load shedding (UFLS) [4] or under voltage load shedding (UVLS) [5]. These plans, on the other hand, are inefficient and do not conduct a thorough assessment of the optimal amount of load to shed, which leads to load shedding that is either excessive or insufficient. To stop this from happening, ADNs need to be switched over to smart grids (SG) that have demand response (DR) capabilities [6].

Many researchers in the literature focused on load shedding for managing islanded microgrids (IMG) primarily on technical grounds [7]. Anticipating likely abnormalities and possibilities, as well as planning energy management approaches before and after islanding, is critical [8]. In [9], steady-state distributive load shedding under contingencies is solved by prioritising significant loads and Glowworm swarm optimization (GSO). In [10], an improved harmony search algorithm (IHSA) is proposed for optimal load shedding to avoid blackouts considering generator and generation shortage uncertainties. In [11], higher eigen-value load buses are considered for load shedding under generation shortage and contingencies, and the optimal amount of load shed is derived using a hybrid genetic algorithm and neural network (GA-NN) approach. In [12], conventional UFLS with fixed load priorities is surpassed by different heuristic approaches, namely binary evolutionary programming (BEP), binary genetic algorithm (BGA), and binary particle swarm optimization (BPSO) for managing frequency deviations for high photovoltaic (PV) penetration. Aan adaptive neural fuzzy inference system (ANFIS) is developed to avoid UFLS caused by variation in PV and wind turbine (WT) generation [13]. In [14], minimization of load shed and voltage profile improvement are used to formulate multi-objective functions while solving optimal load shedding for variation of PV generation using the hybrid firefly algorithm and particle swarm optimization (FAPSO). In [15], a backtracking search algorithm (BSA) is proposed for voltage stability assurance with a distributed optimal amount of load shed and is evaluated for balancing the hourly load demand with available DG generation under islanding conditions. In [16], fast voltage stability index (FVSI) values based on loads are selected for the UVLS scheme for managing contingencies. The objective function is formulated for the minimum amount of load shed and voltage profile improvement using hybrid GA-PSO. In [17], the UFLS scheme is solved under DG tripping by mixed integer linear programming (MILP) by categorising load buses as non-critical, semi-critical, and critical using the voltage stability index (VSI). In [18], artificial bee colony (ABC) based priority based load shed is solved in islanded MG with RES for sudden load increment and line contingencies. In [19], a multiple-deme parallel genetic algorithm (MDPGA) is introduced for load balance when there is a low voltage stability margin due to either line contingencies and/or generator failures. In [20-22], based on the coordination of the load importance factor (LIF), the reciprocal phase angle sensitivity (RPAS), and the voltage electrical distance (VED) to rank the load buses, the analytical hierarchy process (AHP) algorithm-based approach to load shedding for restoring the frequency under generation shortage is used. In [23], conservative voltage reduction (CVR) based load shedding is implemented while restoring the RE integrated distribution network from an intentional island using mixed-integer quadratic constraint programming (MIQCP). In [24], non-critical and critical buses are identified for UFLS by evaluating power imbalance using polynomial regression and the optimal load shed problem is solved using MILP. In [25], nodal analysis and participation factors are employed for identifying weak buses, and later, differential evaluation (DE) is used for optimal load shed for improving voltage profile. In [26], to balance the hourly load demand with the available DG generation under islanding conditions, a grasshopper optimization algorithm (GOA) is proposed for voltage stability guarantee with a distributed optimal amount of load shed is analysed. ischaotic slime mould algorithm (CSMA) [27] for optimal load control (OLC) for voltage stability improvement in islanded RE integrated AND. In [28], an adaptive inertia weight teaching-learning-based optimization (ATLBO) for OLC is introduced with the goal of maximising social welfare in a smart grid (SG) environment.

According to the works reviewed above, prioritising loads and then determining the optimal amount of load to be shed for maintaining frequency, voltage, and energy balance is unavoidable, especially under islanding conditions. is a significant difference between load shedding (LS) in a traditional power system and load control (LC) in a smart grid environment. Only energy balance and technical aspects were considered in LS, with no regard to consumer satisfaction. However, LC considers not only energy balance and technical aspects but also consumer satisfaction. There are many works in literature that focus on LS, but only a few works that focus on LC. On the other hand, adaption of meta-heuristic approaches can ensure optimal results compared to conventional approaches. The majority of the reviewed works are focused on load shed in conventional ADNs, whereas a few works [15, 26–28] are focused on OLC in a SG environment. In this background, the research has the following contributions.

- Introduces a recent pelican optimization algorithm (POA) for OLC in the SG environment for sustaining islanding conditions.
- A multi-objective function for optimising the amount of load to be shed and the voltage deviation index (VDI) is formulated.
- Distributed optimal direct load control (DLC) is determined by using the consumer load control range.
- Simulations are performed on the IEEE 33-bus considering the uncertainty of PV, WT, and DGs and load..
- POA's global optima have been identified as competitive to other algorithms PSO, TLBO, GOA, and BOA.

The rest of the essay is organised as follows: section 2 provides details on the mathematical modelling of various AND components. A problem formulation with multiple equal and unequal bounds is described in section 3. In section 4, the modelling of the pelican optimization algorithm is described. Section 5 provides an explanation of the simulation outcomes for the IEEE 33-bus RDN. Section 6 of the study's conclusion provides a summary of its key contributions.

2. Modelling of active distribution system

In this work, the proposed AND is assumed to have photovoltaic (PV) and wind turbine (WT) based DGs. Also, all of the network's consumers are presumptively outfitted with some controllable loads from a central control centre, such as heat pumps and electric vehicles. In this work, each consumer enters into an agreement with the network operator (NO) for a demand response (DR) program based on direct load control (DLC) by defining the maximum allowable load control throughout the day.

2.1 Photovoltaic system

A solar photovoltaic (PV) system uses the photovoltaic effect to directly convert light energy into electrical energy. PV inverters, in general, prefer to operate at unity power factor, and their impact can thus be generalised as a negative active power injection at their incident bus.

$$\overline{P_{ld(k),h}} = P_{ld(k),h} - P_{pv(k),h} \tag{1}$$

where $P_{ld(k),h}$ and $\overline{P_{ld(k),h}}$ are the active power demands of a bus-k, at time-h, before and after PV system integration respectively; $P_{pv(k),h}$ is the active power generation by PV system at bus-k during time-*h*.

2.2 Wind turbine system

The free wind stream transmits some of its kinetic energy to the turbine rotor as it interacts with it, which causes the rotor's speed to decrease. Mechanical power is created from this differential in kinetic energy. The AC power is then stabilised via an AC/AC converter and then connected to the grid. In general, the WT inverter preferred to operate at a constant power factor of 0.866. As a result, its impact can be summed up as a negative real and reactive power injection at the incident bus.

$$\overline{P_{ld(k),h}} = P_{ld(k),h} - P_{wt(k),h} \tag{2}$$

$$\overline{Q_{ld(k),h}} = Q_{ld(k),h} - Q_{wt(k),h} \tag{3}$$

$$Q_{wt(k),h} = P_{wt(k),h} \times tan(\emptyset_{wt}) \tag{4}$$

where $Q_{ld(k),h}$ and $\overline{Q_{ld(k),h}}$ are the reactive power demands of a bus-*k*, at time-*h*, before and after WT system integration respectively; $P_{wt(k),h}$ and $Q_{wt(k),h}$ are the active and reactive power generations by WT system at bus-*k* during time-*h*, $\emptyset_{wt}$ is the operating power factor of WT.

2.3 Diesel generator

Diesel generators (DGs) are extremely helpful pieces of equipment that convert diesel fuel into electric current. These machines use a combination of a diesel engine and an electric generator to produce electricity for their users. The following equation can be used to determine the DG's hourly fuel consumption.

$$F_{DG,t} = \alpha_{fc} \times P_{DG,t} + \beta_{fc} \times P_{DG,r} \tag{5}$$

where $F_{DG,t}$ are the DG's hourly fuel conception, α_{fc} =0.2461 and β_{fc} =0.084151 are the coefficients of DG's fuel consumption curve in Lt/kWh, respectively; $P_{DG,t}$ and $P_{DG,r}$ are the actual power generation and the power ratings of the DG, respectively.

2.4 Direct load control

The load control of a bus is also assumed to be maintained at all times at its original power factor, and thus the active and reactive powers are multiplied by a scaling factor.

$$\overline{P_{ld(k),h}} = P_{ld(k),h} \times \rho_{(k),h} \quad (6)$$

$$\overline{Q_{ld(k),h}} = Q_{ld(k),h} \times \rho_{(k),h} \quad (7)$$

where $\rho_{(k),h}$ is the load control factor (LCF) of bus-k at time-h.

3. Problem formulation

In this section, the proposed multi-objective function and its equal and unequal constraints are expressed mathematically.

3.1 Objective function

In this research, the load control is to balance available distribution generation (DG) units' apparent power with apparent loading conditions on the network under islanding conditions anticipating at any time. In addition, loss minimization and VSI maximization are also considered for attaining good operating conditions. Mathematically,

$$OF = \{(S_{dg,h} - S_{ld,h}) + P_{ls,t} + VSI_h\} \quad (8)$$

where $S_{dg,t}$ and $S_{ld,t}$ are the apparent powers of total DGs' generation and network load, at a time-h, respectively; $P_{ls,t}$ and VSI_t are the distribution losses and voltage stability index of the network at a time-h, respectively.

3.2 Constraints

The OF is subjected to the following equal and unequal constraints such as (i) real and reactive power supply-demand balances, (ii) voltage limits, (iii) branch current/MVA limits, and (iv) consumer's load control limits, as defined below:

$$\sum_{i=1}^{ndg} P_{dg(i),h} = P_{ls,h} + \sum_{k}^{nbus} P_{ld(k),h} \quad (9)$$

$$\sum_{i=1}^{ndg} Q_{dg(i),h} = Q_{ls,h} + \sum_{k}^{nbus} Q_{ld(k),h} \quad (10)$$

$$|V_{(k)}|_{min} \leq |V_{(k)}| \leq |V_{(k)}|_{max} \quad (11)$$

$$|I_{(l)}| \leq |I_{(l)}|_{max} \quad (12)$$

$$\rho_{\mathrm{min(k)}} \leq \rho_{(k)} \leq \rho_{\mathrm{max(k)}} \quad (13)$$

where $P_{dg(i),h}$, $Q_{dg(i),h}$ are the active and reactive powers of ith DG at time-h, respectively; $P_{ls,h}$ and $Q_{ls,h}$ are the active and reactive power losses, at time-h, respectively; $P_{ld(k),h}$, $Q_{ld(k),h}$ are the real and reactive power loads at bus-k, at time-h, respectively; $|V_{(k)}|_{min}$, $|V_{(k)}|_{max}$ are the minimum and maximum limits of voltage magnitudes at bus-k, respectively; $|I_{(l)}|$, $|I_{(l)}|_{max}$ are the current of branch-l and its maximum limit, respectively; $nbus$ and ndg are the number of buses and number of DGs, respectively.

4. Pelican optimization algorithm

Pelicans dive from 10 to 20 metres to catch their prey after locating it. Some animals hunt at lower elevations. Then, they spread their wings on the water to mislead fish into shallower water, where they can easily catch and eat them. Because of the water that enters the pelican's beak when it catches fish, it must tilt its head forward before swallowing. Pelicans have become skilled hunters as a result of their clever hunting behaviour and tactics. The modelling of the aforementioned strategy served as the primary source of inspiration for the design of the proposed POA [29].

4.1 Modeling of pelican optimization algorithm

Pelicans are included in the POA's population-based approach. Each member of a population-based algorithm is a solution. Every candidate has a spot in the search space, which impacts the values they offer for optimization variables. Starting with the problem's lower and upper bounds, random members are chosen.

$$p_{ij} = p_{j,min} + rand \times (p_{j,max} - p_{j,min}),$$
$$i = 1,2,\dots,d_s,\ j = 1,2,\dots,s_v \quad (14)$$

where p_{ij} is the jth variable of ith solution, d_s is the dimension of search space, s_v is the number of search variables, $rand$ is a random number between 0 and 1, $p_{j,min}$ and $p_{j,max}$ are the minimum and maximum limit of jth variable, respectively.

Pelican's movement towards prey is modelled as exploration phase in POA.

$$p_{ij}^{m1} = \begin{cases} p_{ij} + rand(l_{pj} - R.p_{ij}) & f_p < f_i \\ p_{ij} + rand(p_{ij} - l_{pj}) & else \end{cases} \quad (15)$$

where l_{pj} is the location of prey, p_{ij}^{m1} is the jth variable of ith solution describing first movement of pelican, f_p is the objective function, R is a random number, which may become either 1 or 2 in each

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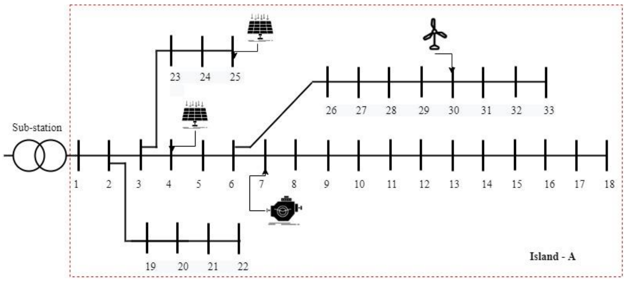

Figure. 1 Islanding scenario – A

iteration. If R becomes 2, then pelican's scan space increases significantly. This way, R is the major controlling variable of POA for influencing its exploration phase.

The suggested POA accepts a pelican's new position if the objective function improves than earlier iteration. Effective updating prevents the algorithm from shifting to non-optimal locations.

$$P_i = \begin{cases} P_i^{m1} & F_i^{m1} < f_i \\ P_i & else \end{cases} \tag{16}$$

where P_i^{m1} is the new position of jth variable in first movement of pelican and F_i^{m1} is its corresponding objective function.

The second phase of POA is the movement of pelicans winging on the water surface as an exploitation phase. Pelicans swim to the surface of the water and flap their wings to make fish jump up. They then catch the fish in a pouch around their necks. This strategy helps the pelicans in the attacked area catch more fish. Modelling how pelicans act changes the suggested POA to better places to hunt. This method makes both local search and the use of POAs better. This hunting behaviour of pelicans is modelled by,

$$p_{ij}^{m2} = p_{ij} + R_{nb}(2.rand - 1).p_{ij} \tag{17}$$

$$R_{nb} = R.\left(1 - \frac{k}{K}\right) \tag{18}$$

where P_i^{m2} is the new position of jth variable in the second movement of pelican, R is a constant equal to 0.2, k and K are the number of current and maximum iteration, respectively; R_{nb} represents the population's neighbourhood radius to try to find a better solution close to each member. This parameter changes how much the POA can be used, which brings us closer to a global solution.

The pelican's new position if the objective function improves more than in the earlier iteration. Effective updating prevents the algorithm from shifting to non-optimal locations..

$$P_i = \begin{cases} P_i^{m2} & F_i^{m2} < f_i \\ P_i & else \end{cases} \tag{19}$$

where P_i^{m1} is the new position of jth variable in first movement of pelican and F_i^{m1} is its corresponding objective function.

After all members of the population have been changed based on the first and second phases, the best candidate solution is changed based on the new status of the population and the values of the objective function. The algorithm moves on to the next iteration, during which the stages of the proposed POA based on Eqs. (15–18) are repeated until the end of execution. The best candidate solution from the algorithm's steps is almost the best way to solve the problem.

5. Results and discussion

All simulations are performed on IEEE 33-bus system The simulations are run on a PC with 4 GB of RAM, a 64-bit operating system, and an Intel® CoreTM i5-2410M CPU running at 2.30 GHz. For two scenarios, simulations are run. Scenario 1 considers various islanded modes based on existing research [15, 26-27], and a load control program is implemented. In Scenario 2, the uncertainty w.r.t. RES is considered. All simulations are performed on the IEEE 33-bus system.

5.1 Load control for different islanded scenarios

In this case study, optimal load control for four different islanding conditions is determined.

5.1.1. Islanding mode – A

In this case, the entire network is assumed to be islanded from the substation bus, thus separated MG consists of all 4 DGs and all load buses as shown in Fig. 1. By considering all DGs operating at their maximum level, then the total real power is equal to 1830 kW, i.e., PV_1 = 30 (bus-4), PV_2 = 600 (bus-25), WT=400 (bus-30), and DG = 800 (bus-7). The maximum reactive power is equal to 692.9016 kVAr, (i.e., WT and DGs at 0.866 leading power factor). Thus, the available DGs' power is 1956.8 kVA. Whereas the network has total peak loading condition is 4369.4 kVA (3715 kW + j 2300 kVAr). This is around 55.22% extra than available generation, which is also equal to the required amount of load for control using the proposed algorithm.

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Table 1. Performance after load control in different islanding scenarios

Method	P_{load} (kW)	Q_{load} (kVAr)	P_{loss} (kW)	Q_{loss} (kVAr)	V_{min} (p.u.)	AVD (p.u.)	S_{load} (kVA)	$\Delta S_{dg,extra}$ (kVA)
A	1326.46	1386.87	26.694	18.192	0.9696	0.4917	1950.69	6.11
B	728.24	569.32	18.165	13.178	0.9648	0.3276	946.79	3.09
C	1066.20	1015.77	21.329	14.939	0.9680	0.3785	1498.36	4.44
D	812.09	1105.78	28.457	20.009	0.9705	0.4610	1404.97	6.73

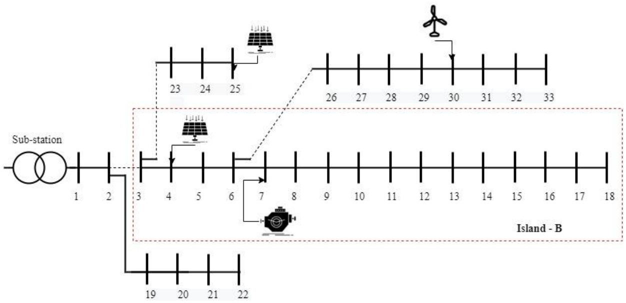

Figure. 2 Islanding scenario – B

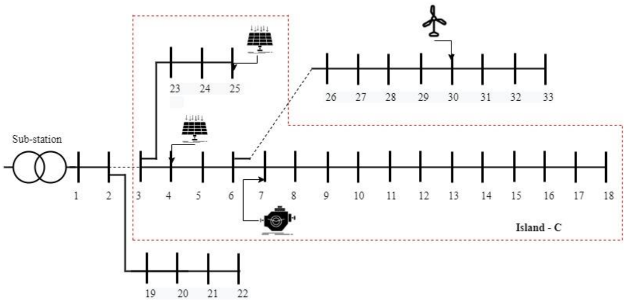

Figure. 3 Islanding scenario – C

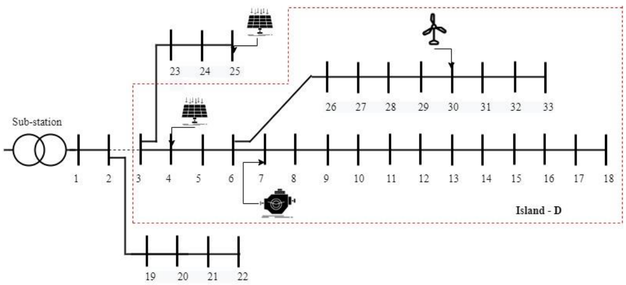

Figure. 4 Islanding scenario – D

5.1.2. Islanding mode – B

In this case, the network (bus-3 to bus-18) is assumed to be islanded from the rest of network, thus separated MG consists of all 2 DGs and all load buses as shown in Fig. 2. By considering 2 DGs operating condition at their maximum level, then the total real power is equal to 830 kW, i.e., PV_1 = 30 (bus-4), and DG = 800 (bus-7). The maximum reactive power is equal to 461.9344 kVAr, (i.e., DGs at 0.866 leading power factor). Thus, the available DGs' power is 949.886 kVA. Whereas the network has total loading condition is 1560.905 kVA (1405 kW + j 680 kVAr). This is around 39.15% extra than available generation, which is also equal to the required amount of load for control using the proposed algorithm.

5.1.3. Islanding mode – C

In this case, the network (bus-3 to bus-18 and bus-23 to bus-25) is assumed to be islanded from the rest of network, thus separated MG consists of all 3 DGs and all load buses as shown in Fig. 3. By considering all 3 DGs operating condition at their maximum level, then the total real power is equal to 1430 kW, i.e., PV_1 = 30 (bus-4), PV_2 = 600 (bus-25), and DG = 800 (bus-7). The maximum reactive power is equal to 461.9344 kVAr, (i.e., DG at 0.866 leading power factor). Thus, the available DGs' power is 1502.8 kVA. Whereas the network has total loading condition is 2594.056 kVA (2335 kW + j 1130 kVAr). This is around 42.07% extra than available generation, which is also equal to the required amount of load for control using the proposed algorithm.

5.1.4. Islanding mode – D

In this case, the network (bus-3 to bus-18 and bus-26 to bus-33) is assumed to be islanded from the rest of network, thus separated MG consists of all 3 DGs and all load buses as shown in Fig. 4. By considering 3 DGs operating condition at their maximum level, then the total real power is equal to 1230 kW, i.e., PV_1 = 30 (bus-4), WT=400 (bus-30), and DG = 800 (bus-7). The maximum reactive power is equal to 692.9016 kVAr, (i.e., WT and DGs at 0.866 leading power factor). Thus, the available DGs' power is 1411.7 kVA. Whereas the network has total loading condition is 2839.46 kVA (2325 kW + j 1630 kVAr). This is around 42.07% extra than available generation, which is also equal to the required amount of load for control using the proposed algorithm.

For all four cases, the results of POA are given in Table 1. The energy balance ($S_{Generation}$ ~ S_{Demand}) should be positive and minimum. As seen in last column in Table 1, the POA is effectively controlled the load in all islanding scenarios.

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Table 2. Comparison of POA results with literature and other algorithms

Method	Load to be curtailed (kW)	Actual load curtailed (kW)	Mismatch in load control
BSA [15]	1161	1390.5	229.5
GA [15]	1161	1287.5	126.5
GA [26]	1161	1351	190
PSO [26]	1161	1264	103
GW [26]	1161	1184	23
GOA [26]	1161	1176	15
PSO	1161	1175.23	14.23
TLBO	1161	1172.56	11.56
GOA	1161	1170.98	9.98
BOA	1161	1168.14	7.14
POA	1161	1165.24	4.24

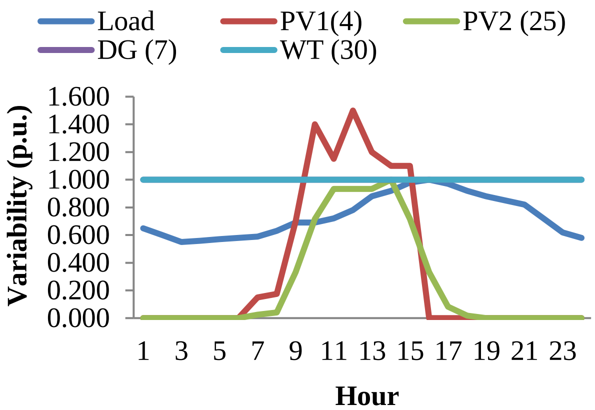

Figure. 5. Hourly variability factors for loads, PVs, DG and WT as considered in [15, 26-28]

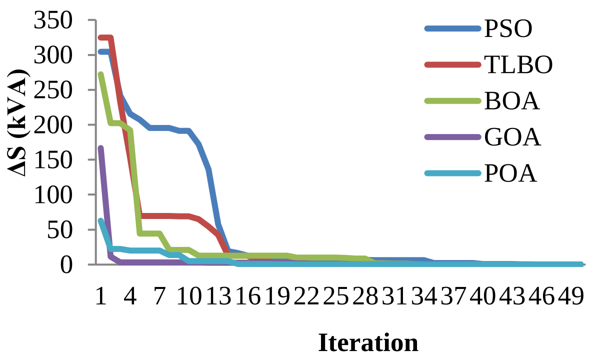

Figure. 6 The convergence characteristics of POA in different cases are given in Fig. 5

5.2 Comparative analysis with literature

As considered in [15, 26-28], the hourly variation in network loading profile and power generations are given in Fig. 5. The islanded scenario-A is considered as similar to Fig. 1. For each hour, the best results of POA over 25 independent runs are given in Table 2. The changes in generation (kVA), load (kVA), extra load (%) before and after optimization, correspondingly network performance are given. An explanation of results obtained for hour-9 is presented here. During hour-9, the PV_1 = 14 kW, PV_2 = 200 kW, WT = 400 W and DG = 800 kW and thus, the total generation is 1414 kW. Whereas the network load is around 0.6931 p.u. and it is equal to 2575 kW, thus it is around 1161 kW extra than available generation (i.e, 45.09%), which is needed to be shed.

The comparison of POA with literature is given in Table 2. In [15], BAS as well as GA are used but, the amount of load controlled is more than required. Similarly, in [26], GA, PSO, GW and GOA are also caused for extra load control than POA. However, these works have reported extra load curtailment, which cannot be treated as global optima. From this, POA exhibits very good results than literature and shown its computational superiority over other algorithms. The convergence characteristics of different algorithms are given in Fig. 6.

Since consumers are voluntarily participating in the demand response programme in a smart grid environment, there is a need for economic benefits or incentives to be settled. This aspect can be treated as one of the possible future extensions of this work. On the other hand, as per the free lunch theorem (NFLT), there is no such algorithm for all kinds of optimization problems for proving global optima. In this regard, the computational efficiency of POA should be compared to that of other recent algorithms, such as the multi leader optimizer (MLO) [31], the three influential members based optimizer (TIMBO) [32], the randomly selected leader based optimizer (RSLBO) [33], the squirrel search optimizer (SSO) [34], the puzzle optimization algorithm (POA) [35], and the ring toss game-based optimization algorithm (RTGBO) [36].

6. Conclusion

In this research, a modern pelican optimization algorithm, also known as POA, for OLC in SG environment is presented in order to maintain islanding requirements. There is a formulation of a multi-objective function with the goal of optimising the amount of load that can be shed and the voltage deviation index (VDI). The distributed optimal direct load control, also known as DLC, is figured out by employing the load control range of the consumers. Simulations are carried out using the IEEE 33-bus, taking into account the unpredictability of the PV, WT, and DGs loads. Four islanding scenarios have been considered. The

DGs' available powers in kVA are 1956.8, 949.9, 1502.8 and 1411.7, under islanding scenarios A, B, C and D, respectively. Whereas, the network loading conditions in kVAr are 4369.4, 1560.9, 2594.1 and 2839.46 during islanding scenarios A, B, C and D, respectively. These situations are caused to have load control. Including distribution losses, the proposed POA is able to curtail the load effectively for all the load points nearly to the available DGs power and thus, energy balance are obtained consumers satisfactory. By having optimal load control and dispatching remaining amount of loads, the available DGs' powers in kVA are 6.11, 3.09, 4.44 and 6.73, under islanding modes A, B, C, and D, respectively. In comparison to literature, POA is resulted for less load control and also converged highly competitive with other algorithms such as PSO, TLBO, GOA, and BOA by its global optimal solution.

Conflicts of interest

Authors declare that no conflicts of interest.

Author contributions

Anjani Parvathi K: Conceptualization, software, investigation, writing—original draft preparation, Kotaiah N.C and Radha Rani K: validation, formal analysis, and supervision.

References

[1] E. Papadis and G. Tsatsaronis, "Challenges in the decarbonization of the energy sector", *Energy*, Vol. 205, p. 118025, 2020.

[2] S. Impram, S. V. Nese, and B. Oral, "Challenges of renewable energy penetration on power system flexibility: A survey", *Energy Strategy Reviews*, Vol. 31, p. 100539, 2020.

[3] P. D. N. Porras, A. López, and J. C. S. Elena, "Deregulation in the energy sector and its economic effects on the power sector: A literature review", *Sustainability*, Vol. 13, No. 6, p. 3429, 2021.

[4] L. Sigrist, L. Rouco, and F. M. Echavarren, "A review of the state of the art of UFLS schemes for isolated power systems", *International Journal of Electrical Power & Energy Systems*, Vol. 99, pp. 525-539, 2018.

[5] R. M. Larik, M. W. Mustafa, and M. N. Aman, "A critical review of the state-of-art schemes for under voltage load shedding", *International Transactions on Electrical Energy Systems*, Vol. 29, No. 5, p. e2828, 2019.

[6] M. Hussain and Y. Gao, "A review of demand response in an efficient smart grid environment", *The Electricity Journal*, Vol. 31, No. 5, pp. 55-63, 2018.

[7] N. N. Bakar, M. Y. Hassan, M. F. Sulaima, M. N. M. Nasir, and A. Khamis, "Microgrid and load shedding scheme during islanded mode: A review", *Renewable and Sustainable Energy Reviews*, Vol. 71, pp. 161-169, 2017.

[8] A. A. Anderson and S. Suryanarayanan, "Review of energy management and planning of islanded microgrids", *CSEE Journal of Power and Energy Systems*, Vol. 6, No. 2, pp. 329-343, 2019.

[9] R. Mageshvaran and T. Jayabarathi, "GSO based optimization of steady state load shedding in power systems to mitigate blackout during generation contingencies", *Ain Shams Engineering Journal*, Vol. 6, No. 1, pp. 145-160, 2015.

[10] R. Mageshvaran and T. Jayabarathi, "Steady state load shedding to mitigate blackout in power systems using an improved harmony search algorithm", *Ain Shams Engineering Journal*, Vol. 6, No. 3, pp. 819-834, 2015.

[11] V. Tamilselvan and T. Jayabarathi, "A hybrid method for optimal load shedding and improving voltage stability", *Ain Shams Engineering Journal*, Vol. 7, No. 1, pp. 223-232, 2016.

[12] M. Dreidy, H. Mokhlis, and S. Mekhilef, "Application of meta-heuristic techniques for optimal load shedding in islanded distribution network with high penetration of solar PV generation", *Energies*, Vol. 10, No. 2, p. 150, 2017.

[13] F. Conteh, S. Tobaru, M. E. Lotfy, A. Yona, and T. Senjyu, "An effective Load shedding technique for micro-grids using artificial neural network and adaptive neuro-fuzzy inference system", *Aims Energy*, Vol. 5, No. 5, pp. 814-837, 2017

[14] J. Jallad, S. Mekhilef, H. Mokhlis, J. Laghari, and O. Badran, "Application of hybrid meta-heuristic techniques for optimal load shedding planning and operation in an islanded distribution network integrated with distributed generation", *Energies*, Vol. 11, No. 5, p. 1134, 2018.

[15] A. Khamis, H. Shareef, A. Mohamed, and Z. Y. Dong, "A load shedding scheme for DG integrated islanded power system utilizing backtracking search algorithm", *Ain Shams Engineering Journal*, Vol. 9, No. 1, pp. 161-172, 2018.

[16] R. M. Larik, M. W. Mustafa, M. N. Aman, T. A. Jumani, S. Sajid, and M. K. Panjwani, "An improved algorithm for optimal load shedding in power systems", *Energies*, Vol. 11, No. 7, p. 1808, 2018.

[17] S. Sarwar, H. Mokhlis, M. Othman, M. A. Muhammad, J. A. Laghari, N. N. Mansor, H. Mohamad, and A. Pourdaryaei, "A mixed integer linear programming based load shedding technique for improving the sustainability of islanded distribution systems", *Sustainability*, Vol. 12, No. 15, p. 6234, 2020.

[18] L. O. Mogaka, G. N. Nyakoe, and M. J. Saulo, "Islanded microgrid congestion control by load prioritization and shedding using ABC algorithm", *International Journal of Electrical & Computer Engineering*, Vol. 10, No. 5, pp. 4552-4561, 2020.

[19] A. G. Rahimabadi, H. Razmi, H. D. Mojarrad, "Multiple-deme parallel genetic algorithm based on modular neural network for effective load shedding", *Soft Computing*, Vol. 25, No. 21, pp. 13779-13794, 2021.

[20] N. T. Le, A. T. Nguyen, T. T. Hoang, H. M. V. Nguyen, A. H. Quyen, and B. T. Phan, "Distributed Load Shedding considering the Multicriteria Decision-Making Based on the Application of the Analytic Hierarchy Process", *Mathematical Problems in Engineering*, Vol. 2021, p. 6834501, 2021.

[21] A. T. Nguyen, N. T. Le, A. H. Quyen, B. T. Phan, T. P. Trieu, and T. D. Hua, "Application of AHP algorithm on power distribution of load shedding in island microgrid", *International Journal of Electrical and Computer Engineering*, Vol. 11, No. 2, p. 1011, 2021.

[22] L. T. Nhung, T. T. Phung, H. M. Nguyen, T. N. Le, T. A. Nguyen, and T. D. Vo, "Load Shedding in Microgrids with Dual Neural Networks and AHP Algorithm", *Engineering, Technology & Applied Science Research*, Vol. 12, No. 1, pp. 8090-8095, 2022.

[23] J. Xu, B. Xie, S. Liao, Z. Yuan, D. Ke, Y. Sun, X. Li, and X. Peng, "Load shedding and restoration for intentional island with renewable distributed generation", *Journal of Modern Power Systems and Clean Energy*, Vol. 9, No. 3, pp. 612-624, 2021.

[24] S. Sarwar, H. Mokhlis, M. Othman, H. Shareef, L. Wang, N. N. Mansor, A. S. Khairuddin, and H. Mohamad, "Application of polynomial regression and MILP for under-frequency load shedding scheme in islanded distribution system", *Alexandria Engineering Journal*, Vol. 61, No. 1, pp. 659-674, 2022.

[25] O. T. Amusan, N. I. Nwulu, and S. L. Gbadamosi, "Identification of Weak Buses for Optimal Load Shedding Using Differential Evolution", *Sustainability*, Vol. 14, No. 6, p. 3146, 2022.

[26] M. Ahmadipour, M. M. Othman, Z. Salam, M. Alrifaey, H. M. Ridha, and V. Veerasamy, "Optimal load shedding scheme using grasshopper optimization algorithm for islanded power system with distributed energy resources", *Ain Shams Engineering Journal*, p. 101835, 2022.

[27] M. S. Abid, H. J. Apon, A. Ahmed, and K. A. Morshed, "Chaotic slime mould optimization algorithm for optimal load-shedding in distribution system", *Ain Shams Engineering Journal*, Vol. 13, No. 4, p. 101659, 2022.

[28] N. John, V. Janamala, and J. Rodrigues, "Optimal Load Control for Economic Energy Equilibrium in Smart Grid Using Adaptive Inertia Weight Teaching-Learning-Based Optimization", *International Journal of Intelligent Engineering and Systems*, Vol. 15, No. 2, pp. 243-250, 2022, doi: 10.22266/ijies2022.0430.22.

[29] P. Trojovský and M. Dehghani, "Pelican optimization algorithm: A novel nature-inspired algorithm for engineering applications", *Sensors*, Vol. 22, No. 3, p. 855, 2022.

[30] S. H. Dolatabadi, M. Ghorbanian, P. Siano, and N. D. Hatziargyriou, "An enhanced IEEE 33 bus benchmark test system for distribution system studies", *IEEE Transactions on Power Systems*, Vol. 36, No. 3, pp. 2565-2572, 2020.

[31] M. Dehghani, Z. Montazeri, A. Dehghani, R. A. R. Mendoza, H. Samet, J. M. Guerrero, and G. Dhiman, "MLO: Multi leader optimizer", *Int. J. Intell. Eng. Syst.*, Vol. 13, No. 6, pp. 364-373, 2020, doi: 10.22266/ijies2020.1231.32.

[32] F. A. Zeidabadi, M. Dehghani, O. P. Malik, "TIMBO: Three Influential Members Based Optimizer", *Int. J. Intell. Eng. Syst.*, Vol. 14, No. 5, pp. 121-128, 2021, doi: 10.22266/ijies2021.1031.12.

[33] F. A. Zeidabadi, M. Dehghani, and O. P. Malik, "RSLBO: Random Selected Leader Based Optimizer", *Int. J. Intell. Eng. Syst.*, Vol. 14, No. 5, pp. 529-538, 2021, doi: 10.22266/ijies2021.1031.46.

[34] M. Sumanl, V. P. Sakthivel, and P. D. Sathya, "Squirrel search optimizer: nature inspired metaheuristic strategy for solving disparate economic dispatch problems", *Int. J. Intell. Eng. Syst.*, Vol. 13, No. 5, pp. 111-121, 2020, doi: 10.22266/ijies2020.1031.11.

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[35] F. A. Zeidabadi and M. Dehghani, "POA: Puzzle optimization algorithm", *Int. J. Intell. Eng. Syst.*, Vol. 15, No. 1, pp. 273-281, 2022, doi: 10.22266/ijies2022.0228.25.

[36] S. A. Doumari, H. Givi, M. Dehghani, and O. P. Malik, "Ring toss game-based optimization algorithm for solving various optimization problems", *Int. J. Intell. Eng. Syst.*, Vol. 14, No. 3, pp. 545-554, 2021, doi: 10.22266/ijies2021.0630.46.