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Unit Commitment Solution Using Particle Swarm Optimisation (PSO)

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Abstract: - Existing unit commitment methods have the problem of stopping at local optimum and slow convergence. So it is replaced by a new method known as Particle Swarm Optimisation (PSO) which is a biological method based on particle swarming. It consists of a group of particles moving towards optimal solution. Feasible solutions are obtained as particles move in feasible solution space rather than infeasible ones. Thus the method reduces computational time. In this paper PSO is applied to IEEE 30 bus test system with six generators so that fuel cost of each generator is reduced using PSO.

Keywords: - $C_p C_g$, GA,G_{best} , K, P_{best} ,PSO,UC,v_i,W,x_i U_i

I. INTRODUCTION

Due to the nature of changing technology, unit commitment is also undergoing a change in its solution method. This is because there must be an efficient method to commit the generators to meet the load. Many methods have been introduced to solve unit commitment. Even if the methods have advantages, most of the methods suffer from local convergence and curse of dimensionality. So a new method known as PSO is introduced to solve unit commitment.

The method was introduced by Eberhart and Kennedy in the year 1995.It is a biological based method based on the motion of particles in a hyperspace towards optimal solution. The project deals with the solution of unit commitment using PSO. Other applications of PSO are optimal placement of facts devices, reactive power dispatch, state estimation and fuzzy systems.

One such area is the commitment of thermal units. Particle swarm optimization has roots in biological simulation and behavior of birds and animals such as bird flocking, fish schooling, and swarming theory. It is also related to evolutionary computation, and has ties to both genetic algorithms and evolutionary programming.

Particle swarm optimization as developed by the authors comprises a very simple concept, and paradigms can be implemented in a few lines of computer code. It requires only primitive mathematical operators, and is computationally inexpensive in terms of both memory requirements and speed. Early testing has found the implementation to be effective with several kinds of problems.Particle swarm optimization has also been demonstrated to perform well on genetic algorithm test functions.

II. PROBLEM FORMULATION

Unit commitment can be defined as the selection of generators that must be operated to meet the forecasted load demand on the system over a period of time so that fuel cost is minimum [2,3,4,5,6,7,8]. The Unit Commitment Problem (UCP) is to determine a minimal cost turn-on and turn-off schedule of a set of electrical power generating units to meet a load demand [23] while satisfying a set of operational constraints.It is a well known problem in power industry and helps in saving fuel cost if units are committed correctly so that fuel cost is saved.

2.1 NEED FOR UNIT COMMITMENT

(i)Enough units will be committed to supply the load.
(ii)To reduce loss or fuel cost.
(iii)By running the most economic unit load can be supplied by that unit operating closer to its better efficiency.

2.2 FACTORS CONSIDERED IN UNIT COMMITMENT

(i) For finding the nature of fluctuating load as well as to commit the units accordingly a graph is drawn between load demand and hours of use. This graph is known as load curve. In the solution load pattern for M period is formed using load curve.
(ii)The possible numbers of units are committed to meet the load.
(iii)The load dispatch is calculated for all feasible combinations and operating limits of the units have to be calculated.

Unit Commitment is considered as a complex optimization problem where the aim is to minimize the objective function in the presence of heavy constraints
The objective function is given by
Minimize Total cost = Fuel cost + Start up cost +Shut down cost
Fuel cost: It is a quadratic function of power generated Pg.
It is given by fuel cost=$a_i P_{gi}^2+b_iP_{gi}+c_i$
Where a_i, b_i and c_i are the fuel cost coefficients of generator i and P_{gi} is the power generated by generator i.
Start up cost: When the unit is at rest, some energy is required to bring the unit online. This is the start up cost. It is maximum when the unit is at cold start (start up cost when cooling).The unit is given sufficient energy input to keep it at operating temperature(start up cost when banking).So it requires some energy input to the system to keep it at operating temperature.
Shut down cost: It is the cost for shutting down the unit. Sometimes during the shutdown period boiler may be allowed to cool down naturally and thus no shut down cost will be incurred.

2.3. CONSTRAINTS IN UNIT COMMITMENT

The constraints in unit commitment are [1, 2, 3, 4, 11, 15, 16,17]
(i) Load balance constraints: The real power generated must be able to meet the loads.

$$\sum_{i=1}^{N} Pgi=P_D$$

(ii) Spinning reserve: It is the total power available from all units synchronised on the system minus present loads plus the losses. It is given by

$$\sum_{i=1}^{N}(P_{\max\ i}\text{-}P_{gi})U_i \geq \text{SR}$$

(iii) Thermal constraints: The temperature and pressure of units increase gradually as the units are started. So they must be synchronised before bringing online.
(iv) Must run units: Some of the units must be given a must-run status in order to provide voltage support for the network. For such units U_i=1.
(v) Power limits: Each generator has upper power limits and lower power limits within which the generators should run. It is given by

$$P_{gimin} \leq P_{gi} \leq P_{gimax}$$

(vi) Ramp rate constraints: The ramp rate constraint ensures that sufficient ramp rate capacity is committed to accommodate required generation changes. Any generation changes beyond the required changes are due strictly to economics of the committed generators.
(vii) Fuel constraints: The constraint means limited availability of fuel or burning of some amount of fuel.

III. SOLUTION FOR THE OPTIMISATION PROBLEM

The electric power industry has been using many methods to solve the unit commitment for decades. Due to complexity of the problem different solution methods are necessary [8].Reduction in computation time and fuel cost makes one method better than the other. In restructured market, small change in total cost can produce big changes in annual fuel cost.
A literature survey on unit commitment reveals that several methods have been developed to solve unit commitment [1,2,3,4,5].They include

3.1. DYNAMIC PROGRAMMING METHOD

It is a stochastic search method which searches for solution from one state to the other. The feasible states are then saved [1,11,19]. Dynamic programming was the earliest optimization-based method to be applied to the UC problem. It is used extensively throughout the world. It has the advantage of being able to solve problems of a variety of sizes and to be easily modified to model characteristics of specific utilities[11].But the disadvantage of this method is curse of dimensionality. ie, the computational effort increases exponentially as problem size increases and solution is infeasible[4] and its suboptimal treatment of minimum up and downtime constraints and time-dependent startup costs[11].

3.2. MIXED INTEGER LINEAR PROGRAMMING METHOD

The method is widely used in the commitment of thermal units [2].It uses binary variables (0 or 1) to represent start up, shut down and on/off status of units. It linearises the quadratic production cost into linear system and the start up cost into a staircase function. Even it guarantees optimal solution in finite number of steps, it fails when number of units increases because they require large memory space and suffer from great computational delay [4, 8].

3. 3 LAGRANGE RELAXATION METHOD

In this method the constraints are relaxed using Lagrange multipliers. A brief description of the method is given in [11].Unit commitment is written as a cost function involving a single unit and coupling constraints. Solution is obtained by adjoining coupling constraints and cost by Lagrange multipliers [11].[17] explains the scheduling of hydrothermal units using LA method. It provides a faster solution but solution feasibility and solution quality problem when number of units increases [4]. Lagrangian Relaxation is also being used regularly by some utilities [11]. Its utilization in production UC programs is much more recent than the dynamic programming.[19,24].But the disadvantage is that unit commitment obtained from an LR dual solution, even a "near-optimal" dual solution, usually displays over-commitment[35].

3.4. FUZZY LOGIC METHOD

Zadeh introduced the concept of fuzzy sets in 1965 as a mathematical means of describing vagueness in linguistics. It was later developed by mathematical researchers in 1970[11]. The idea may be considered as a generalization of classical set theory. UC is a complex decision-making process [1,3,5]which operates appropriate units at different hours and schedules the outputs of the committed units to meet a predicted demand, such that the operating cost is minimized. Due to the uncertainty of the demand and outages of generating units, fuzzy is used to represent the uncertainty.The method is an intelligence based technique that quantifies linguistic terms so that variables are treated as continuous. It establishes the relation between input and output according to some fuzzy control rules.eg by using "if-then". The result is defuzzified to obtain numerical solution [4].But the disadvantage of this method is that it cannot handle large scale systems [5].

3.5. SIMULATED ANNEALING

SA is a recently developed optimization technique, proposed by Kirkpatrick, Gelatt, and Vecchi in 1983, which takes advantage of the analogy between the minimization of the cost function of an optimization problem and the slow procedure of gradually cooling a metal, until it reaches its "freezing" point, where the energy of the system has acquired the globally minimal value [11,32]. The algorithm is based on the iterative method which simulates the transition of atoms in equilibrium at a given temperature. SA serves for solving difficult combinatorial optimization problems without specific structure. The main drawback of this method is that it requires long CPU time, due to the large number of iterations needed for the convergence of the algorithm.

3. 6. GENETIC ALGORITHM

It consists of an initial member of population. It is a matrix of number of generators and time of scheduling. The generators are given status of 0 or 1. Most highly fit members in a population are selected to pass on information to the next population of members [12]. A crossover point is then selected at random and information from one parent, up to the crossover point, exchanged with the other member thus creating two new members for the next generation. The better performing members are rewarded well [20].The benefits of using a genetic algorithm (GA) are: a robust optimization technique, easy implementation and production of multiple UC schedules.

They operate on a population of potential solutions applying the principle of survival of the fittest to produce successively better approximations to a solution [27].GA has also been applied for solving the UCP of hydro-thermal power system.

IV. EVOLUTION OF PSO

Since all the previous methods suffer from dimensionality and computation problems, a new method has been evolved in solving the unit commitment. It is known as Particle Swarm Optimisation method.[6,15,21].The method was developed [13] by simulation of social model. The method is inspired from social behaviour such as "bird flocking" or "fish schooling". Concept of bird flocking was introduced by Reynolds. Later Hepner modelled group motion, disintegration and changing direction of group.

4.1 CONCEPT OF PSO

The method consists of a group of particles in a given dimension moving towards optimal solution. The particles move based on their previous best position, the position of neighbours and the best among all particles[15,33].Each particle move towards the optimal solution based on its previous best position given by P_{best} ,position of other particles and the best among all the other particles given by G_{best}. The search is continued until a globally best solution is obtained or specific number of iteration is reached.

4.2 SOLUTION METHODOLOGY:

Consider a system having N particles moving in D dimensional space. Let the position of i_{th} particle be x_i and its velocity be V_i. When the particle move from one position to the other, its velocity is updated using the rule,

V_i^{k+1}=WV_i^k+C_p*rand1 (P_{besti}^k -x_i^k) + C_g*rand2 (G_{best}^k -x_i^k)

Where,

W is the inertia weight.

C_p and C_g are acceleration constants which accelerate the particle towards P_{best} and G_{best} respectively.k is the iteration number.

rand1 and rand2 are random numbers of the range 0 to 1.

The equation for W is given by

$W=W_{final}+\frac{k_{max}-k}{K_{max}}(W_{initial}-W_{final})$

Where,

$W_{initial}$ =initial inertia weight.

W_{final} =final inertia weight.

K_{max}=final inertia weight.

Value of W is varied between 0.9 and 0.4 to find optimal solution.

Later the position of the particle is updated using the rule,

$x_i^{k+1}=x_i^k+V_i^{k+1}$

4.3. PSO ALGORITHM

According to the formulation above, the following procedure can be used for implementing the PSO algorithm.

1) Initialize the swarm by assigning a random position in the problem hyperspace to each particle.
2) Evaluate the fitness function for each particle
3) For each individual particle, compare the particle's fitness value with its P_{best}. If the current value is better than the P_{best} value, then set this value as the P_{best} and the current particle's position, x_i as P_i .
4) Identify the particle that has the best fitness value. The value of its fitness function is identified as G_{best} and its position as P_g .
5) Update the velocities and positions of all the particles using (1) and (2).
6) Repeat steps 2–5 until a stopping criterion is met (e.g., maximum number of iterations or a sufficiently good fitness value)

4.4. ADVANTAGES OF PSO COMPARED TO CONVENTIONAL METHODS:

1. Easy to implement and potential to achieve a high quality solution with stable convergence characteristics.
2. The particles are treated as volume less and each particle update position and velocity according to its own experience and partners experience. [8]
3. PSO is more capable of maintaining diversity of the swarm.
4. One of reasons that PSO is attractive is that there are very few parameters to adjust [21]

4.5. PSO CONCEPTS:

The basic concepts of PSO are classified as

1. Social concepts: Human intelligence is based on social interaction, evolution, comparison and imitation from others.
2. Swarm Intelligence Principle: It has five fundamental principles

(i)Proximity principle: Particle should carry simple space and time computation.
(ii)Quality principle: Particle should respond to quality factors in environment.
(iii)Diverse response principle: Particle should not commit its activity in extensively narrow channel.
(iv)Stability principle: Particle should not commit its activity in extensively narrow channels.
(v)Adaptability principle: Particle should change its behaviour when worth computational.

4.6. APPLICATIONS OF PSO

PSO has found great applications in many fields such as unit commitment, economic dispatch, power quality, reactive power control, voltage security etc.The important two applications are scheduling of pumped storage plant [9] and electromagnetics [10].Other applications are human tremor analysis, power system load stabilisation and product mix optimisation [32]

The pumped storage unit generates at peak load and pumps at light load. It uses a PSO method and a mutation operation to find solution. The electromagnetic problem uses a robust PSO where particles are arranged in ascending order according to feasibility and energy is reduced.

V. RESULT

In this paper PSO is applied on IEEE 30 bus system. It consists of 6 generators as shown in figure.

Single line diagram of the IEEE 30-bus test system

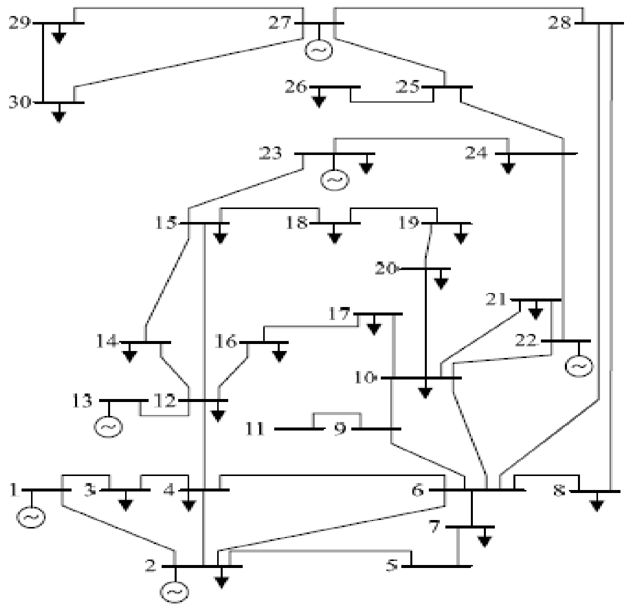

Fig 1

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The generator data is given in table below

Generator data of IEEE 30 bys system								
UNIT	**BUS**	**COST COEFFICIENT**			**PMAX**	**PMIN**	**MIN UP TIME**	**MIN DOWN TIME**
		A	**B**	**C**				
1	1	0.02	15	0	80	15	2	2
2	2	0.0175	14.75	0	80	15	2	2
3	13	0.025	16	0	50	10	3	3
4	22	0.0625	14	0	50	10	4	4
5	23	0.025	16	0	30	5	3	3
6	27	0.0083	15.25	0	55	10	4	4

The PSO algorithm is applied to IEEE 30 bus system considering three random particles. Each particle undergoes 10 iterations. The minimum value of fuel cost as well as the power generated at minimum fuel cost is calculated and tabulated below.

A Priority list of Units are created according to the input data and the units are turned on as shown in table below.

Ranking Order	Unit	L (Mw)	U (Mw)
1	6	10	55
2	6+2	25	135
3	6+2+1	40	215
4	6+2+1+5	45	245
5	6+2+1+4+5	55	295
6	6+2+1+5+4+3	65	345

Where L is Lower bound of units and U is upper bound of units.

The table shows the turn on and turn off status of units.

Time	Unit Status					
	1	2	3	4	5	6
1.	1	1	0	0	0	1
2.	1	1	0	0	1	1
3.	1	1	1	1	1	1
4.	1	1	1	1	1	1
5.	1	1	1	1	1	1
6.	1	1	1	1	1	1
7.	1	1	0	1	1	1
8.	1	1	0	1	1	1
9.	1	1	0	0	1	1
10.	1	1	0	0	0	1
11.	1	1	0	0	0	1
12.	1	1	0	0	0	1
13.	1	1	0	0	0	1
14.	1	1	0	0	1	1
15.	1	1	0	1	1	1
16.	1	1	0	1	1	1
17.	1	1	0	1	1	1
18.	1	1	0	1	1	1
19.	1	1	0	1	1	1
20.	1	1	0	1	1	1
21.	1	1	0	0	1	1
22.	1	1	0	0	0	1
23.	1	1	0	0	0	1
24.	1	1	0	0	0	1

The PSO algorithm is applied to above system considering three random particles. Each particle undergoes 10 iterations. The Spinning Reserve is taken as 10% of maximum demand. The minimum value of fuel cost as well as the power generated at minimum fuel cost is calculated and tabulated below.

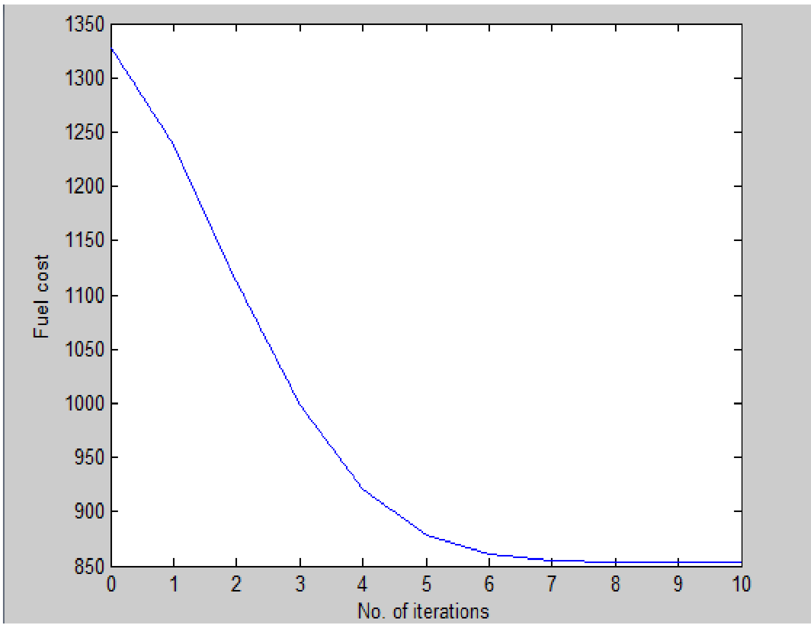
Load Demand	G1	G2	G3	G4	G5	G6
166	66.0251	72.6845	-	-	-	54.6221
196	66.0251	72.6845	-	-	29.8964	54.6221
229	61.55	70.406	38.93	36.716	29.8945	54.577
267	61.55	70.406	38.93	36.716	29.8945	54.577
283.4	68	73.7	42.8	41.36	29.8985	54.6899
272	61.55	70.406	38.93	36.716	29.8945	54.577
246	68	73.7	-	41.36	29.8985	54.6899
213	55.2768	67.1397	-	32.1156	29.8926	54.4719
192	61.55	70.406	-	-	29.8945	54.577
161	61.55	70.406	-	-	-	54.577
147	53.5938	66.2687	-	-	-	54.4630
160	61.55	70.406	-	-	-	54.577
170	68	73.7	-	-	-	54.6899
185	75	77.4	-	-	-	54.8
208	74.0605	76.8352	-	-	29.9081	54.7259
232	61.55	70.406	-	36.716	29.8945	54.577
246	68	73.7	-	41.36	29.8985	54.6899
241	68	73.7	-	41.36	29.8985	54.6899
236	66.0251	72.6845	-	39.8867	29.8964	54.6221
225	61.55	70.406	-	36.716	29.8945	54.577
204	68	73.7	-	-	29.8985	54.6899
182	75	71.4	-	-	-	54.8
161	61.55	70.406	-	-	-	54.577
131	52	52	-	-	-	55

The total fuel cost obtained using this method is Rs. 91281/- The results are compared with Lambda Iteration Method and following schedule is obtained.

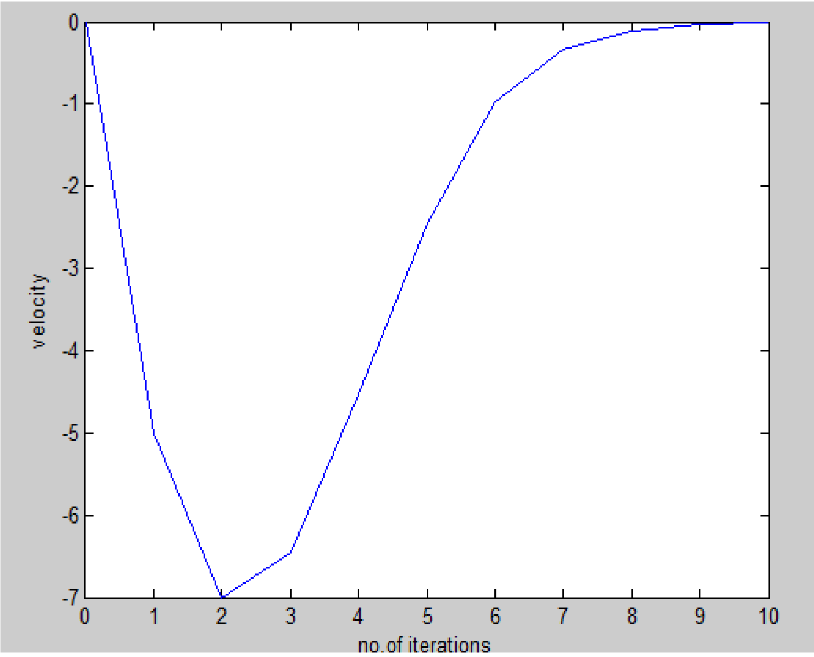
Load Demand	λ Value	G1	G2	G3	G4	G5	G6
166	17.4613	61.5239	77.4662	-	-	-	55
196	17.4718	61.7961	77.767	-	-	29.4369	55
229	17.5476	63.6891	79.9304	-	28.3805	30	55
267	17.6792	66.9811	80	33.5849	29.434	30	55
283.4	17.9887	74.7170	80	39.7736	31.9094	30	55
272	17.7736	69.3396	80	35.4717	30.1887	30	55
246	18.0606	76.5151	80	-	32.4848	30	55
213	17.3398	58.4939	73.993	-	26.7180	26.7951	55
192	17.3335	60.4369	76.2136	-	-	28.3495	55
161	17.368	59.2	74.8	-	-	-	55
147	17.1067	52.6667	67.3333	-	-	-	55
160	17.3493	58.7333	74.2667	-	-	-	55
170	17.5360	63.4	79.6	-	-	-	55
185	18.12	80	80	-	-	-	55
208	17.84	71	80	-	-	30	55
232	17.6364	65.9091	80	-	29	30	55
246	18.0606	76.5151	80	-	32.4848	30	55
241	17.9091	72.7273	80	-	31.2727	30	55
236	17.7576	68.9394	80	-	30.0606	30	55
225	17.4869	62.1716	78.1961	-	27.8949	29.7373	55
204	17.68	67	80	-	-	30	55
182	18	75	80	-	-	-	55
161	17.368	59.2	74.8	-	-	-	55
131	16.9096	50	64.2857	-	-	-	55

The fuel cost obtained using this method is Rs.91923/- it shows that PSO method is more efficient than Lambda Iteration Method because it reduces the fuel cost.

Simulations are performed in mat lab software and a graph is drawn between number of iterations and fuel cost. The graph obtained is exponentially decreasing showing convergence. The graph is shown below.



The graph is drawn between velocity and no.of iterations. The graph shows that velocity increases at the beginning for fast convergence and later reaches the constant value showing convergence.



VI. CONCLUSION

PSO method is applied to IEEE 30 bus system and the fuel cost is reduced. The result is compared with Lambda Iteration Method showing the efficiency of PSO Method. The method can also be extended to above 30 bus system. The graph obtained also shows convergence.

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