Optimal Power Flow Analysis for Power Loss Reduction using Jaya Algorithm

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Abstract

This paper is engrossed in the usage of metaheuristic optimization methods named the JAYA algorithm and the teacher learning based optimization (TLBO) algorithm, which deal with the objective function of the optimal power flow (OPF) problem. TLBO and Jaya are parameter-free algorithms, which reduce the complexity of algorithms. The objective function of this paper is to reduce the real power losses and maintain the voltages and tap positions within their limits. IEEE-39 bus system data is considered for the practice of the algorithms. The results obtained by using the JAYA algorithm show better progress in objective function reduction. This entire work is done in a MATLAB environment.

Keywords: Optimal power flow, JAYA Algorithm, TLBO algorithm, Active power loss, IEEE-39, MATLAB.

1. Introduction

The Optimal power flow (OPF) problem was first formulated by J. Carpentier [1].Solutions for optimal power flow (OPF) are essential tools for running electric power networks[3,16]. It is a power flow that adjusts power grid management settings appropriately while dealing with various restrictions [2]. Numerous traditional optimization strategies, such as non-linear programming, the Newton algorithm and decomposition algorithms[4,5], have been used to cope with the OPF problem. The prior deterministic (conventional) optimization techniques used are offered in-depth examination. These approaches have various drawbacks, including as being stuck in local optima (i.e., having insecure convergence qualities)(3), not being able to handle goal functions that are not differentiable, and having a high sensitivity to beginning search sites, despite the fact that they can sometimes find the globally optimum solution. Additionally, these algorithms cannot provide a universal fix. It is therefore necessary to suggest alternate solutions to the aforementioned problems.

The recent advancements in the computer led the OPF problem solving using the novel algorithms termed as nature inspired algorithms [6]. In the earlier century a lot of advancements leads to the proposal of nature inspired algorithms, which helpful in solving the problems of real time avoiding the miniature errors. The OPF is a convex problem, till now no algorithm is compatible to solve the problem, the nature inspired algorithms are able to provide the optimal solutions of the problem. The OPF problem is solved by using the different types of meta heuristic algorithms such as particle swarm optimization algorithm [7], Gravitational search algorithm [8], BAT algorithm [9,13], artificial bee colony algorithm [10], and cuckoo search algorithm [12]. These algorithms reduce the complexity of the problem and the optimal solution is provided.Regrettably, despite their benefits, each of these population-based optimization techniques requires properly designed algorithm-specific controlling parameters because inappropriate tuning of such variables will increase the computational burden[11] (i.e., affect the convergence property) or results in an inadequate solution.

The Teaching-Learning-Based Optimization (TLBO), a population-based optimization approach that draws inspiration from knowledge transfer in the classroom where students first learn from their teachers and then from their peers, is one of the newly developed optimization strategies. The TLBO algorithm is parameter free algorithm [14], which reduces the complexity of the aforementioned above.

The Jaya algorithm, which Rao presented in 2016 to overcome the aforementioned issue, is one of the recently created population-based optimization techniques[15].The Jaya algorithm's optimization process does not entail fine-tuning any algorithm-specific regulating parameters, in contrast to other population-based techniques. As was already said, regulating such factors is not always easy. With this feature, the Jaya algorithm gains a significant advantage by eliminating the challenge of regulating these parameters and cutting down on the amount of time needed to complete the optimization process. The method is very straightforward to develop and straightforward to use. The idea that the response to a particular problem must move toward the ideal answer and avoid subpar ones serves as the inspiration for this technique's optimization strategy.

The two algorithms with specific parameter less algorithms are reviewed which are named as TLBO[17] and Jaya[18] are plays a key role in the electrical engineering to solve the problems of constrained and unconstrained type parameters. These algorithms are belonging to the class of Meta-heuristics algorithms which are quite popular in this generation. The TLBO algorithm is more weighed up then Jaya algorithm, because TLBO is two step methodology which is closer to the classroom learning environment. The two phases are 1). Teacher and 2). Learner .

the meta heuristic algorithms require the specific algorithm parameters including population size and iterations. Unlike these algorithms, Jaya and TLBO require only population size and iterations. So, Jaya and TLBO algorithms are specific parameter less algorithms.

The bus system used in this paper is known as the New England power system and commonly referred as the IEEE-39. This bus systems consist of 10 Generators and 46-line transmission line system. The parameters of this bus system are taken from the book titled as" Energy function analysis for power system analysis stability" [19].

The idea of this paper is mainly due to the attractiveness and simplicity of the Jaya algorithm. The arrangement of paper is discussed briefly, the second chapter details the problem formulation and next provides the detailed procedure of the two algorithms in the continuous chapters, the results and discussion are raised in the following chapter after the algorithms and the final chapter is conclusion.

2. Problem formulation

This paper dealt with the single objective function type of OPF problem. The objective function is minimization of active power losses. An optimized objective function is formulated involving the equality and inequality constraints.

A. Objective Function

The objective function is achieved by finding the optimal values of the control variables, such as voltage (V) and tap values of transformers, which sinks the active power loss. The formula for this objective function is shown in equation (1)

$P_{li} = \frac{1}{Y_{ij}}({V_i}^2 + {V_j}^2 - 2 * V_i * V_j * \cos(\theta_i - \theta_j))(1)$

The total losses of the system are expressed as:

$P_{LOSSES} = \sum_{i=1}^{br} P_{li}$ (2)

V_i=Voltage from sending end.;V_j=Voltage from receiving end.;Y_{ij}=admittance of branch.

θ_i, θ_j=voltage angle.

A.1. Constraints

The OPF problem involves two types of constraints

- Equality constraints.
- Inequality constraints.

A.1.1.Equality constraints

The equality constraints are Real and Reactive power limits.

Real power generation limits

$P_{Gi} = P_{di} + P_{Li}(3)$

P_{Gi}= real power generation (P_G) at i^{th} bus.;P_{di}=real power demand (P_d) at i^{th} bus.

P_{Li}=real power losses (P_L) at i^{th} bus.

Reactive power generation limits

$Q_{Gi} = Q_{di} + Q_{Li}(4)$

Q_{Gi}= reactive power generation at i^{th} bus.;Q_{di}=reactive power demand at i^{th} bus.

Q_{Li}=reactive power losses at i^{th} bus.

A.1.2. Inequality constraints

a) Real power generation limits

$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}$ (5)

The real power acceptable limits must be within the range is shown above.

Where

i = 1,2,3…ng

ng = no. of generators;P_{gi}^{min} = minimum real power level (P_g) at bus i;

P_{gi}^{max} = maximum real power level (P_g) at bus i.

b) Bus Voltage limits

The voltage levels must be maintained within limits.

$V_i^{min} \leq V_i \leq V_i^{max}$ (6)

Where,

i = 1,2,3…ng; ng = no. of generators; V_i^{min} = minimum voltage level at bus i.

V_i^{max} = maximum voltage level at bus i.

c) Tapping limits

The tap positions of transformer always maintained within the limits.

$t_i^{min} \leq t_i \leq t_i^{max}$ (7)

Where,

i = 1,2,3…ng; ng = no. of generators; t_i^{min} = minimum tapping position level at bus i.

t_i^{max} = maximum tapping position level at bus i.

It is important to note that the modified objective function's aforementioned mathematical formulation is only employed when one or more dependent variables break the upper/lower bound. The key objective is to identify and clear of any impractical solutions that may be found throughout the optimization process. The penalty factors may vary depending on the application and the designer's experience. Different penalty components have various outcomes. This research considers a high unity penalty of 10,000 on every dependent variable in case of violation of the upper/lower limit in order to address this issue.

3. TLBO Algorithm

The teacher-student relationship in a learning environment, the teacher's influence over learners or pupils, and the interactions and effects that learners have on one another are the main sources of inspiration for the TLBO algorithm. The teacher phase and learner phase are the two primary components of the algorithm, respectively. This algorithm is proposed by Rao[13].

The step-by-step procedure of the TLBO algorithm is as discussed below.

1. Initialize the parameters.
2. Define the objective function
3. Generate population.
4. Compute X_{best}, mean, T_f.

   Where, X_{best} = the best student/candidate from the class.

   Mean = Mean of the all marks.

T_f = teacher factor based on ability (random variable).

5. Teacher phase
   - Find the difference between the average marks and best marks (X_{di}).

     $X_{di} = r_i(X_{best} - T_f \times Mean)$ (8)

     $$r_i = \text{random number between}(0, 1)$$

   - By using the X_{di} , find the solution obtained by student interaction between the two students i, j.

$X_{j,i,x} = X_{i,j} + X_{di}$ (9)

$X_{i,j}$ = the marks obtained by j in i iteration.

- If $X_{best} < X_{i,j}$, then X_{best} is passed to learner phase.

  else $X_{i,j}$ is passed to the learner phase.
- Check the new solution with the bounds, the solution must be within limits.

6. Greedy selection
   - Generate new solution for given objective function.
   - Store the parameters for the above solution.
7. Learner phase.
   - Randomly select two studentsas partners (A, B)
   - Generate population for both partners (A, B).
   - If$X_{i,j,A} < X_{i,j,B}$

     $X_{j,i\,new} = X_{j,i-A} + rand \times (X_{j,i-A} - X_{j,i-B})$ (10)

     Else

     $X_{j,i\,new} = X_{j,i-A} - rand \times (X_{j,i-A} - X_{j,i-B})$ (11)
8. Perform greedy selection repeat step 6.
9. End

4. Jaya algorithm

Rao developed the novel population-based optimization technique called Jaya [14] to get the best results for both constrained and unconstrained optimization issues. Jaya, in contrast to other population-based heuristic algorithms, just uses the two standard regulating parameters of population size(n) and the number of iterations(i). This technique's optimization method is based on the notion that the solution chosen for a given problem must go toward the ideal answer and avoid the less desirable one. According to the aforementioned idea, the fundamental Jaya algorithm just includes one phase, making it a straightforward optimization method. The procedure for implementing Jaya algorithm is as discussed below. This algorithm is proposed by Rao.

1. Initialize parameters required for algorithm (population size, iterations).
2. Define the objective function.
3. Generate the population.
4. Identify the best and worst solutions among the population size.

5. Update the candidate solution using the best and worst solution.

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i}\left(X_{j,best,i} - |X_{j,k,i}|\right) - r_{2,j,i}\left(X_{j,worst,i} - |X_{j,k,i}|\right) \quad (12)$$

6. Check if the previous solution is $(X_{j,k,i})$ better than new solution $(X'_{j,k,i})$.
   - Update the solution with the old solution
   - Else update the new solution.
7. Check the new solution is within the limits.
8. End.

5. Results and discussion

The objective function of this paper is to reduce the active and reactivepower loss reduction using the Jaya and TLBO algorithms to check the efficacy of the algorithms. These algorithms are employed to IEEE-39 bus system which is also called as New England power system. For, the IEEE-39 bus system the population size and the maximum number of iterations are set to 210 and 35. IEEE-39 bus system consists of 10 generators and 46 lines. The OPF problem is convex type of problem, solving the complex problems is arduous. So, it needs special type of algorithms to yield better solutions.The procedure for the implementation of algorithms to the OPF problem formulated is shown in following figure 1. The control variables in this algorithm are tap positions of transformer and voltages at busses. These variables should strictly within the limits. Fig 2 illustrates the step-by-step process of how this OPF problem is solved by using the different algorithms considering the best algorithm in the pictorial representation. The below flowchart represents the process of the application of the Jaya algorithm. The population is randomly generated, the best and worst candidates are selected and the candidates are updated as shown in equation 12. The active power losses in the Jaya algorithm diminishes when compared with the TLBO algorithm tabulated in Table 1. The IEE-39 one line diagram is shown in following fig 1.

Figure 1 Simulink diagram of IEEE-39 bus system

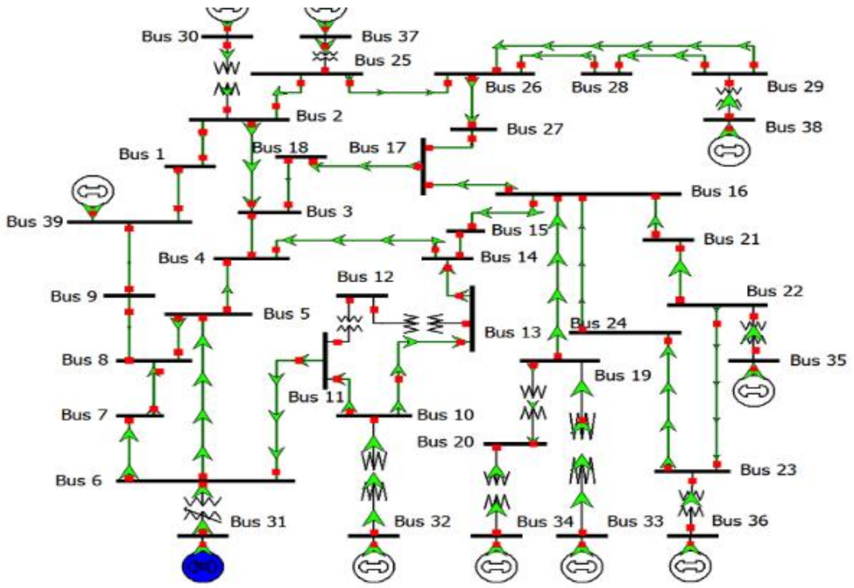
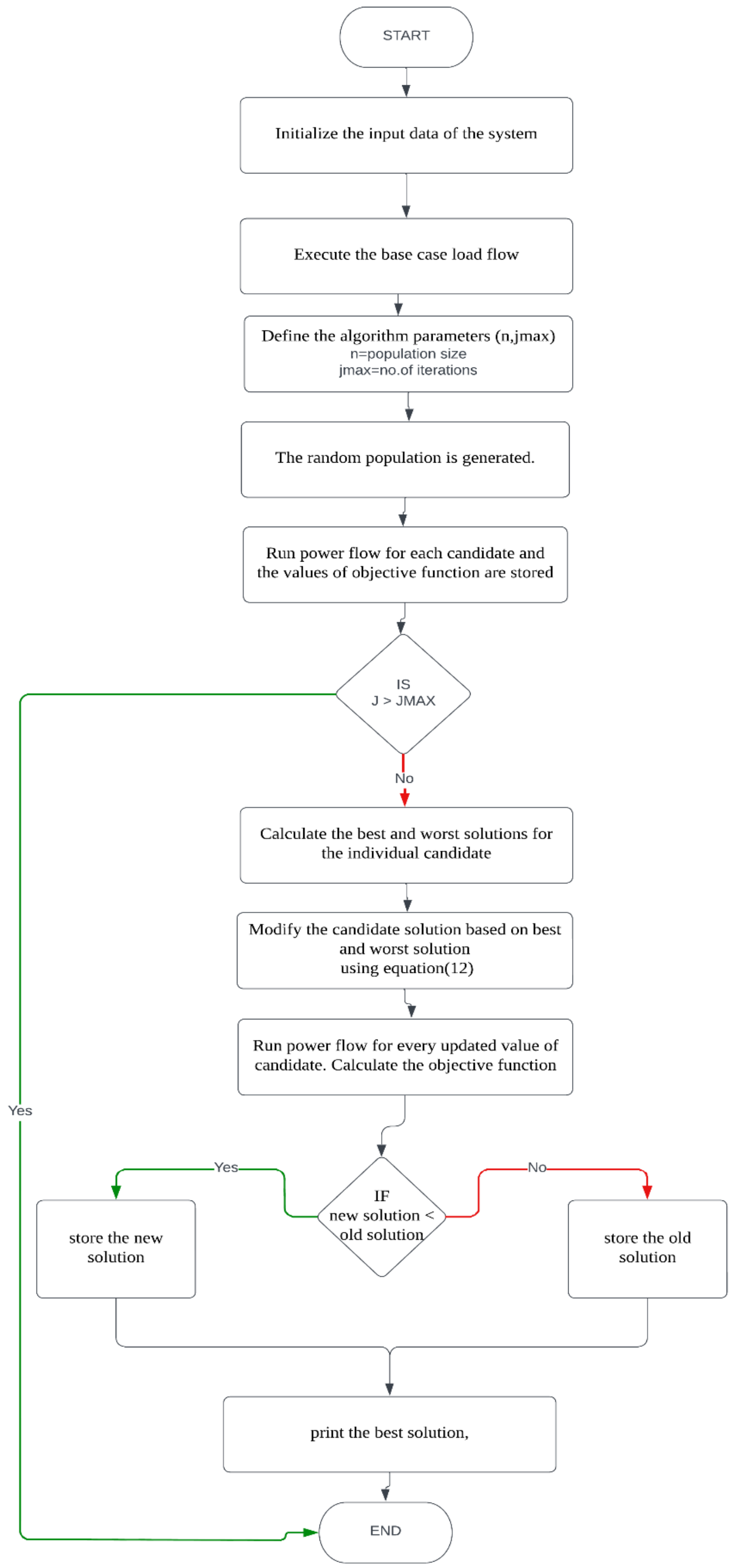
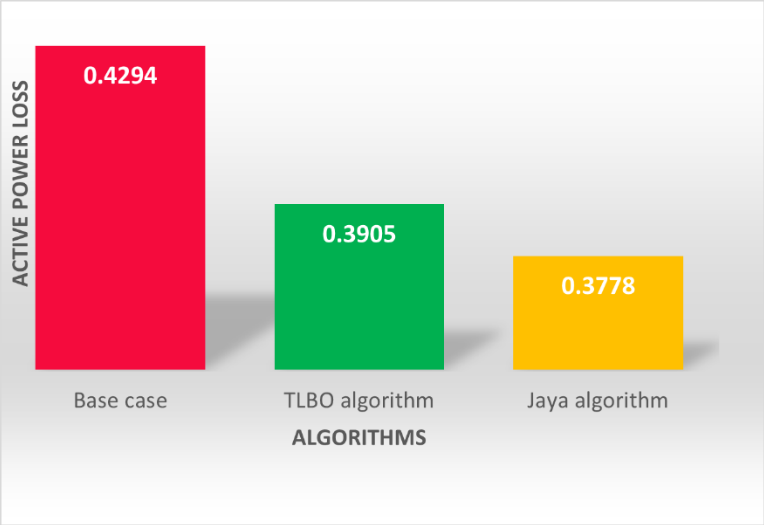


Figure 2 Flowchart of the algorithm applied to OPF problem



The below fig 3 represents the active power loss reduction values. The objective of this paper is active power loss minimization subjecting the respected constraints.in the base case the active power losses are observed as 0.4294 p.u. to reach the desired outcome , different types of algorithms are implemented. TLBO algorithm is applied, the losses observed are 0.3905 p.u. further, to achieve the defined objective, Jaya algorithm is implemented the losses are recorded are 0.3778p.u.

Figure 3 Active power loss reduction of two algorithms



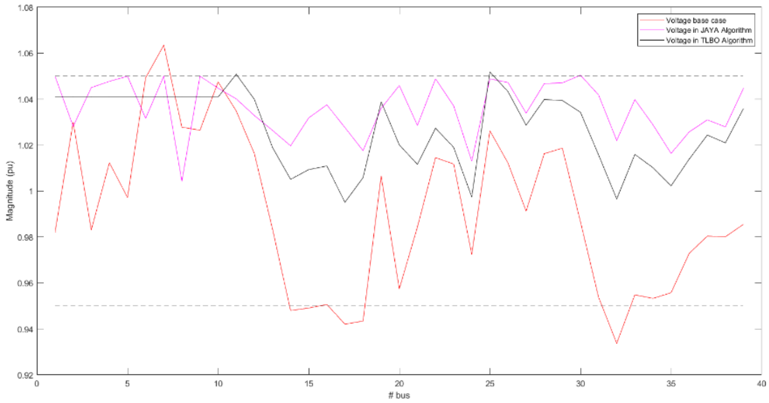
The below table 1 shows the active and reactive power loss reduction in the IEEE-39 system, when the system is applied to the different algorithms. The base case losses in the system are 42.94MW the corresponding reactive power losses are 54.20MW. By applying the TLBO algorithm and Jaya algorithm the losses are reduced which are listed in the below table. The losses are very low when the system is applied to Jaya algorithm. Active power losses are reduced simultaneously the reactive power loss are also affected.

Table 1 Active and Reactive power values

Types of loss / Algorithm	Active power loss(MW)	% Loss reduction	Reactive power loss (MVAR)	% Loss reduction
Base case	42.94	-	54.20	-
TLBO algorithm	39.05	9.05	49.81	8.09
Jaya algorithm	37.78	12.01	48.78	10

The control variables in this methodology are Voltage and Tap positions of transformer. By adjusting the control variables, the objective function is achieved. Fig 4 represents the graphs of control variables at which the optimal solution is accomplished. The below figure shows the voltage profiles of the system under different algorithms. In the base case the voltage profiles are violating limits imposed on the system. LaterTLBO algorithm is implemented and the voltage profiles are within the limits, but the active power losses are reduction is not appreciable. To further satisfy the objective of the algorithm, Jaya algorithm is considered the voltage limits are satisfied and losses are also minimized. The limits of the voltages are 0.95 is lower limit and 1.05 is the upper limit.

Figure 4 Voltages of IEEE-39 Bus system with TLBO and Jaya algorithm.



6. **CONCLUSION**

In this paper TLBO and Jaya algorithm are applied to solve the optimal active power flow problem.IEEE-39 bus system is used to demonstrate the effectiveness of the two algorithms. The test results unambiguously show that Jaya performs better in terms of solution quality than other algorithms. As demonstrated by the IEEE-39 bus system, the proposed Jaya method's superiority is clearer for large systems. Finally, from all the above test case results it can be concluded that Jaya algorithm is capable to solve large scale problems and it's good in solving power system optimization problems.

References:

1. Carpentier J. Contribution a l'etude du dispatching economique. Bulletin de la Societe Francaise des Electrician's. 1962 Aug;3(1):431-47.
2. O. Alsac and B. Stott, "Optimal Load Flow with Steady-State Security," in IEEE Transactions on Power Apparatus and Systems, vol. PAS-93, no. 3, pp. 745-751, May 1974, Doi: 10.1109/TPAS.1974.293972.
3. h. H. Happ, ―optimal power dispatch-a comprehensive survey‖, ieee trans. Power apparat. Syst., vol. Pas-90, pp. 841-854, 1977.
4. avid i. Sun, bruce Ashley, brian brewer, art Hughes, William f. Tinney ―optimal power flow by newton approach ―, ieee transactions on power apparatus and systems, vol.pas-103, no. 10, pp. 2864-2879, oct 1984
5. D. Xia-oying, w. Xifan, s. Yonghua and g. Jian, ― the interior point branchandcutmethodforoptimalflow‖0-780374592/02/$17.00©ieee, pp.651-655,2002.
6. Yang, Xin-She. (2014). Nature-Inspired Optimization Algorithms.
7. M.A. Abido, ―optimal power flow using particle swarm optimization‖, electrical power and

energy systems 24, pp. 563 –571. 2002
8. Duman, Serhat & Guvenc, Ugur & Sönmez, Yusuf & Yörükeren, Nuran. (2012). Optimal power flow using gravitational search algorithm. Energy Conversion and Management. 59. 86–95. 10.1016/j.enconman.2012.02.024.
9. B Venkateswara Rao and g. V. Nagesh Kumar, “optimal powerflow by bat search algorithm for generation reallocation with unified power flow controller,” int. J. Elect. Power energy syst.,vol. 68, pp. 81– 88, jun. 2015.
10. He X, Wang W, Jiang J, Xu L. An Improved Artificial Bee Colony Algorithm and Its Application to Multi-Objective Optimal Power Flow. Energies. 2015; 8(4):2412-2437. https://doi.org/10.3390/en8042412
11. Karafotias, Yorgos & Hoogendoorn, Mark & Eiben, A. (2015). Parameter Control in Evolutionary Algorithms: Trends and Challenges. Evolutionary Computation, IEEE Transactions on. 19. 167-187. 10.1109/TEVC.2014.2308294.
12. G. Chen, S. Qiu, Z. Zhang, Z. Sun, and H. Liao, “optimal powerflow using gbest-guided cuckoo search algorithm with feedback control strategy and constraint domination rule,” math. Probl. Eng., vol.2017,pp.1–14, 2017.
13. Y. Yuan, x. Wu, p. Wang, and x. Yuan, “application of improved bat algorithm in optimal power flow problem,” appl. Intel., vol. 48, no. 8, pp.2304–2314,Aug.2018.
14. Sarzaeim, parisa & bozorg-haddad, Omid& chu, Xuefeng. (2018). Teaching-learning-based optimization (TLBO) algorithm. 10.1007/978-981-10-5221-7_6.
15. Venkata Rao, Ravipudi. (2016). Jaya: A simple and new optimization algorithm for solving constrained and unconstrained optimization problems. International Journal of Industrial Engineering Computations. 7. 19-34. 10.5267/j.ijiec.2015.8.004.
16. Frank, S., Steponavice, I. & Rebennack, S. Optimal power flow: a bibliographic survey I. Energy Syst **3**, 221–258 (2012). https://doi.org/10.1007/s12667-012-0056-y
17. Venkata Rao, Ravipudi. (2016). Review of applications of TLBO algorithm and a tutorial for beginners to solve the unconstrained and constrained optimization problems. Decision Science Letters. 5. 1-30. 10.5267/j.dsl.2015.9.003.
18. Ananta Pai. Energy Function Analysis for Power System Stability. Springer, 1989.