A Survey on Economic Load Dispatch Problem Using Particle Swarm Optimization Technique

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Abstract – Economic load dispatch (ELD) problem play a vital role in the operation of power system it is the short-term determination of the optimal output of the number of electricity generation facilities, to meet the system load, at the lowest possible cost subjected to transmission and operational constraints. Traditionally economic load dispatch is done for minimizing generation cost while maintaining set of equality and inequality constraints. A particle swarm optimization is an effective computational method that optimizes problem by iteratively trying to improve a candidate solution. It is a method of determine, most efficient low cost and reliable operation of a power system by dispatching the available electricity generation resources to supply the load on the system the application of particle swarm optimization in ELD problem which is consider as one of the most complex optimization problem has been summarized in this paper.

Keywords - Economic load dispatch, Problem formulation, Optimization, PSO

I. INTRODUCTION

The efficient optimal economic operation and planning of electric power generating system has always occupied an important position in the electric power industry. With large interconnection of the electric networks, energy crisis in the world, continuous rise in fossil fuel and tariff structure necessitates the optimal operation of committed power generating units. A small saving in the operation of generating system results a significant reduction in operating cost as well as in the quantities of fuel consumed. The classic problem is the economic load dispatch of generating systems to achieve minimum operating cost.

The Economic Load Dispatch (ELD) is an important part of modern electrical power system like Unit Commitment, Load Forecasting, Available Transfer Capability (ATC) calculation, Security Analysis (SA), scheduling of fuel purchase etc. As power demand increase and fuel cost booms in recent years, reduction the operation costs of power system becomes an important issue. One of the choices is to operate generators efficiently and economically. The primary objective of economic dispatch is to minimize the total cost of generation while honoring the operational constraints of the available generation resources. It is formulated as an optimization problem of minimizing the total fuel cost of all committed plants while meeting the demand and losses.

The variants of the problem are numerous, which modeled the objective and constraints in different ways. The optimum load dispatch problem involves the solution of two different problems. The first of these is the unit commitment or pre dispatch problem wherein it is required to select optimally out of the available generating sources to operate to meet the expected load and provide a specified margin of operating reserve over a specified period time. The second aspect of economic dispatch is the on line economic dispatch whereas it is required to distribute load among the generating units actually paralleled with the system in such manner as to minimize the total cost of supplying the minute to minute requirements of the system. The goal of this work is to provide detailed overview of many conventional and non-conventional techniques such as quadratic linear programming [3], mathematical linear programming [4], non-linear programming [5], dynamic programming [6][7] are the conventional methods.

Conventional methods have simple mathematical model and high search speed but they are failed to solve such problem because they have the drawbacks of Multiple local minimum points in the cost function, Algorithms require that characteristics be approximated, however, such approximations are not desirable as they may lead to suboptimal operation and hence huge revenue loss over time, restrictions on the shape of the fuel-cost curves. Other methods based on artificial intelligence have been proposed to solve the economic dispatch problem, these are genetic algorithm [8][9], Tabu search [10], particle swarm optimization [11]. The PSO was primarily introduced by kennedy and eberhart [1][2], is a flexible, robust, population based algorithm. This method solves variety of problems of power system due to its simplicity, superior convergence characteristics and high solution quality. Classical PSO approach suffers from premature convergence, particularly for complex functions having multiple minima.

II. PROBLEM STATEMENT

The main goal in this optimization problem is to obtain a particular set of points, including all outputs of the power generation units, such that all equality and inequality constraints are satisfied. In addition, the total cost function is minimized. In this paper, the equality and inequality constraints indicate the real power balance and limitation of power generation of each unit, respectively.
Some of the other constraints including voltage level and security are assumed to be constant.

A. Objective function

The primary objective of any ED problem is to reduce the operational cost of system fulfilling the load demand within limit of constraints. The various kinds of objective function are given below.

1) Simplified economic cost function

Simplified economic dispatch problem can be represented as a quadratic fuel cost objective function as described in eqn (2.1)

\[
FT = \sum_{i=1}^{n} F_i(P_i) \quad \ldots \ldots \ldots (2.1)
\]

\[
F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \ldots \ldots \ldots (2.2)
\]

Where

- \(FT\) : Total generating cost
- \(F_i\) : Cost function of \(i^{th}\) generating unit
- \(a_i, b_i, c_i\) : Cost coefficient of generator \(i\)
- \(P_i\) : Output power of generator \(i\)
- \(N\) : Number of generators

2) Economic cost function with valve point loading effect

The generating units with multiple valves in steam turbines are available. The opening and closing of these valves are helpful to maintain the active power balance. However it adds the ripples in the cost function, which makes the objective function highly non-linear. The sinusoidal functions are added to the quadratic cost function as given in equation (2.3).

\[
F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \pm \text{abs}(\sin(f_i(P_i^{min} - P_i))) \ldots \ldots \ldots (2.3)
\]

Where \(e_i\) and \(f_i\) are the coefficients of generator \(i\) considering valve point loading effects.

3) Economic cost function with multiple fuels

The different type of fuels can be used in thermal generating unit hence fuel cost objective function can be represented with piece wise quadratic function reflecting the effect of fuel type changes.

\[
F_i(P_i) = a_{i_1} + b_{i_1} P_i + c_{i_1} P_i^2 \quad \text{if} \quad P_i \leq P_i^{min} \leq P_i \leq P_i^{1}
\]

\[
a_{i_2} + b_{i_2} P_i + c_{i_2} P_i^2 \quad \text{if} \quad P_i^{1} \leq P_i \leq P_i^{2}
\]

\[
a_{i_n} + b_{i_n} P_i + c_{i_n} P_i^2 \quad \text{if} \quad P_i^{n-1} \leq P_i \leq P_i^{max} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.4)
\]

3) Emission function

The global warming is a concern for power industry, as it is accountable for the emission of green house gases in environment. As discussed earlier that amendment of clear air act and environmental friendly policies (Carbon Credit System) develops an interest of power sector towards reduction of emissions of NOx, SOx, CO2 gases. Different mathematical formulations are used to represent the emission of green house gases in EMD problem. It can be represented in quadratic form, addition of quadratic polynomials with exponential terms, or addition of linear equation with exponential terms of generated power.

\[
E_i(P_i) = a_i + \beta_i P_i + \gamma_i P_i^2 + \xi_1 \exp(\lambda_1 \times P_i)
\]

\[
E_i(P_i) = a_i + \beta_i P_i + \gamma_i P_i^2 + \xi_i \exp(\lambda_1 \times P_i) + \xi_2 \exp(\lambda_2 \times P_i)
\]

Where

- \(a_i, \beta_i, \gamma_i, \xi_1, \lambda_1, \xi_2, \lambda_2\) are the emission function coefficients.

B. Equality and inequality constraints

The optimal solution of any optimization problem is needed to determine within feasible region. This feasible range can be represented by equality or inequality constraints. In economic load dispatch problems following are the constraints that should satisfy.

1) System power balance equation

In economic load dispatch of power system the total power generated should exactly match with the load demand and losses which is mathematically represented by the eqn (2.5). It is a kind of equality constraint.

\[
\sum_{i=1}^{n} P_i + \sum_{j=1}^{m} P_j + P_{loss} = D_L \ldots \ldots \ldots (2.5)
\]

Where

- \(P_i, P_j\) : Power output from \(i^{th}\) thermal unit and \(j^{th}\) hydro unit.
- \(n, m\) : Number of thermal and hydro generating units.
- \(P_{loss}\) : Transmission Loss.
- \(D_L\) : Load Demand.
2) **Power generation limits**

Each thermal generating unit is having minimum and maximum generation limits and the optimal generations schedule should be in within bounds.

\[ p_i^{\text{min}} \leq P_i \leq p_i^{\text{max}} \quad \text{.................(2.6)} \]

\[ p_j^{\text{min}} \leq P_j \leq p_j^{\text{max}} \quad \text{.................(2.7)} \]

\( p_i^{\text{min}}, p_i^{\text{max}}, p_j^{\text{min}}, p_j^{\text{max}} \) are the minimum and maximum limits of generation for thermal and hydro plants.

3) **Generator ramp limits**

One of the assumptions taken in conventional economic dispatch problem is that the adjustment of power output is instantaneous. But in practical circumstances ramp rate limit restricts the operation of all online units. The generation may decrease or increase within corresponding range so that the units are constrained due to the ramp rate limits as below:

\[ P_i - P_i^{l-1} \leq UR_i \]

\[ P_i^{l-1} - P_i \leq DR_i \]

Modified generation limits after considering ramp rate limits are not given as

\[ \max(p_i^{\text{min}}, UR_i - P_i) \leq P_i \leq \min(p_i^{\text{max}}, P_i^{l-1} - DR_i) \]

\[ \text{......... (2.8)} \]

Where \( UR_i, DR_i \) are the upward and downward ramp rate limits of generator respectively.

4) **Prohibited operating zone**

The generators may have certain range where operation is restricted due to the physical limitation of machine component, steam valve, vibration in shaft bearing etc. The consideration of prohibited operating zones creates discontinuities in cost curve and converts the constraints as below:

\[ P_i = p_i^{\text{min}} \leq P_i \leq P_i^{l_1} \]

\[ P_i^{l_{k-1}} \leq P_i \leq P_i^{l_k} \quad \text{.................(2.9)} \]

\[ P_i^{l_{2i}} \leq P_i \leq P_i^{\text{max}} \]

\( p_i^{l_k}, P_i^{l_k} \) are the lower and upper boundary of \( k^{th} \) prohibited operating zone of unit \( i \), \( k \) is the index of prohibited operating zone, \( z_i \) is the number of prohibited operating zones.

III. **PARTICLE SWARM OPTIMIZATION**

Optimization is a procedure of finding and comparing feasible solutions unless best solution has been found.

Numerous optimization technique, conventional and nonconventional have been used for decision support of different kinds of real world problems ranging from short term generation scheduling to long term transmission line planning. Conventional algorithms like linear, nonlinear, quadratic, integer and geometric programming suffers from unidirectional search, single solution update by point by point approaches, sensitive to initial condition, use of deterministic transition rule, not efficient for discrete search space and stuck into suboptimal solution. Different from conventional search algorithms, non-conventional technique i.e. evolutionary or non-gradient probabilistic techniques work on a population of potential solution (point) of the search space and offers an advantages of getting multiple suitable solution in single run, stochastic search, easy to implement, robust, parallel computing and many more. Through cooperation and competition among the potential solution, these techniques even find optima more quickly when applied to complex optimization problem. Amongst all evolutionary techniques PSO is a comparatively new computation technique which is inspired by natural aspects such as fish schooling, bird flocking and human social relation. It explores global optimal solution through exploiting the particle’s memory and swarm memory. PSO has gained incredible recognition during last decade due to convenience of realization, fast convergence and promising optimization ability in various problems. This optimization algorithm was initially suggested by Kennedy & Eberhart in 1995, which was further modified by lot of researchers to improve the performance of it. Hence lot of variants of PSO is now available in literature, which shown superior results over basic PSO in terms of solution accuracy and speed of convergence. The velocity of each particle in the swarm is updated using the following equation:

\[ v_i^{k+1} = v_i^k + c_1 r_1 (x_{\text{p best}} - x_i^k) + c_2 r_2 (x_{\text{g best}} - x_i^k) \]

\[ \text{................................. (3.1)} \]

Where \( v_i^k \): Particle velocity at current iteration (k+1)

\( v_i^k \): Particle velocity at iteration k

\( r_1, r_2 \): Random number between [0, 1]

\( c_1, c_2 \): Acceleration constant

Current position change equation is given as

\[ x_i^{k+1} = x_i^k + v_i^{k+1} \]

\[ \text{................................. (3.2)} \]

Where, \( x_i^k \): Current particle position at iteration k+1

\( x_i^k \): Current particle position at iteration k
The performance further improves when time-varying acceleration coefficients were included. The results show that the proposed approach performed better over previous method for NCED.

Agrawal Shubham et al. [16] in this paper, a fuzzy clustering-based particle swarm (FCPSO) algorithm has been proposed to solve the highly constrained EED problem involving conflicting objectives. FCPSO uses an external repository to preserve non-dominated particles found along the search presses. The proposed fuzzy clustering technique, manages the size of the repository within limits without destroying the characteristic of the pareto front. To avoid entrapment into local optima and enhances the exploratory capability of the particles, a self-adaptive mutation operator has been proposed. In addition, the algorithm incorporates a fuzzy based feedback mechanism and iteratively uses the information to determine the compromise solution. Result shown that the proposed approach obtained high quality solution and was able to provide a satisfactory compromise solution in all the trails.

Park Jong-Bae et al. [17] This paper proposes an improved PSO framework employing chaotic sequences combined with conventional linearly decreasing inertia weights and adopting a cross over operation scheme to increase both exploration and exploitation capability of the PSO. In addition, an effective constraint handling frame work is employed for considering equality and inequality constraints the proposed IPSO is applied to three different non convex ED problems with valve point effects, prohibited operating zones with ramp rate limits as well as transmission network losses and multi-fuels with valve point effects.

Meng Ke et al. [18] In this paper, a quantum inspired particle swarm optimization (QPSO) is proposed, which has stronger search ability and quicker convergence speed, not only because of the introduction of computing theory, but also due to two special implementation: self-adaptive probability selection and chaotic sequence mutation. The proposed approach is tested with five standard benchmark function and three power system cases consisting of 3, 13, and 40 thermal units. Comparison with similar approaches including with the evolutionary programming (EP), genetic algorithm (GA), immune algorithm (IA), and other versions of particle swarm optimization are given. The promising results illustrate the efficiency of the proposed method and show that it could be used as a reliable tool for solving ELD problems.

Chakraborty S. [19] this work presents a solution strategy to solve ELD problem in an efficient way while considering several aspects of ELD. The strategy employs a hybrid mechanism involving a quantum mechanics inspired particle swarm optimization (PSO).
The conventional PSO is modified by integrating quantum mechanics theory that redefine the particle position and velocity in more diverse manner and therefore explore more search space. The PSO is further upgraded a single population based to a multi population one. Such feature of the method delivers a fine balance between local and global searching abilities. The simulations are carried by considering several cases of thermal unit by varying different combination of system configuration such as with/ without ball point effect, with/ without network loss and for one or several hours of load demand. The result is quite promising and effective compared with several benchmark methods.

Niknam T. et al [20] in this paper the authors have proposed a modified $\theta$-PSO algorithm by using a new mutation. Moreover, the inertia weight factor as a significant adjusting parameter of $\theta$-PSO algorithm is tuned by using fuzzy IF/THEN rules such that the cognitive and social parameters are self adaptively adjusted. The proposed MA $\theta$-PSO algorithm maintains a finite-sized repository of non-dominated solution. As the cost and emission functions have conflicting behaviours, a fuzzy clustering technique is used to control the size of the repository. The propose algorithm is tested on two standard IEEE test systems. The obtained result demonstrates the satisfying capability of the proposed method to generate well-distributed pareto optimal non-dominated solution of the MEED problem.

Yao Fang et al. [21] In this paper, a computational framework for integrating wind power uncertainty and carbon tax in economic dispatch (ED) model is developed. The probability of stochastic wind power based on nonlinear wind power curve and Weibull distribution is included in the model. In order to solve the revised dispatch strategy, quantum-inspired particle swarm optimization (QPSO) is also adopted, which shows stronger search ability and quicker convergence speed. The dispatch model is tested on a modified IEEE benchmark system involving six thermal units and two wind farms using the real wind speed data obtained from two meteorological stations in Australia.

Zhao JunHua et al. [22] in this paper, an economic dispatch model, which can take into account the uncertainties of plug-in electric vehicles (PEVs) and wind generators, is developed. A simulation based approach is first employed to study the probability distributions of the charge/discharge behaviors of PEVs. The probability distribution of wind power is also derived based on the assumption that the wind speed follows the Rayleigh distribution. The mathematical expectations of the generation costs of wind power and V2G (vehicle to grid) power are then derived analytically.

An optimization algorithm is developed based on the well-established particle swarm optimization (PSO) and interior point method to solve the economic dispatch model. The proposed approach is demonstrated by the IEEE 118-bus test system.

Abarghooee R.A. et al. [23] In this study, a new solution method of integrating the classical gradient-based optimization technique and a new enhanced simplified swarm optimization algorithm is comprehensively presented and successfully applied to determine the feasible, robust, fast and globally or near-globally optimal solution within a rapid timeframe for the ED problems. The simulations are carried out on four-test systems, including 10-, 15-, 40- and 80-units using the proposed optimization technique in the Fortran Power Station 4.0 software.

Chamba M. S. [24] The authors proposed the use of an innovative hybrid methodology that integrates traditional linear programming to calculate the optimal power flow nested within a meta-heuristic algorithm, whose control variable is the reserve vector (reserve assigned to each unit). Thus, faults and congestion of the transmission system are taken into account by providing an optimal location of the reserve. In addition, the authors compare two meta-heuristic models: An evolutionary model widely used in various optimization problems, Evolutionary Particle Swarm Optimization (EPSO) and a novel model known as Mean-Variance Mapping Optimization (MVMO).

Jun Sun et al. [25] In this paper the authors introduced random drift particle swarm optimization (RDPPO) algorithm for solving economic dispatch ED problems of power system areas. This method is inspired by the free electron model in metal conductors placed in an external electric field and it employs a novel set of evolution equations that can enhance the global searchability of the algorithm. The proposed method is used in particle for optimizing the generators’ operation. The performance of the RDPPO method is evaluated on three different power system, and compared with that of other optimization method in terms of the solution quality, robustness, and convergence performance. The experimental results shows that the RDPPO method perform better in solving the ED problem that any other tested optimization techniques.

V. CONCLUSION

This Review present a survey of particle swarm optimization (PSO) implement. in solving a problem of economic load dispatch. The basic PSO insufficient to address problem of practical economic load dispatch.
The global optimal solution and global search ability, premature convergence and convergence speed, and stuck in local optima are certain major issues for particle swarm optimization. In present review, it is shown that many new algorithms are developed to solve this problem of PSO. By adopting modified particle swarm optimization (MPSO), improved particle swarm optimization (IPSO), self-organizing particle swarm optimization (SOH-PSO), fuzzy clustering-based particle swarm optimization (FCPSO), quantum-inspired particle swarm optimization (QPSO), modified adaptive θ – particle swarm optimization (MA 0-PSO), random drift particle swarm optimization (RDPSO), we can get global optimum solution and global search ability, our review paper conclude that in comparison of conventional optimization techniques PSO has given an improved result with in less computational time, this paper summarized the work reported in literature in the field of economic load dispatch using PSO.

REFERENCES
