Combined Economic Emission Dispatch Considering Renewable Energy Sources

Dr. E. B. Elanchezhian

Abstract: Currently, Renewable Energy Sources (RES) has become one of the mainstream topics in power system studies and a trend in power generation. These days, the concept of microgrid comes out as the natural alternative to the conventional power systems, which provide an effective and sustainable alternative for the integral use of renewable energies. This paper proposes a convex model of Combined Economic Emission Dispatch (CEED) considering RES in a microgrid environment. A new methodology based on Teaching Learning Based Optimization (TLBO) algorithm is implemented on an islanded 3 unit microgrid system comprises of three conventional thermal generators, one wind farm and one solar photovoltaic system to assess the economic impact of inclusion of renewable sources in microgrid for CEED studies. The proposed approach contemplate the proficient operation of a microgrid with minimal pollutant emissions considering various renewable power sources, which makes it a practical methodology to apply in real-time operating conditions. In addition, the results are compared with recent heuristic methods, which allow validating the accuracy and quality of the proposed optimization methodology.

Index Terms: Combined Economic Emission dispatch, Pollution, Renewable energy sources, Solar power, Teaching Learning Based Optimization, Wind power.

1. INTRODUCTION

In the present situation, endeavors are being made to design productive microgrid solutions to aid penetration of power supply in the remote regions through segments like energy storage and Renewable Energy Sources (RES) [1]. Microgrid can be characterized as a small-scale form of the centralized power framework. It typically comprises of distributed generation (DG) units, energy storage resources and loads that are designed and sited near to the customers in small communities. The DG units used in the microgrid can either be conventional generators or renewable energy sources (i.e. wind power and solar power). However, recently renewable energy sources have been used widely in microgrids due to their expense and environmental benefits in comparison with the conventional generators. Renewable energy sources are cleanest sources available almost free of cost. Unlike the conventional thermal units, Solar and wind power generators have intermittent nature which results in a new challenge to the economical operation problems. One of the major difficulties in optimizing the operation problem is the uncertainty associated with weather profiles. Unpredicted weather variations cause fluctuations in the renewable power outputs. Such fluctuations can cause operational challenges to maintain the generation-load balance [2]. The variability and uncertain nature of renewable power plants poses challenges in terms of operation and control when they are integrated with the existing grid. Economic dispatch is generally allocating the loads, optimally on the available generators. Recently renewable sources are also incorporated in generation dispatch along with thermal generators. For this, suitable modeling of the renewable energy sources is a required.In the present scenario, meta-heuristic techniques are widely used for solving non linear problems like economic dispatch, optimal power flow and unit commitment. These techniques are essential tools for attaining a global best solution. Several methods such as Firefly Algorithm (FA) [3], Whale Optimization Algorithm (WOA) [4], [5], Differential Evolution Immunized Ant Colony Optimization (DEIACO) [6], Ant Lion Optimization (ALO) Algorithm [7], Self-Adaptive Gravitational Search Algorithm (SAGSA) [8] and Harmony Search Algorithm (HSA) [9] are implemented to perform optimization of economic dispatch problem on Microgrid by considering the operational constraints. In this paper, Combined Economic Emission Dispatch considering Renewable Energy Sources (CEED-RES) is carried out in an isolated Microgrid. The bi-objective functions fuel cost and emission functions can be converted into a single objective function by price penalty factor ‘h’ [10]. Teaching Learning Based Optimization (TLBO), a recent optimization technique [11], [12] is used to solve this CEED-RES problem due to its simplicity and robustness in solving constrained problems. The remaining paper is organized as follows: In Section 2, CEED model of microgrid for both conventional as well as for with RES is presented. Section 3 explains the basic steps involved in TLBO algorithm. In Section 4 the results obtained using TLBO are discussed and the performance of TLBO is shown. Finally the conclusions of the proposed method are given.

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2 CEED MODEL OF MICROGRID

Traditional economic dispatch of power system is not sufficient for controlling the environmental pollution caused by combustion of fossil fuels in power plants. Due to increased awareness and concern over the degrading environment, operating strategies are giving emphasis not only on fuel cost minimization, but also on the emission minimization. Hence, the main objective of this Combined Economic Emission Dispatch (CEED) function is to minimize both the fuel cost and greenhouse gas emissions to get environmental friendly power generation system.

2.1 CEED considering Thermal power plants

In the deterministic CEED formulation (1), both fuel cost and emission should be minimized simultaneously. The biobjective economic and emission dispatch problem is converted into single optimization problem (2) by introducing price penalty factor h [10] as follows

$$F_T = \sum_{i=1}^{N} F_{Con} + h_i \; x \; E_{Con} \quad (1)$$

(2)

Where F_T is the total cost ($) considering thermal power plants alone, F_{Con} and E_{Con} are the fuel cost in $/h and emission in Kg/h while considering conventional thermal power plants alone.

2.2 CEED considering Thermal power plants and RES

The inclusion of renewable energy resources such as wind and solar power reduces both the fuel cost and emissions. They are clean resources of energy which neither incur any extra fuel costs nor does it emits harmful toxic gases in the atmosphere. Nevertheless, renewable energy sources do include some operational and maintenance cost and hence the CEED model of microgrid considering renewable energy sources (3) can be modeled as below.

(3)

Where a_i, b_i, c_i are the cost coefficients and α_i, β_i, γ_i are the emission coefficients of the conventional thermal generators. P_{Solar} and P_{wind} are the power generation by solar PV system and wind power system respectively. $F_{T\text{-}RES}$ is the total cost ($) of CEED considering both thermal power plants and RES.

2.3 Constraints

Power balance constraint

At any instant of time, the total generated power by conventional power sources and RES must satisfy the load demand, which is defined as

(4)

where P_D and P_{RES} is the demand and renewable power generation respectively.

Output power constraints

The real power output of each generating unit must lie within its minimum and maximum limits, which can be formulated as:

$$P_{i,\min} \le P_i \le P_{i,\max} \quad (5)$$

$$P_{RES,\min} \le P_{RES} \le P_{RES,\max} \quad (6)$$

where $P_{i,min}$ and $P_{i,max}$ are minimum and maximum power outputs of the thermal generating unit i, respectively and $P_{RES, min}$ and $P_{RES, max}$ are minimum and maximum generation limits of the renewable energy units respectively.

3 TEACHING LEARNING BASED OPTIMIZATION

By inspiring a teaching-learning process Rao [11] and his team proposed a Teaching Learning Based Optimization (TLBO) algorithm [12]. The TLBO method works on the beliefs of teaching and learning. In this optimization algorithm, a group of learners is considered as population and different design variables are considered as different subjects offered to the learners and the learners' result is analogous to the 'fitness' value of the optimization problem. In the entire population, the best solution is considered as the teacher. The working of TLBO is divided into two parts, 'teacher phase' and 'learner phase'. Functioning of both the phases is explained below.

3.1 Teacher phase

During this phase a teacher tries to increase the mean result of the classroom from any value M_1 to his or her level (i.e. T_A). But practically it is not possible and a teacher can move the mean of the classroom M_1 to any other value M_2 which is better than M_1 depending on his or her capability. Consider M_j be the mean and T_i be the teacher at any iteration i. Now T_i will try to improve existing mean M_j towards him or her so the new mean will be designated as M_{new} and the difference between the existing mean and new mean is given by (7).

$$\text{Difference mean}_i = r_i (M_{new} - T_F M_j) \quad (7)$$

where T_F is the teaching factor which decides the value of mean to be changed, and r_i is the random number in the range [0, 1]. Using (8) the value of T_F can be determined which is either 1 or 2, which is a heuristic step and it is decided randomly with equal probability. The existing solution is updated using (8).

$$T_F = \text{round}\,[1+\text{rand}\,(0, 1)\,\{2-1\}] \quad (8)$$

$$X_{new,\,i} = X_{old,\,i} + \text{Difference Mean}_i \quad (9)$$

3.2 Learner phase

It is the second part of the algorithm where learners increase their knowledge by interaction among themselves. A learner interacts randomly with other learners for enhancing his or her knowledge. A learner learns new things if the other learner has more knowledge than him or her. Mathematically the learning phenomenon of this phase is expressed below. At any iteration i, considering two different learners X_i and X_j where $i \ne j$.

$$X_{new,i} = X_{old,i} + r_i(X_i - X_j) \text{ if } f(X_i) < f(X_j)$$

$$X_{new,i} = X_{old,i} + r_i(X_j - X_i) \text{ if } f(X_j) < f(X_i) \quad (10)$$

Accept X_{new} (10) if it gives better function value.The candidate solution composes of design variables and is qualified according to its fitness. The solution having best fitness in the population is determined as the teacher.

3.3 Termination

The algorithm is terminated when a predetermined maximum iteration number is reached.

4 SIMULATION RESULTS AND DISCUSSION

The CEED is executed with TLBO method to substantiate the achievability and effectiveness of the proposed algorithm for microgrid considering renewable energy sources. The data to evaluate the CEED is in use from [4] and is having 3 thermal generators, 30MW wind farm and a 40 MW PV system. The operating range, cost and emission coefficients of the traditional thermal generators are obtained from [4]. Among the 24h output of PV system and wind power calculated at a location east coast of USA [4], the 19th hour data is considered for simulation. The proposed algorithm has been implemented in Matlab 7.9 and executed on HP personal computer with Intel core i3 processor with 4GB ram. Two different scenarios have been carried out. In scenario 1, the CEED considering thermal generators alone is carried out. Scenario 2 details the simulation of CEED considering thermal power source and renewable sources. In both the scenarios, the similar power demand of 200 MW is considered for simulation. For blending the two different conflicting objectives cost and emission, the price penalty factor is used. Among the different penalty factors available in literature $h_{min-max}$ penalty factor is used in this article as this penalty factor proves to be the paramount among all other penalty factors for CEED problem solutions in literature [10].

4.1 Scenario 1: CEED considering Thermal power units

In this scenario, combined economic emission dispatch is carried out considering three conventional thermal power plants alone. The dispatch results obtained by TLBO are listed and compared with other renowned algorithms in Table 1. The total cost obtained while performing CEED by PSO is 8878.36 $ and the total cost achieved by BBO is 8868.09 $.

***Table.1** – Microgrid CEED results considering thermal power units*

	TLBO	BBO	PSO
P_1 (MW)	90.4234	69.5363	60.6668
P_2 (MW)	49.9493	42.0002	50.2139
P_3 (MW)	59.6273	88.4635	89.1194
F_{Con} ($/h)	7345.79	7414.70	7409.28
E_{Con} (Kg/h)	157.890	185.273	187.330
F_T ($)	8817.92	8868.09	8878.36

The total cost obtained by proposed TLBO algorithm considering $h_{min-max}$ penalty factor is 8817.92 $, which is much less than the cost achieved by PSO and BBO algorithms. Similarly, the pollutant emission obtained by TLBO is 157.89 kg which is much lesser than the emission fetched by other methods.

4.2 Scenario 2: CEED considering Thermal power units and RES

The ever increasing load demand along with the necessity of minimizing environmental pollution and with the integration of renewable sources makes the CEED problem more complex to be solved. This scenario depicts the impact of inclusion of renewable sources like PV system and wind power plant in CEED process of microgrid. A 30 MW wind farm and 40 MW PV system is considered along with the 3 conventional thermal power plants in this scenario. The penalty factor $h_{min-max}$ is used to blend both the fuel cost and emission in this scenario. For the same demand of 200 MW as considered in Scenario 1, the CEED-RES is carried out and the results are listed in Table.2. The obtained result depicts the significance of renewable sources. The total cost realized by PSO and BBO are 8841.02 $ and 8814.27 $ respectively, while the total cost obtained by proposed methodology is 8808.72 $ which is comparatively much less in compared to PSO and BBO algorithms.

***Table.2** – Microgrid CEED results considering thermal power units and RES*

	TLBO	BBO	PSO
P_1 (MW)	74.2847	73.5259	65.9505
P_2 (MW)	68.5157	74.3748	80.0030
P_3 (MW)	56.4496	51.3493	53.2965
F_{Con} ($/h)	7308.60	7297.35	7295.72
E_{Con} (Kg/h)	155.640	154.906	159.015
F_T ($)	8693.68	8699.23	8725.98
F_{T-RES} ($)	8808.72	8814.27	8841.02

4.3 Comparative Analysis of both Scenarios

The main objective of power entities is to reduce both the pollutant emissions and the fuel cost to a greater extent during power generation process. In this paper, two different scenarios of CEED with and without RES are carried out considering min-max penalty factor. The total cost fetched by proposed TLBO, PSO and BBO for each scenario is presented in Table. 3 and are illustrated in Figure. 1. The total cost attained by TLBO were 8817.92 $ and 8808.72 $ for the scenarios 'with thermal plants alone' and 'with thermal and RES' respectively. These costs are the minimum among the total cost obtained by the rest of heuristic techniques for the aforementioned scenarios, which clearly portrays the superiority of the proposed approach. Due to the inclusion of RES in conventional system, the total cost in CEED-RES is reduced by 9.2 $ and emission is reduced from 157.89 Kg to 155.64 Kg which makes the proposed system more economical and pollution less.

***Table.3** – Comparison of Microgrid CEED results*

	TLBO	BBO	PSO
F_T ($)	8817.92	8868.09	8878.36
F_{T-RES} ($)	8808.72	8814.27	8841.02

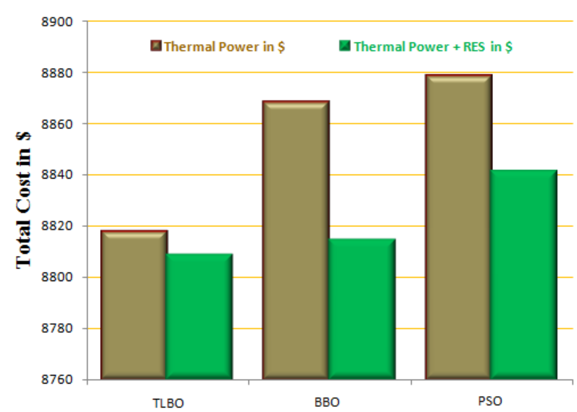

***Figure. 1.** Comparison of Total cost for both scenarios by Different Algorithms*

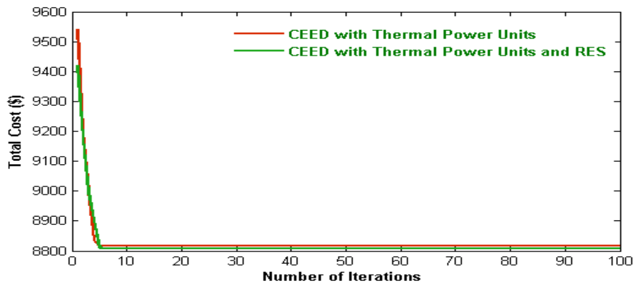

***Figure. 2**. Convergence Characteristics of TLBO for both scenarios*

The convergence characteristics of TLBO algorithm in 100 iterations for both scenarios are illustrated in Figure 2, which clearly depicts the higher convergence rate of the proposed algorithm.

5 CONCLUSION

The CEED-RES problem is formulated with the inclusion of renewable wind power and solar power and solved using TLBO methodology to find out the most optimal schedule. The studied results in both the scenarios confirm that the proposed TLBO algorithm is indeed capable of finding the higher quality solution compared to other heuristic techniques. The CEED-RES result infers that inclusion of renewable sources not only reduces the pollutant emissions but also lessens the overall cost of the system. The upshot of this research concerning renewable sources to the highest degree persuades the modern power systems to consider renewable energy sources to greater extent to diminish fossil fuel usage in isolated microgrid system.

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