# Distribution Network Reconfiguration Under Uncertainties In Load And Renewable Generation Forecast

**Arjun Tyagi, Krishan Kumar, Kamaldeep, Nitin Tyagi and Vinaya Rana**

**Abstract :**Nowadays, forecasted data for load and renewable generation is available with a very short time interval. These load and renewable generation forecasts always have uncertainties. Hence, in the presence of renewable-based distributed generations, conventional approaches of reconfiguration may not be effective. Very few efforts in a probabilistic manner exist to perform these types of uncertainties. It requires the historical database to be presented. It is still a challenge to account for the haphazard uncertainties. Hence, the uncertainties in load and forecasts of renewable generation are considered in this work and the optimal reconfiguration of the distribution network is proposed.

**Index Terms**: Boundary power flow, distribution network, forecast, optimization, reconfiguration, renewable generation, uncertainties.

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## 1 INTRODUCTION

In the recent years, the increasing use of distributed generations (DGs) based on renewable energy in distribution network is creating new type of challenges in the operation and planning of distribution network. Moreover, in present distribution network, the change in system configuration is not too frequent. However, in future distribution networks/grids the distribution network reconfiguration will become much more appropriate and frequent [1,2]. Due to these envisioned capabilities, the distribution network reconfiguration gains the significant consideration of power system researchers [3-5]. Extensive research has been carried out on distribution network reconfiguration with various objective and algorithms. A well-established branch exchange (BE) approach is proposed in [6-8]. In this method, by changing the on/off state of switches, load is transferred from one feeder. In [9], utilized two essential components of meta-heuristic algorithms: solution representation and fitness evaluation. It employed decimal encoding as an alternative of the popular binary and integer encoding, which assure the radial tree structure in least effort. A vector shift operation-based algorithm in view of DGs is presented in [10]. In this method, the power loss variation is calculated after branch exchange using power vectors and resistance instead of highly computationally challenging load flow calculations. Various optimization algorithms are also applied in distribution network reconfiguration as, particle swarm optimization (PSO), genetic algorithm [11-13], and improved harmony search algorithm. In [14], two two-stage method is proposed, in which heuristics from first phase are utilized in second phase to minimize the high computational constraint of metaheuristic algorithms. In [15], a hybrid distribution network reconfiguration of PSO technique with the inclusion of ant colony optimization (ACO) technique is proposed for optimum distribution network reconfiguration with the inclusion of distributed generation (DG). These optimization algorithms have limitation of high computational burden especially for large systems [16]. Due to fast depletion of fossil fuel resources, and more importantly, due to serious environmental concerns, the renewable power generation (especially wind and solar) penetration in distribution network has been increasing at a very high rate. The DGs have various other operational benefits as system reliability, power loss reduction, power quality enhancement and voltage profile improvement. In the last decade, extensive work has been carried out to examine the optimal location and size of DGs. The overviews of the state of art is presented in [17]. Besides, a grey wolf optimization algorithm for the placement of DG at optimal location is used in [7]. Optimal placement of DGs are done to satisfied various objectives as enhancement of voltage stability, power loss minimization and multi-objective optimization. A harmony search algorithm to resolve the problem of network reconfiguration with the placement of DG and its size is presented in [18]. Considering the power loss sensitivity in the optimal location of DGs in respective branch with respect to the load power at branch end. In the proposed methodology, the DG should not install at the location of busses which gives the maximum reduction in losses [19-21]. Despite their significant advantages, distributed renewable energy resources have problems of high uncertainty. Moreover, loads are also the most vital and unpredicted part of distribution network. Therefore, the uncertainties associated with load and renewable generation need to be incorporated in distribution network reconfiguration. Very few efforts are present which considers these uncertainties in a proper manner [16]. It is required the previous data to be presented. Accounting of haphazard uncertainties still remains a challenging task. Hence, this paper aims to report this specific problem; it presents a boundary power flow (BPF) embedded distribution network reconfiguration with the inclusion of

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handling the non-statistical uncertainties of the load and the renewable energy resources.

## 2 FRAMEWORK OF PROPOSED METHODOLOGY

The distribution network consists of two switches; sectionalizing switch and tie switch. Normally open switches are tie switches and sectionalizing switch are normally closed switches. In this work, both sectionalize and tie switches are used for the participation in the distribution system reconfiguration process. The proposed algorithm utilizes the boundary power flow [2] to consider the non-statistical uncertainty conditions with the connotation of load and renewable generations forecast. Using boundary power flow, for a given range of input data the output variable range can be obtained. Therefore, the data range can also be used instead of crisp data by the system designer/planner, to address the uncertainties. The optimization of discrete nature of switch opening/closing can be achieved efficiently by a meta-heuristic technique. This work used the grey wolf optimization (GWO) technique, due to its faster convergence and arbitrary parameters selection/tuning.

## 3 MATHEMATICAL MODELING

### 3.1 Proposed Objective

The main objective of the proposed methodology is to identify the optimal reconfiguration of the distribution network, so that the total losses remain minimum when uncertainties of load demand and DG generation are taking into account. Using boundary power flow technique, the range of output variables can be calculated for the definite range of input data. So, the objective is to minimize the boundary total power loss. The boundary total active power losses are calculated with the removal operation as:

$$F_{removal\ P_L} = Minimize\ \{removal\ P_L\} \qquad (1)$$

In sequence to calculate the total loss in the existence of particular range of random uncertainties, upper-lower limit values of active losses in active power are calculated as in [3, 4]. With the help of BPF the active power loses can be found. To find the breakpoints of output variables in boundary power flow approach, a number of crisp solutions for power flows are required. The relationship between active power loss at two breakpoints, subjected to their minimum and maximum limits is shown in Fig. 1.

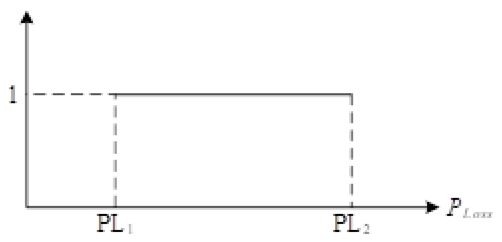


*Fig. 1 . Distribution of active power losses in rectangular*

Depending upon the calculation of min or max value for output variable using boundary power flow, the crisp input variable set is selected from the range of input variables. The min and max values of output variable with respect to the solution of uttermost case. Therefore, removal function of rectangular possibilities of boundary value calculation of active power loss is written as (PL1+PL2)/2.

$$removal\ P_l = \frac{P_{l\_boundary}^{upper} + P_{l\_boundary}^{lower}}{2} \qquad (2)$$

Where, $P_{l\ boundary}^{upper}$ is upper and $P_{l\ boundary}^{lower}$ lower boundary values for output variable Pl.

Subjected to the following constraints:

$$V_i \sum_{j=1}^{n} V_j \left(g_{ij} cos\theta_{ij} + b_{ij} sin\theta_{ij}\right) - P_i^D = P_i \qquad (3)$$

$$V_i \sum_{j=1}^{n} V_j \left(g_{ij} sin\theta_{ij} - b_{ij} cos\theta_{ij}\right) - Q_i^D = Q_i \qquad (4)$$

$$V_i^{min} \leq V_i \leq V_i^{max} \qquad (5)$$

$$I_l \leq I_l^{max},\ l=1,2\ldots NL \qquad (6)$$

Feasibility and Radiality: For feasibility, All the nodes must have a connection with a node/line, no other node should be disconnected. For radiality, to maintain the system in radial, each loop must have one branch opened. And both the conditions satisfied simultaneously.

Where, $P_i^G$ is the generated power and $P_i^D$ is the demand power at the i<sup>th</sup> bus. (i,j)<sup>th</sup> element of bus admittance matrix has terms $g_{ii}$ is the real term and $b_{ii}$ is the imaginary term. The voltage at i<sup>th</sup> bus is $V_i$. $V_i^{min}$, min voltage limit and $V_i^{max}$ is max voltage limit. $I_l$ is the current in l<sup>th</sup> branch and $I_l^{max}$ is the corresponding maximum limit of current flow.

### 3.2 Algorithm

For algorithm design basic concept of the proposed algorithm is required which is well explained in section 2. The basic stages of Grey wolf optimization algorithm for reduction in boundary active power loss are given in this section and the complete steps with neat flow chart diagram GWO is well explained in Fig. 2.

The detailed stepwise description is given as:

1. Take the data of system.
2. Initialize the algorithm parameters (gray wolves position $\acute{X}_p(i)$ and parameters $\vec{a}$, $\acute{A}$ and $\acute{C}$).
3. Initially develop the switch opening matrix randomly.
4. Perform the distribution network load flow considering crisp system data to calculate the Jacobian matrix ‘J’ and evaluate for the constraint destruction.
5. If a single constraint is desecrated, go for the new switch opening matrix.
6. If all the constraints are satisfied, perform the boundary power flow analysis for a given area of uncertainties in generation and load.
7. The extreme point of active power loss Pl upper/lower is evaluated as:
   $$P_{l\ upper/lower} = P_{l\ 0}^{m} + H\left(Y_{sp} - Y_{cal}\right) \qquad (7)$$
   Where, H = sensitivity vector with the elements of $H_j$.
   $H_j$ = sensitivity of Pl with the change in generation/load at j<sup>th</sup> bus.
8. Calculate the objective function F(x) for Grey wolf optimization technique as given in Equation 1.
9. Evaluate fitness value for each search agents and

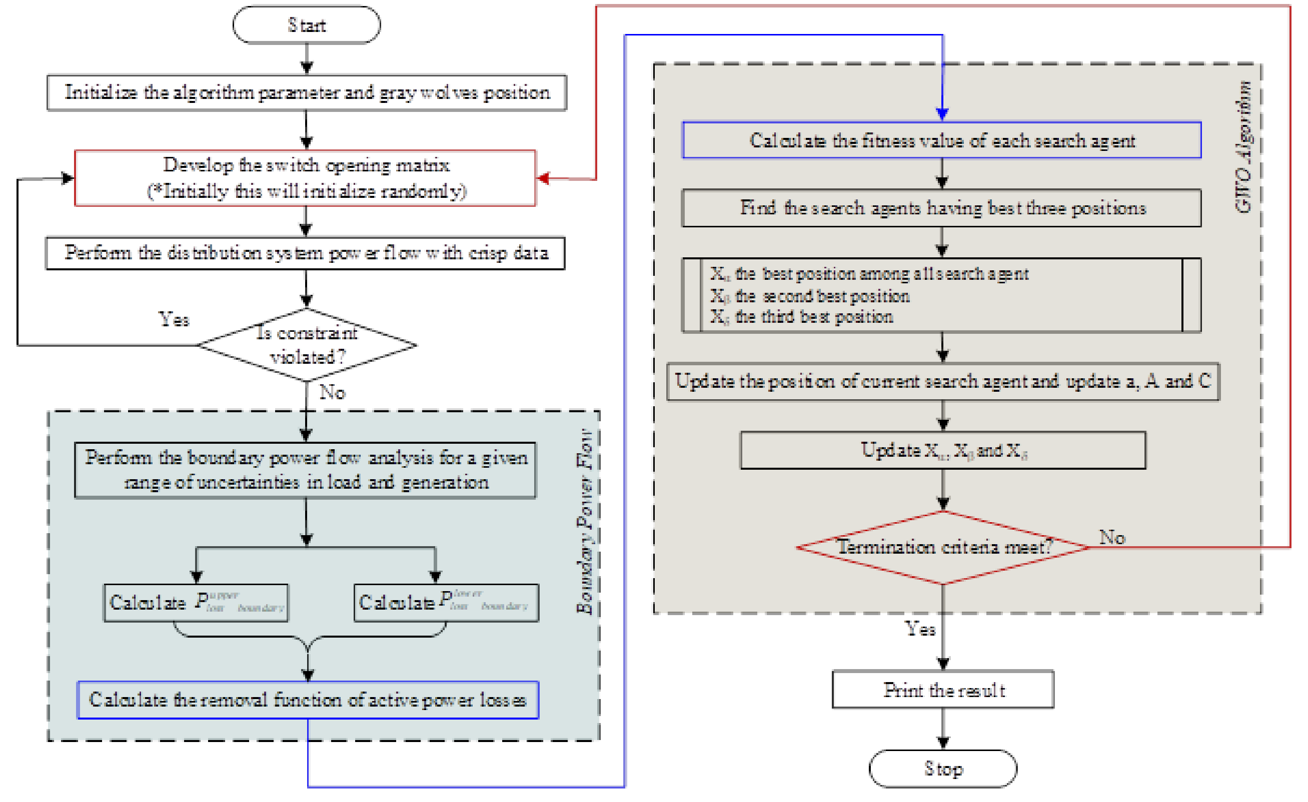


***Fig. 2**. Proposed flow chart for GWO algorithm*

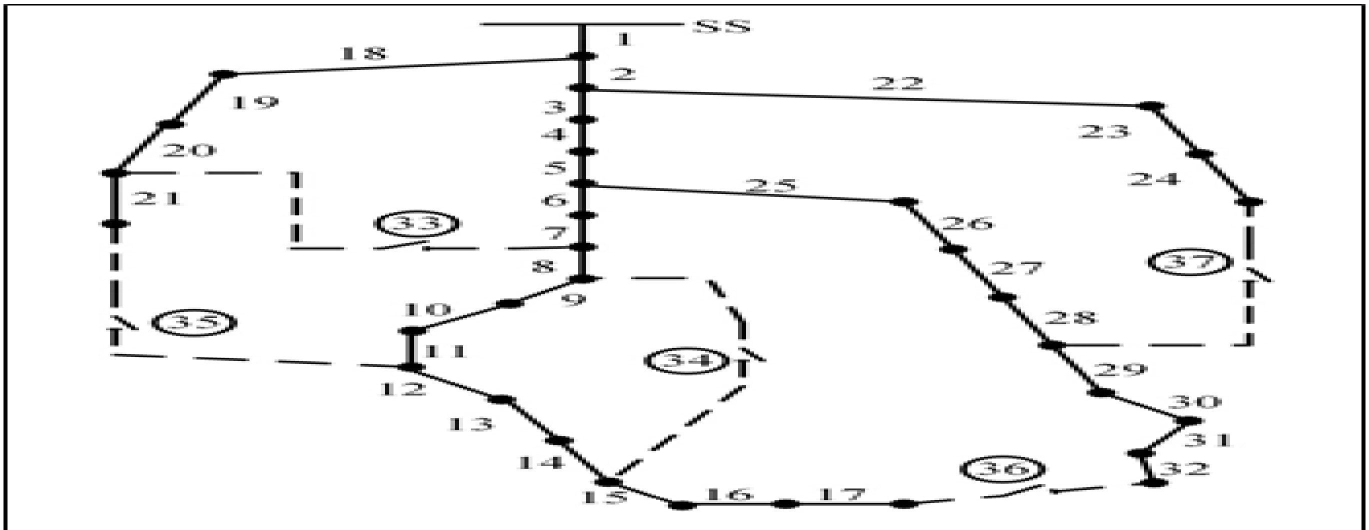


Fig. 3. Layout of standard 33-bus distribution network

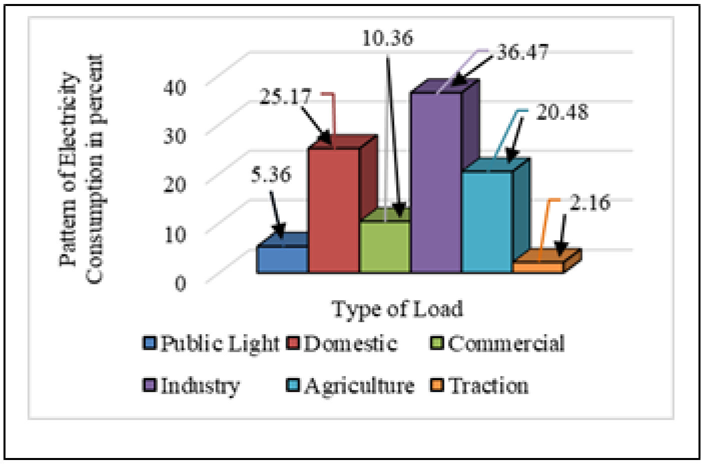
calculate the search agents having first, second and third best positions as

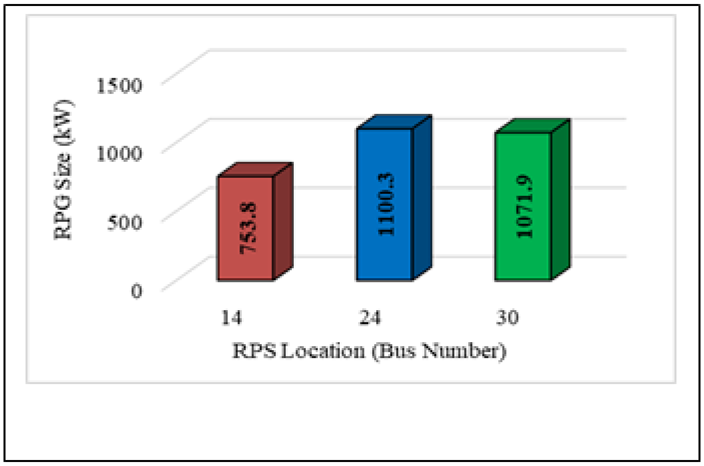
$X_\alpha$ → The best position among the all search agent.
$X_\beta$ → The second-best position among the all search agent.
$X_\delta$ → The third best position among the all search agent.

10. Change the location of each agent of current search and update the parameters $\vec{a}$ $\vec{A}$ and $\vec{C}$.
11. Change $X_\alpha$, $X_\beta$ and $X_\delta$.
12. Check for the termination criteria, if termination criteria is met, then print the position of $X_\alpha$ (This position matrix is the switch opening matrix); else go to the Step 4.

## 4 DISCUSSION ON RESULTS

The proposed technique is established on standard 33-bus [5] distribution network. The representation of the tested system is shown in Fig. 3. There are total 33 nodes and 37 lines, among them the dotted line 33, 34, 35, 36 and 37 are the tie lines. In this research, all lines and sectionalizing switches are taken into account for the participation in reconfiguration. In this work, loads are divided into various categories as domestic, commercial, industry, agriculture, traction and public light. It is considered that these loads are equally distributed on each bus. Percentage electricity consumption of different types of loads is shown in Fig. 4 [6].





In 33-bus distribution network, the initial losses found are 202.68 kW. Three renewable based distributed generators are placed optimally at buses 14, 24 and 30. The location of the DGs are found using the algorithm proposed in [7], and the total DG penetration is kept around 80%. The size and location of renewable power sources (RPS) is shown in Figure 5. By optimal placement of the renewable power sources in 33-bus distribution network, the losses are reduced by 64.74% as compared to the base case (without RPS). Optimal reconfiguration is evaluated with the help of boundary value approach implanted GWO for the different cases given as:

- Case I (a): Reconfiguration is done with 0% uncertainty in generation and load.
- Case I (b): Reconfiguration is done with 0% uncertainty. However, losses of reconfigured network are calculated with ±5 % ambiguity in the load at each bus and ±20 % ambiguity in renewable power generation.
- Case II: Reconfiguration is done by proposed boundary value approach embedded GWO algorithm with ±5 % ambiguity in load at each bus and ±20 % ambiguity in generation of renewable power.

After applying the reconfiguration in the presence of renewable power sources (Case I (a)) the losses are reduced by 14.96 % as compared to without reconfigured system. But if we use similar reconfiguration in the presence of ±5 % uncertainty in load and ±20 % uncertainty renewable generation (Case I (b)), then the losses are increased as compared to Case I (a), as shown in Table 1. Moreover, in the presence of load and renewable generation uncertainties, after applying the proposed algorithm (Case II) the switches 7, 8, 9, 32 and 37 remain open and losses are reduced by 5.28 % as compared to Case I (b). The benefit is shown in Table 1 are for peak load conditions and for one time instant only. However, the cumulative benefit would be very significant over a period of month or year. It can be detected from the Table 1, that the optimal switches and losses with uncertainties may be different than without uncertainties. The study is also performed at lower DG penetration. Table 2 shows the comparative results with 55% DG penetration. In this study, three renewable based distributed generators of size 453.81, 820.34 and 771.91 kW are considered at bus 14, 24 and 30 respectively. With 55% DG penetration the system losses are reduced to 85.0203 kW and further reduce to 63.2742 kW by applying the reconfiguration (Case I (a)). But, if we use similar reconfiguration of Case I (a), in the presence of ±5 % uncertainty in load and ±20 % uncertainty in renewable generation (Case I (b)), then the losses will increase. However, in the presence of load and renewable generation uncertainties, after applying the proposed algorithm (Case II), the losses are reduced as compare to Case I (b), as shown in Table 2.

***TABLE 1***

*QUALIFIED ANALYSIS FOR 33-BUS DISTRIBUTION NETWORK WITH 80% DG PENETRATION*

| Case | Losses (kW) | Switches to Open |
|---|---|---|
| Before Reconfiguration (with DGs) | 71.4575 | 33, 34, 35, 36, 37 |
| Case I (a) | 60.7662 | 7, 11, 21, 32, 37 |
| Case I (b) | 62.5093 | 7, 11, 21, 32, 37 |
| Case II | 59.2043 | 7, 8, 9, 32, 37 |

***TABLE 2***

*COMPARATIVE RESULTS FOR 33-BUS DISTRIBUTION NETWORK WITH 55% DG PENETRATION*

| Case | Losses (kW) | Switches to Open |
|---|---|---|
| Before Reconfiguration (with DGs) | 85.0203 | 33, 34, 35, 36, 37 |
| Case I (a) | 63.2742 | 7, 9, 13, 28, 32 |
| Case I (b) | 65.0078 | 7, 9, 13, 28, 32 |
| Case II | 64.7293 | 7, 9, 13, 28, 36 |

## 3 CONCLUSION

This work presents a simple and efficient technique for reevaluation of distribution networks under uncertainties of load and renewable power generation. The proposed process uses limit power flows to deal with non-statistical uncertainties associated with load and renewable power generation forecasts, models and system parameters. The objective range is to minimize active power loss. GWO algorithm is considered to reduce the active power losses using reconfiguration. Results for 33-bus distribution networks demonstrate the potential and need for handling non-statistical uncertainties in generation and load at each bus. The proposed method in this work can be easily applied for reconfiguration of complex power distribution networks.

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