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Minimisation of Generation Cost using Particle Swarm Optimization

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Abstract
In a power system, the ultimate output is electric power, which is produced in the power plant, transmitted and distributed to the consumers. The power system needs to fulfill the consumers demand in the most economical manner. This paper presents a solution of reducing the generation cost of generators involved in a power system. A power system's entire cost may be stated as the sum of its fuel, labor, and maintenance expenses. Fuel cost is easier to minimize than other costs. This paper attempts to reduce the fuel cost with the help of Particle Swarm Optimization (PSO) to a value lower than that obtained using traditional optimization method called Linear Programming (LP). The process is exemplified using a 14 bus and 30 bus power system. The findings show that the PSO technique minimizes fuel costs better than the LP approach.

Keywords: *Linear Programming, Particle Swarm Optimization, Fuel Cost, Power Generation, Power Demand, Power loss.*

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I. INTRODUCTION

Power systems are complicated and dynamic [1]. Power system networks worldwide are getting more intricate, with a growing number of units and nodes, as a result, the financial aspect of the power supply ecosystem is becoming enormously relevant [2]. The primary goal of the power system should be to provide a good degree and gratifying electricity supply to customers at a reasonable potential expense while managing to avoid exceeding any restrictions previously set for the generating units. The task is to create the best possibility or scenario of running a power system. As a result, in order to provide cheaper electricity, load must be divided among the several powerplants in a way that results in the lowest fuel expense [3]. Fuel costs must be lowered since they make for a substantial portion of a generating platform's expenditure, close to 60 percent [4]. In other words, to satisfy the load's requirement at the lowest possible fuel cost, the generators' power output have to be controlled under prescribed limits [5]. Traditional cost-minimization approaches, such as linear programming (LP) [6] and quadratic programming [7], are based on consecutive interpolation, including searching paths for the initial two variants of objective function, as well as their limitations [8]. Furthermore, they operate on the assumption of uniformly increasing cost activity, which intensifies the problem [9]. So, Particle Swarm Optimization (PSO) is preferred because of high efficiency and rapid convergence speed. It is a type of swarm based random optimistic method [10]. Majority of the metaheuristic algorithms in recent use have been a result of observational and analytical study of living organisms around the planet. These metaheuristic approaches are gaining popularity thanks to their ability to find the global optimum while coping with multiple limits [11]. Particle Swarm Optimization generates a population and through iterative techniques and finds the best possible particle in the population. It is one of the best to solve continuous non-linear functions [12]. The adjustment of parameters is also very simple. The algorithm is easy to implement and has good performance of optimization and being applied in many fields [13]. In recent years, The PSO method is extensively used in power system voltage regulation, power grid state assessment, active power distribution, and optimal power computation, among other things [14].

II. PROBLEM STATEMENT

The major aim is to decrease cost of generation by guaranteeing that load demand is met and by obeying the equality and inequality limits that come with grid operation [15]. The problem works on optimizing the power produced at each generator which will lead to an optimum cost of generation while assuring the load demand is successfully met. The objective function is a function that represents the total of generator costs, which differ based on the generation at each generator node in the system. This is expressed as follows

$$C_T = \sum_{z=1}^{G} (a_z P_{gz}^2 + b_z P_{gz} + c_z)$$
(1)

where C_T is fuel cost, G is number of generators, a_z, b_z and c_z are the cost parameters at bus z .

2.1 Equality constraints

Equality constraint is nothing but the condition that the generated power should serve the power demand despite the practical unavoidability of the phenomenon of power loss which could be expressed as

$$\sum_{z=1}^{G} P_{gz} = P_D + P_L$$
(2)

where P_{gz} is power generation at bus z, P_D is power demand and P_L is power loss.

2.2 Inequality constraints While emphasizing on minimizing cost, there should not arise such a scenario where the prescribed boundaries set for each variable in the power system are neglected. The boundaries set for power system variables are the inequality constraints. In simple words, these define the operating channel for each variable in the power system as shown below.

Generator Constraints: $P_{gz}^{min} \leq P_{gz} \leq P_{gz}^{max}$ (3)

Voltage Constraints : $V_{min} \leq V_z \leq V_{max}$. (4)

III. PARTICLE SWARM OPTIMISATION

Optimisation is a handy tool for improving a system's performance. The usage of smart techniques such as PSO has gained a lot of importance because of its accuracy and involving very less mathematics [16]. In simple terms, from a wide range of possibilities of executing a task, optimization is the process of finding the best possibility without violating the mandatory limits of the task. For example, if the task is to reduce the area of a circle, optimisation method checks various possibilities of reduction and finds the optimum coordinates which give the least area. Particle swarm optimisation is one such optimisation method which finds the best possibility of executing a task by creating a wide range of solutions called population and iteratively performing the task of generating possibilities, where the possibilities keep getting better by each iteration. The PSO method seeks the lowest possible value of the objective function, hence lowering it, by emulating particle motion and interplay in a population [17]. The idea of the algorithm arose after studying the behavior of birds in their respective groups. This approach has been proven to be more successful than other adaptive stochastic technologies such as the genetic algorithm in tackling various optimization tasks [18]. PSO has a relatively high potential than other techniques, as it needs fewer variables, and is easier to solve large-scale scientifically optimal situations [19]. The approach entails determining the optimum combination of design variable values that yields the best objective function value while meeting all equality and inequality criteria [20]. A random population of certain amount is created and after each iteration the position of the particle is newly created and so the velocity as well. Each particle will have its own position, memory and velocity since a particle is the representation of a prospective solution of the issue [21, 22]. The particle position and velocity are the important parameters which are modified in each iteration in the algorithm and the most optimum solution is the Global Best [23]. The performance and efficiency are affected by iteration and swarm dimensions [24]. The PSO program enables the user to continue the process until the optimum value is attained. The workflow of PSO is illustrated step by step in the algorithm as follows.

3.1 Algorithm

(1) Initialise particles.
(2) Initialise positions and velocity for each particle.
(3) Utilise the particles and positions to find the objective function
(4) Renew the position and velocity of particles.
(5) For each particle generate a solution
(6) The solution with the lowest value (Personal Best) is chosen.
(7) Update the position and velocity in the search space.
(8) Solution Converged? If yes, go to (9), else go to (4).

(9) Last solution is the Global Best, which is the optimized value.

IV. PROPOSED METHODOLOGY

A 30 Bus and a 14 Bus test case, each possessing six generating units system are used here whose single line diagrams are shown in Figures 2 and 3 [25]. The entire generation capacity of the 30 bus system is 435 megawatts (MW) with a load capacity of 260.4 MW. The overall generation capacity of the 14 bus system is 435 MW supplying a load of 259 MW.

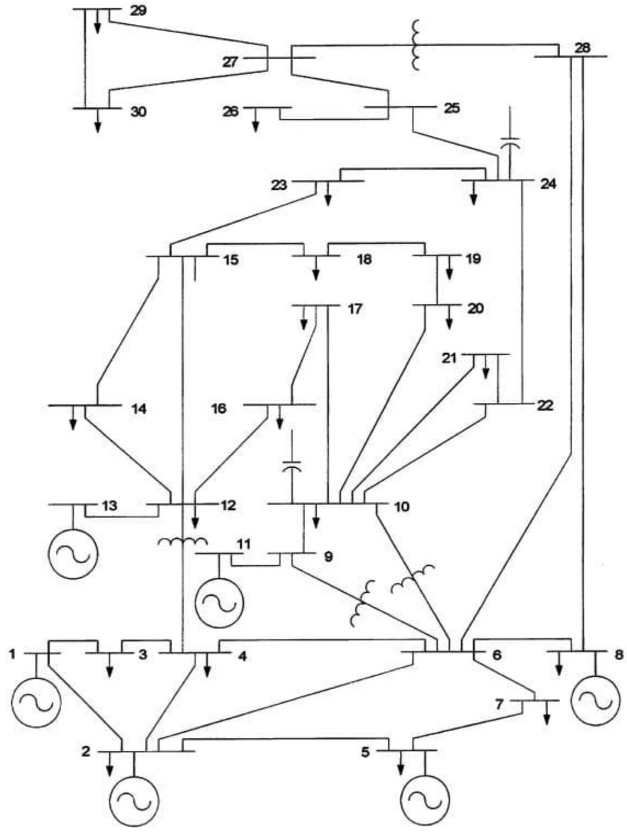

Figure 1: 30 Bus System

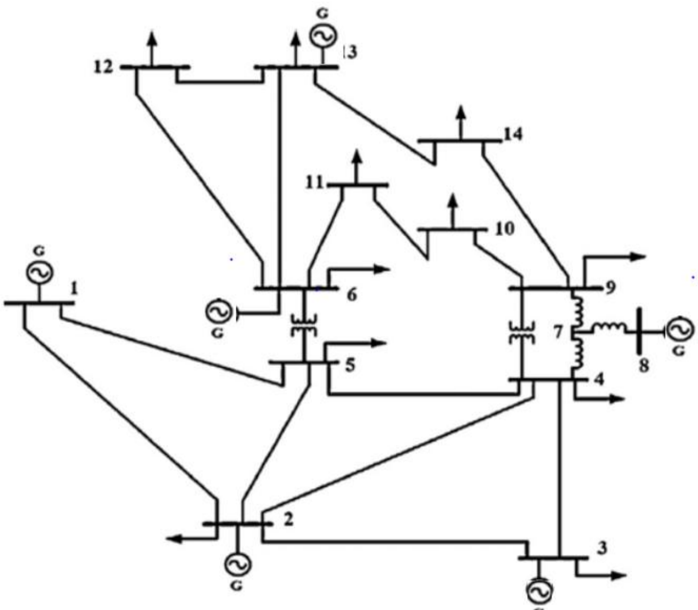

Figure 2 : 14 Bus System

Taking in to account the generator cost data of individual generators with their functional extremes optimization procedure is performed using Linear Programming. Objective function value which represents the total fuel cost and the optimal power generated at each unit to meet the load demand is observed.

Table 1 : Generator data of 14 Bus and 30 Bus system

Bus number		Cost graph parameters			Functional extremes	
Figure1	Figure 2	a_z	b_z	c_z	Pg(min)	Pg(max)
1	1	0.00375	2	0	50	200
2	2	0.0175	1.75	0	20	80
5	3	0.0625	1	0	15	50
8	6	0.0083	3.25	0	10	35
11	8	0.0025	3	0	10	30
13	13	0.0025	3	0	12	40

Secondly, Particle Swarm Optimization is executed on the bus system keeping intact all the previous data on the same bus system. Table 1 presents the cost data and functioning restrictions of each unit, as well as the bus to which it is linked. The results section will depict a relative interpretation of the suggested methodology's outputs.

V. RESULTS AND DISCUSSION

For a power requirement of 260.4 megawatts (MW) in 30 bus system, the LP technique optimizes overall generation to 268.63 MW with a power loss of 8.23 MW, resulting in fuel cost of $719.72 per hour. PSO approach decreases the fuel cost to $719.35 per hour for the same power demand of 260.4 MW, with total generation of 268.58 MW and power loss of 8.18 MW, giving 0.05 percent reduction in fuel cost compared to LP. Similarly, in a 14 bus system with a power requirement of 259 MW, the fuel cost achieved using LP is $718.31 per hour, whereas PSO reduces the fuel cost to $716.87 per hour, giving a 0.2 percent drop.

Tables 2 and 3 show the numerical data of generation at each generation unit, total generation, power demand, power loss and the fuel cost value for both LP and PSO techniques, tested with 30 and 14 bus systems respectively

Table 2 : Comparison of PSO with LP (30 Bus System)

Parameters		Linear Programming	Particle Swarm Optimization
Generation at each unit (MW)	P_1	164.55	165.14
	P_2	45.91	45.99
	P_5	20.47	20.45
	P_8	15.49	15.00
	P_{11}	10.21	10.00
	P_{13}	12.00	12.00
Power Generated P_g (MW)		268.63	268.58
Power Demand P_D (MW)		260.4	260.4
Power Loss P_L (MW)		8.23	8.18
Fuel Cost ($/hr)		719.72	719.35

Table 3 : Comparison of PSO with LP (14 Bus System)

Parameters		Linear Programming	Particle Swarm Optimization
Generation at each unit (MW)	P_1	165.64	163.44
	P_2	46.15	46.56
	P_3	20.55	21.16
	P_6	11.87	10
	P_8	10.38	12.7
	P_{13}	12	13.69
Power Generated P_g (MW)		266.59	267.56
Power Demand P_D (MW)		259	259
Power Loss P_L (MW)		7.586	8.599
Fuel Cost ($/hr)		718.31	716.87

VI. CONCLUSION

With the implementation of the proposed algorithm (PSO), the fuel cost is minimized by 0.2 percent in 14 bus system and 0.05 percent in 30 bus system in comparison with the fuel costs resulting from Linear Programming. The Particle Swarm Optimization technique outperforms the Linear Programming approach in two separate bus systems in terms of cost minimization without breaching the limitations. As a result, it can be deduced that by employing the suggested approach, the cost of power generation in a power plant may be reduced, hence adding to the power system's overall economic efficiency.

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