Maximal optimal preventive control actions in unit commitment using particle swarm optimization

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This paper proposes two approaches for optimal scheduling of unit commitment (UC) considering reserve generating for power system operation. The particle swarm optimization (PSO) technique is used to find out the solution of both optimal UC and their power generation problems, simultaneously. The two proposed approaches depend on various sigmoid functions to obtain the binary values PSO. The first approach takes the fuzzification of generation costs as a sigmoid function; while the second approach takes the fuzzification of power generations as sigmoid function. A proposed objective function is presented dependent on the exponential form which leads to fast convergence of PSO solution. This objective aims to minimize the generation costs as well as maximize their preventive control actions. Hence, the generations companies (GENCO) can re-schedule their generators with maximizing their own preventive control actions in power system operation. This means that, this objective helps GENCO to make a decision, how much power and reserve should be generated and how to schedule generators in order to receive the maximum preventive control actions. Different comparisons are carried out using 4-unit test systems to show the capability of the two proposed sigmoid approaches and the proposed objective function compared with other techniques.

يقدم هذا البحث أسلوبان مقترحان للجدولة المثلي لوحدات التوليد مع الأخذ في الاعتبار القدرة الاحتياطية لوحدات التوليد في حالات التشغيل المختلفة (حالات التشغيل العادية، حالات التنبأ بحدوث حالة طارئة وفي حالات التشغيل الطارئة) حيث تم استخدام طريقة مثلي للأسراب (SWARM) لإيجاد الحل الأمثل لمشكلة جدولة إشراك وحدات التوليد ومشكلة التوزيع الاقتصادي لتلك الوحدات . أعتمد الأسلوبان المقترحان علي معادلتين جديدتين لإيجاد القيمة الثنائية (Sigmoid) الأسلوب الأول أعتمد على الشكل الغيمي لدالة التكاليف، بينما اعتمد الأسلوب الثاني على الشكل الغيمي لقيم قدرات التوليد للنظام. كما تم اقتراح دالة هدف تعتمد على الشكل الأسى الذي أدي إلي تقارب سريع في الحل باستخدام الطريقة المثلي للأسراب وكذلك تقليل تكاليف التوليد مع زيادة الضمانات الوقائية للوحدات المشاركة ومن ثم اعادة جدولة اشراك الوحدات للحصول علي ضمانات وقائية مثالية للوحدات المشاركة والقدرة المولدة للتغلب علي أي حالة طارئة يمكن ان تحدث للنظام حيث ان هذه الدالة المتعددة الاهداف المقترحة تقلل تكلفة التوليد وتزيد القدرة الاحتياطية المولدة من كل مولد ولجميع المولدات. تم في هذا البحث العديد من المقارنات مختلفة باستخدام نظم كهربية قياسية متعددة لتوضيح قدرة وكفاءة الأسلوبين المقترحين وكذلك دالة الهدف المقترحة مقارنة بطرق أخرى.

Keywords: Hybrid Particle Swarm Optimization (HPSO), Emergency conditions, Preventive control action, Unit commitment, power generation dispatch

1. Introduction

In normal operation of power systems, the Security-Constraint Unit Commitment (SCUC) aims to minimize the total operational cost and satisfy the minimum up and down-time constraints, crew constraints, unit capability limits, generation constraints and reserve constraints. It has been recognized for many years that the UC may be unsafe, that is, it may not be capable to keep the system in normal state after a major disturbance (sudden increase of load, generator and / or line outages). Preventive security actions ensure that in the event of a contingency enough resources are available for the quick execution of corrective security actions that guarantee the normal operation of the system once the contingency has taken place [1]. Examples of preventive actions include the turning-on of extra generating units or the redispatch of already committed units in the precontingency state. Corrective actions include the fast redispatching of generation or the curtailment of selected loads under a specific contingency. In addition, for certain types of slowly-developing contingencies, corrective actions may require turning-on some standby generation.

A survey of literature on UC methods reveals that various numerical optimization techniques have been employed to address the UC problems. Specifically, there are priority list methods [2], integer programming [3], dynamic programming [4], mixed-integer programming [5], branch-and-bound methods [6], and Lagrangian Relaxation (LR) methods [7]. There other classes of numerical techniques applied to the UC problem which are: Meta-heuristic approaches include Expert Systems (ES) [8], Fuzzy Logic (FL) [9], Artificial Neural Networks (ANNs) [10], genetic algorithm (GA) [11], Evolutionary Programming (EP) [12], Simulated Annealing (SA) [13], and Tabu Search (TS) [14]. These methods can accommodate more complicated constraints and are claimed to have better solution quality.

The PSO has been used to solve the optimal power flow problem [15], the reactive power and voltage control problem [16], and the distribution state estimation problem [17].

In solving the unit commitment problem, generally two basic decisions are involved, namely the 'Unit Commitment' (UC) decision and the 'Economic Dispatch' (ED) decision. The UC decision involves the determination of the generating units to be running during each hour of the operation and planning horizon, considering system capacity requirements, including the reserve, and the constraints on the start up and shut down of units. The ED decision involves the allocation of the system demand and spinning reserve capacity among the operating units during each specific hour of operation.

This paper proposes two Hybrid Particle Swarm Optimization (HPSO) approaches in solving the UC problem. The main difference of the two approaches are in binary decision. A proposed objective function is presented dependent on the exponential form which leads to fast convergence of PSO solution.

This paper is organized as follows. Part 2 describes the particle swarm optimization technique. Part 3 briefly describes the UC problem in the preventive control action. Part 4 discusses implications of the updated UC on bidding strategies. Part 5 describes the proposed approaches. Part 6 presents the results of some illustrative examples. Finally, Part 7 provides some conclusions.

2. Particle swarm optimization technique

PSO is inspired by particles moving around in the search space. The individuals in a PSO thus have their own positions and velocities. These individuals are denoted as particles. Traditionally, PSO has no crossover between individuals, has no mutation, and particles are never substituted by other individuals during the run [18-19]. The update of the particles is accomplished to calculate a new velocity for each particle (potential solution) based on its previous velocity (v_{id}), the particle's location at which the best fitness so far has been achieved ($pbest_{id}$), and the population global location ($gbest_d$) at which the best fitness so far has been achieved. Then, each particle's position in the solution hyperspace is updated. The modified velocity and position of each particle can be calculated using the current velocity and distance from $pbest_{id}$ to $gbest_d$ as shown in the following equations, [18]:

$$v_{id}^{(tn+1)} = w.v_{id}^{(tn)} + c_1.rand_1(.).(pbest_{id} - x_{id}^{(tn)}) + c_2.rand_2(.).(gbest_d - x_{id}^{(tn)})\,. \tag{1}$$

$$x_{id}^{(tn+1)} = x_{id}^{(tn)} + v_{id}^{(tn+1)}\,. \tag{2}$$

Velocity of particle i at iteration tn; in d-dimensional space is limited by: $v_{d,\min} < v_{id}^{(tn)} < v_{d,\max}$.

Appropriate selection of inertia weight in eq. (1) provides a balance between global and local explorations. As originally developed, it often decreases linearly during a run. In general, the inertia weight factor (w) is set to the following equation:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} iter\,. \tag{3}$$

The velocity of particle i in d-dimensional space is limited by some maximum value, $v_{d,\max}$. This limit enhances the local exploration of the problem space and it realistically simulates the incremental changes of human learning. To ensure uniform velocity through all dimensions, the maximum velocity in the d-dimension is presented as:

$$v_{d,\max} = \frac{x_{di,\max} - x_{di,\min}}{Nt} . \quad (4)$$

3. Problem formulation

3.1. Emergency conditions problem

The emergency condition may occur as a result of unexpected outage of one or more generation units and sudden increase in power demand. A serious emergency condition is outage of generation units, which is limited by the load requirements and leads to system de-loading [20].

In this paper, the outage of generation plant is achieved by gradually outage of partial generation units. In the case of sufficient power generation outages to feed load requirements, the main problem is the violation of one or more generators. The use of the preventive actions from these generators present high guarantee for the power systems operation. But in case the power generation units is not sufficient to meet the load requirement, another procedure is proposed based on load shedding procedure.

3.2. Unit commitment problem

The UC problem aims to minimizing the total generation cost as:

$$Min\,TC = \sum_{i}^{N}\sum_{t}^{T}[F(P_{it})].U_{it} + SUC_{it}.(1-U_{it}).U_{it} . \quad (5)$$

The generator fuel-cost function can be expressed as:

$$F(P_{it}) = a_i + b_i.P_{it} + c_i.P_{it}^2 . \quad (6)$$

Subject to:

3.2.1. Demand constraint:

The power generation UC must be equal to the load demand plus the power loss i. e.,

$$\sum_{i=1}^{N} P_{it}U_{it} = D_t + Pl_t \quad t = 1,...,T . \quad (7)$$

3.2.2. Power generation limits

The power generation UC must be limited between the maximum and minimum values as:

$$P_{i\min} \le P_{it} \le P_{i\max} . \quad (8)$$

3.2.3. Power reserve constraint:

The power reserve in power system must be within two constraints [20] as:

$$\sum_{i=1}^{N}[P_{\max i} - P_{it} - Y_{it}].U_{it} \ge R_t \quad \text{for } t = 1,.......,T . \quad (9)$$

$$[P_{\max,i} - P_{it} - Y_{it}].U_{it} \le SPNMAX_i$$
$$\text{for } i = 1,.......,N , \quad (10)$$

where, $SPNMAX_i$ is the maximum spinning reserve of generator i and it is equal 10% of the maximum power limit of generator i in 10 minutes.

However, the power reserve is used in the case of a unit failure or an unexpected increase in the load demand.

3.2.4. Minimum up and down time constraints

The minimum up and down time constraints can be expressed as:

$$[X_{(i,\,t-1)}^{on} - T_i^{on}][\,U_{(i,\,t-1)} - U_{it}\,] \ge 0 . \quad (11)$$

$$[X_{(i,\,t-1)}^{off} - T_i^{off}][U_{it} - U_{(i,\,t-1)}] \ge 0 , \quad (12)$$

and the start-up cost is calculated from:

$$SUC_{it} = \begin{cases} \mathrm{HSC_i}, & \mathrm{X^{off}_{(i,\,t-1)}} \le \mathrm{T^{off}_i} + CH_i \\ CSC_i, & \mathrm{X^{off}_{(i,\,t-1)}} > \mathrm{T^{off}_i} + CH_i . \end{cases} \quad (13)$$

3.3. Preventive control action procedure

The preventive control actions can be prepared from one or more generation units by increasing their reserve.

3.3.1. Preventive control action for each generation unit

The maximal effect of the preventive control action for each generation unit can be expressed as:

$$Max Y_{it} [P_{io,t} - P_{it}].U_{it} \le Y_{it}.U_{it} . \quad (14)$$

Y_{it}: is the maximal preventive control action due to increase in the power generation reserve at certain operating condition of generator i at hour t.

3.3.2. Preventive control action for all generation unit

Eq. (14) are restated, as a multi-objective problem to obtain the maximal effect of the preventive control action for all generators simultaneously, as:

$$\begin{aligned} & Max Y_{it} \\ & [P_{io,t} - P_{it}].U_{it} \le Y_{it}.U_{it} \end{aligned} \qquad i = 1,\ldots,N . \quad (15)$$

4. Optimal proposed procedures for UC

Two hybrid Particle Swarm Optimization (HPSO) approaches in solving the UC problem are proposed. The main difference of the two approaches is in binary decision in the PSO technique.

4.1. Based HPSO method [19]

The term "hybrid particle swarm optimization" was mentioned in [17], whereby the term hybrid meant the combination of PSO and GA. However, in this approach, hybrid is meant to highlight the concept of blending real valued PSO (solving economic load dispatch (ELD)) with binary valued PSO (solving UC) running independently and simultaneously. The binary PSO (BPSO) is made possible with a simple modification to the particle swarm algorithm. This BPSO solves binary problems similar to those traditionally optimized by GA. It was seen that the particle swarm found global optima faster than any of the three kinds of GA in all conditions except for problems featuring low dimensionality. In binary particle swarm, X_i and $Pbest$ can take values of 0 or 1 only. The V_i velocity will determine a probability threshold. If V_i is higher, the individual is more likely to choose 1, and lower values favor the 0 choice. Such a threshold needs to stay in the range [0, 1]. One straightforward function for accomplishing this is common in neural networks. The function is called the sigmoid function which is defined as follows [19]:

$$\mu(V_i) = \frac{1}{1 + \exp(V_i)} . \quad (16)$$

The function squashes its input into the requisite range and has properties that make it agreeable to be used as a probability threshold. Random number (drawn from a uniform distribution between 0 and 1) is then generated, whereby X_i is set to 1 if the random number is less than the value from the sigmoid function as illustrated in the following equation:

$$\text{If } Rand() < \mu(V_i), \text{then } U_i = 1, \text{ else } U_i = 0 . \quad (17)$$

In the UC problem, U_i represents the on or off state of generator i. In order to ensure that there is always some chance of a bit flipping (on and off of generators); a constant $V_{\max}$ can be set at the start of a trial to limit the range of V_i. A large $V_{\max}$ value results in a low frequency of changing state of generator, whereas a small value increases the frequency of on/off of a generator. In practice, $V_{\max}$ is often set at ±4.0, so that there is always at least a good chance that a bit will change state. The $\mu(V_i)$ does not approach too close to 0.0 or 1.0. In this binary model, V_{max} functions similarly to the mutation rate in GA.

4.2. First proposed HPSO approach

This approach is dependent on the suggested formulation of sigmoid function which is related to define the membership function, shown in fig. 1. This approach depends on the fuzzy membership of the generation cost function which can be expressed as:

$$\mu(c) = \begin{cases} \dfrac{C_{\max} - C}{C_{\max} - C_{\min}}, & C_{\min} < C < C_{\max} \\ 1, & C < C_{\max} \end{cases}. \quad (18)$$

where, $C_{\min}$ and $C_{\max}$ are the minimum and maximum generation cost, which are calculated using the minimum and maximum power generation, respectively.

4.3. Second proposed HPSO approach

This approach is dependent on the suggested formulation of sigmoid function, shown in fig. 2, and depends on the membership function of the power generation, which can be represented as the following equation:

$$\mu(P) = \begin{cases} \dfrac{P - P_{\min}}{P_{\max} - P_{\min}}, & P_{\min} < P < P_{\max} \\ 1, & P < P_{\max} \end{cases}. \quad (19)$$

where, $P_{\min}$ and $P_{\max}$ are the minimum and maximum values for each generation unit.

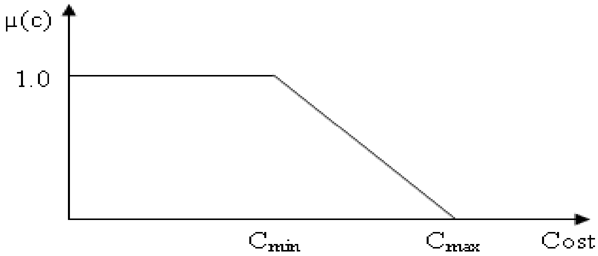

Fig. 1. Membership function of the first proposed HPSO approach.

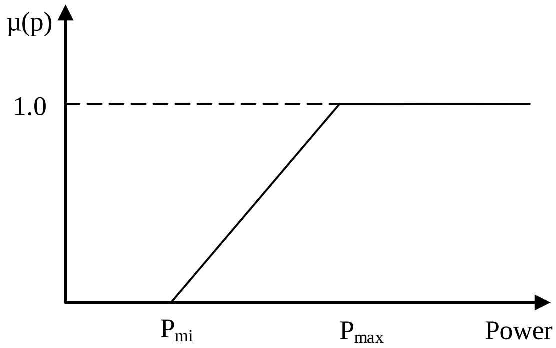

Fig. 2. Membership function of the second proposed HPSO approach.

5. Proposed feature of fitness function

Recently, several methods for handling infeasible solutions for continuous numerical optimization problems had emerged [11, 18]. Some of them are based on penalty functions. They differ, however, in how the penalty function is designed and applied to infeasible solutions. They commonly use the total cost function TC and the preventive control action as multi-objective function to evaluate a feasible solution, i.e.

$$Min\,\Phi_f(x) = A_1.TC - A_2.Y\,. \quad (20)$$

where, A_1 is set to 1 the system operator needs to minimize the generation cost and A_2 = 0 whenever the preventive control action is not required. Likewise, A_2 is also set to 1 when the system operator needs to prepare preventive control actions.

And the constraint violation measure $\Phi_u(x)$ for the $k+m$ constraints were defined in [18].

Then, the total evaluation of an individual, which can be interpreted as the error (for a minimization problem) of an individual x, is obtained as:

$$\Phi(x) = \Phi_f(x) + \Phi_u(x)\,. \quad (21)$$

In this paper, a proposed approach of the constraint violation measure $\Phi_u(x)$ is proposed, which results in reducing formulation and computation requirement for the $k+m$ constraints, as:

$$\Phi_u(x) = \sum_{i=1}^{k+m} \exp(g_i^+(x)) , \quad (22)$$

where, $g_i^+(x) = \max\{0, g_i(x)\}$. In other words, $g_i^+(x)$ is the magnitude of the violation of the i_{th} equality and inequality constraint, where $1 \le i \le k+m$; where, k is the number of inequality constraints, and m is the number of equality constraints.

The objective of the UC problem can be formulated as a combination of total production cost (as the main objective) with power balance (as equality constraints) and spinning reserve and generation limits (as inequality constraints), whereby $\Phi_f(x)$ and $\Phi_u(x)$ are equivalent to the blend of power balance and spinning reserve constraints. Consequently, the formulation of the proposed fitness function can be expressed as:

$$\Phi(x) = \Phi_f(x) + w_1.\exp(cc_1.\Phi_d(x)) + w_2 .\exp(cc_2.\Phi_R(x)) + w_3.\exp(cc_3.\Phi_g(x)) . \quad (23)$$

In this study, w_1 to w_3 are the weighting factors for the power demand, the power reserve and the power generation constraints are equal to 1.

The choice of cc_1, cc_2 and cc_3 are dependant on the accuracy and speed of convergence requirement. From experience, the values of cc_1, cc_2 and cc_3 are equal to 2.

The first term in the penalty factor ($\Phi_d(x)$) is the power balance constraint which is formulated as:

$$\Phi_d(x) = (D_t - \sum_{i=1}^{N} P_{it} U_{it}) . \quad (24)$$

The second term in the penalty factor ($\Phi_R(x)$) is the reserve constraint, where R_t is 10% of power demand D_t. This term can be formulated as:

$$\Phi_R(x) = \Phi_{R_1}(x) + \Phi_{R_2}(x) . \quad (25)$$

Where, the maximal preventive control action due to increase the power generation reserve at certain operating condition from each generator can be formulated as:

$$\Phi_{R_1}(x) = \max\left\{0, \sum_{i=1}^{N} (SPNMAX_i - (P_{i,\max} - P_{it} - Y_{it})).U_{it}\right\}. \quad (26)$$

And the maximal preventive control action due to increase the power generation reserve at certain operating condition from all generators can be formulated as:

$$\Phi_{R_2}(x) = \max\left\{0, R_t - \sum_{i=1}^{N} (P_{i,\max} - P_{it} - Y_{it}).U_{it}\right\}. \quad (27)$$

The third term in the penalty factor is the power generation constraint. This term can be formulated as:

$$\Phi_g(x) = \Phi_{g\max}(x) + \Phi_{g\min}(x) , \quad (28)$$

where, the maximum power generation limit is defined as:

$$\Phi_{g\max}(x) = \max\left\{0, \sum_{i=1}^{N} (P_i - P_{i,\max}).U_{it}\right\} . \quad (29)$$

And the minimum power generation limit is defined as:

$$\Phi_{g\min}(x) = \max\left\{0, \sum_{i=1}^{N} (P_{i,\min} - P_i).U_{it}\right\} . \quad (30)$$

By substituting eqs. (20 into 21), the fitness function for evaluating every particle in the population of PSO for an hour is defined as:

$$\Phi(x) = \sum_{i}^{N} [A_1 . (F(P_{it}) + SUC_{it} . (1 - U_{it}) U_{it}) - A_2 . Y_{it}]$$
$$+ w . \exp(cc_1 . \Phi_d(x)) + w_2 . \exp(cc_2 . \Phi_R(x))$$
$$+ w_3 . \exp(cc_3 . \Phi_g(x))) \quad . \qquad (31)$$

while the fitness function for evaluating every particle in the population of PSO for some hours can be expressed as:

$$\Phi(x) = \sum_{t=1}^{T} \left\{ \begin{array}{l} \sum_{i=1}^{N} [A_1 . (F(P_{it}) + SUC_{it} . (1 - U_{it})) \\ - A_2 . Y_{it} . U_{it}] + w_1 . \exp(r_1 . \Phi_d(x)) \\ + w_2 . \exp(r_2 . \Phi_R(x)) + w_3 . \exp(r_3 . \Phi_g(x)) \end{array} \right\} . \qquad (32)$$

In this paper, the technique used to satisfy the Min-Up (MU) and Min-Down (MD) time, is extremely simple. As the solution is based upon the best particle (gbest) in the history of the entire population, constraints are taken care of by forcing the binary value to change its state whenever either MU or MD constraint is violated. However, this may change the current fitness, which is evaluated using (21). It implies that the current might no longer be the best among all the other particles. To correct this error, the gbest will be revaluated using the same equation.

6. Simulation results

In this section, a test system [18] is studied to illustrate the effectiveness of the proposed approaches in terms of its solution quality. The system consists of four generation units, 8-hour scheduling periods. The simulating parameters of the proposed approaches are given bellows:

- Population size = 100;
- Initial inertia weight (w_{max}) = 0.9;
- Final inertia weight (w_{min}) = 0.4;
- Acceleration constant, c_1 = 2 and c_2 = 2;

Table 1 shows the UC and their OPD for 4-unit test system at the normal operation. In this table, the generator 1 operate at the maximum limit because it is the cheapest generator. The total reserve can be taken equl to 13.57% of the load at hour 6.

Table 2 shows the results of the proposed approaches solution of unit commitment problem compared with that obtained using LR and PSO-LR. It can be seen that, the first proposed approach is the best method which has minimum generation costs and computational time compared to other approaches. Therefore, the first proposed approach will be used to obtain the optimal preventive action.

Two cases are considered in the emergency condition, which are:
Case 1: normal condition is considered as an initial condition;
Case 2: predicted emergency condition is considered as an initial condition.

Table 1
UC and their OPD for 4-unit test system using the first proposed approach at normal condition

H	Unit				Fuel cost ($)	St. cost ($)
	1	2	3	4		
1	300	150	0	0	9145.36	0
2	300	205	25	0	10892.2	150
3	300	250	30	20	12570.5	0.02
4	300	215	25	0	11079.4	0
5	300	0	80	20	8532.18	0.02
6	255	0	25	0	5845.57	0
7	265	0	25	0	6024.79	0
8	300	200	0	0	10066.4	170
Total cost					74476.4	

Table 2
A comparison between the total generation costs and CPU time of the difference approaches for 4-unit test system

	SCUC	
Method	Cost ($)	CPU (sec)
HPSO	74812.02	14.016
Approach 1	74476.4	10.219
Approach 2	74645.88	13.203
LR[7]	75232	-
PSO-LR [18]	74675	-

6.1. Generation outages

Case 1 is considered as an initial condition

Tables 3 shows the UC and their OPD for 4-unit test system using the proposed approach when unit 3 is outage at hours 5 using the first proposed approach dependent on case 1. In this table, the power generation of unit 4 is increased using the available spinning reserve which equals 6 MW (10% of their maximum limit), while the remaining power demand should be shed with 74 MW. The unit 4 is remaining ON at hours 6 and 7 to meet the load demand without load shedding. However, no preventive control actions are prepared before the occurrence of emergency condition (as a corrective control action).

Case 2 is considered as an initial condition

Table 4 shows the UC and their OPD for 4-unit test system using the first proposed approach for outage of unit 3 at hour (5) dependent on case 2. In this table, the load still consumes 400 MW.

However, the schedule of the generators has changed (as the preventive control action), requiring the commitment of the expensive generator 2. In this action, there is spinning reserve equal to 48.81 MW (12.2% of the load) but the total cost is increased by 331.6 $ compared to the normal condition. Since, the unit 3 is operated within the permissible min-up time (4 hour before its outage), the schedule of UC is considered as an optimal solution to face the outage of unit 3.

Table 3
UC and their OPD for 4-unit test system using the first proposed approach for outage unit (3) at hour (5) (without predicted emergency condition)

H	Unit				Fuel cost ($)	St. C ($)	load shedding
	1	2	3	4			
1	300	150	0	0	9145	0	0
2	300	205	25	0	10892.2	150	0
3	300	250	30	20	12571	0.02	0
4	300	215	25	0	11079	0	0
5	300	0	out	26	6791.2	0	74
6	260	0	0	20	5928.2	0	0
7	270	0	0	20	6107.7	0	0
8	300	200	0	0	10066	170	0
Total					72900		74

Table 4
UC and their OPD for 4-unit test system using the first proposed approach for outage unit (3) at hour (5) with predicted emergency)

H	Unit				Fuel cost ($)	S.C ($)	Load shedding
	1	2	3	4			
1	300	125	25	0	9425	150	0
2	300	205	25	0	10892	0	0
3	300	250	30	20	12571	0.02	0
4	300	215	25	0	11079	0	0
5	276.19	123.81	out	0	8242	0	0
6	196.19	83.807	0	0	6103	0	0
7	202.91	87.092	0	0	6280	0	0
8	300	200	0	0	10066	0	0
Total					74808		0

Table 5 shows a comparison between the load shedding, the generation costs and the spinning reserve with and without predicted emergency conditions for various outage of generation units at difference hours. In this table, the predicted emergency condition is very important to reduce the load shedding procedure and increase the spinning reserve in the system to alleviate any emergency that may occur.

6.2. Sudden increase in power demand

Case 1 is considered as an initial condition
The range of the increase in load demand from (0% - 13.57%) is shown in table 1.

Case 2 is considered as an initial condition
Table 6 shows the UC and their OPD for 4-unit test system using the proposed approach for various sudden increasing in load demand (13.57% - 19.64%) at hour (6). In this table, the load demand still consumes 280 MW. However, the schedule of the generators has changed (as a preventive security action), requiring the commitment of the expensive generators to meet the required spinning reserve.

Fig. 3 and table 7 show the total generation costs against the percentage reserve variation for sudden increasing in load demand (0% - 24.64%), as steps, at hour (6). In this table, the cost is increased with increasing the spinning reserve.

Fig. 4 shows the total generation costs against the sudden increasing in load demand at hour (6). The total generation costs are increased when the load demand is increased.

Table 5
A comparison between all case studies for various generation outages at difference hours

Outage unit	Without predicted emergency condition			Predicted emergency condition		
	Load sh. (MW)	Cost ($)	Sp. R MW)	Load sh. (MW)	Cost ($)	Sp. R (MW)
Unit (3) at hour (5)	74	72900	0	0	74808	48.81
Unit (3) at hour (6)	0	73909	5	0	74812	55
Unit (1) at hour (5)	954	62546.2	0	120	73196	0
Unit (1) at hour (6)	627	62291	0	110	73069	0
Normal operation = 74476.4 ($)						

Table 6
UC and their OPD for 4-unit test system using the first proposed approach for sudden increase in load (13.57% - 19.64%) at hour 6

H	Unit				Fuel cost ($)	St. cost
	1	2	3	4		
1	300	150	0	0	9145	0
2	300	205	25	0	10892	150
3	300	250	30	20	12571	0.02
4	300	215	25	0	11079	0
5	259.64	115.36	25	0	8526	0
6	196.19	83.807	0	0	6103	0
7	202.91	87.092	0	0	6280	0
8	300	200	0	0	10066	0
Total					74812.3	

Table 7
Total generation costs and reserve variation for sudden increasing in load demand at hour (6) for 4-unit system

	Load demand = 280 MW			
%Reserve variation	0-13.57%	13.57-19.64%	19.64-22.5%	22.5-24.64%
Cost ($)	74477	74808	75105	75480

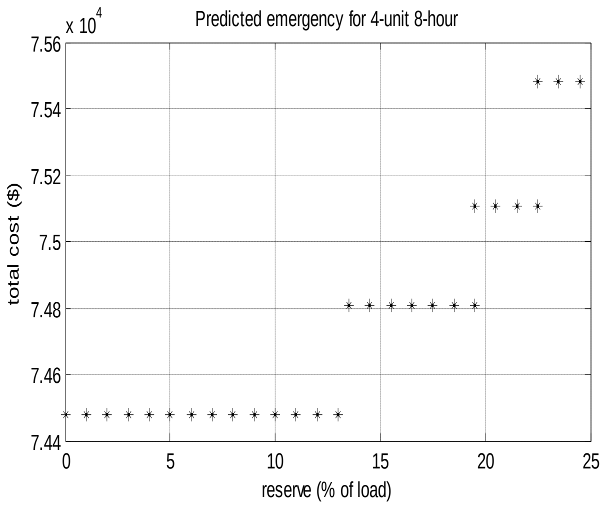

Fig. 3. Total generation costs against the percentage reserve variation for sudden increasing in load demand at hour (6) for 4-unit system.

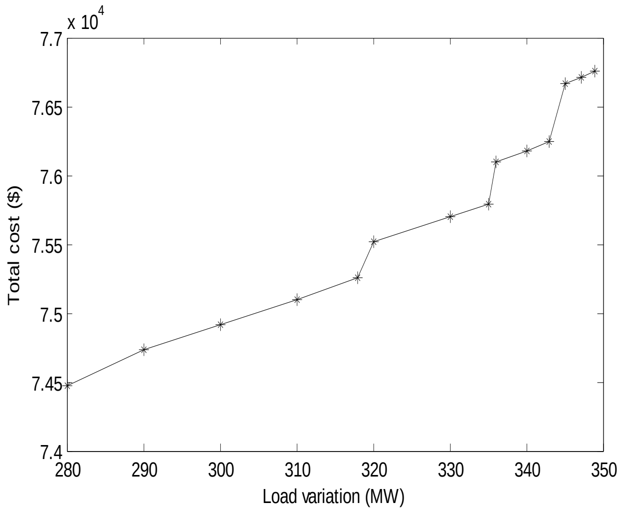

Fig. 4. Total generation costs against sudden increasing in load demand at hour (6) for 4-unit system.

7. Conclusions

This paper presents two efficient and accurate approaches for optimal scheduling of Unit Commitment (UC) considering the power generation and reserve generating for preventive control action. The two proposed approaches depend on various sigmoid functions to obtain the binary values for PSO technique. These approaches have the fastest convergence fitness function compared with base HPSO technique.

In this paper, a proposed preventive control action for optimal scheduling of UC has been efficiently applied to remove the effects of difference emergency conditions.

Comparison procedure can be used for helping GENCO to decide how much power and reserve should be sold in energy and ancillary markets in order to receive minimum generation cost and maximum spinning reserve as a preventive control action. Based on predicted emergency condition, the UC has been solved by considering power and reserve generation simultaneously. A proposed fitness objective function has been successfully applied dependent on the exponential form which leads to fast convergence of the first approach of HPSO solution.

A comparison between the occurrence of emergency conditions based on case1 and case 2 has shown that the predicted emergency condition (case 2) is very useful to face the emergency condition compared with the another case (case 1) which the load shedding has been used.

Symbols and abbreviations

a_i, b_i and c_i	Present the unit fuel cost coefficients,
$F(P_{it})$	Production cost of unit in time period ($),
SUC_{it}	Start-up cost for unit i time period ($),
TC	Total cost of GENCO ($),
CH_i	The cold start hour (h),
CSC_i	The unit's cold start-up cost ($),
HSC_i	The unit's hot start-up cost ($),
D_t	Load demand at hour t (MW),
N	Number of generator units,

P_{it}	Power generation of generator i,
$P_{i\max}$	Maximum generation limit of generator i (MW),
$P_{i\min}$	Minimum generation limit of generator i (MW),
R_{it}	Reserve generation of generator i at hour t (MW),
SDC_{it}	Shut-down cost for unit i time period ($),
P_{it}	is the power generation of new operating condition of generator i at hour t (MW),
Y_{it}	The maximal preventive control action due to increase in the power generation reserve at certain operating condition of generator i at hour t,
R_t	The spinning reserve at interval t,
$SPNMAX_i$	The maximum spinning reserve of generator i,
T	Number of hours (hr),
T_i^{off}	Minimum off time of unit i (hr),
T_i^{on}	Minimum on time of unit i (hr),
U_{it}	On/off status of generator i at hour t $X_{(i,\ t\ -1)}^{on}$ time duration for which unit i has been on at hour t (hr),
$X_{(i,\ t\ -1)}^{off}$	Time duration for which unit i has been off at hour t (hr),
$v_{id}^{(tn)}$	Velocity of particle i at iteration t,
$x_{id}^{(tn)}$	Current position of particle i at iteration t ,
W	Inertia weight factor,
tn	Number of iterations ,
n	Number of particles in a group ,
m	Number of members in a particle,
c_1 and c_2	Acceleration constant of PSO,
$rand_1(\cdot)$ and $rand_2(\cdot)$	Random numbers between 0 and 1
N_t	a chosen number of intervals
$iter_{\max}$ and $iter$	The maximum and the current number of iterations,
SCUC	Security-constraint unit commitment,
HPSO	Hybrid particle swarm Optimization, and
$P_{io,t}$	The initial power generation for unit i .

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