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Operation cost reduction in unit commitment problem using improved quantum binary PSO algorithm

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Article Info	ABSTRACT
	Unit Commitment (UC) is a nonlinear mixed integer-programming problem. UC 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. This paper proposes an Improved Quantum Binary Particle Swarm Optimization (IQBPSO) algorithm. The tests have been made on a 10-units simulation system and the results show the improvement in an operation cost reduction after using the proposed algorithm compared with the ordinary Quantum Binary Particle Swarm Optimization (QBPSO) algorithm

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1. INTRODUCTION

Unit commitment is a hard problem that to be optimized in a power system in order to minimize the total operation cost of generators for a specified time horizon according to the load demand satisfying the power outputs of 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 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 UC problem 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]; Lagrangian Relaxation (LR) [5]; second order cone programming [6]; Mixed Integer Programming (MIP) [7]; Mixed Integer Linear Programming (MIP) [8] and Branch and Bound (BB) [9]. 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) [10]; Evolutionary Programming (EP) [11]; Simulated Annealing (SA) [12]; Particle Swarm Optimization (PSO) [13]; Quantum Evolutionary Algorithm (QEA) [14]; Ant Colony Search Algorithm (ACSA) [15];

Differential Evolution approach (DE) [16]; Artificial Neural Networks (ANN) [17]; Tabu Search (TS) [18]; Eagle strategy based crow search algorithm (ES-CSA) [19] and Grey Wolf Optimizer (GWO) [20]. In this paper, the proposed algorithm is Improved Quantum Binary Particle Swarm Optimization (IQBPSO) algorithm which the product of the hybridization of Binary Particle Swarm Optimization (BPSO) algorithm and the Quantum Computing because the BPSO may fail to find the global minimum therefore this improvement has been made to achieve the better solution.

2. PROBLEM FORMULATION

The objective function of UC problem was formulated to minimize the total operation cost over the time horizon [1]. This minmization 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 formulation of cost function for the UC problem that must be minimized by the sum of the starting cost of the generators and operational cost for each unit over a specefied period of time and it can be expressed by the following equation:

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

where f_{gk} is the fuel cost function, U_{gk} is the state of unit g which can be 0 or 1 at the hour k, N is the number of generation units, T is the time horizon, g is the index of the unit, k is the index of time, 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 calculated as follows

$$f_{gk}(P_{gk}) = c_g (P_{gk})^2 + b_g (P_{gk}) + a_g \tag{2}$$

where c_g, b_g, a_g are the fuel cost coeficients and the start-up are represented by the following equation:

$$STC_{gk} = \begin{cases} HSC_g \text{ if } MDT_g \leq T_g^{off} \leq MDT_g + CSH_g \\ CSC_g \text{ if } T_g^{off} > MDT_g + CSH_g \end{cases} \tag{3}$$

where (HSC_g, CSC_g) are the hot and cold start-up cost of the unit g; CSH_g is the cold start hours for the unit g; (MUT_g, MDT_g) are the minimum up and downtime of the unit g and (T_g^{on}, T_g^{off}) are the time of the unit g is continuously ON or OFF

The objective function of UC problem is resterercted 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.

$$\sum_{g=1}^{N} P_{gk} U_{gk} = D_k \tag{4}$$

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

$$\sum_{g=1}^{N} P_g^{max} U_{gk} \geq D_k + R_k \tag{5}$$

3. The generator can produce power in the range between the maximum and minimum values.

$$P_g^{max} \geq P_{gk} \geq P_g^{min} \tag{6}$$

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

$$T_g^{on} \geq MUT_g \tag{7}$$

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

$$T_g^{off} \geq MDT_g \tag{8}$$

where D_k is the load demand of the system at the hour k; R_k is the spinning reserve of the system at the hour k and (P_g^{max}, P_g^{min}) are the maximum and minimum power that can be supplied from the unit g.

3.   PARTICLE SWARM OPTIMIZATION AGORITHM

Particle Swarm Optimization (PSO) is introduced firstly by James Kennedy and Russell Eberhart in 1995 [21]. 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 [21]. 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 that 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 [22]. Furthermore, the experience can be accelerated by two set of the acceleration factors, (c_1, c_2) are the cognitive and asocial acceleration constant factors respectively; (φ_1, φ_2) are two random numbers generated between [0, 1]. The movement is also can be controlled by multiplying it by inertia factor that lies in the range of $[\omega_{max}, \omega_{min}]$ and the typical range is $\omega_{max}= 0.9$ to $\omega_{min} = 0.4$. The velocity update is described by the following equation:

$$V^{m+1} = \omega V^m + c_1\varphi_1(Pbest_i^m - X_i^m) + c_2\varphi_2(Gbest^m - X_i^m) \tag{9}$$

where m is the current itration. The position of the particles can be updated as follows equation:

$$X_i^{m+1} = X_i^m + V_i^{m+1} \tag{10}$$

the inertia factor is represented by the following equation:

$$\omega = \omega_{max} - \frac{(\omega_{max}-\omega_{min})}{iter_{max}} \times m \tag{11}$$

where $(\omega_{max}, \omega_{min})$ are the initial and final weights, $iter_{max}$ is the maximum iteration number and m is the current iteration number. The binary version of the PSO (BPSO) has been presented by James Kennedy and Russell Eberhart to be used in discrete spaces [23]. The update proces of the position for the particles can be achieved by using a new variable known as Sigmoid Limiting Transformation and can be written as

$$S(V_{ij}^{m+1}) = \frac{1}{1-exp(V_{ij}^{m+1})} \tag{12}$$

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

$$X_{ij}^{m+1} = \begin{cases} 1 \text{ if } r_{ij} < S(V_{ij}^{m+1}) \\ \\ 0 \text{ } otherwise \end{cases} \tag{13}$$

where r_{ij} is a random number distributed uniformly between [0, 1].

4.   HYBRIDIZATION OF QUANTUM COMPUTING WITH BPSO ALGORITHM

The quantum bit is known as the smallest unit of information that store in the quantum computer [24]. The quantum bit can be in two states, the first state is 0 and the second is 1 .These states may be written as $|0\rangle$ and $|1\rangle$ and the quantum bit state can be reproduced as follows:

$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle \tag{14}$$

where α and β are two complex numbers that identifies 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 and for examples of these gates, NOT gate, Hadamard gate and rotation gate [25]. The novel QEA has been proposed by Kim and Han as-[24]. 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 α and β and the quantum bit can be formulated as a string of

$$q = \begin{bmatrix} \alpha_1 & | & \alpha_2 & | & \cdot & \cdot & | & \alpha_n \\ \beta_1 & | & \beta_2 & | & \cdot & \cdot & | & \beta_n \end{bmatrix} \tag{15}$$

where $|\alpha_j|^2 + |\beta_j|^2 = 1$ and j = 1, 2 ……n .

The rotation gate can be used as a variance factor to update the individual of the quantum bit and the rotation gate is represented by the following equation:

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

(16)

where $\Delta\theta_j$ is the jth quantum bit rotation angle that goes to 0 or 1state. A lookup table as shown in Table 1 is used to determine the value of $\Delta\theta_j$ and adjusted as $\theta_1 = 0$, $\theta_2 = 0$, $\theta_3 = 0.01\pi$, $\theta_4 = 0$, $\theta_5 = -0.01\pi$, $\theta_6 = 0$, $\theta_7 = 0$, $\theta_8 = 0$ and B is the best solution where B $= (b_1, b_2, b_3, \ldots\ldots, b_n)$ as described in reference [24].

Table 1. Lookup table to determine rotation angle

x_j	b_j	Fitness (X) ≥ Fitness (B)	$\Delta\theta_j$
0	0	False	θ_1
0	0	True	θ_2
0	1	False	θ_3
0	1	True	θ_4
1	0	False	θ_5
1	0	True	θ_6
1	1	False	θ_7
1	1	True	θ_8

A new BPSO inspired by quantum computing which is known as Quantum Binary Particle Swarm Optimization (QBPSO) [26]. 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 ith quantum bit individual (q_i). Therefore, the jth element of the ith particle takes a value of 1 or 0 as in the following equation [26]:

$$X_{ij}^{m+1} = \begin{cases} 1 \text{ if } r_{ij} < |\beta_{ij}|^2 \\ 0 \text{ otherwise} \end{cases}$$

(17)

The rotation angle can be determined by using the current position $Pbest$ and the global position $Gbest$ of the swarm as in the following equation:

$$\Delta\theta_{ij} = \theta \times \{\gamma_{1i} \times (x_{ij}^P - x_{ij}) + \gamma_{2i} \times (x_j^G - x_{ij})$$

(18)

where θ is the rotation angle magnitude and (γ_{1i}, γ_{2i}) can be found by a comparison among the fitness of the current position of the particle i, the fitness of the best position $Pbest$ and the fitness of the global position $Gbest$ respectively as in equations (19) and (20):

$$\gamma_{1i} = \begin{cases} 0 \text{ if } Fitness \text{ of } (X_i) \geq Fitness(Pbest_i) \\ 1 \text{ otherwise} \end{cases}$$

(19)

$$\gamma_{2i} = \begin{cases} 0 \text{ if } Fitness \text{ of } (X_i) \geq Fitness(Gbest_i) \\ 1 \text{ otherwise} \end{cases}$$

(20)

The magnitude of the rotation is decreased monotonously from a maximum value θ_{max} to a minimum value θ_{min} along the iteration by the following equation:

$$\theta = \theta_{max} - \frac{\theta_{max} - \theta_{min}}{iter_{max}} \times m$$

(21)

5. IMPROVED QBPSO ALGORITHM

The QBPSO algorithm may fail in finding the optimum value of the solution, therefor; 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 $Pbest$ for the first half of the iterations and after finding it the fitness in the global best $Gbest$ will be searched in the second half of the iterations. This improvement can be expressed as the following equations:

$$\gamma_{1i} = \begin{cases} 0 \text{ if } m \geq (iter_{max}/2) \\ \\ 1 \text{ } otherwise \end{cases} \tag{22}$$

$$\gamma_{2i} = \begin{cases} 1 \text{ if } m \geq (iter_{max}/2) \\ \\ 0 \text{ } otherwise \end{cases} \tag{23}$$

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

6. RESULTS AND ANALYSIS

The simulation is implemented using MATLAB program version (R17b) for test system consist of 10 generation units over a time horizon of 24 hours [26]. The values of θ_{min} and θ_{max} are chosen equal to 0.05π and 0.1π respectively. The number of population and iterations are 50 and 26 respectively. Table 2 lists the generation of each unit. The total operation cost that has been obtained by the IQBPSO is 563938.4 $ where the total fuel cost of the generation units is 559848.4 $ and the sum of the startup cost for all the units is 4090 $. The results showed minimum cost has been achieved from using the IQBPSO compared with the ordinary QBPSO which produces a total cost of 563977$ as in reference [26].

Table 2. Results of UC problem in the simulation system

hour	Unit1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10	Demand MW
1	455	245	0	0	0	0	0	0	0	0	700
2	455	295	0	0	0	0	0	0	0	0	750
3	455	370	0	0	25	0	0	0	0	0	850
4	455	455	0	0	40	0	0	0	0	0	950
5	455	390	0	130	25	0	0	0	0	0	1000
6	455	360	130	130	25	0	0	0	0	0	1100
7	455	410	130	130	25	0	0	0	0	0	1150
8	455	455	130	130	30	0	0	0	0	0	1200
9	455	455	130	130	85	20	25	0	0	0	1300
10	455	455	130	130	162	33	25	10	0	0	1400
11	455	455	130	130	162	72.8	25	10.2	10	0	1450
12	455	455	130	130	162	80	25	43	10	10	1500
13	455	455	130	130	162	33	25	10	0	0	1400
14	455	455	130	130	85	20	25	0	0	0	1300
15	455	455	130	130	30	0	0	0	0	0	1200
16	455	310	130	130	25	0	0	0	0	0	1050
17	455	260	130	130	25	0	0	0	0	0	1000
18	455	360	130	130	25	0	0	0	0	0	1100
19	455	455	130	130	30	0	0	0	0	0	1200
20	455	455	130	130	162	33	25	10	0	0	1400
21	455	455	130	130	85	20	25	0	0	0	1300
22	455	455	0	0	145	20	25	0	0	0	1100
23	455	425	0	0	0	20	0	0	0	0	900
24	454.79	345.21	0	0	0	0	0	0	0	0	800

7. CONCLUSION

The unit commitment problem is a hard optimization process that the power system has to be deal with it to get a minimum operation cost. This paper proposes an improved quantum binary particle swarm optimization (IQBPSO) algorithm to solve the unit commitment problem. The algorithm has been tested on 10 unit simulation system during 24-hour time horizon and a minimized operational cost has been achieved.

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