Solving the unit commitment problem in large systems using hybrid PSO algorithms

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Abstract. Unit Commitment (UC) is a nonlinear mixed integer-programming problem. UC is used to minimize the operational cost of the generation units in a power system by scheduling some of generators in ON state and the other generators in OFF state according to the total power outputs of generation units, load demand and the constraints of power system to increase the saving in the power system by applying the Unit Commitment (UC) to the power system. This work proposes Local Attracting Quantum Particle Swarm Algorithm (LAQPSO) to solve the unit commitment problem in power systems. The local attractor in the LAQPSO algorithm is used to obtain the rotation angle direction and magnitude for updating the quantum angle using the quantum rotation gate. The proposed algorithm is applied to solve the UC problem for a 26 units power system. A comparison with the Binary PSO (BPSO), Improved Quantum BPSO (IQBPSO) and other techniques in the literature was implemented to show the efficiency and the accuracy of the proposed algorithm. The results show the superior performance of the proposed LAQPSO algorithm to minimize the total cost when compared with BPSO, IQBPSO and the literature works.

1. Introduction

UC is one of the hardest problems in power system optimization which must be optimized in order to minimize the total operation cost of generators for a specified time horizon according to the load demand while satisfying the generators and system constraints [1]. UC has to make a decision to properly operate the generators to get a lower cost by making some generators ON and the others OFF according to the demand and these generators must be economically dispatched. UC problem (UCP) is NP-hard problem and it can be presented as mixed integer nonlinear optimization problem. As the number of the generators grow up, the solution will take a longer time because the combinations 0-1 that for each hour in the time horizon will grow exponentially. Two types of constraints must be satisfied in the unit commitment problem solution, the first one is related to the system such as the transmission constraints and the power reserve constrains in case of increase the demand or the outage of a generator from the system and the other types of constraints are related to the generators such as ramp-up limit, ramp-down limit, minimum time up and minimum time down [2].

Different ideas have been developed to solve UC problem. The solution methods of the UCP can be separated into two kinds, the first one is known as deterministic solution techniques such as Priority List (PL) [3]; Dynamic Programming (DP) [4]; Improved Lagrangian Relaxation (ILR) [5]; second order cone programming [6]; Mixed Integer Programming (MIP) [7]; and Branch and Bound (BB) [8]. The other solution method is known as stochastic approaches and they were successful in UC problem solution and as an example for these methods Genetic Algorithm (GA) [9]; Evolutionary
Programming (EP) [10]; Simulated Annealing (SA) [11]; Particle Swarm Optimization (PSO) [12]; Quantum Evolutionary Algorithm (QEA) [13]; Ant Colony Algorithm [14]; differential evolution approach [15]; Artificial Neural Networks (ANN) [16]; and Tabu Search (TS) [17].

In this paper, a LAQPSO algorithm is proposed to solve the UCP. The LAQPSO algorithm is compared with the BPSO algorithm, IQBPSO and other algorithms in the literature.

2. MATHEMATICAL FORMULATION FOR UNIT COMMITMENT PROBLEM

The objective of formulating UCP is to achieve the goal of minimization of the total operation cost during a specified time horizon assuring that all the constraints are satisfied [1]. This minimization may be done by selecting the combination of the generation units that satisfies all the constraints of the power system and the generation unit itself and these combinations 0-1 that represented the status of each generator ON/OFF. The UCP objective function is the sum of the start-up cost of the generators and operational cost for each unit over a the time horizon and it can be stated by the following equation:

$$C_{total} = \sum_{k=1}^{T} \sum_{g=1}^{N} \left[ f_{gk}(P_{gk}) + STC_{gk}(1-U_{g(k-1)}) + SDC_{gk}(1-U_{gk}) \right] U_{gk} \quad (1)$$

where T is the time horizon; k is the index of time; N is the number of generation units; g is the index of the unit; $f_{gk}$ is the fuel cost function, $U_{gk}$ is the state of unit g which can be 0 or 1 at hour k; $P_{gk}$ is the power delivered from the unit g at the hour k and STC$_{gk}$ is the start-up cost of the unit g at the hour k. The fuel cost function is stated as follows

$$f_{gk}(P_{gk}) = c_{g}(P_{gk})^2 + b_{g}(P_{gk}) + a_{g} \quad (2)$$

where $c_{g}, b_{g}, a_{g}$ are the fuel cost coefficients, the start-up cost is represented by the following equation:

$$STC_{gk} = \begin{cases} 
HSC_{g} & \text{if } MDT_{g} \leq T_{g}^{off} \leq MDT_{g} + CSH_{g} \\
CSC_{g} & \text{if } T_{g}^{off} > MDT_{g} + CSH_{g} 
\end{cases} \quad (3)$$

where (HSC$_{g}$, CSC$_{g}$) are the hot start-up and cold start-up costs of the generation unit g; (MDT$_{g}$) is the minimum downtime of the unit g; CSH$_{g}$ cold start-up hours for the generation unit g and (T$_{g}^{off}$) is the time of the unit g is continuously OFF.

The UCP objective function is restercted by some constraints and these constraints are the system constraints and the generation unit constraints [1].

1- The demand must be supplied by the generators at each hour.

$$\sum_{g=1}^{N} P_{gk} U_{gk} = D_{k} \quad (4)$$

where $D_{k}$ is the load demand of the system at the hour k

2- The constraint of spinning reserve in case of increase the demand or loss generator unit from the group.

$$\sum_{g=1}^{N} P_{gk}^{max} U_{gk} \geq D_{k} + R_{k} \quad (5)$$

where $R_{k}$ is the spinning reserve of the power system at the hour k.

3- The generation unit g can produce power in a range between its maximum and minimum capacities .

$$p_{g}^{max} \geq P_{gk} \geq p_{g}^{min} \quad (6)$$

4- The generation unit must be operated at least for a time equals to the minimum up-time.

$$T_{g}^{on} \geq MUT_{g} \quad (7)$$

where $T_{g}^{on}$ is the continuous ON time of the generator (g) and MUT$_{g}$ is the minimum up-time.

5- The generation unit must be shut-down or in the OFF state at least for a time equals to the minimum downtime.

$$T_{g}^{off} \geq MDT_{g} \quad (8)$$
3. PSO ALGORITHM

The PSO algorithm is introduced by Kennedy and Eberhart in 1995 [18]. PSO algorithm is a heuristic optimization method based on the parallel experience of the individuals to search for the optimum solution. The PSO particles spread in a search space D of the problem and each of them has a position vector X and speed vector V [18]. In this algorithm, the particles are guided using the personal experience for each particle which is known as Pbest and the overall or the global experience among all particles which is termed as Gbest. Then, the velocity and location of each particle in the population are modified by using the calculation of the current particle velocity and the distance from Pbest location and Gbest location [19]. Also, the experience can be accelerated by two acceleration factors, (c1, c2) and recognized as the cognitive and asocial acceleration constant factors respectively; (ϕ1, ϕ2) are two random numbers generated between [0, 1]. The movement is also can be controlled by multiplying it by inertia factor (ω) that lies in the range of [ωmax, ωmin] and the typical range is ωmax = 0.9 to ωmin = 0. The particle velocity and position in the PSO algorithm can be updated using equations (9) and (10) respectively:

\[ V_r^{m+1} = \omega V_r^m + c_1 \varphi_1 (P_{\text{best}}^m - X_r^m) + c_2 \varphi_2 (G_{\text{best}}^m - X_r^m) \]  \hspace{1cm} (9)

\[ X_r^{m+1} = X_r^m + \omega V_r^{m+1} \]  \hspace{1cm} (10)

where \( r = 1, 2, 3 \ldots \) population size, \( (V_r^{m+1}, X_r^m) \) are the speed and position of the \( r \)th particle at the iteration \( m \). The inertia factor \( \omega \) is represented by the following equation:

\[ \omega = \omega_{\text{max}} - \frac{(\omega_{\text{max}} - \omega_{\text{min}})}{\text{iter}_{\text{max}}} \times m \]  \hspace{1cm} (11)

where \( \text{iter}_{\text{max}} \) is the maximum iteration number. The binary version of the PSO (BPSO) has been presented by James Kennedy and Russell Eberhart which is used in discrete spaces [20]. The update procex of the position for the particles can be achieved by using a new variable known as Sigmoid Limiting Transformation (SLT) and can be written as

\[ S(V_{ri}^{m+1}) = \frac{1}{1 + e^{\exp(V_{ri}^{m+1})}} \]  \hspace{1cm} (12)

where \( S(V_{ri}^{m+1}) \) is the SLT function of the \( i \)th element in the \( r \)th particle.

By using the sigmoid function, the position update of the particle in the binary version of the PSO algorithm is done as the following equation

\[ X_{ri}^{m+1} = \begin{cases} 1 & \text{if } \ r n_{ri} < S(V_{ri}^{m+1}) \\ 0 & \text{otherwise} \end{cases} \]  \hspace{1cm} (13)

where \( r n_{ri} \) is a uniformly distributed random number between [0, 1].

4. HYBRIDIZATION OF THE BPSO ALGORITHM WITH QUANTUM COMPUTING

The quantum bit or qubit is known as the smallest unit of information stored in the quantum computer [21]. The quantum bit can be in the 0 state (|0\rangle), 1 (|1\rangle) state or any superposition of them. The quantum bit state can be reproduced as follows:

\[ |\Psi\rangle = \alpha |0\rangle + \beta |1\rangle \]  \hspace{1cm} (14)

where \( \alpha \) and \( \beta \) are two complex numbers which identify the probability amplitude of the relative conditions. The state of the quantum bit can be normalized to unity to guarantee that |\( \alpha \)|² + |\( \beta \)|² = 1. Quantum gates have been used to change the state of the quantum bit, examples of these gates are the
NOT gate, Hadamard gate and rotation gate [22]. A novel QEA has been proposed by Kim and Han [21]. This QEA is inspired from the quantum-computing concept so the quantum bit has been designed to get the binary solutions. The quantum bit is defined by pair of numbers which are $\alpha$ and $\beta$ and the quantum bit can be formulated as a string of (n) qubits as in equation (15):

$$q = \begin{bmatrix} \alpha_1 \\ \beta_1 \\ \vdots \\ \alpha_n \\ \beta_n \end{bmatrix}$$

(15)

where $|\alpha_i|^2 + |\beta_i|^2 = 1$ and $i = 1, 2 \ldots \ldots$ number of elements. The rotation gate can be used as a variance factor to update the individual of the quantum bit. The rotation gate is defined as in the following equation:

$$\Delta \theta_i = \begin{bmatrix} \cos(\Delta \theta_i) & -\sin(\Delta \theta_i) \\ \sin(\Delta \theta_i) & \cos(\Delta \theta_i) \end{bmatrix}$$

(16)

where $\Delta \theta_i$ is the $i$th quantum bit rotation angle that goes to 0 or 1 state. For determining the value of $\Delta \theta_i$, a lookup table is utilized and modified as $(\theta_1, \theta_2, \theta_4, \theta_6, \theta_7, \theta_8 = 0)$, $\theta_3 = 0.01\pi$, $\theta_5 = -0.01\pi$, and $B$ is the best solution where $B = (b_1, b_2, b_3, \ldots, b_n)$ as described in reference.

**Table 1.** Predetermined lookup table for the determination of the rotation angle.

| $x_i$ | $b_i$ | Fitness ($X$) $\geq$ Fitness ($B$) | $\Delta \theta_i$ |
|------|------|---------------------------------|------------------|
| 0    | 0    | False                          | $\theta_1$       |
| 0    | 0    | True                           | $\theta_2$       |
| 0    | 1    | False                          | $\theta_3$       |
| 0    | 1    | True                           | $\theta_4$       |
| 1    | 0    | False                          | $\theta_5$       |
| 1    | 0    | True                           | $\theta_6$       |
| 1    | 1    | False                          | $\theta_7$       |
| 1    | 1    | True                           | $\theta_8$       |

A new BPSO inspired by quantum computing is presented which is known as Quantum Binary Particle Swarm Optimization (QBPSO) [23][24]. Each element in the particle has a state of 1 or 0 according to the probability of $|\alpha|^2 + |\beta|^2 = 1$.

The QBPSO proposes a new way to update the velocity of each particle by the use of Quantum Computing. The inertia factors ($\omega_{max}, \omega_{min}$) and the acceleration factors ($c_1, c_2$) are omitted in the QBPSO and replaced by the rotation angle. The update process of the position vector can be done by using the probability $|\beta|^2$ that has been stored in the $r$th quantum bit individual $(q_r)$. Therefore, the $i$th element of the $r$th particle takes a value of 1 or 0 as in the following equation [23]:

$$X^{m+1}_{r_i} = \begin{cases} 1 & \text{if } r\eta_{ri} < |\beta_{ri}|^2 \\ 0 & \text{otherwise} \end{cases}$$

(17)

The rotation angle is determined by using the current position $P_{best}$ and the global position $G_{best}$ of the swarm as in the following equation:

$$\Delta \theta_{ri} = \theta \times (\gamma_{1r} \times (x_{ri}^n - x_{ri}) + \gamma_{2r} \times (x_r^n - x_{ri}))$$

(18)

where $\theta$ is the magnitude of the rotation angle and $(\gamma_{1r}, \gamma_{2r})$ can be found by a comparison among the fitness of the current position of the particle $r$, the fitness of the best position $P_{best}$ and the fitness of the global position $G_{best}$ respectively as in equations (19) and (20):
The rotation angle magnitude is monotonously decreased from a maximum value $\theta_{\text{max}}$ to a minimum value $\theta_{\text{min}}$ along the iteration by the following equation:

$$\theta = \theta_{\text{max}} - \frac{\theta_{\text{max}} - \theta_{\text{min}}}{\text{iter}_{\text{max}}} \times m$$  \hspace{1cm} (21)

5. IMPROVED QBPSO ALGORITHM
The QBPSO algorithm may fail in finding the optimum value of the solution, therefore; an improvement is made on the QBPSO to get the better solution. The improvement on QBPSO is to search for the fitness in the personal best $P_{\text{best}}$ for the first half of the iterations and after finding then the fitness in the global best $G_{\text{best}}$ will be searched in the second half of the iterations [25]. This improvement can be expressed as the following equations:

$$\gamma_{1r} = \begin{cases} 0 & \text{if} \quad \text{Fitness of } (X_r) \geq \text{Fitness}(P_{\text{best}}_r) \\ 1 & \text{otherwise} \end{cases}$$ \hspace{1cm} (19)

$$\gamma_{2r} = \begin{cases} 0 & \text{if} \quad \text{Fitness of } (X_r) \geq \text{Fitness}(G_{\text{best}}) \\ 1 & \text{otherwise} \end{cases}$$ \hspace{1cm} (20)

and the rotation angle is updated as in equations (18, 21).

6. THE IMPROVEMENT OF QPSO ALGORITHM USING THE LOCAL ATTRACTOR
In order to explain the concept of the local attractor, another subject must be clarified, which is the quantum angle. According to the condition of normalization ($|\alpha|^2 + |\beta|^2 = 1$), the quantum angle is expressed as in equation (24):

$$q^m_{r1} = \left[\begin{array}{c} a^m_{r1} \\ \beta^m_{r1} \end{array}\right] \quad \quad \text{yields} \quad \theta^m_{r1} : \begin{cases} |q^m_{r1}| = \cos \theta^m_{r1} |0\rangle + \sin \theta^m_{r1} |1\rangle \\ \theta^m_{r1} = \arctan \frac{a^m_{r1}}{\beta^m_{r1}} \end{cases}$$ \hspace{1cm} (24)

It can be concluded that the quantum angle identifies the quantum bit. Therefore, the population of the quantum bit particles can be shaped using the quantum angle format:

$$q^m = [q^m_{r1}, q^m_{r2}, q^m_{r3}, ..., q^m_{r_d}] , \quad Q(m) = [q^m_{r1}, q^m_{r2}, q^m_{r3}, ..., q^m_{r_d}]$$

$$\theta^m = [\theta^m_{r1}, \theta^m_{r2}, \theta^m_{r3}, ..., \theta^m_{r_d}] , \quad \theta(m) = [\theta^m_{r1}, \theta^m_{r2}, \theta^m_{r3}, ..., \theta^m_{r_d}]$$

where $d$ is the length of the quantum bit individual. Also, the quantum rotation gate can be replaced by the quantum angle operator:

$$\left[\begin{array}{c} a^{m+1}_{r1} \\ \beta^{m+1}_{r1} \end{array}\right] = \left[\begin{array}{cc} \cos (\Delta \theta^m_{r1}) & -\sin (\Delta \theta^m_{r1}) \\ \sin (\Delta \theta^m_{r1}) & \cos (\Delta \theta^m_{r1}) \end{array}\right] \left[\begin{array}{c} a^m_{r1} \\ \beta^m_{r1} \end{array}\right]$$ \hspace{1cm} (25)

Which leads to

$$\theta^m_{r1} = \Delta \theta^m_{r1} + \theta^m_{r1}$$ \hspace{1cm} (26)
thus, it can be concluded that the quantum angle is an angle vector in a complex vector space which is a two-dimensional vector as demonstrated as in Figure (1) [26].

![Figure 1. The Quantum angle.](image)

In the search space, the particles of the PSO algorithm move randomly and the updating of the velocity is made at constant rate depending on the experience of every individual and its neighbours. A trajectory analysis has been made by Kennedy and Clerc for discussing the PSO algorithm convergence [27]. This study revealed that best convergence to the solution is reached when a particle in the swarm is approaching its local attractor \( P^m_{ri} = [p^m_{r1}, p^m_{r2}, p^m_{r3}, \ldots, p^m_{rd}] \) as the particle flies in a real search space and it can be expressed as in the following equation:

\[
P^m_{ri} = r_{ri}^m. P_{best^m_{ri}} + (1 - r_{ri}^m). G_{best^m_i}
\]  

(27)

where \( r_{ri}^m \) is a uniformly distributed random number between zero and 1.

Sun et al. had presented a new crossover process which is analogous to the genetic algorithm for reproducing. This is due to the fact that the generated local attractor in the equation (27) is not used in discrete binary search spaces [28]. The local attractor that will be used in binary discrete search spaces is obtained by selecting two offspring randomly and the generation of these offsprings is the product of the application of the crossover process on the two parents \( P_{best^m_{ri}} \) and \( G_{best^m_i} \) as in equation (28) [26]:

\[
P^m_{ri} = \lambda_{ri}^m. P_{best^m_{ri}} + (1 - \lambda_{ri}^m). G_{best^m_i}
\]  

(28)

where \( \lambda_{ri}^m \) is a random integer number which takes a value of either zero or 1. From equation (28), it can be noted that the point \( P^m_{ri} \) position is located between \( P_{best^m_{ri}} \) and \( G_{best^m_i} \) in discrete spaces. The quantum angle in LAQPSO algorithm is utilized for encoding all the particles qubits in the population and this will produce a swarm of quantum angles.

In the LAQPSO algorithm, the quantum angles are initialized by the value of \( \frac{\pi}{4} \). The qubits state values are defined depending on the probabilities of \( (\alpha^2 = 0) \) or \( (\beta^2 = 1) \), as described in the following equation:

\[
x^m_{ri} = \begin{cases} 
0 & \text{if } H_{ri} < |\cos(\theta^m_{ri})|^2 \\
1 & \text{otherwise}
\end{cases}
\]  

(29)

where \( H_{ri} \) is uniformly distributed random number between zero and 1.

According to equation (29), the particles are formed as a binary string \( \chi^m_{ri} = [x^m_{r1}, x^m_{r2}, x^m_{r3}, \ldots, x^m_{rd}] \) which have the length of \( d \) and it is produced from the transformation of the \( r \)th particle \( \theta^m_{ri} \) and the fitness value can be evaluated for each particle so as to find the values of \( P_{best} \) and \( G_{best} \). Then the quantum angle is updated using the rotation angle which is obtained from
the local attractor. The direction of the rotation angle is determined by the local attractor and current swarm individual as in the following equation:

$$ \text{DIR}(\theta_{ri}^m) = P_{ri}^m - X_{ri}^m $$  \hfill (30)

According to equation (27), the local attractor is obtained with a probability of 100% if the initial value of $\Phi_{ri}^m$ is taken in the range of $[0, \frac{\pi}{2}]$ which means that $P_{ri}^m$ equals 0 or 1. For this reason, the quantum angle will take a value equals to $\left( \frac{\pi}{2} \right)$ or 0 and the value of $\Phi_{ri}^m$ can be described as in equation (31):

$$ \Phi_{ri}^m = \frac{\pi}{2} P_{ri}^m $$  \hfill (31)

Thereafter, the current quantum angle $\theta_{ri}^m$ and $\Phi_{ri}^m$ are used for obtaining the magnitude of the rotation angle as in equation (32):

$$ |\Delta \theta_{ri}^m| = C_f |\Phi_{ri}^m - P_{ri}^m| \cdot \rho_n $$  \hfill (32)

where $C_f$ is called the contraction factor which is an important element to adjust the rotation angle magnitude. Lastly, the rotation angle is represented as in equation (33):

$$ \Delta \theta_{ri}^m = \text{DIR}(\theta_{ri}^m) \cdot |\Delta \theta_{ri}^m| $$  \hfill (33)

And the quantum angle is updated by the use of equation (24).

7. SIMULATION AND RESULTS

The BPSO, IQBPSO and LAQPSO algorithms were simulated using MATLAB R2017b environment to solve the UCP. The used computer in the simulation has the following features: Core i5 CPU and 8 GB of RAM. For verifying the potentiality and the ability of the three algorithms in solving the UCP, the IEEE 26 generation unit test system is employed as a power system. This test system consists of 26 generation units to supply the load demand through a time horizon of 24 hours. The spinning reserve criteria in this system is set equal to the largest capacity of the committed generation units (i.e. 400 MW) [29]. The dimension of search space for the IEEE 26-unit system equals 26x24, where 26 is the number of the generation units and 24 is the time horizon (number of hours). Table 2. Represents the load demand of the system for 24 hours. Table 3 tabulates the generation units parameters of the simulation system. The population size is set equal to 100 and the maximum number of iteration is 500 iterations. The optimal choice of the parameters for the three algorithms are BPSO ($c_1 = c_2 = 1.9, \omega_{\text{max}} = 0.9$ to $\omega_{\text{min}} = 0.4$), IQBPSO ($\theta_{\text{max}} = 0.1\pi$ and $\theta_{\text{min}} = 0.05\pi$) and LAQPSO ($C_f = 0.1$). Table 4. Shows a comparison of the produced total operation cost by BPSO, IQBPSO, ILR [5] and Binary/Real PSO (BRPSO) [29] algorithms, were the least cost is produced by the LAQPSO algorithm ($720921 \$ $). Tables 5, 6 and 7 show the simulation results of the BPSO, IQBPSO and LAQPSO algorithms. Figure (2) represents the convergence to the solution of the three algorithms were the x-axis represents the iteration number and the y-axis represents the total operation cost ($\$ $). It can be noticed from Figure (2) that the LAQPSO algorithm is faster in the solution of the UCP compared with the BPSO and IQBPSO.

Table 2. Load Demand of the IEEE 26 Generation units simulation system

| Hour | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Demand | 1700 | 1730 | 1690 | 1700 | 1750 | 1850 | 2000 | 2430 | 2540 | 2600 | 2670 | 2590 |
| Hour | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  | 23  | 24  |
| Demand | 2590 | 2550 | 2620 | 2650 | 2550 | 2530 | 2500 | 2550 | 2600 | 2480 | 2200 | 1840 |
Table 3. Generation units Parameters of the IEEE 26 Generation units Simulation System.

| Unit | a ($/h) | b ($/MWh) | c ($/MW^2 h) | $P_{\text{max}}$ (MW) | $P_{\text{min}}$ (MW) | MUT (h) | MDT (h) | HSC ($) | CSC ($) | CSH ($) | Ini.state (h) |
|------|---------|-----------|--------------|-------------------------|------------------------|--------|--------|--------|--------|--------|--------------|
| 1    | 311.9102| 7.5031    | 0.0019       | 400                    | 100                    | 8      | 5      | 500    | 500    | 10     | 10           |
| 2    | 310.0021| 7.4921    | 0.0019       | 400                    | 100                    | 8      | 5      | 500    | 500    | 10     | 10           |
| 3    | 177.0575| 10.8616   | 0.0015       | 350                    | 140                    | 8      | 5      | 300    | 300    | 8      | 10           |
| 4    | 260.176 | 23.2      | 0.0026       | 197                    | 68.95                  | 5      | 4      | 200    | 200    | 8      | -4           |
| 5    | 259.649 | 23.1      | 0.0026       | 197                    | 68.95                  | 5      | 4      | 200    | 200    | 8      | -4           |
| 6    | 259.131 | 23        | 0.0026       | 197                    | 68.95                  | 5      | 4      | 200    | 200    | 8      | -4           |
| 7    | 143.5972| 10.7583   | 0.0049       | 155                    | 54.25                  | 5      | 3      | 150    | 150    | 6      | 5            |
| 8    | 134.3179| 10.7367   | 0.0048       | 155                    | 54.25                  | 5      | 3      | 150    | 150    | 6      | 5            |
| 9    | 143.0288| 10.7154   | 0.0047       | 155                    | 54.25                  | 5      | 3      | 150    | 150    | 6      | 5            |
| 10   | 142.7348| 10.694    | 0.0046       | 155                    | 54.25                  | 5      | 3      | 150    | 150    | 6      | 5            |
| 11   | 218.7752| 18.2      | 0.006        | 100                    | 25                     | 4      | 2      | 70     | 70     | 4      | -3           |
| 12   | 218.335 | 18.1      | 0.0061       | 100                    | 25                     | 4      | 2      | 70     | 70     | 4      | -3           |
| 13   | 218.8952| 18        | 0.0062       | 100                    | 25                     | 4      | 2      | 70     | 70     | 4      | -3           |
| 14   | 81.6259 | 13.4073   | 0.0093       | 76                     | 15.2                   | 3      | 2      | 50     | 50     | 3      | 3            |
| 15   | 81.4681 | 13.3805   | 0.0091       | 76                     | 15.2                   | 3      | 2      | 50     | 50     | 3      | 3            |
| 16   | 81.298  | 13.3538   | 0.0089       | 76                     | 15.2                   | 3      | 2      | 50     | 50     | 3      | 3            |
| 17   | 81.1364 | 13.3272   | 0.0088       | 76                     | 15.2                   | 3      | 2      | 50     | 50     | 3      | 3            |
| 18   | 118.8206| 37.8896   | 0.0143       | 20                     | 4                      | 0      | 0      | 20     | 20     | 2      | -1           |
| 19   | 118.4576| 37.777    | 0.0136       | 20                     | 4                      | 0      | 0      | 20     | 20     | 2      | -1           |
| 20   | 118.1083| 37.6637   | 0.0126       | 20                     | 4                      | 0      | 0      | 20     | 20     | 2      | -1           |
| 21   | 117.7551| 37.551    | 0.012        | 20                     | 4                      | 0      | 0      | 20     | 20     | 2      | -1           |
| 22   | 24.8882 | 26.0611   | 0.0285       | 12                     | 2.4                    | 0      | 0      | 0      | 1      | -1      |               |
| 23   | 24.7605 | 25.9318   | 0.0284       | 12                     | 2.4                    | 0      | 0      | 0      | 0      | 1      | -1           |
| 24   | 24.6382 | 25.8027   | 0.028        | 12                     | 2.4                    | 0      | 0      | 0      | 0      | 1      | -1           |
| 25   | 24.411  | 25.6753   | 0.0265       | 12                     | 2.4                    | 0      | 0      | 0      | 0      | 1      | -1           |
| 26   | 24.3891 | 25.5472   | 0.0253       | 12                     | 2.4                    | 0      | 0      | 0      | 0      | 1      | -1           |

Table 4. Total operation cost produced by different approaches.

| Solution Algorithm | Total Operation Cost ($) |
|--------------------|--------------------------|
| ILR [5]            | 725,996.9                |
| BRPSO [29]         | 721208                   |
| BPSO               | 721958                   |
| IQBPSO             | 721261                   |
| LAQPSO             | 720921                   |
Table 5. Output power of the generators produced by the BPSO algorithm.

| Hour | G1   | G2   | G3   | G4   | G5   | G6   | G7   | G8   | G9   | G10  |
|------|------|------|------|------|------|------|------|------|------|------|
|      | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   |
| 1    | 117.1972 | 120.9045 | 125.2009 | 130.2161 |
| 2    | 120.7345 | 124.4859 | 128.8429 | 133.9367 |
| 3    | 116.0429 | 119.7357 | 124.0124 | 129.0019 |
| 4    | 116.8674 | 120.5705 | 124.8614 | 129.8692 |
| 5    | 122.2489 | 126.0192 | 130.4022 | 135.5297 |
| 6    | 140.5688 | 144.5676 | 149.2643 | 154.7992 |
| 7    | 155     | 155     | 155     | 155     |
| 8    | 155     | 155     | 155     | 155     |
| 9    | 155     | 155     | 155     | 155     |
| 10   | 155     | 155     | 155     | 155     |
| 11   | 155     | 155     | 155     | 155     |
| 12   | 155     | 155     | 155     | 155     |
| 13   | 155     | 155     | 155     | 155     |
| 14   | 155     | 155     | 155     | 155     |
| 15   | 155     | 155     | 155     | 155     |
| 16   | 104.5414 | 155     | 155     | 155     |
| 17   | 155     | 155     | 155     | 155     |
| 18   | 155     | 155     | 155     | 155     |
| 19   | 155     | 155     | 155     | 155     |
| 20   | 155     | 155     | 155     | 155     |
| 21   | 155     | 155     | 155     | 155     |
| 22   | 155     | 155     | 155     | 155     |
| 23   | 155     | 155     | 155     | 155     |
| 24   | 138.1262 | 142.0945 | 146.7494 | 152.2299 |

| Hour | G11  | G12  | G13  | G14  | G15  | G16  | G17  | G18  | G19  | G20  |
|------|------|------|------|------|------|------|------|------|------|------|
|      | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   |
| 1    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| 2    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| 3    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| 4    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| 5    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| 6    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 |
| 7    | 24.1235 | 26.1793 | 28.1096 | 30.2376 |
| 8    | 61.1096 | 67.8816 | 74.7088 | 76     |
| 9    | 76     | 76     | 76     | 76     |
| 10   | 76     | 76     | 76     | 76     |
| 11   | 76     | 76     | 76     | 76     |
| 12   | 76     | 76     | 76     | 76     |
| 13   | 76     | 76     | 76     | 76     |
| 14   | 76     | 76     | 76     | 76     |
| 15   | 76     | 76     | 76     | 76     |
| 16   | 76     | 76     | 76     | 76     |
| 17   | 76     | 76     | 76     | 76     |
| 18   | 76     | 76     | 76     | 76     |
| 19   | 76     | 76     | 76     | 76     |
| 20   | 76     | 76     | 76     | 76     |
| 21   | 76     | 76     | 76     | 76     |
| 22   | 55.8589 | 58.682  | 61.1571 | 64.0018 |
| 23   | 15.2 | 15.2 | 15.2 | 15.2 |
| 24   | 15.2 | 15.2 | 15.2 | 15.2 |
| Hour | G21 | G22 | G23 | G24 | G25 | G26 | Reserve | Demand | STC ($) |
|------|-----|-----|-----|-----|-----|-----|---------|--------|---------|
| 1    | 4   | 0   | 0   | 0   | 2.4 | 0   | 406     | 1700   | 20      |
| 2    | 4   | 0   | 2.4 | 2.4 | 0   | 2.4 | 400     | 1730   |         |
| 3    | 0   | 0   | 0   | 0   | 2.4 | 2.4 | 408     | 1690   |         |
| 4    | 0   | 0   | 2.4 | 2.4 | 0   | 418 | 1700    | 20     |         |
| 5    | 0   | 0   | 0   | 2.4 | 0   | 424 | 1750    | 70     |         |
| 6    | 0   | 0   | 0   | 0   | 0   | 424 | 1850    | 70     |         |
| 7    | 0   | 0   | 0   | 2.4 | 0   | 483 | 2000    | 200    |         |
| 8    | 4   | 0   | 2.4 | 0   | 0   | 410 | 2430    | 330    |         |
| 9    | 0   | 0   | 0   | 0   | 0   | 424 | 2540    | 200    |         |
| 10   | 0   | 0   | 2.4 | 2.4 | 0   | 401 | 2600    |        |         |
| 11   | 0   | 0   | 2.4 | 2.4 | 2.4 | 403 | 2670    | 60     |         |
| 12   | 0   | 0   | 2.4 | 2.4 | 2.4 | 411 | 2590    |        |         |
| 13   | 0   | 0   | 2.4 | 2.4 | 2.4 | 411 | 2590    |        |         |
| 14   | 0   | 0   | 0   | 0   | 0   | 415 | 2550    |        |         |
| 15   | 0   | 2.4 | 2.4 | 2.4 | 2.4 | 405 | 2620    |        |         |
| 16   | 0   | 2.4 | 2.4 | 2.4 | 0   | 403 | 2650    | 40     |         |
| 17   | 0   | 0   | 0   | 0   | 0   | 415 | 2550    |        |         |
| 18   | 0   | 0   | 0   | 0   | 0   | 435 | 2530    |        |         |
| 19   | 0   | 0   | 0   | 0   | 0   | 465 | 2500    |        |         |
| 20   | 0   | 0   | 0   | 0   | 0   | 415 | 2550    |        |         |
| 21   | 4   | 0   | 2.4 | 0   | 2.4 | 409 | 2600    | 20     |         |
| 22   | 0   | 0   | 0   | 0   | 0   | 485 | 2480    |        |         |
| 23   | 0   | 0   | 2.4 | 0   | 0   | 480 | 2200    |        |         |
| 24   | 0   | 0   | 0   | 0   | 0   | 434 | 1840    |        |         |

**Total operation cost = $721958**

Table 6. Output power of the generators produced by the IQBPSO algorithm.
| Hour | G11 | G12 | G13 | G14 | G15 | G16 | G17 | G18 | G19 | G20 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1    | 0   | 0   | 25  | 15.2| 15.2| 15.2| 15.2| 15.2| 0   | 0   |
| 2    | 0   | 0   | 25  | 15.2| 15.2| 15.2| 15.2| 15.2| 0   | 0   |
| 3    | 0   | 0   | 25  | 0   | 15.2| 15.2| 15.2| 15.2| 0   | 0   |
| 4    | 0   | 0   | 25  | 0   | 15.2| 15.2| 15.2| 15.2| 0   | 0   |
| 5    | 0   | 0   | 25  | 15.2| 15.2| 15.2| 15.2| 15.2| 0   | 0   |
| 6    | 0   | 25  | 25  | 15.2| 15.2| 15.2| 15.2| 15.2| 0   | 0   |
| 7    | 25  | 25  | 25  | 33.798| 36.0876| 38.184| 40.5305| 0   | 0   | 4   |
| 8    | 42.5362| 49.7331| 56.8807| 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 9    | 79.9895| 86.3296| 92.831| 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 10   | 100  | 100  | 100  | 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 11   | 100  | 100  | 100  | 76  | 76  | 76  | 76  | 0   | 0   | 4   |
| 12   | 100  | 100  | 100  | 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 13   | 100  | 100  | 100  | 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 14   | 83.3943| 89.6565| 96.0992| 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 15   | 100  | 100  | 100  | 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 16   | 100  | 100  | 100  | 76  | 76  | 76  | 76  | 0   | 0   | 4   |
| 17   | 83.3943| 89.6565| 96.0992| 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 18   | 76.5846| 83.0026| 89.5628| 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 19   | 66.3701| 73.0218| 79.7581| 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 20   | 83.3943| 89.6565| 96.0992| 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 21   | 100  | 100  | 100  | 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 22   | 59.5604| 66.3679| 73.2217| 76  | 76  | 76  | 76  | 0   | 0   | 0   |
| 23   | 25   | 25   | 25   | 65.3397| 68.3919| 71.0298| 74.0886| 0   | 0   | 0   |
| 24   | 0    | 25   | 25   | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 0   | 0   |

| Hour | G21 | G22 | G23 | G24 | G25 | G26 | Reserve | Demand | STC ($) |
|------|-----|-----|-----|-----|-----|-----|---------|---------|--------|
| 1    | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 474     | 1700   | 70     |
| 2    | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 444     | 1730   |        |
| 3    | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 408     | 1690   |        |
| 4    | 0   | 0   | 0   | 2.4| 0   | 0   | 0       | 424     | 1750   | 50     |
| 5    | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 424     | 1850   | 70     |
| 6    | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 406     | 2000   | 90     |
| 7    | 0   | 2.4 | 0   | 0   | 0   | 0   | 0       | 535     | 2430   | 600    |
| 8    | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 425     | 2540   |        |
| 9    | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 401     | 2600   |        |
| 10   | 0   | 0   | 0   | 2.4| 2.4| 2.4| 2.4     | 415     | 2670   | 60     |
| 11   | 0   | 0   | 0   | 2.4| 2.4| 2.4| 2.4     | 411     | 2590   |        |
| 12   | 0   | 0   | 0   | 2.4| 2.4| 2.4| 2.4     | 411     | 2590   |        |
| 13   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 415     | 2550   |        |
| 14   | 0   | 2.4 | 0   | 0   | 0   | 0   | 0       | 401     | 2620   | 20     |
| 15   | 0   | 0   | 0   | 2.4| 2.4| 2.4| 2.4     | 403     | 2650   | 20     |
| 16   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 415     | 2550   |        |
| 17   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 435     | 2530   |        |
| 18   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 465     | 2500   |        |
| 19   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 415     | 2550   |        |
| 20   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 401     | 2600   |        |
| 21   | 0   | 0   | 0   | 2.4| 2.4| 2.4| 2.4     | 401     | 2600   |        |
| 22   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 485     | 2480   |        |
| 23   | 0   | 0   | 0   | 2.4| 2.4| 2.4| 2.4     | 407     | 2200   |        |
| 24   | 0   | 0   | 0   | 0   | 0   | 0   | 0       | 434     | 1840   |        |

Total operation cost = 721261 $
Table 7. Output power of the generators produced by the LAQPSO algorithm.

| Hour | G1   | G2   | G3     | G4     | G5     | G6     | G7     | G8     | G9     | G10    |
|------|------|------|--------|--------|--------|--------|--------|--------|--------|--------|
|      | MW   | MW   | MW     | MW     | MW     | MW     | MW     | MW     | MW     | MW     |
| 1    | 117.0873 | 120.7931 | 125.0877 | 130.1004 |
| 2    | 118.7638 | 122.4906 | 126.8139 | 131.8639 |
| 3    | 115.3558 | 119.04  | 123.305  | 128.2792 |
| 4    | 116.4002 | 120.0975 | 124.3803 | 129.3777 |
| 5    | 122.2489 | 126.0192 | 130.4202 | 135.5297 |
| 6    | 140.5688 | 144.5676 | 149.2643 | 154.7992 |
| 7    | 155     | 155    | 155     | 155     |
| 8    | 155     | 155    | 155     | 155     |
| 9    | 155     | 155    | 155     | 155     |
| 10   | 155     | 155    | 155     | 155     |
| 11   | 155     | 155    | 155     | 155     |
| 12   | 155     | 155    | 155     | 155     |
| 13   | 155     | 155    | 155     | 155     |
| 14   | 155     | 155    | 155     | 155     |
| 15   | 155     | 155    | 155     | 155     |
| 16   | 155     | 155    | 155     | 155     |
| 17   | 155     | 155    | 155     | 155     |
| 18   | 155     | 155    | 155     | 155     |
| 19   | 155     | 155    | 155     | 155     |
| 20   | 155     | 155    | 155     | 155     |
| 21   | 155     | 155    | 155     | 155     |
| 22   | 155     | 155    | 155     | 155     |
| 23   | 155     | 155    | 155     | 155     |
| 24   | 138.1262 | 142.0945 | 146.7494 | 152.2299 |

| Hour | G11   | G12   | G13   | G14   | G15   | G16   | G17   | G18   | G19   | G20   |
|------|------|------|------|------|------|------|------|------|------|------|
|      | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   | MW   |
| 1    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 0    | 0    | 0    | 5    | 40.5305 |
| 2    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 0    | 0    | 0    | 0    | 155   |
| 3    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 0    | 0    | 0    | 0    | 155   |
| 4    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 0    | 0    | 0    | 0    | 155   |
| 5    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 0    | 0    | 0    | 0    | 155   |
| 6    | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 0    | 0    | 0    | 0    | 155   |
| 7    | 33.798 | 36.0876 | 38.184 | 40.5305 | 0    | 4    | 0    | 0    | 0    | 0    |
| 8    | 56.8807 | 76    | 76    | 76    | 76    | 0    | 0    | 0    | 0    | 0    |
| 9    | 86.3296 | 92.831 | 76    | 76    | 76    | 0    | 0    | 0    | 0    | 0    |
| 10   | 100   | 100   | 100   | 76    | 76    | 76    | 0    | 0    | 0    | 0    |
| 11   | 100   | 100   | 100   | 76    | 76    | 76    | 0    | 4    | 4    | 0    |
| 12   | 100   | 100   | 100   | 76    | 76    | 76    | 0    | 0    | 0    | 0    |
| 13   | 100   | 100   | 100   | 76    | 76    | 76    | 0    | 0    | 0    | 0    |
| 14   | 89.6565 | 96.0992 | 76    | 76    | 76    | 0    | 0    | 0    | 0    | 0    |
| 15   | 100   | 100   | 100   | 76    | 76    | 76    | 0    | 0    | 0    | 0    |
| 16   | 100   | 100   | 100   | 76    | 76    | 76    | 0    | 0    | 0    | 4    |
| 17   | 89.6565 | 96.0992 | 76    | 76    | 76    | 0    | 0    | 0    | 0    | 0    |
| 18   | 89.6565 | 96.0992 | 76    | 76    | 76    | 0    | 0    | 0    | 0    | 0    |
| 19   | 73.0218 | 89.6565 | 76    | 76    | 76    | 0    | 0    | 0    | 0    | 0    |
| 20   | 100   | 100   | 100   | 76    | 76    | 76    | 0    | 0    | 0    | 0    |
| 21   | 66.3701 | 73.0218 | 76    | 76    | 76    | 0    | 0    | 0    | 0    | 0    |
| 22   | 73.2217 | 73.2217 | 76    | 76    | 76    | 0    | 0    | 0    | 0    | 0    |
| 23   | 65.3397 | 68.3919 | 71.0298 | 74.0886 | 0    | 0    | 0    | 0    | 0    | 0    |
| 24   | 15.2 | 15.2 | 15.2 | 15.2 | 15.2 | 0    | 0    | 0    | 0    | 0    |
Figure 2. Convergence of BPSO, IQBPSO and LAQPSO algorithms.

| Hour | G21 | G22 | G23 | G24 | G25 | G26 | Reserve | Demand | STC ($) |
|------|-----|-----|-----|-----|-----|-----|---------|--------|--------|
| 1    | 0   | 0   | 0   | 2.4 | 2.4 | 2.4 | 410     | 1700   |        |
| 2    | 0   | 0   | 0   | 0   | 0   | 0   | 444     | 1730   | 70     |
| 3    | 0   | 0   | 0   | 0   | 0   | 0   | 408     | 1690   |        |
| 4    | 0   | 0   | 2.4 | 0   | 0   | 0   | 410     | 1700   |        |
| 5    | 0   | 0   | 0   | 0   | 0   | 0   | 424     | 1750   | 50     |
| 6    | 0   | 0   | 0   | 0   | 0   | 0   | 424     | 1850   | 70     |
| 7    | 0   | 2.4 | 0   | 0   | 0   | 0   | 406     | 2000   | 70     |
| 8    | 0   | 0   | 0   | 0   | 0   | 0   | 535     | 2430   | 600    |
| 9    | 0   | 0   | 0   | 0   | 0   | 0   | 425     | 2540   |        |
| 10   | 0   | 0   | 2.4 | 2.4 | 2.4 | 2.4 | 401     | 2600   |        |
| 11   | 4   | 2.4 | 0   | 2.4 | 2.4 | 2.4 | 403     | 2670   | 60     |
| 12   | 0   | 0   | 2.4 | 2.4 | 2.4 | 2.4 | 411     | 2590   |        |
| 13   | 0   | 0   | 2.4 | 2.4 | 2.4 | 2.4 | 411     | 2590   |        |
| 14   | 0   | 0   | 0   | 0   | 0   | 0   | 415     | 2550   |        |
| 15   | 0   | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 405     | 2620   |        |
| 16   | 4   | 0   | 2.4 | 2.4 | 2.4 | 2.4 | 403     | 2650   | 60     |
| 17   | 0   | 0   | 0   | 0   | 0   | 0   | 415     | 2550   |        |
| 18   | 0   | 0   | 0   | 0   | 0   | 0   | 435     | 2530   |        |
| 19   | 0   | 0   | 0   | 0   | 0   | 0   | 465     | 2500   |        |
| 20   | 0   | 0   | 0   | 0   | 0   | 0   | 415     | 2550   |        |
| 21   | 0   | 0   | 2.4 | 0   | 2.4 | 2.4 | 401     | 2600   |        |
| 22   | 0   | 0   | 0   | 0   | 0   | 0   | 485     | 2480   |        |
| 23   | 0   | 0   | 2.4 | 2.4 | 2.4 | 2.4 | 407     | 2200   |        |
| 24   | 0   | 0   | 0   | 0   | 0   | 0   | 434     | 1840   |        |

Total operation cost = 720921 $
The simulation results have showed that the best solution for the UCP was achieved by the LAQPSO algorithm if compared with the BPSO, QBPSO, IQBPSO and other algorithms in the literature. Also, from the results of the UC schedule, all the constraints have been satisfied. This shows that the LAQPSO algorithm has a better performance for achieving the goals of minimizing the total operation cost than the other algorithms that are employed for this test system. It can be shown that LAQPSO has an excellent convergence characteristic to reduce the total operation cost and it is more efficient than the other algorithms.

8. CONCLUSION

UCP in a power system is a very complex decision procedure among many studying fields in power system. To simplify the making of decisions and contain the problem of complexity and large dimensionality, the intelligent techniques should have a major part in the searching process to find the results of the most optimist solution when dealing with such type of problems. The LAQPSO algorithm is the product of the quantum computing and the PSO algorithm with a local attractor to form this hybrid algorithm. The local attractor helped the PSO algorithm to overcome its disadvantages such as lower convergence speed and being trapped in the local optima solutions. An IEEE 26 generation unit power system is used to validate the effectiveness of the proposed LAQPSO algorithm. The comparison results evidence the superiority, flexibility, affectivity, robustness and great potentiality of the LAQPSO algorithm among all algorithms such as the BSO, IQBPSO and other algorithms in the literature to solve UCP when simulating large power systems. Also, the results confirm that LAQPSO algorithm has the best performance, ability and speed convergence when solving the complex and non-linear problems. Also, it achieved all the constraints of the UC problem and increased the savings compared with different techniques in the literature.

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