Harris hawks optimization algorithm based power loss minimization in micro grid incorporated with distributed generation

Santhosh Kasi$^{1,*}$ and R Neela$^2$

$^1,2$Department of Electrical Engineering, FEAT, Annamalai University, Chidambaram, India

*E-mail: santhoshkeee@gmail.com

Abstract. In this paper, Harris hawks optimization algorithm is used to solve the distributed generation placement problem in the micro grid. Distributed generation will effectively mitigate the loss of a real power system and improve the voltage profile. Thus, reducing actual power loss is viewed as a fitness function to optimally locate and rate the distributed generation in the micro grid. The method presented is applied in the IEEE test systems, such as the 33-bus and 69-bus micro grids. Simulation analyses are performed in MATLAB simulation software and simulation results are compared with existing PSO and ES-PSO algorithms. The results show the superiority and consistency of the Harris hawks optimization algorithm in terms of power loss minimization, voltage profile, and execution time.

Keywords. Distributed generation, Harris hawks optimization algorithm, Micro grid, Real power loss minimization, Voltage profile enhancement.

1. Introduction

Electricity is one of the most commonly used energies in the world. Power generation comes from a variety of devices, and the key source has a simple rule of rotational motion to extract energy from the generator. The aim of the power generation system is to generate the power that needs to be used over a time span, by considering the different levels of voltage provided and the energy loss associated with the micro grid [1].

The globalization of energy would greatly increase demand for electricity and will involve community awareness of the environmental effects of the broader power generation industry on more conventional or centralized power generation. With this in mind, it has led to numerous developments in micro grids, with a particular interest in distributed generation (DG) or decentralized generation [2]. DG is a small-scale power generation system, also known as an embedded power source, a decentralized power source, or a distributed power source, which generates electricity from 3 kW to 10,000 kW from wind, solar, biomass, micro-turbines, fuel cells, and so on [3].

The DG unit is more closely interconnected with the loads and is employed for commercial, domestic, and industrial applications. The key benefits of using the DG unit are reduced active power loss, improved voltage stability, improved reliability, enhanced grid, and reduced gas emission. Although DG has many advantages, the choice of the best size and position for the DG unit is an important problem in DG optimization. Studies have shown that inappropriate rating and positioning of DG units...
can result in increased transmission losses, increased costs, and voltage fluctuations due to reverse current flow from mounted DGs. Therefore in order to minimize the loss of control, it is necessary to consider options for the availability of resources to find the optimum position and capability of DG [4].

Renewable energy applications such as solar photovoltaic (PV) system, wind, biomass, and hydro demand better power efficiency, higher reliability, higher versatility, lower cost, and less environmental effects [5]. Renewable energy sources (RES) are projected to play a major role with a prosperous future in electricity boards of developed countries [6]. Many developing countries have also started the shift to a higher share of green energy in their power supply systems by encouraging the business adoption and growth of these technologies. Changes aimed at improving the environment are becoming globally politically accepted, particularly in developed countries. Society is moving slowly towards more sustainable generation techniques, generation of distributed energy, reduction of greenhouse gas emissions, minimization of waste, reduction of vehicle air pollution, and conservation of primeval forests. Meanwhile, DG is expected to bring a vital function in potential energy supplies and minimizing the polluted NOx, SOx, CO2 emissions [7]. Nonetheless, as DG’s integration into grid conditions progresses, it presents various disruptions to the safe and effectual service of the micro grid. These issues can be partially solved by DGs optimally placed in the micro grid. The approaches employed to manage and control the behavior of micro grids are therefore constantly altering to optimize and maintain the system active [8]. Therefore, there is an immediate need to focus on more precise scheduling of DGs on micro grids with different objectives. These types of DGs have various benefits but there are several factors to consider. Incorporating the DGs to the micro grid presents a series of various operating constraints that can seriously affect the overall system operation, including voltage limits, power generation limits, power balance constraints, harmonic distortion, fault levels, and system stability issues [9]. This severely impacts the operation and control of micro grids when the system operates without proper attention.

The future benefits of DG power generation rely on the rating and location of the DG units in a micro grid [10], [11]. The appropriate evaluation and placement of the DGs can reduce energy loss and improve the reliability level of the entire network. Nevertheless, determining the optimum location and capacity of the DG units is a complicated task and requires computational research on the parameters, while considering the intermittence and unpredictability with RES [12]. The underlying research of this option should be conducted to meet system constraints while minimizing DG operating costs or other objectives in the functioning of the DG deployment. As the adoption of DGs in the grid increases, optimal operation and planning of the distribution system can enable the deployment of a smart micro grid. It is one of the considerable interests in the global power market today.

The DG placement problem can be solved using analytical or artificial intelligent techniques like ant colony optimization (ACO), cuckoo search algorithm (CSA), particle swarm optimization (PSO), simulated annealing (SA), intelligent water drops (IWD), eagle strategy with particle swarm optimizer (ES-PSO), genetic algorithm (GA), firefly algorithm (FA), and hybrid intelligent techniques [1], [9], [13].

Many researchers have suggested new artificial intelligence methods in recent years to explore the optimum position and rating of DGs for the minimization problem in the micro grids based on the real power loss and operating cost of micro grid [13]. In [4], combined GA and IWD are applied for reduction of micro grid’s power loss, improvement of voltage profile, and enhancing the voltage stability in the micro grids with subject to security and system operating limitations. In [14], the loss sensitivity factors (LSF) are employed for the detection of DG sites with the aid of the bus voltages. Further, the invasive weed optimization algorithm (IWOA) has been implemented to find DG size. Many researchers have considered the voltage profile enhancement and real power loss minimization as objective functions and solved using modified plant growth simulation technique [1], [9], [13], [14]. In the above approaches, the key disadvantages are low convergence speed and achieve near-optimal solutions only. This paper is aimed to overtake all the disadvantages in the existing methods by implementing a recently developed Harris hawks optimization algorithm (HHOA) to solve the DG placement problem in micro grids with objective function as minimization of active power loss, with subject to various constraints such as DG location, DG power generation limits and voltage limit.
constraint [15]. The HHOA is employed to optimize the location and size of DG in a microgrid test system, inspired by nature, to compete with other optimizers. Roused from the attacking nature and accommodative conduct of Harris’ hawks, a novel technique called Harris hawks optimization algorithm was formulated by Heidari and co-authors [15]. A portion of the hawks means to astound the prey by pouncing it from various ways. It is noted that the hawks choose the attacking way to depend on the prey’s flying path.

In this proposed work, HHOA is employed to explore the optimal position and operating rating of DG in IEEE 33-bus and 69-bus micro grids [9]. Thus, the real power loss minimization problem of the microgrid is optimized using the HHOA technique and the obtained results are compared to that of the existing methods, providing helpful conclusions conceiving the effectuality and skillfulness of the proposed HHOA technique. After the introduction, a description of the DG placement issue colligated with its mathematical problem formulation is detailed in Section 2. Section 3 explains the implementation of the purported HHOA technique to determine the optimal bus position and rating of DG in the microgrid. Simulation analyses are discussed in Section 4. At last, Section 5 depicts the conclusion of the purported work.

2. Problem formulation

2.1. Real power loss equation

The backward forward sweep technique is employed to solve the power flow in the microgrid. The real power loss equation for the microgrid with and without DG is given as [9],

\[ P_{L,DG} = P'_{L,DG} - \sum_{i=1}^{nb} (P'_i - P_{DG}) \]  
\[ P_i = P'_i - \sum_{k=1}^{nb} (P'_{DG}) \]

where, \( P_{L,DG} \) is the total system real power loss of the microgrid with DG installed; \( P_i \) is the total system real power loss of the microgrid without DG; \( P'_i \) is the total real power injected from the substation or main grid at the main feeder (bus 1) of the microgrid without DG; \( P'_{L,withDG} \) is the total real power injected at the main feeder of the microgrid incorporated with DG source; \( P_D \) is the total real load demand at bus \( i \); \( P'_{DG} \) is the real power produced from \( k^{th} \) DG installed at bus \( i \); \( P_{DG} = P'_{DG} \); and \( nb \) is the total number of buses in the microgrid. In case of no DG is installed at bus \( i \) or only reactive power supporting DG is installed in bus \( i \), \( P'_{DG} = 0 \).

The objective of the purported work is to reduce the real power loss of the microgrid installed with optimal DG. Hence, the objective function of this work can be formulated as,

\[ \text{Min} \quad P_{L,DG} = P'_i - \sum_{i=1}^{nb} (P'_i - P_{DG}) \]  

(3)

2.2. Reactive power loss equation

The reactive power loss equation with and without DG for the microgrid is given as [9],

\[ Q_{L,DG} = Q'_{L,DG} - \sum_{i=2}^{nb} (Q'_i - Q_{DG}) \]  
\[ Q_i = Q'_i - \sum_{k=1}^{nb} (Q_{DG}) \]

(4)

where, \( Q_{L,DG} \) is the total system reactive power loss of the microgrid with DG installed; \( Q_i \) is the total system reactive power loss of the microgrid without DG; \( Q'_i \) is the total reactive power injected from the substation or main grid at the main feeder (bus 1) of the microgrid without DG; \( Q'_{L,withDG} \) is the total reactive power injected at the main feeder of the microgrid incorporated with DG source; \( Q_D \) is the reactive load demand at bus \( i \); and \( Q_{DG} \) is the reactive power produced from \( k^{th} \) DG installed at bus \( i \); \( Q_{DG} = Q'_{DG} \). In case of no DG is installed at bus \( i \) or only real power supporting DG is installed in bus \( i \), \( Q_{DG} = 0 \).
2.3. Performance indices

**Percentage of reduction in real power loss**

The percentage of reduction in real power loss is the ratio between the system’s real power loss with DG to that of the system without DG.

\[
\Delta P_L = \frac{P_{L,DG}}{P_L} \times 100
\]  

\((6)\)

**Percentage of reduction in reactive power loss**

The percentage of reduction in reactive power loss is the ratio between the system reactive power loss with DG to that of the system without DG.

\[
\Delta Q_L = \frac{Q_{L,DG}}{Q_L} \times 100
\]  

\((7)\)

2.4. Subject to constraints

**DG real power generation limit**

The active power \(P^i_{DG}\) produced from the DG unit at bus \(i\) must be within the lower and upper generation capacity.

\[
P_{DG,min} \leq P_i^{DG} \leq P_{DG,max}
\]  

\((8)\)

where, \(P_{DG,max}\) is the upper operating range for active power generated from the DG units; and \(P_{DG,min}\) is the lower operating range for active power generated from the DG units. In this study, the upper and lower limits are considered as,

\[
P_{DG,max} = \sum_{i=2}^{nb} (P_i^*)
\]  

\((9)\)

\[
P_{DG,min} = 0
\]  

\((10)\)

**DG reactive power generation limit**

The reactive power \(Q^i_{DG}\) produced from the DG unit at bus \(i\) must be within the lower and upper generation capacity.

\[
Q_{DG,min} \leq Q_i^{DG} \leq Q_{DG,max}
\]  

\((11)\)

where, \(Q_{DG,max}\) is the upper operating range for reactive power generated from the DG units; and \(Q_{DG,min}\) is the lower operating range for reactive power generated from the DG units. In this study, the upper and lower limits are considered as,

\[
Q_{DG,max} = \sum_{i=2}^{nb} (Q_i^*)
\]  

\((12)\)

\[
Q_{DG,min} = 0
\]  

\((13)\)

**Bus voltage constraint**

The bus voltage must be within the voltage lower and upper range.

\[
V_{min} \leq V^i \leq V_{max}
\]  

\((14)\)

where \(V^i\) is the voltage at bus \(i\); \(V_{max}\) is the maximum voltage limit of the micro grid; and \(V_{min}\) is the minimum voltage limit of the micro grid. The values are considered as,

\[
V_{max} = 1.05 \quad p.u
\]  

\((15)\)

\[
V_{min} = 0.95 \quad p.u
\]  

\((16)\)

**DG location constraint**

The DG must be located between bus 2 and the last bus of the micro grid.
where, \( Bus_{DG}^k \) is the bus location of \( k^{th} \) DG.

2.5. Load model

Different load models are obtained by varying the factors \( \alpha \) and \( \beta \) in the mathematical equation (18) and (19) which give the relation between the real & reactive power and the voltage at bus \( i \).

\[
P_i^o = \rho P_{D,base}^i (V_{base}^i)^\alpha
\]

(18)

\[
Q_i^o = \rho Q_{D,base}^i (V_{base}^i)^\beta
\]

(19)

where, \( V_{base}^i \) is the \( i^{th} \) bus voltage at base case; \( P_{D,base}^i \) is the active base load at bus \( i \); \( Q_{D,base}^i \) is the reactive base load at bus \( i \); \( \rho \) is the load factor is varied by which the load demand is increased or decreased; \( \alpha \) and \( \beta \) are load coefficients.

The above factors are varied, in order to validate the usefulness of the purported HHOA algorithm in the practical execution. The values are given in Table 1.

| Type of Load              | \( \rho \) | \( \alpha \) | \( \beta \) |
|---------------------------|----------|---------|---------|
| Constant Power (CP) - Light | 0.5      | 0       | 0       |
| Constant Power (CP) - Base | 1.0      | 0       | 0       |
| Constant Power (CP) - Heavy | 1.6      | 0       | 0       |

3. Harris hawks optimization algorithm (HHOA)

Roused from the attacking nature and accommodative conduct of Harris’ hawks, a novel technique called Harris hawks optimization algorithm (HHOA) was formulated by Heidari and co-authors [15]. A portion of the hawks means to astound the prey by pouncing it from various ways. It is noted that the hawks choose the attacking way to depend on the prey’s flying path. HHOA is a population-based exploration technique that optimizes the problem with respect to three significant phases such as exploration, exploitation, and transition that are clarified in the following sections [15].

3.1. Exploration stage

In the exploration stage, it is resolved to numerically pause, explore, and find the ideal chase. The position of hawks at iter+1 is numerically computed as,

\[
x_{(iter+1)} = \begin{cases} 
X_{(iter)} - r_1(X_{(iter)} - X_{rand}) - r_2(LB + r_3(UB - LB)) & \text{if } q < 0.5 \\
X_{(iter)} - r_1(X_{(iter)} - 2r_2X_{(iter)}) & \text{if } q \geq 0.5 
\end{cases}
\]

(20)

where, \( iter \) indicates the current iteration, \( X_{rand} \) represents the position of rabbit, \( X_{rand} \) is the haphazardly chosen hawk in the group of Harris hawks, \( r_1, r_2, r_3 \) and \( r_4 \) are randomly distributed numbers between 0 to 1, and \( X_m \) depicts the mean location of all Harris hawk and is estimated as,

\[
x_{(iter)} = \frac{1}{N} \sum_{i=1}^{N} X_{(iter)},
\]

(21)

where \( N \) is the population size of Harris hawks and \( X \) refers to the location of \( i^{th} \) hawks.

3.2. The transition between exploration and exploitation

Let \( T \) is the maximum iteration count and \( E_0 \in (-1, 1) \) is the initial energy of the rabbit at each iteration, HHOA computes the rabbit’s escape energy \( E \) as,

\[
E = 2E_0 \left( 1 - \frac{iter}{T} \right).
\]

(22)
Based on the rabbit’s escape energy, the exploitation and exploration stage of HHOA can change, i.e., when $|E| \geq 1$, the exploration stage begins; or else the algorithm moves to the exploitation stage.

### 3.3. Exploitation stage
Contingent upon the availability of the rabbit’s escape energy, Harris hawks can conceive a hard or soft blockade for chasing it from a different side. A parameter $r$ is characterized to quantify the rabbit’s escape possibility. If escape possibility $r < 0.5$, then the rabbit escapes without any trouble. Likewise, if $|E| \geq 0.5$, HHOA uses a soft surround, and if $|E| < 0.5$, the hard surround is employed. This can be significant that regardless of whether the rabbit gets escape i.e., $|E| \geq 0.5$, the prey’s successful escape relies upon $r$ also.

The chasing process is affected by the pursuing and escaping schemes of the Harris hawks and rabbits correspondingly. In this sense, four significant algorithmic steps are analyzed that are extensively clarified as follows.

More insights regarding the four stages of the exploitation stage in the HHOA technique are detailed as follows.

1. **Soft surround** [15], if $|E| \geq \frac{1}{2}$, and $r \geq \frac{1}{2}$, then the position of hawks at iter+1 is numerically computed as,
   
   $\Delta X (\text{iter}) = X_{\text{old} (\text{iter})} - X (\text{iter})$

   $X (\text{iter} + 1) = X (\text{iter}) + \Delta X (\text{iter}) - E (\text{iter})|Jk_{\text{old} (\text{iter})} - X (\text{iter})|

   where the term $\Delta X$ stands for the distance between the rabbit location and the variable $J$ represents the rabbit jump severeness.

2. **Hard surround** [15], if $|E| < \frac{1}{2}$, and $r \geq \frac{1}{2}$, then the present location is estimated as,

   $X (\text{iter} + 1) = X_{\text{old} (\text{iter})} - E (\text{iter})|\Delta X (\text{iter})|

3. **Advanced rapid jumps** during soft surrounding [15], if $|E| \geq \frac{1}{2}$, and $r < \frac{1}{2}$, the following activity of the hawks is computed as,

   $Y = X_{\text{old} (\text{iter})} - E (\text{iter})|Jk_{\text{old} (\text{iter})} - X (\text{iter})|

   Then, the plunging of the hawks is estimated as,

   $Z = Y + S \times LF (D)$

   where $LF$ is the Levy’s flight; $S_{1xD}$ represents the stochastic vector; and $D$ is the problem dimension. Let $\beta$ and $\mu$ be randomly distributed numbers in the range $[0, 1]$, then $LF$ is determined as,

   $\begin{align*}
   LF (D) &= 0.01 \times \frac{\mu \times \sigma}{|\beta|^{2}} \left[ \frac{T (1 + \beta \times \sin (\frac{\pi \beta}{2}))}{T (1 + \beta \times \sin (\frac{\pi \beta}{2}))} \right] \\
   \beta &= 1.5
   \end{align*}

4. **Advanced rapid jumps** during hard surrounding [15]: if $r < \frac{1}{2}$, and $|E| < \frac{1}{2}$, then the conduct of the Harris hawks that are assumed as close to the rabbit. Hence, the location of hawks is determined as,

   $X (\text{iter} + 1) = \begin{cases} 
   Y & \text{if } F (Y) < F (X (\text{iter})) \\
   Z & \text{if } F (Z) < F (X (\text{iter}))
   \end{cases}$

   In the above equation, $Y$ and $Z$ ought to be determined as,

   $Y = X_{\text{old} (\text{iter})} - E (\text{iter})|Jk_{\text{old} (\text{iter})} - X (\text{iter})|

   $Z = Y + S \times LF (D)$

3.4. Decision variables and fitness value of HHOA for optimal placement of DG in micro grid

**Decision variables**
In the DG placement problem, the position of each Harris hawk comprises of DG’s location and rating with subjective to constraints (8), (11), and (17).
The position of $i^{th}$ Harris hawks (decision variables) is expressed as,

$$X_i = \begin{bmatrix} \text{Bus}_{DG}^1, \text{Bus}_{DG}^2, ..., \text{Bus}_{DG}^k, \text{Pg}_{DG}^1, \text{Pg}_{DG}^2, ..., \text{Pg}_{DG}^k, \text{Qg}_{DG}^1, \text{Qg}_{DG}^2, ..., \text{Qg}_{DG}^k \end{bmatrix}$$ (32)

where $k$ is the number of DGs installed in the micro grid. Thus, the dimension of the problem is $3 \times k$.

**Fitness value**

For Harris hawks $X_i$, place all DGs at $\text{Bus}_{DG}^j$, $j = 1, 2, ..., k$ in the micro grid and treat DGs’ power $P_{g}^j$ and $Q_{g}^j$ as negative load. Run the backward forward sweep load flow solution on the micro grid installed with $k$ number of DGs to estimate the system's real power loss using (1). The estimated real power loss is considered as the fitness value of the $i^{th}$ Harris hawks.

4. **Simulation results and analysis**

In order to verify the performance of the purported HHOA technique, the simulation case studies are implemented on two test systems such as 33-bus and 69-bus micro grids. The m-script coding is developed in MATLAB simulation software. The control factors employed in the purported HHOA for the DG placement problem are shown in Table 2.

| Table 2. Parameters used in proposed HHOA |
|------------------------------------------|
| Number of search agents, $H$            | 20               |
| Maximum number of iterations, $iter_{max}$ | 100             |

The purported HHOA approach may be employed to install many DGs, but in this study, the number of DG is constrained to one. For both the micro grids, the main feeder is assumed as a slack bus for backward forward sweep load flow analysis.

4.1. 33-bus micro grid

The case study consists of an IEEE 33-bus test micro grid with 32 branches. The total power demand of the micro grid is about $3.715 \text{ MW}$ and $2.3 \text{ MVAR}$ with $12.66 \text{ kV}$ base voltage. The total real power loss of the micro grid without DG is about $210.9876 \text{ kW}$ for base loading conditions (base case). The optimum rating and location of DG obtained from the presented HHOA technique are depicted in Table 3. In Table 3, it is seen that the system's real power loss is diminished to $111.0198 \text{ kW}$ when a DG unit is located at the 6th bus of the micro grid with an operating rating of $2.5817 \text{ MW}$. In addition, to validate the efficacy of the presented HHOA algorithm for discovering the optimum location and rating of DG in the micro grid, the proposed HHOA is employed on the same network with different load conditions such as half loading condition of $50\%$ CP and heavy loading condition of $160\%$ CP. The simulation outcomes for all loading conditions are depicted in Table 3. The convergence property of the proposed HHOA, ES-PSO, and PSO is depicted in Figure 1.

| Table 3. Results after placement of DG using HHOA in 33-bus micro grid with different loading conditions |
|----------------------------------------------------------|
| Parameters | CP load |
|            | Light (50%) | Base (100%) | Peak (160%) |
| Load flow results | | | |
| $P_{L}$ (kW) | 48.787 | 210.9876 | 603.4308 |
| $Q_{L}$ (kVAR) | 33.0486 | 143.1284 | 410.2075 |
| Low voltage @ bus no. (p.u) | 18 / 0.954 | 18 / 0.9038 | 18 / 0.836 |
| High voltage @ bus no. (p.u) | 2 / 0.9986 | 2 / 0.997 | 2 / 0.995 |
| Proposed Method | | | |
| DG's bus no. / Rating (kW) | 6 / 1.3633 | 6 / 2.5817 | 6 / 4.6416 |
| $P_{L,DC}$ (kW) | 26.7395 | 111.0198 | 301.937 |
| $Q_{L,DC}$ (kVAR) | 19.7218 | 81.7079 | 222.742 |
As shown in Figure 1, the proposed HHOA technique achieves the optimal solution within the 5th iteration, whereas ES-PSO achieves the same optimal solution at the 38th iteration. Thus the proposed algorithm converges much quicker than the existing methods. The graphical representation of voltage profile with and without DG is portrayed in Figure 2. Table 4 gives the comparison results of the proposed algorithm and the existing methods [9]. As per Table 4, it is clearly seen that the results obtained from the HHOA provide a better solution than the existing methods. The simulation outcome of the ES-POS algorithm provides a similar optimal solution obtained from the proposed HHOA algorithm. However, the execution time taken to obtain the optimal solution for 100 iterations is about 1.128 sec for the ES-PSO technique where the proposed HHOA technique takes 0.992 sec and which is much lesser than that of both PSO and ES-PSO algorithms.

**Figure 1.** Convergence characteristic for 33-bus micro grid - base load

**Table 4.** Comparison results for 33-bus micro grid - base load

| Algorithms   | DG's bus no. / Rating (kW) | Bus voltage (p.u) | P_{L,dc} (kW) | ΔP_{L} (%) | Q_{L,dc} (kVAR) | ΔQ_{L} (%) | Simulation time (sec) |
|--------------|-----------------------------|-------------------|---------------|------------|-----------------|------------|-----------------------|
|              | Low voltage @ bus no. (p.u) | High voltage @ bus no. (p.u) | Worst | Average | Best | Worst | Average | Best | Worst | Average | Best |  |
| PSO [9]      | 6 / 3.15                    | 0.95 @ 18         | 1.0 @ 2      | 157.6088  | 115.3428     | 115.2900  | 45.36      | 105.518     | 83.6505 | 85.0800  | 40.56 | 5.02 |
| ES-PSO [9]   | 6 / 2.5817                  | 0.95 @ 18         | 1.0 @ 2      | 115.9922  | 115.3428     | 111.0198  | 47.38      | 82.5703     | 83.6905 | 81.7079  | 42.91 | 1.128 |
| Proposed HHOA | 6 / 2.5817                | 0.95 @ 18         | 1.0 @ 2      | **111.0423** | **111.0281** | **111.0198** | **47.38** | **81.6861** | **81.7516** | **81.7079** | **42.91** | **0.992** |
Figure 2. Bus voltage with and without DG for 33-bus micro grid - base load

4.2. 69-bus micro grid
The case study consists of an IEEE 69-bus micro grid with 68 branches. The total power demand of the micro grid is about $3.8014 \text{ MW}$ and $2.6936 \text{ MVAR}$ with $12.66 \text{ kV}$ base voltage. The total active power loss of the micro grid without DG is about $224.8949 \text{ kW}$ for base loading conditions (base case). The optimum rating and location of DG obtained from the presented HHOA technique are tabulated in Table 5. In Table 5, it is seen that the system active power loss is diminished to $83.1476 \text{ kW}$ when a DG unit is located at the 61st bus of the micro grid with an operating rating of $1.8725 \text{ MW}$. In addition, to validate the efficacy of the presented HHOA approach for discovering the optimum location and rating of DG in the micro grid, the proposed HHOA is employed on the same network with different load conditions such as half loading condition of $50\% \text{ CP}$ and heavy loading condition of $160\% \text{ CP}$. The simulation outcomes for various loading conditions are depicted in Table 5. The convergence property of the proposed HHOA is depicted in Figure 3.

Table 5. Results after placement of DG using HHOA in 69-bus micro grid with different loading conditions

| Parameters                      | Load flow results | Proposed Method |
|---------------------------------|-------------------|-----------------|
|                                |                   | CP load         |
|                                |                   | Light (50%)     | Base (100%) | Peak (160%)  |
| $P_L$ (kW)                     |                   | 51.5822         | 224.8949    | 638.0838     |
| $Q_L$ (kVAR)                   |                   | 23.54           | 102.1155    | 251.4235     |
| Low voltage @ bus no. (p.u)    |                   | 65 / 0.9567     | 65 / 0.9092 | 65 / 0.8445  |
| High voltage @ bus no. (p.u)   |                   | 2 / 1           | 2 / 1       | 2 / 0.9999   |
| DG's bus no. / Rating (kW)     |                   | 61 / 0.922      | 61 / 1.8725 | 9 / 2.9442   |
| $P_{L, DG}$ (kW)               |                   | 20.2837         | 83.1476     | 510.2787     |
| $Q_{L, DG}$ (kVAR)             |                   | 9.9076          | 40.4996     | 221.2228     |
| Low voltage @ bus no. (p.u)    |                   | 27 / 0.9844     | 27 / 0.9684 | 65 / 0.8652  |
| High voltage @ bus no. (p.u)   |                   | 2 / 1           | 2 / 1       | 2 / 1        |
As shown in Figure 3, the proposed HHOA technique achieves the optimal solution within the 7th iteration, whereas ES-PSO achieves the same optimal solution at the 87th iteration. Thus the proposed algorithm converges much quicker than the existing methods. The graphical representation of the voltage profile with and without DG is depicted in Figure 4. Table 6 gives the comparison results of the proposed algorithm and the existing methods [9]. As per Table 6, it is clearly seen that the results obtained from the HHOA provide a better solution than the existing methods. As like seen in the 33-bus micro grid, the simulation outcome of the ES-PSO algorithm provides a similar optimal solution obtained from the proposed HHOA algorithm. However, the execution time taken to obtain the optimal solution for 100 iterations is about 5.143 sec for the ES-PSO technique where the proposed HHOA technique takes 1.51 sec and which is much lesser than that of both PSO and ES-PSO algorithms.

![Convergence characteristic for 69-bus micro grid - base load](image1)

### Figure 3. Convergence characteristic for 69-bus micro grid - base load

| Algorithms | DG's bus no. / Rating (kW) | Bus voltage (p.u) | $P_{L,DC}$ (kW) | $Q_{L,DC}$ (kVAR) | $\Delta P_L$ (%) | $\Delta Q_L$ (%) | Simulation time (sec) |
|------------|----------------------------|-------------------|----------------|----------------|-----------------|----------------|---------------------|
| PSO [9]    | 61 / 1.8                   | 0.9679 @ 27      | 1.0 & 2        | 112.0245       | 111.1560        | 83.3700        | 62.93               | 51.3124            | 51.1623           | 40.6854            | 60.16             | 5.97               |
| ES-PSO [9] | 61 / 1.8725                | 0.9684 @ 27      | 1.0 @ 2        | 86.1516        | 83.7229         | 83.1480        | 63.03               | 41.6469            | 40.9306           | 40.4990            | 60.34             | 5.143              |
| Proposed HHOA | 61 / 1.8725               | 0.9684 @ 27      | 1.0 @ 2        | 83.1496        | 83.1483         | 83.1476        | 63.03               | 40.4891            | 40.5067           | 40.4964            | 60.34             | 1.51               |

The presented HHOA technique has enhanced local and global positions at the end of each generation. For both 33-bus and 69-bus micro grids, the percentage of loss reduction in the proposed HHOA is much better than the existing PSO algorithm. Similarly, the bus voltage profile of the micro grid is also enhanced quite well in the presented algorithm when compared to the PSO algorithm. The computational time of the proposed HHOA technique is also less than that of the existing PSO and
ES-PSO algorithms for both 39-bus and 69-bus micro grids. This can be seen clearly from Table 4 and 6. Moreover, the presented procedure takes a very less number of generations to achieve the optimal rating of DG in micro grids.

![Figure 4. Bus voltage with and without DG for 33-bus micro grid - base load](image)

5. Conclusion
Metaheuristic techniques influenced by nature have in recent days gained growing prominence. Metaheuristic techniques have the versatility and potential to solve any issues in engineering optimization. This paper underlines the significance of the main components of exploration and exploitation in the presented Harris hawks optimization algorithm for power system DG placement problem in the micro grid. The proposed technique has been implemented to discover the optimal rating and location of DG in 33-bus and 69-bus micro grids using the Harris hawks optimization algorithm. The simulated studies have been carried out in a MATLAB simulation environment. It is also clear that the proposed Harris hawks optimization algorithm depicts the advantages and superiority over the existing algorithms in terms of real power loss minimization and execution time. The approach presented can thus be applied in future work to a large-scale power system to find DG's optimal rating and location. Similarly, the approach presented with Harris hawks optimization algorithm can also be expanded with the usage of multi-DG positioning in micro grids to minimize power loss and voltage profile enhancement.

6. References
[1] Kasi, S. & Neela, R. Operation Cost Minimization of Micro Grid using Particle Swarm Optimizer and Eagle Strategy. in 2020 Fourth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC) 1207–1212 (2020). https://doi.org/10.1109/I-SMAC49090.2020.9243485
[2] Wolsink, M. The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. Renew. Sustain. Energy Rev. 16, 822–835 (2012). https://doi.org/10.1016/j.rser.2011.09.006
[3] Bharothu, J. N., Sridhar, M. & Rao, R. S. A literature survey report on Smart Grid technologies. in 2014 International Conference on Smart Electric Grid (ISEG) 1–8 (IEEE, 2014). https://doi.org/10.1109/ISEG.2014.7005601
[4] Moradi, M. H. & Abedini, M. A novel method for optimal DG units capacity and location in Microgrids. *Int. J. Electr. Power Energy Syst.* **75**, 236–244 (2016). https://doi.org/10.1016/j.ijepes.2015.09.013

[5] Banik, R. & Das, P. A Review on Architecture, Performance and Reliability of Hybrid Power System. *J. Inst. Eng. India Ser. B* 1–13 (2020).

[6] Mahesh, A. & Sandhu, K. S. Hybrid wind/photovoltaic energy system developments: Critical review and findings. *Renew. Sustain. Energy Rev.* **52**, 1135–1147 (2015). https://doi.org/10.1016/j.rser.2015.08.008

[7] Munawer, M. E. Human health and environmental impacts of coal combustion and post-combustion wastes. *J. Sustain. Min.* **17**, 87–96 (2018). https://doi.org/10.1016/j.jsm.2017.12.007

[8] Moghaddam, A. A., Seifi, A., Niknam, T. & Alizadeh Pahlavani, M. R. Multi-objective operation management of a renewable MG (micro-grid) with back-up micro-turbine/fuel cell/battery hybrid power source. *Energy* **36**, 6490–6507 (2011). https://doi.org/10.1016/j.energy.2011.09.017

[9] Santhosh, K. & Neela, R. Optimal Placement of Distribution Generation in Micro-Grid using Eagle Strategy with Particle Swarm Optimizer. *Int. J. Pure Appl. Math.* **118**, 3819–3825 (2018).

[10] Gupta, Y., Doolla, S., Chatterjee, K. & Pal, B. C. Optimal DG Allocation and Volt–var Dispatch for a Droop Based Microgrid. *IEEE Trans. Smart Grid* (2020). https://doi.org/10.1109/TSG.2020.3017952

[11] Justo, J. J., Mwasilu, F., Lee, J. & Jung, J.-W. AC-microgrids versus DC-microgrids with distributed energy resources: A review. *Renew. Sustain. Energy Rev.* **24**, 387–405 (2013). https://doi.org/10.1016/j.rser.2013.03.067

[12] Alzaidi, K. M. S., Bayat, O. & Uçan, O. N. Multiple DGs for Reducing Total Power Losses in Radial Distribution Systems Using Hybrid WOA-SSA Algorithm. *International Journal of Photoenergy* vol. 2019. https://doi.org/10.1155/2019/2426538

[13] Santhosh, K. & Neela, R. Optimization of Distributed Generation in Micro Grid using a Hybrid Metaheuristic Technique. *Int. J. Emerg. Trends Eng. Res.* **8**, 5104–5110 (2020). https://doi.org/10.30534/ijeter/2020/36892020

[14] Rama Prabha, D. & Jayabarathi, T. Optimal placement and sizing of multiple distributed generating units in distribution networks by invasive weed optimization algorithm. *Ain Shams Eng. J.* **7**, 683–694 (2016). https://doi.org/10.1016/j.asej.2015.05.014

[15] Heidari, A. A. *et al.* Harris hawks optimization: Algorithm and applications. *Future Gener. Comput. Syst.* **97**, 849–872 (2019). https://doi.org/10.1016/j.future.2019.02.028