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Multi-Objective Optimization for Optimal Photovoltaic Source Placement and Size in Distribution Network using Metaheuristic Approach

Samir H.Oudjana[1], Mustafa. Mosbah[2]*, Salem. Arif[2], Ridha Djamel. Mohammedi[3]

[1]*Unité de Recherche Appliquée en Energies Renouvelables, (URAER), Ghardaia, Algeria*
[2]*LACoSERE Laboratory, Department of Electrical Engineering, Amar Telidji University of Laghouat, Laghouat, Algeria*
**Engineer Operating in Company of Algerian Distribution Electricity and Gas*
[3]*Department of Electrical Engineering, University of Djelfa, Djelfa, Algeria*
[1] *samirehamid@yahoo.fr*

***Abstract*— this paper present a multi-objective optimization approach to determine the optimal location and size of Photovoltaic Source (PVS) in electrical distribution networks. The fitness functions considered in this work to minimize active power losses and improvement voltage stability index. The hybrid metaheuristic technique based on non-dominated sorting genetic algorithm and fuzzy logic(NSGA-II/FL) algorithm is applied to determine the best solutions. The proposed technique is tested on IEEE networks (10, 34, and 85 bus) and validated on Algerian distribution network (116 bus).**

***Keywords*— Photovoltaic source, distribution network, NSGA-II optimization, multi-objective, active power losses, voltage stability index.**

I INTRODUCTION

Sources is massively deployed in power system. Indeed, by dint of renewals technological in the field of renewable energies, and with the development of new energy laws, national and international incentives to use these energies, and with the constraint of climate change, it is expected that the penetration of renewable sources connected to the Algerian electricity grid will continue to increase significantly in the coming decades [1].

Multiple projects have been set up by the Algerian Ministry of Energy to take advantage of this source whose forecast and to have 30% of the national production is to provide renewable sources by 2030 [2, 3]. The different types of sources interested in this program are: solar thermal, solar photovoltaic, wind, geothermal and biomass. At the end of 2017, an important program was developed on the Algerian networks namely, 344.1 MW in photovoltaic, a wind farm of 10.2 MW, a solar thermal source with a capacity of 25 MW. According to the projected program for the horizon of 2030, photovoltaic energy has the largest share. For this purpose this study focuses on the location of PVS. The challenge for a power system operator is to have the proper size and location of these sources in the power system. Note that a non-optimal integration of PVS will cause negative impacts, as example, exceeding voltage admissible limits, exceeding transit capacity for some equipment, protection dysfunction against short circuits, power losses increasing [4].

The efficient solution to avoid this impact passes throw optimal integration of PVS. Size and location optimization on PVS in distribution network is a nonlinear problem with constraints that requires an optimization technique. In literature, many different types of optimization techniques have been used in solving the optimal PVS placement and size in distribution network. Many methods have been proposed in the literature for DG placement and size in distribution network [5-22].

In this paper a hybrid metaheuristic technique based on NSGA-II/FL has been proposed to determine the optimal placement and size of PVS in distribution network.

II PROBLEM FORMULATION

A. *Objective function*

The PVS placement and size problem is formulated as a multi-objective function considering minimization of active power losses and enhancement of voltage stability index as objectives while satisfying all constraints of distribution network. Two objective functions considered in this study are:

1) *Minimization active power loss*

In radial distribution networks, each receiving bus is fed by only one sending bus. From Fig. 1, the line losses between the receiving and sending end buses P_{loss} (can be calculated using eq. 1.

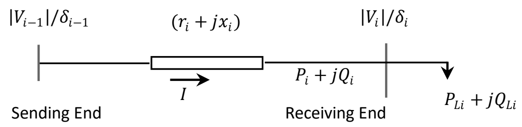


Fig. 1.One line diagram of a two-bus network

$$P_{loss}(i) = I_i^2 R_i = \frac{S_i^2}{V_i^2} R_i = \frac{P_i^2+Q_i^2}{V_i^2} \quad (1)$$

Therefore, the first objective function is calculated as follows:

$$f_1 = P_{loss} = \sum_{i=2}^{Nbus} P_{loss} \quad (2)$$

where $|V_i|,$ is angle and complex voltage at the i^{th} bus, $(r_i + j$ is the impedance of the line connecting buses $i -$ and , $(P_i, Q$ are the active (resp. reactive) power injections at the i^{th} bus, N_i is the number of buses.

2) Maximization voltage stability index

The voltage stability indicator (SI) proposed by *Chakravorty* and *Das* [23] is chosen as objective for the improvement of the stability of the tension. According to Fig. 1, the stability index calculated as follows:

$$V_{i-1}/\delta_{i-1} - V_i/\delta_i = I.(r_i + jx \quad (3)$$

$$(V_i/\delta_i)^*.I = P_i - jQ_i \quad (4)$$

where I is the current amplitude and '*' symbolizes the complex conjugate operator. From Eqs. (3) and (4), we get :

$$V_i^2 - V_i.V_{i-1} + \sqrt{(P_i^2 + Q_i^2).(r_i^2 + x_i^2)} = 0 \quad (5)$$

Roots of Equation (5) are real if

$$V_{i-1}^2 - 4.\sqrt{(P_i^2 + Q_i^2).(r_i^2 + x_i^2)} \geq \quad (6)$$

From this, the voltage stability index for bus i (SI_i) is derived as

$$SI = V_{i-1}^4 - 4.(P_i x_i - Q_i r_i)^2 - 4.(P_i r - Q_i x_i)^2.V_{i-1}^2 \geq \quad (7)$$

Under the stable operation, the value of *SI* should be greater than zero for all buses, i.e. $SI_i\ (i = 2,3, \dots \dots N_{bus}) >$. When the value of *SI* becomes closer to one, all buses become more stable. The bus having the *SI* minimum value is the most sensitive to voltage collapse. In the proposed algorithm, *SI* value is calculated for each bus in the network. For the bus having the *minimum* value of *SI,* will be considered in the second fitness function.

$$f_2 = \frac{1}{1+SI_m} \quad (8)$$

where SI_m is the minimum *SI* value of all the buses.

B. Equality constraints

The equality constraints are the power balance constraints with shunt capacitor, which include two nonlinear recursive power flow equations, for bus *i*, it can be formulated as:

$$\begin{cases} P_G + P_{PV} = +P_D + P_L \\ Q_G + Q_{PV} = Q_D + Q_L \end{cases} \quad (9)$$

where $(P_G,$ are the total active and reactive power of generator, respectively, $(P_D,$ the total active and reactive power of load, respectively, $(P_L,$ are the total active and reactive power losses, respectively, and $(P_{PV}, Q$ represent the total active and reactive power of photovoltaic source.

C. Inequality constraints

The inequality constraints present the physical limits of various equipment of network.

- Generation constraint

$$0 \leq P_{PV} \leq 0.3 * \left(\sum_{i=1}^{Nbus} P_{Di}\right) \quad (10)$$

-Voltage constraints

$$V_{imin} \leq V_i \leq V_{imax}\, for\, i = 1 \quad (11)$$

where V_{im} and V_{im} are the minimum and maximum voltages of the i^{th} bus.

-Line thermal limit

$$S_k \leq S_{kmax}\ for\ k = 1 \dots \dots NB \quad (12)$$

where S_k is a line loading and S_{kmax} is a maximum permissible loading limit of k^{th} branch.

D. Handing of constraints

It's agreed upon to mention that the control variables are generated in their admissible limits using the random strategy. In order to manipulate the inequality constraints of the stat variables, including load bus voltage magnitudes and lines loading, the extended objective function is mathematically formulated as [24, 25, 26, 27, 28, 29]:

$$F_n^{Penalized} = F_n + \sum_{i=1}^{Nbus} K_v (V_i - V_i^{lim})^2 + \sum_{i=1}^{Nline} K_s (S_{Li} - S_{Li}^{lim})^2 \quad (13)$$

where F_n is nth objective function value, V_i^{lim} and S_{Li}^{lim} are described as :

$$V_i^{lim} = \begin{cases} V_i^{max} & if V_i > V_i^{max} \\ V_i^{min} & if V_i < V_i^{min} \\ V_i & if V_i^{min} \leq V_i \leq V_i^{max} \end{cases} \quad (14)$$

$$S_{Li}^{lim} = \begin{cases} S_{Li}^{max} & if\ S_{Li} > S_{Li}^{max} \\ S_{Li}^{min} & if\ S_{Li} < S_{Li}^{min} \\ S_{Li} & if\ S_{Li}^{min} \leq S_{Li} \leq S_{Li}^{max} \end{cases} \quad (15)$$

where K_v and K_s are the penalty factors. In this study the values of penalty factors have been considered 10000.

E. Distributed generation models

In literature, the distributed generation modelled by four types, such as [30, 31]:

Type 1: DG capable of injecting P only
Type 2: DG capable of injecting P and Q
Type 3: DG capable of injecting P and consuming Q
Type 4: DG capable of injecting Q only

III ALGORITHM BASED ON NSGA-II

In this study a hybrid metaheuristic technique based on NSGA-II/FL has been proposed to determine the Pareto optimum and the best solution of the problem of optimal PVS placement size.

```
procedure NSGAII
    Create random solutions to build an initial population set;
        while stop Criterion Not Satisfied() do
            for s←0; s < P; s ← s + 2 do
                Select two parents P1 and P2;
                Execute crossover of P1, P2 and generate offsprings O1 and O2;
                Mutate O1 and O2;
                Evaluate O1 and O2 and insert them in the offspring set;
            end for
            Create a union set from population and offspring and clear population;
            Build Pareto fronts pfs from union based on the dominance rule;
            Set the current front as pfs[0];
            while length of population < P do
                Sort solutions from the current front by Crowding Distance;
                for each solution in the ordered front do
                    if length of population < P then
                        Include the solution in population;
                    end if
                end for
                Go to the next Pareto front;
            end while
        end while
    end procedure
```

III. 1 SELECTING BEST COMPROMISE SOLUTION

A fuzzy logic technique is employed in this paper to select the best compromise solution from the obtained Pareto-optimal set. For each objective , a fuzzy membership function is calculated as follows [32]:

$$\mu_{fi} = \frac{f_i^{max} - f_i}{f_i^{max} - f_i^{min}} \tag{16}$$

where f_i^{min} , f_i^{max} are the minimum and maximum value of i^{th} objective function of all Pareto optimal solutions. For each Pareto solution k, the normalized membership function is found as follows:

$$\mu^k = \frac{\sum_{i=1}^{m} \mu_i^k}{\sum_{k=1}^{D} \sum_{i=1}^{m} \mu_{fi}^k} \tag{17}$$

where D is the total number of Pareto solutions and m is the total number of objective functions. The best compromise solution is that having maximum value of μ^k.

IV APPLICATION OF THE NSGA-II

The PVS placement and size problem can be expressed as:
Minimize

$$F_{obj} = [f_1, f_2] \tag{18}$$

Subject to the constraints in Eqs. (9) – (12).

The flowchart of the DG placement and size algorithm is given as in Fig. 3.

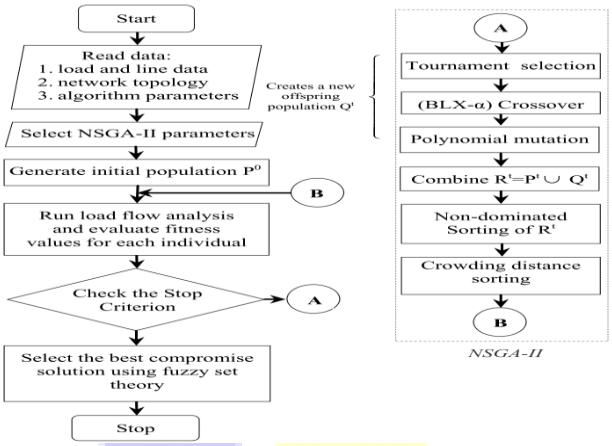
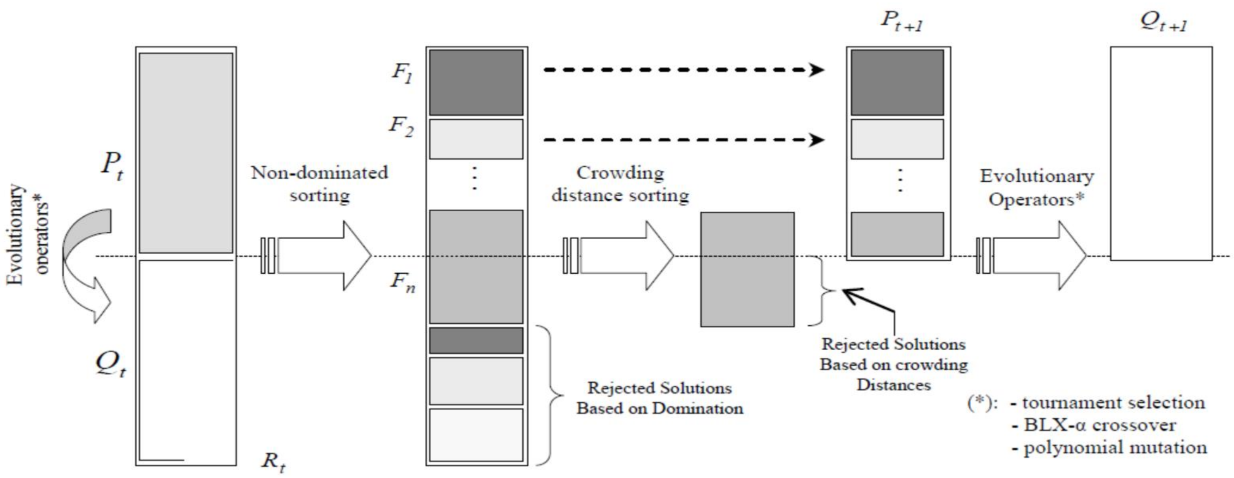


Fig. 3. Flowchart of the DG placement and size

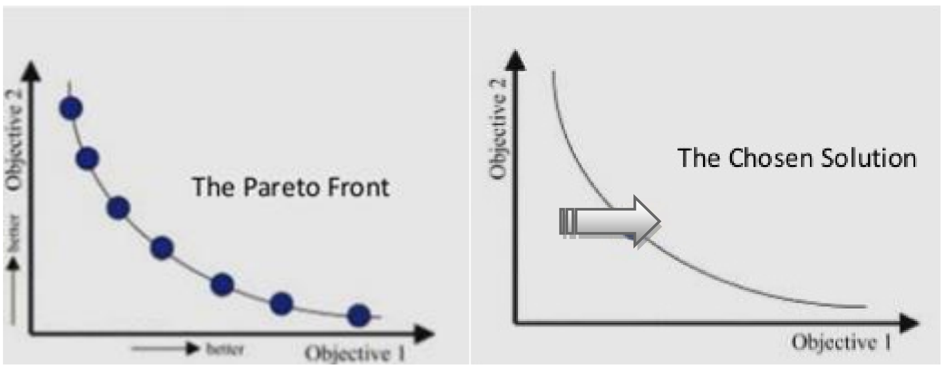
V SIMULATIONS AND RESULTS

In this section, the proposed algorithm is tested on 10-bus, 33-bus, 69-bus and validated on Algerian distribution network (116 bus). IEEE networks are generally known, but the Algerian network is an urban type network comprising 116 buses, 124 lines including 09 looping lines, and feeds a total load of 23886.36 kW and 17914.68 kVAR, this load is spread over 09 feeders. The nominal voltage of this network is 10 kV. The substation is connected to the medium voltage network via a 30/10 kV transformer. The lower and upper of voltages limits considered in this work are 0.95pu and 1.05pu, respectively.

The application on a real network (116 bus) has been proposed in this work. Table. I present the simulation results for two cases (before and after installation of PVS). Fig. 4 present voltage profile of each distribution network. From the simulation results shown in Table. I, we found that the power losses were reduced in a significant manner in the presence PVS. As well as voltage stability index it was improved after PVS installation. According to Fig. 4, it will be noted that the voltages of all the networks within the allowable limits. According to Table 1, the voltage stability margin has been improved and consequently the network operating point is far from the voltage collapse point. Fig 5 present the Pareto-optimal front for various test distributions networks.



(a) NSGA-II Main Loop Strategy



(b) Pareto-optimal determined by NSGA-II (c) Best compromise solution determined by Fuzzy logic

Fig. 2. Multi-objective optimization based on NSGA-II and Fuzzy Logic combination

TABLE I *RESULTS OF PROPOSED APPROACH* ON VARIOUS TEST DISTRIBUTIONS NETWORKS

Distribution network	Before placement of PVS				After placement of PVS					
	Real power loss (MW)	Min SI (pu)	Min voltage (pu)	System loadability (pu)	Optimal placement	Optimal size (MW)	Real power loss (MW)	Min SI (pu)	Min voltage (pu)	System loadability (pu)
10 bus	0.7838	0.5113	0.8375	1.06	9	3.1590	0.3499	0.9006	0.9748	1.11
34 bus	0.2217	0.7867	0.9416	4.33	27	1.636	0.1924	0.9065	0.9757	4.7
85 bus	0.3161	0.5767	0.8712	1.57	26	1.1012	0.1469	0.8712	0.9661	1.6
116 bus	0.1564	0.9428	0.9853	10.9	38	4.1262	0.0937	0.9657	0.9913	10.99

I. Conclusion

This study presents the optimal placement and size of PVS in the distribution network. A hybrid optimization technique has been proposed, namely, NSGA-II and fuzzy logic. The NSGA-II technique was used to determine the Pareto-optimal front and the fuzzy logic technique to select the best from the obtained Pareto-optimal. The multi-objective function considered in this work is maximize voltage stability index and minimize active power losses. The proposed method was applied on three IEEE networks (10 bus, 34 bus and 85 bus), then a validation on a real network (116 buses).

References

[1] P. Chiradeja and R. Ramakumar, "An approach to quantify the technical benefits of distributed generation," Energy Conversion, IEEE Transactions on, vol. 19, pp. 764-773, 2004.

[2]M. Mosbah, A Khattara, M Becherif, S. Arif, "Optimal PV location choice considering static and dynamic constraints" International Journal of Emerging Electric Power Systems,vol. 18, pp, 2017.

[3] M. Mosbah, M. Kobbi, "Introduction of the renewable energy and SDC Experience"1ér Conference of Heads of Districts Engineers Electrical Company of Distribution Electricity and the Gas Centre, Blida Technical School, 20-21, 2015.

[4] W. EL khattam *et al*, "An integrated distributed generation optimization model for distribution system planning," Power System,IEEE Transactions on, vol, 20, pp. 1158 - 1165, 2005.

[5] P. Lamainae*t al*, "A model for wind turbines placement within a distribution network acquisition market," Industriel, IEEE Transactions on, vol, 11, pp. 210-219, 2015.

[6] P. Siano and G. Mokryani,"Assessingwind turbines placement in a distribution market environment by using particle swarm optimization," Power System, IEEE Transactions on, vol, 28, pp. 3852 - 3864, 2013.

[7] D. J. Burke and M. J. O'Malley, "Maximizing firm wind connection to security constrained transmission networks," Power System, IEEE Transactions on, vol, 25, pp. 749-759, 2010.

[8] Y. M Atwa, and E. F. El-Saadany, "Probabilistic approach for optimalallocation of windbaseddistributed generation in distribution systems," IET Renew Power Gener, vol.5, pp. 79-88, 2011.

[9] W. S. Tan, M. Y. Hassan, M. S. Majid, and H. A. Rahman, "Allocation and sizing of DG using Cuckoo Search algorithm," in Power and Energy (PECon), 2012 IEEE International Conference on, 2012, pp. 133-138.

[10] V. C. V. R. M.Padma Lalitha, V.USHA, "Optimal DG placement for minimum real power loss in radial distribution system using PSO," Journal of Theoretical and Applied Information Technology, vol. 13, pp. 107-116, 2010.

[11] M. M. Aman, G. B. Jasmon, A. H. A. Bakar, and H. Mokhlis, "A new approach for optimum DG placement and sizing based on voltage stability maximization and minimization of power losses," Energy Conversion and Management, vol. 70, pp. 202-210, 2013.

[12] M. H. Moradi and M. Abedini, "A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems," International Journal of Electrical Power & Energy Systems, vol. 34, pp. 66-74, 2012.

[13] J. A. Martín García and A. J. Gil Mena, "Optimal distributed generation location and size using a modified teaching–learning based optimization algorithm," International Journal of Electrical Power & Energy Systems, vol. 50, pp. 65-75, 2013.

[14] F. S. Abu-Mouti and M. E. El-Hawary, "Optimal Distributed Generation Allocation and Sizing in Distribution Systems via Artificial Bee Colony Algorithm," Power Delivery, IEEE Transactions on, vol. 26, pp. 2090-2101, 2011.

[15] L. D. Arya, A. Koshti, and S. C. Choube, "Distributed generation planning using differential evolution accounting voltage stability consideration," International Journal of Electrical Power & Energy Systems, vol. 42, pp. 196-207, 2012.

[16] H. A. Hejazi, M. A. Hejazi, G. B. Gharehpetian, and M. Abedi, "Distributed generation site and size allocation through a techno economical multi-objective Differential Evolution Algorithm," in Power and Energy (PECon), 2010 IEEE International Conference on, 2010, pp. 874-879.

[17] W.-S. Tan, M. Y. Hassan, M. S. Majid, and H. Abdul Rahman, "Optimal distributed renewable generation planning: A review of different approaches," Renewable and Sustainable Energy Reviews, vol. 18, pp. 626-645, 2013.

[18] S.A. ChithraDevi, et al, "Stud Krill herd Algorithm for multiple DG placement and sizing in a radial distribution system" Engineering Science and Technology, an International Journal,vol. 20, pp. 748–759, 2017.

[19] S. Sahu, A. K. Barisal and A. Kaudi, "Multi-objective optimal power flow with dg placement using TLBO and MIPSO: a comparative study" Energy Procedia, vol. 117, pp. 236-243, 2017.

[20] P. D. P. Reddy, V.C.V. Reddy, T. G. Manohar, "Optimal renewable resources placement in distribution networks by combined power loss index and whale optimization algorithms" Journal of Electrical Systems and Information Technology, doi.org/10.1016/j.jesit.2017.05.006.

[21] P. P. Biswas, *et al*, "A multiobjective approach for optimal placement and sizing of distributed generators and capacitors in distribution network" Applied Soft Computing, vol. 60, pp. 268-280, 2017.

[22] M. J. Moghaddam, *et al*, "A multi-objective optimal sizing and siting of distributed generation using ant lion optimization technique" Ain Shams Engineering Journal, doi.org/10.1016/j.asej.2017.03.001.

[23] M. Chakravorty and D. Das, "Voltage stability analysis of radial distribution networks," International Journal of Electrical Power & Energy Systems, vol. 23, pp. 129-135, 2001.

[24] M. Mosbah, S. Arif, R. Zine, R. D. Mohammedi, S. H. Oudjana, "Optimal size and location of PV based DG-unit in transmission system using GA method for loss reduction" *Journal of Electrical Engineering*, Vol. 17, pp. 37, 2017.

[25] M. Mosbah, R. D. Mohammedi, S. Arif, A. Hellal, "Optimal of shunt capacitor placement and size in algerian distribution network using particle swarm optimization" ICMIC-2016, IEEE Proceeding, Algiers, Algeria, November 15-17, 2016.

[26] M. Mosbah *et al*, "Optimal sizing and placement of distributed generation in transmission systems" ICREGA-2016, Belfort, France, February, 8-10, 2016.

[27] M. Mosbah, S. Arif, R. D. Mohammedi, "Optimal of shunt capacitor placement and size in distribution network using ant lion optimization" 3th International Conference on Power Electronic and their Applications, Djelfa, 16-17 Sep 2017.

[28]M. Mosbah, S. Arif, R. D. Mohammedi, "Optimum algerian distribution network reconfiguration in presence wind turbine using genetic algorithm" 1th International Conference on Artificial Intelligence in Renewable Energetic System, Tipaza, 22-24 Oct 2017.

[29]M. Mosbah, S. Arif, R. D. Mohammedi, A. Hellal, "Optimum dynamic distribution network reconfiguration using minimum spanning tree algorithm" 5th International Conference on Electrical Engineering, Boumerdes, 28-31 Oct 2017.

[30] M. Mosbah, S. Arif, R. D. Mohammedi, "Multi-objective optimization for optimal multi DG placement and sizes in distribution network based on NSGA-II and fuzzy logic combination" 5th International Conference on Electrical Engineering, Boumerdes, 28-31 Oct 2017.

[31] M. Mosbah, S. Arif, R. D. Mohammedi, “Bi-Objective Optimization for Optimal Wind Turbine Placement and Size in Distribution Network using NSGA-II Algorithm” 3th International Conference on Electrical Engineering and Control Application, Constantine, 21-22 Nov 2017.
[32] J. S. Dhillon, S. C. Parti, and D. P. Kothari, "Stochastic economic emission load dispatch," Electric Power Systems Research, vol. 26, pp. 179-186, 1993.