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Harris Hawks Optimization Technique for Optimal Reconfiguration of Radial Distribution Networks

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***Abstract* — the reconfiguration process for the electrical radial distribution system is to find a radial operating framework that minimizes power losses of electric distribution networks. It is a combinatorial and complex procedure to determine the optimum radial configuration of the distribution system by frequently varying the operating status of network switches with keeping the network operating constraints. Therefore, this paper proposes the Harris hawks optimization (HHO) to find the optimal combination of switches that results in a radial configuration with minimum system power loss. The main revelation of this algorithm is the cooperative behavior and chasing manner of Harris' hawks in nature. In HHO operation, many hawks attack their victims cooperatively from several paths trying to surprise it. Harris hawks can detect a variety range of chasing patterns based on the dynamic nature of circumstances and escaping patterns of the victim. The validation of suggested HHO method is tested on the 33 IEEE bus distribution network. In addition, the obtained results proved the accuracy and efficiency of the suggested algorithm by comparing with other existing optimization algorithms.**

***Key words_ Distribution system, distribution system reconfiguration, Harris hawks optimization, Real Power loss reduction*.**

I. INTRODUCTION

The radial topological structure of distribution system and the high current ratio to the levels of the voltages cause the total distribution power losses to be increased. Therefore, real power loss is considered a critical problem in reconfiguring the distribution systems [1]. This problem must be solved seriously and efficiently. The presented solution in this paper is the rreconfiguring and changing the topology construction of intended distribution network, which enable to optimize the performance of distribution system especially the power losses issue. It is carried by changing the original topological construction of the distribution system. Reconfiguration procedure is done by altering the switches statuses (on / off states) until getting the global best solution that achieve an optimum network configuration. Selecting these switches during the reconfiguration operation is very combinatorial and complex procedure as the distribution system includes many switching combinations that depends on defining the search spaces of the network. Hence, the random selecting of switches that are opened and those that are closed can cause more voltage drop and higher power losses. Therefore, the rreconfiguration process is important to be optimized to enhance the performance of the distribution network by reducing the total network losses.

Electrical loads require secure and reliable electrical power supply, so the distribution network becomes an important and active portion in the power system that can be improved and controlled by reconfiguring the topology of system. Varying the topology of distribution system and counting the power losses consider an effective tool for improving and evaluating the system performance. Reconfiguration of radial distribution system can be defined as an effective procedure for power losses decreasing by varying the radial topological formation of the network by altering on/off status of switches for transforming the loads from heavy loaded branches to lower loaded branches until getting the best value of total power loss of the network providing keeping the operating constraints [2-35]. Recent resulting topology of the network is the optimal radial construction with global best value of total system power loss and optimal combination of switches that are opened and becomes as new network tie switches group. The other switches of network are in closed state and defined as the sectionalizing switches.

In the last decade, many meta-heuristic optimization algorithms became common in use, they are flexible and avoiding the local optima. These algorithms are considered as optimization algorithms that depends on defining the search spaces and their number as inputs for the problem. Consequently, meta-heuristic optimization techniques have flexibility to provide an optimum solution for different optimization problems. These algorithms divided into two different classes: evolutionary optimization techniques and swarm intelligence optimization techniques. Swarm intelligence techniques depend on the swarm intelligence to achieve the objective based on the attitude of the swarm to reach the required target. Several heuristic optimization algorithms were used to provide a satisfactory solution for the distribution network reconfiguration problem. Marlin et. Al had the start on presenting the solution for the distribution system reconfiguration issue [36]. They solved the distribution system reconfiguration process by using applying heuristic optimization algorithms to attain a global optimum solution[2]. While, Shermohammadi and Hong[37] applied the heuristic algorithms to achieve the best solution for the problem. In [37], Civanlar et al applied the branch exchange heuristic optimization methods to attain optimum power losses by changing the topological construction of the network. Branch and bound applied the optimization algorithm to attain the optimal construction of distribution network [37]. However, some of these Heuristic optimization algorithms that were not efficient for solving the distribution network reconfiguration problem because they do not include simultaneous switching operations. Moreover, they just provide the local optimal solutions but not provide a global best solution. The optimization methods should present solving the nonlinear reconfiguration problems to reduce the power loss by calculating the two values "local and global best solutions". Thus, a modified Honey Bee Mating optimizing algorithm [36] was applied to decrease the power loss by reconfiguration process. Also, Nara et al suggested the Genetic Algorithm for solving the reconfiguring issue with minimum power loss [2]. Furthermore, the modified bacterial foraging optimization technique (MBFO) was proposed for solving reconfiguration issue for minimizing the total power loss of the network [37]. Enhanced Genetic algorithm (EGA) was assumed to achieve the optimum power losses as an optimum solution to solve the reconfiguration problem for distribution network [38], selective particle swarm optimization technique (SPSO) was applied to solve reconfiguration problem comparing with (BPS) binary particle swarm optimization technique [39]. Grasshopper optimization algorithm (GOA) [9] was applied to attain an optimum solution for the reconfiguration problem based on the grasshopper behavior to get the food in an optimal technique the. Augmented Grey Wolf Optimization algorithm (AGW) was used to achieve the optimum switches combination of the radial distribution network [40] depending on the best two groups of wolves to achieve the optimum solution through minimum time. However, most of previous optimization methods take long computing time for large systems. Atom Search optimization Algorithm was applied and it achieved the optimal radial distribution system reconfiguration with optimal value of total system power loss.

Most of the mentioned optimization methods confirm high calculating duration for huge systems. Hence, this paper proposes the utilization of Harris Hawks Optimization algorithm (HHO) [41]. The major inspiration of HHO algorithm is the cooperating and intelligent attitude and chasing method of Harris' hawks in the nature to find the optimal solution for radial distribution network reconfiguration problem to minimize the total real system power loss. In this behavior, the hawks try to attack the prey suddenly from different directions in cooperating manner. The obtained results proved that HHO algorithm is the best comparing with other optimization algorithms when testing it using the standard 33 buses distribution system. The remaining of the paper is organized as follows; Section II reviews the problem formulation and system constraints. Section III introduces the HHO technique. Discussion and simulation results are presented in Section IV. Finally, the conclusion is reviewed in Section V.

I. Problem Formulation And Constraints

Power flow concept in the feeders of distribution system can be reviewed by a single line diagram as depicted in Fig.1. The bus voltage at bus *f is* $V_f\angle\delta_f$ and the voltage at bus *g* is $V_g\angle\delta_g$.

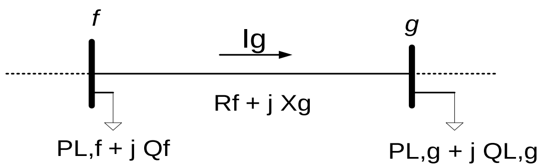

Fig.1 single line schematic diagram for the power flow

The line current flowing in the distribution feeder is calculated as follows:

$$\tilde{I}_g = \frac{V_f\angle\delta_f - V_g\angle\delta_g}{R_g + j\,X_g} \qquad (1)$$

where, R_g Acts the feeder resistance and X_g acts the distribution feeder reactance. The consumed power by the loads is given by:-

$$P_g - j\,Q_g = \tilde{V}_g * \tilde{I}_g \qquad (2)$$

From equations (1), (2), the voltage amplitude at bus g can be calculated as shown in equation (3).

$$V_g = \left\{\left[\left(P_gR_g + Q_gX_g - \frac{|V_f|^2}{2}\right)^2 - ({R^2}_g + {X^2}_g)({P^2}_g + {Q^2}_g)\right]^{1/2} - \left(P_gR_g + Q_gX_g - \frac{|V_f|^2}{2}\right)\right\}^{1/2} \qquad (3)$$

The active power flow P_g and reactive power flow Q_g in the system are calculated equations (4) and (5) as follow:

$$P_g = \sum_{j=g}^{N-1} P_{L,j} + \sum_{j=g}^{N-1} P_{loss,j} \quad (4)$$

$$Q_g = \sum_{j=g}^{N-1} (Q_{L,j}) + \sum_{j=g}^{N-1} (Q_{loss,j}) \quad (5)$$

Where, N is buses number, $P_{L,j}$ and $Q_{L,j}$ is active and reactive powers of loads at bus j, respectively, $P_{loss,j}$ is real power loss and $Q_{loss,j}$ is reactive power loss in the feeder,

$$P_{loss,fg} = \frac{R_{fg}(P^2_{fg}+Q^2_{fg})}{|V_f|^2} \quad (6)$$

$$Q_{loss,fg} = \frac{X_{fg}(P^2_{fg}+Q^2_{fg})}{|V_f|^2} \quad (7)$$

The total system loss is calculated by summing all power loss for all feeders in the network according to this equation:

$$P_{T,loss} = \sum_{f=1}^{Nb} K_{fg} P_{loss,fg} \quad (8)$$

Where, N_b is number of all feeders of the system, K_{fg} is a binary variable that acts the topological state for the feeder in the radial distribution network. The optimization problem is expressed in terms of its objective function "F" as follows:

$$\mathbf{F = min\ (P_{T,loss})} \quad (9)$$

Where, F represents the objective function of the reconfiguration process. The aim of the objective function is to reduce the total network power losses with keeping the following operation constraints: -

1. Radial status: it means that after reconfiguration process, the network must not contain any closed loops.
2. Feasibility: it means keeping the continuous power supplying to all connected loads in the network after the reconfiguration process.
3. Bus Voltage: the bus voltages should not exceed its permissible boundaries as seen in (10).

$$V_f min < |V_f| < V_f max \quad (10)$$

$$0.9 \leq |V_f| \geq 1$$

4. Feeder current: it must still within its permissible boundaries.

$$K_{fg} I_f < I_f max \quad , f \in [1, 2, \dots\dots Nb] \quad (11)$$

5. Kirchhoff's current law and voltage law, respectively.

$$g_i(I, K) = 0 \quad (12)$$

$$g_v(V, K) = 0 \quad (13)$$

II. Harris' Hawks Optimization Algorithm

In HHO algorithm, there are two phases for getting the prey; exploration and exploitation phases, they are inspired from exploration of the prey, the sudden attacking of the hawks and the variety of intelligence methods for attacking the prey [42]. The hawks' behavior to attack the prey is shown in fig.2

Fig.2 Harris's hawk and their sudden attacking behavior

A. Exploration phase

Hawks move in in all directions to detect the prey. Hawks can update their location based on equation (14).

$$\boldsymbol{X(t+1)} = \begin{cases} \boldsymbol{x_{rand}}\,(\mathbf{t}) + \boldsymbol{r_1}\,|\boldsymbol{x_{rand}(t)} - \mathbf{2}\,\boldsymbol{r_2 x(t)}| & \mathbf{q} \geq \mathbf{0.5} \\ (\boldsymbol{x_{rabbit\,(t)}} - \boldsymbol{x_m(t)}) - \boldsymbol{r_3}(\boldsymbol{lb} + \boldsymbol{r_4}(\boldsymbol{ub} - \boldsymbol{lb})) & \boldsymbol{q} < \mathbf{0.5} \end{cases} \quad (14)$$

Where, x(t+1) is the location vector of the hawks in the iteration, t+1, x_{rabbit} acts the location of rabbit, x(t) is the current location of the hawks, r_1, r_2, r_3, r_4 and q are stochastic numbers have values in the range [0,1] , ub and lb are upper and lower boundaries of the variables, x_{rand} (t) is a position of a hawk that is randomly selected , x_m is the mean of the location of the hawks that is defined by equation (15).

$$\boldsymbol{x_m}\,(\mathbf{t}) = \frac{\mathbf{1}}{\boldsymbol{N}} \sum\nolimits_{\boldsymbol{i}=\mathbf{1}} \boldsymbol{x_i}\,(\mathbf{t}) \quad (15)$$

B. Transformation from exploration mode to exploitation mode

HHO can be transferred from exploration phase to exploitation phase, then, the altering between the different exploitative techniques is done depending on the escaping energy value of a rabbit or prey that minimizes when escaping action, this escaping energy can be expressed by equation (16).

$$\mathbf{E} = \mathbf{2}\,\boldsymbol{E_0}\,(\mathbf{t})\,(\mathbf{1} - \frac{\boldsymbol{t}}{\boldsymbol{T}}) \quad (16)$$

where, E refers to the prey escaping energy, t express the current iteration, T expresses maximum iteration, E_0 express an initial escaping energy of the prey, it alters randomly through the range [-1,1]. When the escaping energy reduces from -1 to 0, it means that the prey is weakening and when the escaping energy rises from 1 to 0, this mean that the prey / rabbit is forcing. The exploration process is done when magnitude of escaping energy is equal or more than one $|E| \geq 1$ and the exploitation process starts as well as the magnitude of escaping energy is lower than one $|E| < 1$.

C. Exploitation phase

In this stage of hunting the prey the populations of hawks make a sudden attacking, while the prey attempt to escape by different intelligent styles during this dangerous situation. This phase contains occurring four different chasing techniques. The hawks make two types of blockade around the prey: soft blockade and hard blockade / besiege to hunt the prey.

1. Soft blockade

If the prey ha5 the values of these variable r ≥ 0.5 and magnitude of $E \geq 0.5$, in that case the prey still have some energy enable it for escaping randomly in random directions and the hawks encircle the rabbit to attack it abruptly, so the position of the hawks during that behavior is defined as:

X (t+1) = $\Delta\, \boldsymbol{x}\,(\boldsymbol{t})$ **- E**$|\boldsymbol{J}\boldsymbol{x}_{rabbit}(\boldsymbol{t}) - \boldsymbol{x}_m(\boldsymbol{t})|$ (17)

$\Delta\, \boldsymbol{x}\,(\boldsymbol{t}) = \boldsymbol{x}_{rabbit}(\boldsymbol{t}) - \boldsymbol{x}(\boldsymbol{t})$ (18)

where, *J* express the stochastic jump force of prey J= 2(1-r_5)

2. Hard blockade

This besiege at r ≥ 0.5 and magnitude of $E < 0.5$ at that the escaping energy decreasing notably, the position vector of hawks' population is:

X (t+1) = $\boldsymbol{x}_{rabbit}(\boldsymbol{t}) - \boldsymbol{E}\,\Delta\boldsymbol{x}(\boldsymbol{t})$ **(19)**

In this case the hawks circle hardly the rabbit and make sudden attack. This behavior is shown in fig.3

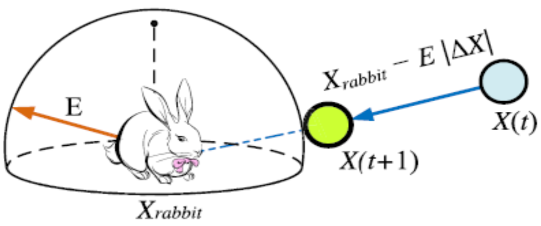

Fig.3 Overall vectors in the case of hard blockade

3. Soft blockade with progressive rapid flop

This behavior occurs when amplitude of E≥ 0.5,$r < 0.5$. Prey has sufficient energy for escaping and the blockade is soft before the sudden attacking. To model the leapfrog motion and escaping mechanism, the levy flight idea is used in the HHO technique, which simulate the zigzag motion of the prey. Inspiring from the attitude of hawks, by suggestion that the hawks able to select the best flop to attack the prey. Therefore, to carrying the soft blockade out, suggest that the hawks decide the next position depending on equation (20).

Y= $\boldsymbol{x}_{rabbit}(\boldsymbol{t}) - \boldsymbol{E}\,|\boldsymbol{J}\boldsymbol{x}_{rabbit}(\boldsymbol{t}) - \boldsymbol{x}_m(\boldsymbol{t})|$ **(20)**

Hawks start to make irregular, sudden and quick flop when oncoming from the rabbit based on levy flight (LF) based rule:

Z = Y+ S * LF (D) (21)

Where, D refers to the problem dimensions, S refers to stochastic vector its size is $1 * D$ and LF refers to the levy flight function. The flight function is determined by following equation:

$$LF(x) = 0.01 * \frac{u * \sigma}{|v|^{\frac{1}{\beta}}} \quad \textbf{(22)}$$

$$\sigma = \left(\frac{\Gamma\,(1+\beta) * \sin(\frac{\pi * \beta}{2})}{\Gamma\left(\frac{1+\beta}{2}\right) * \beta * 2^{\left(\frac{\beta-1}{2}\right)}} \right)^{\frac{1}{\beta}} \quad \textbf{(23)}$$

where, u and v are random variables inside the range of (0, 1), β is a default variable has value of 1.5. Finally, the hawks update their positions as equation:

$$\mathbf{X\ (t+1)} = \begin{cases} Y & if\ F(Y) < F(X(t)) \\ Z & if\ F(Z) < F(X(t)) \end{cases} \quad \textbf{(24)}$$

This step is shown in fig.4, the position history of the jump motion that based on the levy flight function. Colored dots Refer to the footprints of jump motion, then HHO arrive to position Z. In every step, better location is Z or Y is selected, all search agents perform this method (strategy).

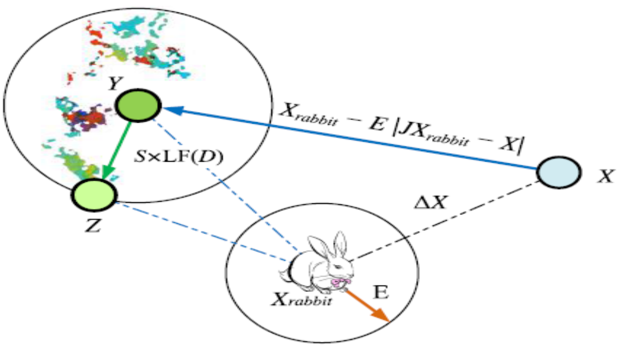

Fig.4 the overall vectors at Soft blockade with progressive rapid flop.

4. Hard blockade with progressive quick flop

This behavior is done when the magnitude of E < 0.5 and also value of r < 0.5, at that situation a prey hasn't the sufficient energy for escaping from hawks and hawks make a hard besiege before attacking the prey. The hawks update the next position based on this equation:

$$\mathbf{X\ (t+1)} = \begin{cases} Y & if\ F(Y) < F(X(t)) \\ Z & if\ F(Z) < F(X(t)) \end{cases} \quad \textbf{(25)}$$

$$\mathbf{Y} = x_{rabbit}(t) - E\,|Jx_{rabbit}(t) - x_m(t)| \qquad \mathbf{(26)}$$

$$\mathbf{Z = Y + S * LF\ (D)} \qquad \mathbf{(27)}$$

Pseudo-code of HHO algorithm

Inputs: The size of the population N and maximum number of iteration T.
Outputs: the prey location and fitness value initialize population randomly X_i (i=1,2,…..,N)
While (if the condition isn't met the procedure, it stops) do
Determining the fitness values of the hawks.
make (X_{rabbit}) as the position of rabbit (the best position) for (every hawk (X_i)) do
Updating the initial energy E_0 and the jumping strength J
E_0 = 2rand () -1, J = 2(1-rand())
Updating the value of the variable E using equation (16).
If ($\|E\| \geq 1$) it is Exploration phase
Updating the position vector by equation (14)
If $\|E\| < 1$ it is Exploitation phase
If $r \geq 0.5\ and\ \|E\| \geq 0.5$ it is soft blockade
Updating the position vector by equation (17)
Else if $r \geq 0.5$ and $\|E\| < 0.5$, then Hard blockade
Update the location by equation (19)
Else if $r <$ 0.5 and $\|E\| \geq 0.5$ then
With progressive quick flop
Updating the position vector using equation (24)
Else if $r <$ 0.5 and $\|E\| < 0.5$ then_____Hard blockade
With progressive quick flop
Updating the Position Vector by using equation(25)

Return X_{rabbit}

III. SIMULATION RESULTS & ANALYSIS

This paper suggests population of Harris hawks is considered as search agents which produce fifty different solutions per each iteration. For every iteration, every search agent produces one solution in item of five switches that are selected from the system with open status and form a new topological configuration as an output of the proposed algorithm. The total solutions (50 solution) are collected in a matrix with size 50*5. The network is considered to have five search spaces as five meshes which are acted by a matrix. Search agent detects one switch from each search area to open it, the selected switch to be in open case with keeping the radial formation of the tested distribution network. In every obtained solution, overall power loss is calculated using Newton Raphson load flow calculation method and the proposed algorithm defines the global best obtained solution. After 100 iterations, the presented optimization technique provides the overall minimal power loss.

To evaluate the accuracy and efficiency of the suggested HHO technique against the combinatorial and complex reconfiguration procedure and then power loss minimization, the standard IEEE radial distribution systems of 33 bus have been applied for this simulation. Lines data and loads data of the proposed system are provided in [42-46]. Whereas the base voltage at substation is 12.66 KV, overall system real power is 3715 KW and reactive power equal 2300 KVA. Before process of reconfiguration, the overall active power loss is 211.0194 KW. There are 5 tie switches acted by dashed feeders and other 32 sectionalizing switches acted by solid lines as shown in Fig. 5. The MATLAB is used to implement the HHO algorithm for the optimal reconfiguration of switches combination. MATLAB programming code is used to estimate desired solution with parameters summarized in Table I.

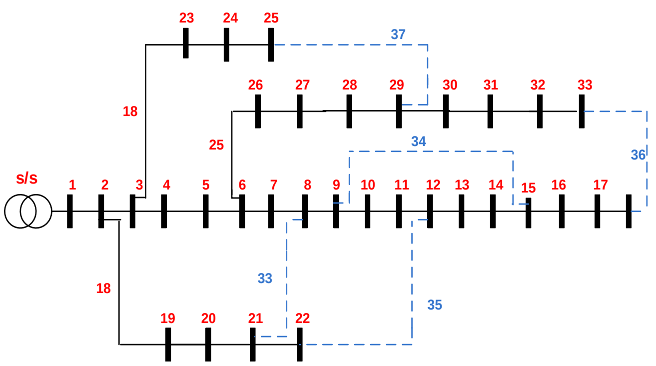

Fig. 5 IEEE 33-Bus distribution network before reconfiguration procedure.

Simulation outputs proved that HHO algorithm can provide enough solution for objective reconfiguration issue, with avoiding occurring local optima or stagnation. The HHO provides good exploration, exploitation and achieve the overall best solution faster than other optimization techniques. Fig.6 reviews the relation between total real power losses and number of iterations. Convergence characteristics prove that the presented method retain the optimal power loss at a satisfied simulation time.

The optimum real power losses after changing the construction using the presented algorithm is 130.8164 KW with tie switches of order (4, 14, 15, 22, and 33) in open status that achieve an optimum configuration of the system as in Fig.7. Table II overviews the result of proposed optimization algorithm when it is compared with other algorithms in terms of tie switches, total real power loss and percentage of power loss. Varying the configuration of network of network varies the bus voltage profile of system as in Fig. 8. This show the efficiency of presented algorithm and ability for solving that combinatorial optimization reconfiguration issue.

TABLE I. PARAMETERS USED IN HHO PRESENTED OPTIMIZATION ALGORITHM

Population size	50
Maximum iteration	100
Dimension of problem	5
Voltage boundaries	0.9≤ Vi ≤1

TABLE II. THE POWER LOSSES OBTAINED BY HHO ALGORITHM COMPARED WITH RESULTS OF OTHER TECHNIQUES.

Algorithm	**Presented (HHO)**	**EGA** [38]	**SPSO** [40]	**FEB**[6]
Real Power loss (KW)	**130.8164**	139.55	138.92	139.83
Tie Switches Combination	**4, 14, 15, 22, 33**	7, 9, 14, 32, 37	7, 9, 14, 32, 37	7, 9, 14, 28, 32
Real Power Loss Reduction (%)	**38.0074 %**	33.86 %	33.36 %	33.79 %

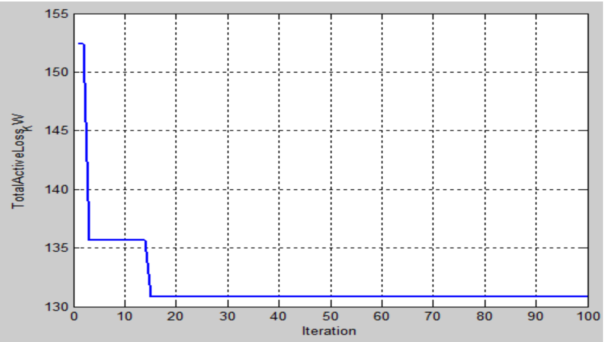

Fig. 6 Convergence characteristics of presented HHO algorithm

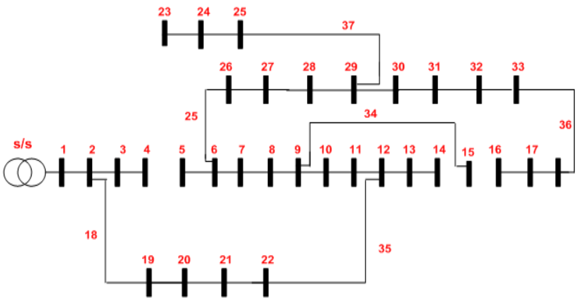

Fig. 7 IEEE 33-Bus radial Distribution network after reconfiguration by HHO technique.

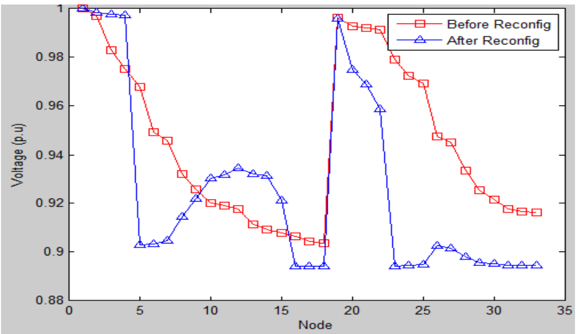

Fig. 8 bus voltages profile resulting from network reconfiguration by HHO algorithm.

IV. CONCLUSION

A new intelligent global optimization algorithm is presented in this paper for obtaining the optimum solution of reconfiguration problem for the radial distribution network called the Harris Hawks Optimization (HHO) algorithm. Inspiration in that algorithm is excluded from the hawks' behavior when catching the rabbit as a prey. The presented technique is efficiently selecting the optimal switches assembly for reconfiguration of radial distribution network and minimize the total real power loss of the standard IEEE 33-bus radial distribution network. The obtained simulation results stated that the real power loss is minimized with 38.0074 % compared to the original state after reconfiguration process. Obtained results shows that the HHO algorithm is effective and robust for radial distribution network reconfiguration to minimize the total active power loss comparing with other algorithms as noted in table II. Convergence characteristics of the presented HHO proved that it provides an optimal solution for combinatorial and difficult optimization problem and help well in the operation of the present and future planning systems.

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