Indonesian Journal of Electrical Engineering and Informatics (IJEEI)
Vol. 2, No. 2, June 2014, pp. 76~85
ISSN: 2089-3272

Atmosphere Clouds Model Algorithm For Solving Optimal Reactive Power Dispatch Problem

K Lenin, B Ravindranath Reddy, M Surya Kalavathi
Electrical and Electronics Engineering, Jawaharlal Nehru Technological University Kukatpally,
Hyderabad 500 085, India
e-mail: gklenin@gmail.com

Abstract

In this paper, a new method, called Atmosphere Clouds Model (ACM) algorithm, used for solving optimal reactive power dispatch problem. ACM stochastic optimization algorithm stimulated from the behavior of cloud in the natural earth. ACM replicate the generation behavior, shift behavior and extend behavior of cloud .The projected (ACM) algorithm has been tested on standard IEEE 30 bus test system and simulation results shows clearly about the superior performance of the proposed algorithm in plummeting the real power loss.

***Keywords**: Optimal Reactive Power, Transmission loss, Termite Colony Optimization, Bio-inspired algorithm*

1. Introduction

Optimal reactive power dispatch (ORPD) problem minimizes the real power loss and keeping the voltage profile index within the limits, by satisfying the physical and operational constraints forced by apparatus limits and security requirements. A variety of numerical techniques like the gradient method [1-2], Newton method [3] and linear programming [4-7] have been adopted to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods has the complexity in controlling inequality constraints. If linear programming is applied, then the input- output function has to be articulated as a set of linear functions which predominantly lead to loss of accuracy. The difficulty of voltage stability and fall down, play a major role in power system planning and operation [8]. Global optimization has received wide-ranging research responsiveness, and enormous number of methods has been applied to solve this problem. Evolutionary algorithms such as genetic algorithm have been already proposed to solve the reactive power flow problem [9,10].Evolutionary algorithm is a heuristic approach used for minimization problems by utilizing nonlinear and non-differentiable incessant space functions. In [11], Genetic algorithm has been used to solve optimal reactive power flow problem. In [12], Hybrid differential evolution algorithm is proposed to perk up the voltage stability index. In [13], Biogeography Based algorithm is planned to solve the reactive power dispatch problem. In [14], a fuzzy based method is used to solve the optimal reactive power scheduling method. In [15], an improved evolutionary programming is used to solve the optimal reactive power dispatch problem. In [16], the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [17], a pattern algorithm is used to solve ac-dc optimal reactive power flow model with the generator capability limits. In [18], proposes a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19], a programming based proposed approach used to solve the optimal reactive power dispatch problem. In [20], presents a probabilistic algorithm for optimal reactive power requirement in hybrid electricity markets with uncertain loads. In this paper we propose a new stochastic optimization algorithm by simulating the generation behaviour, shift behaviour and extend behaviour of cloud and which is nominated as Atmosphere Clouds Model (ACM) algorithm. In this algorithm [21-25], a new - revolve round search method is presented. In which the entire population expand from the present optimal positions to the entire explore space in a ‘cloud’ continuous existence pattern, as a replacement for clustering from all directions to the optimal position. This individual optimization method can produce the ACM algorithm to conserve elevated population assortment and stop the algorithm from fence into local optimal solution. The proposed

Received February 3, 2014; Revised April 10, 2014; Accepted May 5, 2014

algorithm ACM has been evaluated in standard IEEE 30 bus test system & the simulation results shows that our proposed approach outperforms all reported algorithms in minimization of real power loss.

2. Problem Formulation

The OPF problem is calculated as a universal minimization problem with constraints, and can be scientifically written in the following form:

$$\text{Minimize } f(x, u) \tag{1}$$

$$\text{Subject to } g(x,u)=0 \tag{2}$$

and

$$h(x, u) \leq 0 \tag{3}$$

Where f(x,u) is the objective function. g(x.u) and h(x,u) are respectively the set of equality and inequality constraints. x is the vector of state variables, and u is the vector of control variables.

The state variables are the load buses (PQ buses) voltages, angles, the generator reactive powers and the slack active generator power:

$$x = \left(P_{g1}, \theta_2, .., \theta_N, V_{L1}, ., V_{LNL}, Q_{g1}, .., Q_{gng}\right)^T \tag{4}$$

The control variables are the generator bus voltages, the shunt capacitors/reactors and the transformers tap-settings:

$$u = \left(V_g, T, Q_c\right)^T \tag{5}$$

or

$$u = \left(V_{g1}, \dots, V_{gng}, T_1, .., T_{Nt}, Q_{c1}, .., Q_{cNc}\right)^T \tag{6}$$

Where Ng, Nt and Nc are the number of generators, number of tap transformers and the number of shunt compensators respectively.

2.1. Objective Function

Active power loss

The objective of the reactive power dispatch is to reduce the active power loss in the transmission network, which can be mathematically expressed as follows:

$$F = PL = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}\right) \tag{7}$$

or

$$F = PL = \sum_{i \in Ng} P_{gi} - P_d = P_{gslack} + \sum_{i \neq slack}^{Ng} P_{gi} - P_d \tag{8}$$

Where gk : is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. Pd: is the total active power demand, Pgi: is the generator active power of unit i, and Pgsalck: is the generator active power of slack bus.

Voltage profile improvement

To minimize the voltage deviation in PQ buses, the objective function can be written as:

$$F = PL + \omega_v \times VD \tag{9}$$

Where ωv: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \tag{10}$$

Equality Constraint

The equality constraint g(x,u) of the ORPD problem is represented by the power balance equation (where the total power generation must cover the total power demand and the power losses) and expressed in mathematical form as ,

$$P_G = P_D + P_L \tag{11}$$

Inequality Constraints

The inequality constraints h(x,u) imitate the confines on components in the power system as well as the limits are produced to guarantee system security.

Upper and lower bounds on the active power of slack bus and reactive power of generators are:

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \tag{12}$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max}, i \in N_g \tag{13}$$

Upper and lower bounds on the bus voltage magnitudes are:

$$V_i^{min} \le V_i \le V_i^{max}, i \in N \tag{14}$$

Upper and lower bounds on the transformers tap ratios are:

$$T_i^{min} \le T_i \le T_i^{max}, i \in N_T \tag{15}$$

Upper and lower bounds on the compensators reactive powers are:

$$Q_c^{min} \le Q_c \le Q_C^{max}, i \in N_C \tag{16}$$

Where N is the total number of buses, NT is the total number of Transformers; Nc is the total number of shunt reactive compensators.

3. Cloud actions

Clouds are an all over part of our planet. Because of the multifaceted generation procedure and the impermanence of transform, cloud has a multi-coloured look and ever-changing attribute. Basically the cloud is water droplets condensed by water vapour in the air, super cooled water droplets, ice crystals or a perceptible suspension in mixture of them. Convective clouds form when moist air is warmed and becomes buoyant. The air raises-haulage water vapour with it and expands, get cooled as it goes on. In view of the fact that the temperature and pressure of the air decrease, its saturation point, equilibrium point of evaporation and condensation has been reduced. When the water vapour content of the growing air becomes superior to its saturation point, then condensation occurs, which yield the miniature condensed cloud water particles. The water particles acquire jointly and hang in the air by the gather power of updraft, and form clouds what we observe in the sky. But stratus clouds often form, when oodles of warm and cool air combine due to lifting of the air over terrain. Although the generation process, self-motivated movement process, extend and revival processes of cloud are multifaceted in the nature, if we see just from a macroscopic view it can be easy: Firstly, the earth can be considered as a whole space simply composed of many disjoint areas, and every area has its own humidity value and air pressure value. According to universal information we know that area with higher humidity value would produce clouds with higher potential, and the air pressure dissimilarity between areas generates airflow and under the action of which the generated clouds would utter to the areas with low air pressure, and they might get together or extend according to the air pressure of close by areas in the shift process. By simulating the generation behaviour, shift behaviour and extend behaviour of cloud, this paper proposes a new optimization ACM algorithm for Solving reactive power dispatch problem.

4. ACM Algorithm

The ACM algorithm is imitated from the generation behaviour, shift behaviour and extend behaviour of cloud in the search space. The intangible process of ACM algorithm is as follows:

(1) The absolute search space is divided into numerous disjoint regions according to the specified rules, and every region has its own humidity value and air pressure value.
(2) The performance of clouds should follow set of laws as scheduled below:
(a) Clouds are able to be generated in regions whose dampness values are higher than one exact threshold.
(b) Beneath the endeavour of wind, clouds move from regions with enhanced air pressure value to regions with lower air pressure value.
(c) In the moving procedure, the droplets of one cloud would extend or acquire jointly according to the air pressure difference between the region where this cloud locate earlier than shift behaviour and region where cloud locates subsequent to shift behaviour.
(d) One cloud is regarded as departed, when its revelation exceeds a specific value or its droplets number is less than a specific value.
(3) The humidity value and air pressure value of all regions are rationalized each time after the generation behaviour, shift behaviour and extend behaviour of clouds.

The metaphors of important concepts in ACMO algorithm is as follows,

Depiction 1.

Suppose U is the cosmos, the region is defined as subspace after the parting of U according to some system. Every dimension of U is divided into M small intervals

$$I_i = \frac{(u_i - l_i)}{M}, i = 1,2,..,D \quad (17)$$

Where I_i is the length of interval in ith dimension, u_i and l_i express the upper boundary and lower boundary of i dimension respectively, D is the dimension. Then the total search space would be split into MD regions, and each of them meet the following properties:

$$\begin{cases} \cup_{i=1}^{M^D} U_i = U \\ U_i \cap U_j = \emptyset, \forall i, j \in \{1,2,..,M^D\}, I \neq j \end{cases} \quad (18)$$

Depiction 2.

Cloud C is defined as a qualitative perception in U, and x is the stochastic execution of C, $x \in$ U. Each x is called one cloud droplet, and the allocation of x in U is called cloud. In this paper the perception of cloud is described by the normal cloud model. So the qualitative feature of one cloud can be described by the three digital character (Ex, En, He) and the droplets number n, where Ex (Expected value), En (Entropy) and He (Hyper entropy) of one cloud articulate the centre position of cloud, the cover range of cloud and the thickness of cloud correspondingly.

Presume there are m clouds in iteration t, the term of which is:

$$C^t = \{C_1^t, C_2^t, .., C_j^t, .., C_m^t\}. \quad (19)$$

The droplets numbers of clouds can be articulated as

$$n^t = \{n_1^t, n_2^t, .., n_j^t, .., n_m^t\} \quad (20)$$

The droplets numbers of all clouds must convene the two properties listed below:

$$\begin{cases} n_j > dN, \ \forall j = 1,2,..,m \\ \sum_{j=1}^{m} n_j \le N \end{cases} \quad (21)$$

Where dN express the smallest value of the droplets number in one cloud, N express maximum value of droplets number in every iteration. For the communicative expediency the three digital characteristics (Ex, En, He) of one cloud is marked as $C \cdot Ex$, $C \cdot En$, $C \cdot He$. The droplets allocation of one cloud can be articulated as:

$$C(x) \sim N(C \cdot Ex, En'^2) \quad (22)$$

Where $En' \sim N(C \cdot En, (C \cdot He)^2), N(C \cdot En, (C \cdot He)^2)$ express criterion normal random variable when $C \cdot En$ indicates the prospect, $(C \cdot He)^2$ is the variance. Each region has its humidity value and air pressure value.

Depiction 3.

The dampness value of one region is defined as the best fitness value found in this region so far, the expression of which is

$$X_i^* = \underset{x \in U_i}{\arg\max} f(x), \ H_i f(X_i^*) \quad (23)$$

Where f is the objective function; x express the droplets which dropped into region U_i once, X_i^* indicates the position with the maximum fitness value and articulate the humidity value of region U_i.

Depiction 4.

The air pressure value of one region is defined as how much period this region has been searched, which is articulated as:

$$P_i = CNT(x \in U_i), i = 1,2,..,M^D \quad (24)$$

Where CNT function is used to do the statistics of data meeting the obligation.

The comprehensive optimization process of ACM algorithm is addressed in fine points as follows.

Initialization stage

In the initialization segment, ACM algorithm is chiefly to attain the region separation, the initialization of the dampness values and air pressure values of regions, and the limit settings, including threshold factorλ, contract factor ξ, weaken rate γ, . The initialization of the dampness value and the air pressure value of regions is accomplished by disperse the population in the search space arbitrarily and the humidity value and air pressure value of regions are initialized by Equations (23) and (24) correspondingly.

The growth of cloud

Based on the imaginary information of normal cloud model, we recognize that normal cloud can be generated when the three digital features (Ex, En, He) and droplets numbers are prearranged. In this paper, the influence of the super-entropy is ignored, so we assume He as constant and it is set as He = 0.001. Then there are three parameters required to be confirmed earlier than the generation process: (1) the regions where clouds can be generated, and then the middle position Ex can be established; (2) entropy En, which is used to settle on the exposure of one cloud; (3) the droplets figure, which determine the dimension of cloud.

Determination of region

In this paper, we presume that no more than the regions whose dampness values are superior to a threshold value can generate cloud.
The computational principle of the threshold value is expressed as follows:

$$Ht = H_{min} + \lambda^*(H_{max} - H_{min}) \quad (25)$$

Where H_{min} and H_{max} express the minimum and maximum dampness values of the whole search space respectively; λ is threshold factor. Then the regions where clouds can be generated can be articulated by the set $R = \{i|H_i > Ht, i = 1,2,..,M^D\}$. The value of λ determine the regions in which clouds can be generated and the droplets number of cloud recently generated. If λ is set too large, the number of regions where clouds can be generated in is so little and that will cause enthralled into local optimum of ACM. When λ is set too small, there will be too many regions that can generate clouds. This observable fact will go in opposition to the convergence of ACM algorithm. So the setting of λ is vital and we set it as λ =0.7 in this paper.

Estimation of entropy value

For the cause of advancing the convergence precision in ACM algorithm, the paper presumes the initial entropy value of one cloud newly generated decrease with iterations. Firstly, the initial entropy value EnM0 is defined as:

$$EnM0 = \frac{I/M}{A} \quad (26)$$

Where I is the length of explore space; A determines the early coverage of the cloud. According to the 3En rule of normal cloud model [24], we set A = 6 in this paper, which means the cloud generated in the first time can cover one area approximately.

The value of EnM decreases in a non-linear model with iterations, the expression is given as,

$$EnM^t = EnM^0 \times \xi \quad (27)$$

Where ξ is contract factor $0 < \xi < 1$.

Calculation of number of droplets

Presume the greatest number of droplets in the explore space at one time is a steady value N and the droplets numbers of clouds recently generated in diverse regions are related with the humidity values of these regions: upper humidity with more droplets, and lower humidity with fewer droplets.

The total number of droplets can be newly generated in current iteration marked as nNew, the expression of which is:

$$nNew = N - \sum_{j=1}^{m} n_j^t \quad (28)$$

Where N is the maximum value of droplets number in every iteration; m is the number of clouds existed in iteration t; $n_j^t$is the droplets number of cloud C_j^t in the tth iteration. As mentioned in the explanation of cloud, the droplets number of one cloud must be greater than a steady value dN, or else it will be regarded as departed. So if the nNew calculated by Eq. (28) is less than dN, there is no cloud is generated this time, if not we can then determine the droplets number of each cloud.

Presume that the set $R = \{i|H_i > Ht, i = 1,2,..,M^D\}$ has k elements, the clouds newly generated are, $C_{m+1}^t . C_{m+2}^t,..,C_{m+j}^t,..,C_{m+k}^t$. The droplets number of cloud recently generated has a comparative relation with the humidity of regions in R, as given in Eq. (29).

$$n_{m+j}^t = \frac{H_{R(j)}}{\sum_{j=1}^{k} H_{R(j)}} \times nNew \quad (29)$$

Where $j = 1,2,,..,j$; $H_{R(j)}$ is the humidity value of region $R(j)$.

After calculating the droplets number of each cloud newly generated, check out all the values, if there is one or more n_{m+j} < dN, 0 < j ≤ k, remove the element with least humidity rate in R. Then recalculate the droplets number of each cloud until all the droplets numbers are superior than dN.

The numeral features of clouds newly generated can be expressed as

$$C_{m+j}^{t} \cdot Ex = X_{s(j)}^{*}, C_{m+j}^{t} \cdot En = EnM^{t}, C_{m+j}^{t} \cdot He = He, 0 < j \leq k \quad (30)$$

The shift behaviour of cloud

Presume the region where the cloud $c_j^t(j = 1,2,..,m)$ locates is US, randomly select one region whose air pressure value is lower than $U_S's$ as the target region UT . The pressure differentiation between US and UT is $\Delta P = P_S - P_T$. The update equation of cloud's location is expressed as:

$$C_j^{t+1} \cdot Ex = C_j^t \cdot Ex + \vec{V}_j^{t+1}, 0 < j \leq m \quad (31)$$

The shift velocity of cloud can be expressed as follows,

$$\vec{V}_j^{t+1} = \vec{e} \times 6 \times C_j^t \cdot En \quad (32)$$

Where $\vec{e}$ expresses the direction of movement and $\vec{e}$ can be calculated as follows,

$$\vec{e} = \frac{(1-\beta)\times\vec{V}_j^t + \beta\times\left(X_T^* - C_j^t \cdot Ex\right)}{\left\|(1-\beta)\times\vec{V}_j^t + \beta\times\left(X_T^* - C_j^t \cdot Ex\right)\right\|} \quad (33)$$

Where β is air pressure factor and can be calculated as $\beta = \frac{\Delta p}{P_{max} - p_{min}}$ (34)

Where P_{max} is the maximum air pressure differentiation of the search space so far and P_{min} is the least amount one. The value of β indicates the influence degree of air pressure difference on the move velocity of cloud; the fitness value of X_T^* indicates the humidity value within the region UT.

Due to the disappearance or collide between clouds in the move process the energy of cloud would reduce, so this paper propose a perception of weaken rate γ, which means the droplets number of each cloud will decrease γ ×100% after each iteration.
The update expression of droplets number is:

$$n_j^{t+1} = n_j^t \times (1 - \gamma) \;\; 0 < j \leq m \quad (35)$$

If the droplets number of cloud is less than dN after this step, it is regarded as degenerate. The γ is mainly used to determine the moved out speed of clouds, and the set of it is very important. Because a large value of γ will lead to the diminishing of clouds before they left far away from the regions where they are generated, the global explore ability of ACM algorithm will be appalling; while when the value of γ is very small, the sustained continuation time of cloud will be so long that the number of clouds newly generated will be too few, which may put shortcoming to the convergence of ACM algorithm. In this paper we put $\gamma = 0.2$.

The extend behaviour of cloud

Presume the region where the cloud $c_j^t(j = 1,2,..,m)$ locates is US , and the region where cloud will locate after the move process is UT. If UT ≠ US, the extend swiftness of cloud is expressed as:

$$C_j^{t+1} \cdot En = C_j^t \cdot En \times (1 + \alpha) \quad (36)$$

Where α is extend factor and it can be designed as,

$$\alpha = \frac{\Delta P}{P_{max}} \quad (37)$$

Where Pmax is the maximum air pressure difference in the search space; $\Delta P = P_S - P_T$ is the pressure difference between US and UT. If UT = US, the cloud C_j^t will extend according to the greatest pressure difference between US and tangential regions, the extend expression is as same as Eq. (36). ACM algorithm updates the dampness values and air pressure values of all regions every time after the generation process of cloud, the cloud's shift process and extend process.

ACM algorithm for solving reactive power problem

i. Start
ii. Initialization
iii. The Generation of Cloud
iv. Update The Humidity Value And Air Pressure Value of Region
v. The Shift Behaviour of Cloud
vi. The Extend Behaviour of Cloud
vii. Update The Humidity Value And Air Pressure Value of Region
viii. End of Loop? If Yes End or Go To Step iii

5. Simulation Results

ACM algorithm has been evaluated on the IEEE 30-bus, 41 branch system. It has a total of 13 control variables as follows: 6 generator-bus voltage magnitudes, 4 transformer-tap settings, and 2 bus shunt reactive compensators. Bus 1 is the slack bus, 2, 5, 8, 11 and 13 are taken as PV generator buses and the rest are PQ load buses. The calculated security constraints are the voltage magnitudes of all buses, the reactive power limits of the shunt VAR compensators and the transformers tap settings limits. The variables limits are listed in table 1.

Table 1. Initial Variables Limits (PU)

Control variables	Min. value	Max. value	Type
Generator: V_g	0.91	1.05	Continuous
Load Bus: V_L	0.90	1.00	Continuous
T	0.91	1.39	Discrete
Qc	-0.10	0.31	Discrete

The transformer taps and the reactive power source installation are discrete with the changes step of 0.01. The power limits generators buses are represented in Table2. Generators buses are: PV buses 2,5,8,11,13 and slack bus is 1.the others are PQ-buses.

Table 2. Generators Power Limits in MW and MVAR

Bus n°	P_g	P_{gmin}	P_{gmax}	Q_{gmin}
1	96.00	50	200	-20
2	81.00	20	80	-20
5	51.00	15	55	-13
8	21.00	10	31	-13
11	21.00	10	25	-10
13	21.00	11	40	-13

The proposed approach succeeds in maintenance of the dependent variables within their limits.

Table 4 summarize the results of the optimal solution obtained by PSO, SGA and ACM methods. It reveals the decrease of real power loss after optimization.

Table 3. Values of Control Variables after Optimization and Active Power Loss

Control Variables (p.u)	ACM
V1	1.0309
V2	1.0300
V5	1.0189
V8	1.0299
V11	1.0632
V13	1.0443
T4,12	0.00
T6,9	0.03
T6,10	0.90
T28,27	0.90
Q10	0.11
Q24	0.11
PLOSS	4.9191
VD	0.9082

Table 4. Comparison Results of Different Methods

SGA[9]	PSO[10]	ACM
4.98 Mw	4.9262Mw	4.9191Mw

6. Conclusion

In this paper, the ACM has been productively implemented to solve ORPD problem. The main advantages of the ACM to the ORPD problem are optimization of different type of objective function, real coded of both continuous and discrete control variables, and without difficulty of handling nonlinear constraints. The proposed algorithm has been tested on the IEEE 30-bus system .The results are compared with the other heuristic methods such as SGA and PSO algorithm reported in the literature and the ACM algorithm demonstrated its effectiveness and robustness in solving the optimal reactive power problem .

References

[1] O Alsac and B Scott. “Optimal load flow with steady state security”. *IEEE Transaction*. 1973; PAS: 745-751.
[2] Lee KY, Paru YM, Oritz JL. A united approach to optimal real and reactive power dispatch. *IEEE Transactions on power Apparatus and systems*. 1985; PAS-104 : 1147-1153
[3] A Monticelli, MVF Pereira, and S Granville. “Security constrained optimal power flow with post contingency corrective rescheduling”. *IEEE Transactions on Power Systems*. 1987; PWRS-2(1):175-182.
[4] Deeb N, Shahidehpur SM. Linear reactive power optimization in a large power network using the decomposition approach. *IEEE Transactions on power system*. 1990: 5(2) : 428-435
[5] E Hobson. ‘Network consrained reactive power control using linear programming’. *IEEE Transactions on power systems*. 1980; PAS-99(4): 868-877.
[6] KY Lee, YM Park, and JL Oritz. “*Fuel –cost optimization for both real and reactive power dispatches*”. IEE Proc. 131C(3): pp.85-93.
[7] MK Mangoli and KY Lee. “Optimal real and reactive power control using linear programming”. Electr.Power Syst. Res. 1993; 26: 1-10.
[8] CA Canizares, ACZ de Souza and VH Quintana. “*Comparison of performance indices for detection of proximity to voltage collapse*”. 1996; 11(3) 1441-1450.
[9] SR Paranjothi and K Anburaja. “Optimal power flow using refined genetic algorithm”. *Electr.Power Compon. Syst*. 2002; 30: 1055-1063.
[10] D Devaraj and B Yeganarayana. “Genetic algorithm based optimal power flow for security enhancement”. IEE proc-Generation. Transmission and. Distribution. 2005: 152.
[11] A Berizzi, C Bovo, M Merlo, and M Delfanti. “A ga approach to compare orpf objective functions including secondary voltage regulation”. *Electric Power Systems Research.* 2012; 84(1): 187-194.
[12] CF Yang, GG Lai, CH Lee, CT Su, and GW Chang. “Optimal setting of reactive compensation devices with an improved voltage stability index for voltage stability enhancement”. *International Journal of Electrical Power and Energy Systems*. 2012; 37(1): 50-57.

[13] P Roy, S Ghoshal, and S Thakur. "Optimal var control for improvements in voltage profiles and for real power loss minimization using biogeography based optimization". *International Journal of Electrical Power and Energy Systems*. 2012; 43(1): 830-838.
[14] B Venkatesh, G Sadasivam, and M Khan. "A new optimal reactive power scheduling method for loss minimization and voltage stability margin maximization using successive multi-objective fuzzy lp technique". *IEEE Transactions on Power Systems*. 2000; 15(2): 844-851.
[15] W Yan, S Lu, and D Yu. "A novel optimal reactive power dispatch method based on an improved hybrid evolutionary programming technique". *IEEE Transactions on Power Systems*. 2004; 19(2): 913-918.
[16] W Yan, F Liu, C Chung, and K Wong. "A hybrid genetic algorithminterior point method for optimal reactive power flow". *IEEE Transactions on Power Systems*. 2006; 21(3): 1163-1169.
[17] J Yu, W Yan, W Li, C Chung, and K Wong. "An unfixed piecewiseoptimal reactive power-flow model and its algorithm for ac-dc systems". *IEEE Transactions on Power Systems*. 2008; 23(1): 170-176.
[18] F Capitanescu. "Assessing reactive power reserves with respect to operating constraints and voltage stability". *IEEE Transactions on Power Systems*. 2011; 26(4): 2224-2234.
[19] Z Hu, X Wang, and G Taylor. "Stochastic optimal reactive power dispatch: Formulation and solution method". *International Journal of Electrical Power and Energy Systems*. 2010; 32(6): 615-621.
[20] A Kargarian, M Raoofat, and M Mohammadi. "Probabilistic reactive power procurement in hybrid electricity markets with uncertain loads". *Electric Power Systems Research*. 2012; 82(1): 68-80.
[21] MJ Harris and WV Baxter, Thrsten Scheuermann. *Simulation of Cloud Dynamics on Graphics Hardware*. in Proc. ACM SIGGRAPH/EUROGRAPHICS Conf. Graphics Hardware, San Diego. 2003: 92-101.
[22] L Deyi and L Changyu. Study on the universality of the normal cloud model. *Eng. Sci*. 2004; 6: 28-34 (in Chinese).
[23] L Deyi, L Changyu and G Wenyan. Proof of the heavy-tailed property of normal cloud model. *Eng. Sci*. 2011; 13: 20-23 (in Chinese).
[24] L Changeyu, L Deyi and P Lili. Uncertain knowledge representation based on cloud model. *Comput. Eng. Appl*. 2004; 40: 32-35 (in Chinese).
[25] Gao-Wei Yan and Zhan-Ju Hao. A Novel Optimization Algorithm Based On Atmosphere Clouds Model. *International Journal of Computational Intelligence and Applications*. 2013; 12(1): 1350002.