A review of optimization methods for economic and emission dispatch considering PV and wind energy

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Abstract. The power generation system has fossil fuels as their major electricity generation source. This source is not reliable and environmentally friendly so, the alternative source such as renewable energy (RE) is getting much attention in the development of a power generation system. To achieve optimal power output for the power system there is a necessity to solve the economic and emission dispatch (EED) problem considering the operational system constraints. Numerous types of research on optimization of fossil fuel cost and emission roles have been focused to solve the concerned power dispatch issue. This paper represents a comprehensive study on combined economic and emission dispatch (CEED) problem with respect to conventional and unconventional energy sources. To optimize the power dispatch problem, the existing algorithm consisting of optimization methods and objective functions in integrated renewable energy sources (RES) system is tested and reviewed. This paper presented various optimization methods applied to different test systems to minimize emission and cost for power dispatch with PV and wind. Future trends and necessary steps next in the field of power dispatch are also been deliberated.

1. Introduction
Nowadays, the power system is facing more challenges in generation variability as a multitude of RES are accommodated in the operation of the power system. Therefore, the operators of the power system are optimizing the dispatch along with the commitment of generators to supply the demand for electricity while respecting all operational requirements [1].

The incremental power demand along with the reduction rate in environmental pollution can be solved by considering RES as alternative energy sources [2]. Meanwhile, RES can be considered as non-pollutant or lower exhaust emission to supply electricity to consumers [3]. Therefore the integration of the RES such as photovoltaic (PV) [4] and wind turbine [5, 6] in the power system has changed the research direction to mitigate environmental issues of conventional power dispatch [7, 8].

Power dispatch plays an essential role in the planning process and modern control power systems [9]. Thus, optimal power system operation is important in electrical networks for operating the designed flow with minimal energy cost to satisfy the system constraints [10]. Moreover, optimal power dispatch (OPD) is considered as vital planning in the power system to schedule the generator output power around a minimum cost and emission level [11]. Economic dispatch (ED) is a fundamental term used to minimize the total cost of power system operation problem related to system objectives.
Typically, pollution produced by power generation plants have been neglected based on the minimum fuel cost criteria [12]. Furthermore, environmental consideration tools have to minimize the harmful emission producing from the thermal power generation [13]. The implementation of various pollution control acts, power generation companies have to worry about the cost of power generation as well as the effect of the pollutants that result from the power generating units. [14]. This term leads to get an optimal power generation for CEED by considering different system constraints in the power system [15]. In order to dispatch the overall load demand in generating units, the optimization of the CEED problem is to be necessary [16]. Consequently, solving the EED problem with RE is also essential.

This paper introduces a review of optimization methods and problem formulation for CEED considering thermal power generation, PV and wind energy source. Section 2 represents the revised view of problem formulation in accordance with individual ED and emission dispatch as well as CEED. Section 3 introduces the branches of optimization methods related to prospective system algorithm. Section 4 the detail view of integrated RES system is presented. In Section 5 the review of this paper is concluded.

2. Overview of power dispatch formulation
The formulation of Power dispatch can be classified as follow:

2.1. Economic dispatch
ED is an important optimization problem for generation cost minimization. The aim of ED is to minimize the total cost of generation whereas the operating constraints are satisfied. The fuel cost function is used to obtain optimal power output [17]. The function of overall fuel cost is expressed as follows:

\[ F(P_G) = \sum_{i=1}^{N} C_i(P_{Gi}) \]  
(1)

\[ C_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \]  
(2)

where \( F(P_G) \) is the total cost of production, \( C_i(P_{Gi}) \) is the unit function of fuel cost, \( a_i, b_i \) and \( c_i \) are the unit coefficients of fuel cost and \( P_{Gi} \) is the unit output \( i \) of the real power.

Considering valve-point loading of a generator, the ED problem can be formulated as:

\[ C_i(P) = \left(a_i + b_i P_{Gi} + c_i P_{Gi}^2\right) + e_i \sin\left(f_i \left(P_{Gi - \text{min}} - P_{Gi}\right)\right) \]  
(3)

where \( a_i, b_i, c_i, e_i \), and \( f_i \) are the coefficients of the \( i \)th generating unit.

2.2. Emission dispatch
By considering environmental conditions, it should minimize the harmful gases of pollutants resulted from fossil fuels burning in the thermal plant. Therefore, the emission function aims to reduce the pollutants from the powered generation [13]. The total emission can be expressed as follows:

\[ E(P_G) = \sum_{i=1}^{N} \left(\alpha_i P_{Gi}^2 + \beta_i P_{Gi} + \gamma_i\right) + e_i \exp\left(\lambda_i P_{Gi}\right) \]  
(4)

where \( \alpha_i, \beta_i, \gamma_i, e_i \), and \( \lambda_i \) are the coefficients of the characteristic for \( i \)th generator emission.

2.3. Combined economic and emission dispatch
ED and emission dispatch can be combined as a multi-objective CEED to find optimal generation where reduce the emission level and fuel cost simultaneously [18]. The CEED problem can be represented as follows:

\[ \min F = \sum_{i=1}^{N} \left(C_i(P_i) + h_i \times E_i(P_i)\right) \]  
(5)
where $F$ is an objective function that must be reduced, $C_i(P_i)$ is the fuel cost and $E_i(P_i)$ is the emission of the $i$th generating unit and $h_i$ is the penalty factor.

$h_i$ is used to convert the multi-objective function into the single objective function, where $h_i$ can define as:

$$h_i = \frac{C_i(P_i)}{E(P_o)}$$ (6)

3. Optimization methods for optimal power dispatch

Optimization is a procedure to find a superior solution. Optimized power dispatch is the process of optimization to define the generating unit's schedule to meet system constraints and to supply the demand power [19].

The optimization methods of power dispatch are classified into three categories, which are hybrid, non-conventional, classical methods [19]. The conventional approach for solving ED problems is known as a classical method while non-conventional methods are used to handle the practical and non-convex ED problems. The third category is hybrid methods that combine two or more classical and/or non-conventional methods in order to improve the performance of individual methods. Figure 1 illustrates the three types of optimization methods for optimal power dispatch.

![Figure 1. Types of optimization methods for optimal power dispatch.](image)

There are a lot of classical methods have been used in order to solve ED problem such methods include newton's method [20] besides the quadratic programming technique [21] have solved ED problem with different objective functions included cost, loss, and reductions. The proposed algorithms have been achieved best optimal solution and less computational time. Interior point method [22] has considered transmission line flow limits and generation ramp rate in ED. In addition, the system operation is satisfied simultaneously. Lambda iteration method [23] was implemented on 15 and 140 units test system to prove its efficiency. The classical methods are adaptive, flexible when analysing the problem and easy to understand. On the other hand, this type has two main drawbacks: firstly, this method is not appropriate to solve nonconvex or nonsmooth problems; secondly, it generates only one solution in a single run [24, 25].

However, non-conventional methods can deal with the complicated optimization problem and developed to solve the CEED problem. Numerous methods of this type like Ant colony optimization (ACO) [10], Bat algorithm (BA) [24], Genetic Algorithm (GA) [26] and Particle swarm optimization (PSO) [27] have been solved this problem. The performance of these algorithms is better than classical optimization methods in many aspects, for instance, robust and easy to adjust according to the problem.
Furthermore, the hybrid method is combined with two or more algorithms in order to mitigate their weaknesses and use their strengths hence it provides better performance for solving optimization problems [18]. The proposed hybrid algorithms such as GA-PS-sequential quadratic programming [36], NM-FAPSO [36] and differential evolution algorithm-PSO [37] showed a highly efficient technique to solve the EED problem. However, the drawback of this type of algorithm sometimes is a long computational method because it uses two or more algorithms. Table 1 shows the advantages and disadvantages of several optimization techniques.

| Ref  | Optimization method | Advantages                                                                 | Disadvantages                                                                 |
|------|---------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| [10] | ACO                 | Can find the targets under any environment                                 | The hypothetical analysis is difficult to understand.                        |
|      |                     | Suitable for implementation under parallel numerical computation          | More convergence time                                                        |
| [28] | PSO                 | Excellent convergence characteristic.                                       | Weak capacity of local search                                                |
|      |                     | Superior in terms of fuel cost as well as computation time.                 | The iterative process has a low rate of convergence.                        |
| [29] | GA                  | Flexible and powerful                                                       | Response time of stable optimization cannot assure                          |
|      |                     | Less computational time                                                     | Find a global optimum is not guaranteed                                      |
| [30] | Linear programming  | Adaptive and flexible when analyzing the problem.                          | It is not able to solve a problem that has more than two variables.         |
| [31] |                     | Easy to understand.                                                         | It cannot solve the non-linear functions.                                   |
| [32] | Simulated Annealing | Simple coding for the composite problems                                  | Need other methods in order to get an optimal solution.                     |
| [33] |                     | Easy to deal with a cost function                                           |                                                                                |
| [34] | FBHPSO-DE algorithm | Powerful and stable for solving the ED problem                             | Its size is complex                                                          |
|      |                     | The superiority to deal with the large-scale systems                       | A long period of time to execution                                           |
| [35] | ACO–ABC–HS algorithm| Effectively capable to mitigate the problem                                | Complicated structure                                                        |
|      |                     | The superiority in finding out optimum results                             | Need a long time for the implement                                           |

4. Review of power dispatch with renewable energy

Power dispatch is a crucial part of the power system as the responsibility is to plan optimal and effective scheduling of all generators to meet the required power demand. The power dispatcher decides which unit is the most economical to increase the power output. RE has been implemented in the power dispatch as an alternatives way to reduce pollution and saving the cost. A decades ago, the researchers have include RES into power dispatch system instead of focusing mainly on thermal [38].

The RESs have an important feature compared to conventional generation. The availability of RES installation is easy as compared to conventional power plants with the lowest transmission losses.
However, the wide continues dependence on PV and wind power face many challenges. Firstly, the PV and wind power plants are not much reliable to dispatch the power as per regulated power generation demand. Secondly, both still have an expensive investment in many areas of the world [9].

There are several related studies on EED that consider thermal generations and RE. These studies have been done to solve the CEED problem with RE. The author [39] suggested PV generation on CEED of a power system. CEED problem investigated for conventional thermal and PV plants using PSO Algorithm. The test system of this research includes the thirteen PV plants with six thermal units for testing and evaluation under the constraints of generator limits and power balance.

The same method is also used by [40] to analysis solar sharing scheduling for economic and environmental dispatch for inter-area power system dispatch utilization. In this research, the CEED problem was minimized by equality and inequality constraints and to fulfill the load demand by scheduling and sharing of PV and thermal system. Moreover, [41] optimized PV generation with transmission losses for economic and environmental dispatch using PSO algorithm to reduce emission and cost using the constraints of equality and inequality, emission constraints, and transmission losses to maximize solar availability. This research involves two tests system of the thermal generator (6 and 10 thermal) and thirteen PV units. It results to enhance in regards to the lesser overall cost and limited emission for CEED problem with the best perfect solution and lower computational time.

This research [42] proposed a quadratic programming method for hybrid microgrid including energy storage. Equality and inequality constraints used for optimizing dynamic ED. This problem implemented on the IEEE 14 bus of five electric sources that are energy storage, microturbine generator, PV, diesel generator, and the primary grid.

Furthermore, the researcher [43] used a different algorithm to optimize emission and ED for thermal and PV generation. This optimization problem solved by Euclidean affine flower pollination (eFPA) algorithm and binary (FPA). The test system has been applied to IEEE 57 and IEEE 30 bus system by using five thermal and twenty generators. This research [44] proposed new multi-objective for emission and ED using a different method which is Pareto concavity elimination transformation (PaCCEt) to find the most economical operating condition and the best environmentally friendly solutions considering the constraints of equality and inequality. The test system of this research was applied to three distributed energy resources and one PV generation. Thus, this method can find the optimal set of solution solutions not only with less computation time but also with a better diverse result.

Also, [45] used a non-dominated sorting genetic algorithm II (NSGA-II) for electric vehicles taking part in the ED of thermal and wind power systems. The constraints of unit capacity, power balance, line transmission power, node voltage and thermal unit used for solving a multi-objective problem. In addition, [46] proposed hybrid energy storage for ED of off-grid PV generation system. It was used power balance constraints as well as state of charge and hydrogen level constraints to provide stable and continuous PV power. The author [7] suggested a modified harmony search (MHS) algorithm for CEED of microgrid incorporating RE sources. Three types of generators were used as a test system that is the solar unit, wind unit and combined power and heat generator under the constraints such as generation limits and power balance. MHS algorithm gave better cost reduction for various scenarios and showed its efficiency and superiority to solve the problem. Moreover, this paper [2] proposed the whale optimization algorithm (WOA) to solve CEED of RE integrated microgrid using power balance and generation constraints. The proposed approach was applied on one wind farm as well as one PV system. The results of WOA algorithm showed better quality for reducing CEED problem for all test cases and compared with different optimization techniques.

ED algorithm has been proposed by [47] to achieve optimum economic operation of the microgrid with RE sources. This microgrid consists of the wind energy system, PV system and three conventional generators. Three constraints such as power balance, ramp rate limits and generation limits have been used to ensure the optimal output for PV and wind generator. The obtained results of the proposed algorithm can guarantee that the generator’s output adjustment of microgrid can be determined in the best value.

Algorithm of constrained multi-objective population extremal optimization (CMOPEO) presented by [48]. It has been proposed to find an optimal solution and improve the performance of EED
incorporating RE resources by minimizing the objectives of the environment emission and total cost. However, inequality and equality constraints have been considered to solve the problem of EED. Three cases of modified IEEE 30 bus and six generators system with RE generations were used as test systems. CMOPEO algorithm can be observed as a competitive method and it was able to deal well with EED problem.

Table 2 shows the recent papers summarization on CEED considering RE sources such as PV and wind. It describes the optimization methods, objectives, constraints that utilized to solve the problem of power dispatch as well as the test system for PV and wind power.

| No | Ref | Methods | Objectives | Test system |
|----|-----|---------|------------|-------------|
|    |     |         | Cost       | Emission    | CEED | Thermal Unit | RE Sources | Constraints |
| 1  | [40]| PSO Algorithm | √          | √           | √    | √             | PV, W       | A&B         |
| 2  | [41]| PSO Algorithm | √          | √           | √    | √             | A&B         |
| 3  | [46]| Quadratic programming | √          |           |      | √             | A&B         |
| 4  | [42]| eFPA-BFPA algorithm | √          | √           | √    | √             | A&B         |
| 5  | [43]| PaCeET Algorithm | √          | √           | √    | √             | A&B         |
| 6  | [44]| NSGA-II Algorithm | √          | √           | √    | √             | A,B,N,L     |
| 7  | [45]| MHS Algorithm | √          | √           | √    | √             | A&B         |
| 8  | [46]| WOA Algorithm | √          | √           | √    | √             | A&B         |
| 9  | [47]| ED Algorithm | √          | √           | √    | √             | A,B,R       |
| 10 |     | CMOPEO Method | √          | √           | √    | √             | A,B,S       |

Note: W=wind; PV=photovoltaic; A=Equality constraint; B=Inequality constraint; and R=ramp rate limits; S=security constraint; N=Node voltage constraints and L=line transmission power.

5. Conclusion
This paper presented a review of optimization methods of the latest research on CEED of thermal generation and RE such as PV and wind. In power dispatch, it is necessary to consider both cost and emission level in operation and planning to ensure the power generation. Besides, the integration of RE in power dispatch becomes a more complex problem. Optimization methods were classified into three types such as hybrid, non-conventional and classical methods. Then the advantages and disadvantages of several optimization techniques were summarized. Moreover, the optimization methods, constraints and type of RE sources for the previous studies were reviewed. It presented various optimization methods applied to different test systems to minimize emission and cost for power dispatch with PV and wind. According to previous researches, it is clear that hybrid methods and non-conventional methods have high efficiency and more suitable methods for solving the CEED problem. This review study hoped can help and achieve more optimal power dispatch considering PV and wind energy.
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