International Journal of Applied Power Engineering (IJAPE)
Vol. 1, No. 1, April 2012, pp. 21~28
ISSN: 2252-8792

Techno-Economical Unit Commitment Using Harmony Search Optimization Approach

Mohammad Sadegh Javadi
Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Fars, Iran

Article Info

Article history:

Received Feb 2, 2012
Revised Mar 15, 2012
Accepted Mar 25, 2012

Keyword:

Contingency analysis
Harmony search algorithm
security constrained unit commitment
Independent system operator

ABSTRACT

In this paper, Security-Constrained Unit Commitment (SCUC) model is proposed in a restructured power system. This model consists of a closed-loop modified Unit Commitment (UC) and Security-constrained Optimal Power Flow (SCOPF). The objective of this SCUC model is to obtain the maximum social welfare-based system operating cost while maintaining the system security. In conventional power systems, the demand was forecasted before market operation and determined as a fixed constant. Supplying this demand was therefore considered as a constraint. However, in restructured power system which is based on Standard Market Design (SMD), DISCOs offer the demand and their proposed prices; therefore the demand is modeled as an elastic load. Independent System Operator (ISO) is responsible for operating the power market. The ISO performed the power market using the SCUC software to obtain feasible and economical operation as much as possible. In this paper, Harmony Search Algorithm (HSA) has been implemented to solve SCUC problem. Since the SCUC problem is a non-linear, mixed integer, large scale and non-convex problem, harmony search optimization is addressed as an efficient technique to overcome the aforementioned challenges. The simulation results show that the presented method is both satisfactory and consistent with expectation.

Corresponding Author:

Mohammad Sadegh Javadi
Department of Electrical Engineering, Science and Research Branch,
Islamic Azad University, Fars, Iran
e-mail: msjavadi@gmail.com

1. INTRODUCTION

The short-term planning of the market operation has been carried out in three stages. The first stage is three days-ahead load forecasting and receiving the first mature bids from generation companies. The second stage is extracting generation scheduling of accepted proposals and transferring the data to the all market participants. The third one is finalizing the market before 36 hours ahead for day-ahead energy market. After clearing the market before running the market all sharing of the production is announced and because of the pay as bid structure of the market, the participant's accepted price is determined.

In the short-term running the market a Security Constraint Unit Commitment (SCUC) problem should be executed to provides the market share and production schedule of all generating units. The day-ahead operation of market is depended on the execution of the SCUC problem. In large-scale power market, such as Iran's electricity market, the market operator must be equipped with the strong software to carries out this large scale optimization problem.

Enormous algorithms and formulation in this area are presented. Some of them are presented on modeling and formulation of the Unit Commitment problem [1], and some of them addressed the optimization techniques.

Solving methods of unit commitment can be divided into three species: classical ones, which are suboptimal algorithms based on priority list and equal incremental operating cost [2]; optimization ones, such as Lagrangian Relaxation (LR) [3] dynamic programming [4]; intelligent searching ones, which use various intelligent techniques [5]. The first sort can solve the problem quickly, but only give suboptimal results, and from the point of view of optimization theory, they aren't precise. The second sort of algorithms is based on rigorous mathematical model, but there is dimension disaster in dynamic programming, and modeling conditions are very critical in such algorithms. In this paper, a linearalizing approach is implemented to prevent dynamic programming disadvantages. The third sort of algorithm requires mathematically a less complex model but is more time consuming.

The recent developments in restructured electric power systems provide an opportunity for electricity market participants, such as GENCOs, TRANSCOs, and DISCOs, to exercise least-cost or profit-based operations. However, the system security is still the most important aspect of the power system operation, which cannot be overlooked in the Standard Market Design (SMD) [6].

In this environment, the GENCOs propose their bidding to maximizing their revenue and in the other side of the power market; DISCOs are trying to supply their demands by minimum cost and the ISO is supervising market clearing using the SCUC software and finally, the rate and winning amounts of each participant would be announced. Indeed, GENCOs and DISCOs compete in order to contribute in power market. Generation scheduling in a power system considers network security constraints and system’s reliability indices. Hence, economic operation of the network is in the second preference.

ISO is the responsible entity of secure and economic operation of power system and has this authority to reschedule the UC program to maintain security. In security analysis, the ISO implemented SCUC software to ensure that the final generation scheduling has the ability to withstand sudden and potentially extreme disturbances such as short circuits or the loss of a major system component. Contingency Analysis (CA) is one of the main tasks which are incorporated by ISO to do this target. In CA, ISO performs the Security Constraint Optimal Power Flow (SCOPF) and considers both generator and transmission line outages. In network-oriented optimal power flow analysis the outages of transmission lines changes the structure of admittance matrix, which makes it considerably complex.

In this paper we propose the Harmony Search Algorithm to overcome the traditional challenges which are incorporated with non-linearity, non-convex manner of the SCUC problem.

The remainder of this paper is organized as follows. Theoretical consideration of Security constraint Unit Commitment (SCUC) and corresponding mathematical formulation is addressed in next section. Harmony Search Algorithm is addressed in section 3. Also, modeling of the SCUC implementing HSA is presented in this section. Simulation case and results are introduced in section 4. Conclusion of this paper is conducted in last section.

2. SECURITY CONSTRAINED UNIT COMMITMENT

The unit commitment is one of the most important problems in power system operation. The objective function of vertically integrated utility system was minimizing the operation cost. This model is identified as a cost-based operation.

Actually, the output of the SCUC program has two parts, namely defining the units in operation, which are determined by “0” and “1” (integer variables) for on and off units respectively, and determining the quantity of the generation level of operating units considering the pollution criteria.

SCUC provides a financially viable unit commitment (UC) that is physically feasible. The generation dispatch based on SCUC is made available to corresponding market participants [7].

The unit commitment is a very significant optimization task, which plays a major role in the daily operation planning of power systems, especially in the framework of the deregulated power markets. The SCUC objective is to minimize the total operating cost of the generating units during the scheduling horizon, subject to a number of system and unit constraints [8].

The objective function of vertically integrated utility system was minimizing the operation cost. Therefore, this model is named cost-based operating system where the cost-based production, startup, and shutdown functions are considered in the SCUC formulation [9].

SCUC can provide an hourly commitment of generating units with minimum bid-based dispatch cost. The objective function (1) is composed of bid-based fuel costs for producing electric power and startup and shutdown costs of individual units for the given period. A typical set of constraints in SCUC includes:

1) power balance;
2) generating unit capacity;
3) system reserve requirements;
4) ramping up/down limits;
5) minimum up/down time limits;
6) maximum number of simultaneous on/offs in a plant;

7) maximum number of on/offs of a unit in a given period;
8) maximum energy of a unit in a given period

In monopolized and vertically integrated utility the objective was to meet the forecasted demand plus the spinning reserve to minimize the production cost, subject to each individual unit's operation constraints and system constraints.

In the competitive power market the objective for each generation company is now to maximize its profit. A company does not have the obligation to serve the entire load if it is not profitable [10]. On the other hand, in developed restructured power systems, the objective function is maximizing the social welfare. This model is the developed Bid-based one which the Hydro generation units and emission production limits are considered too.

2.1. SCUC Problem Formulation

In this part the SCUC problem is formulated. The first objective function in traditional approaches is shown in (1) which is consists of three parameters: cost of generation, start up and shut down costs. The cost function was described by a quadratic or linear piecewise function. The hourly SCUC constraints listed below include the system power balance (2), system spinning and operating reserve requirements (3), (4), ramping up/down limits (5), (6), minimum up/down time limits (7), (8) and unit generation limits (9). Another constraint which is considered in this SCUC formulation is fuel constraints (10).

$$Min \quad \sum_{i=1}^{NG}\sum_{t=1}^{NT}[F_{ci}(PG_{it})*I_{it}+SU_{it}+SD_{it}] \tag{1}$$

For the sake of simplicity, linear cost function is considered where $F_{ci}(PG_{it})=a_{Gi}+b_{Gi}PG_{it}$

$$S.T:$$

$$\sum_{i=1}^{NG}PG_{it}=P_{D,t}+P_{L,t} \quad (t=1,...,NT) \tag{2}$$

$$\sum_{i=1}^{NG}R_{S,it}*I_{it}\geq R_{S,t} \quad (t=1,...,NT) \tag{3}$$

$$\sum_{i=1}^{NG}R_{O,it}*I_{it}\geq R_{O,t} \quad (t=1,...,NT) \tag{4}$$

$$\begin{gathered}PG_{it}-PG_{i(t-1)}\leq[1-I_{it}(1-I_{i(t-1)})]UR_i+I_{it}(1-I_{i(t-1)})PG_{i,\min}\\(i=1,...,NG)(t=1,...,NT)\end{gathered} \tag{5}$$

$$\begin{gathered}PG_{i(t-1)}-PG_{it}\leq[1-I_{i(t-1)}(1-I_{it})]DR_i+I_{i(t-1)}(1-I_{it})PG_{i,\min}\\(i=1,...,NG)(t=1,...,NT)\end{gathered} \tag{6}$$

$$\begin{gathered}[x_{i(t-1)}^{on}-T_i^{on}]*[I_{i(t-1)}-I_{it}]\geq 0\\(i=1,...,NG)(t=1,...,NT)\end{gathered} \tag{7}$$

$$\begin{gathered}[x_{i(t-1)}^{off}-T_i^{off}]*[I_{it}-I_{i(t-1)}]\geq 0\\(i=1,...,NG)(t=1,...,NT)\end{gathered} \tag{8}$$

$$\begin{gathered}PG_{i\min}\leq RG_{it}+PG_{it}\leq PG_{i\max}\\t=1,2,...,T\end{gathered} \tag{9}$$

$$\sum_{t=1}^{NT}\sum_{i\in FT}[F_{fi}(PG_{it})*I_{it}+SU_{f,it}+SD_{f,it}]\leq F_{FT}^{\max} \tag{10}$$

Where $F_{fi}(PG_{it})$ is a linear function same as the thermal generation cost function, $F_{ci}(PG_{it})$.

HARMONY SEARCH ALGORITHM

The harmony search (HS) algorithm, proposed by [11], is a nature inspired algorithm, mimicking the improvisation of music players. The harmony in music is analogous to the optimization solution vector, and the musician's improvisations are analogous to the local and global search schemes in optimization techniques. The HS algorithm uses a stochastic random search, instead of a gradient search. This algorithm uses harmony memory considering rate and pitch adjustment rate for finding the solution vector in the search space. The HS algorithm uses the concept, how aesthetic estimation helps to find the perfect state of harmony, to determine the optimum value of the objective function. The HS algorithm is simple in concept, few in parameters and easy in implementation. It has been successfully applied to various optimization problems [12-15]. The optimization procedure of the HS algorithm is as follows:

1. Initialize the optimization problem and algorithm parameters
2. Initialize the harmony memory.
3. Improvise a New Harmony Memory.
4. Update the harmony memory.
5. Check for stopping criteria. Otherwise, repeat step 3 to 4.

The detailed description of the above steps are given in [13-14] and the brief explanation is given in the following sections.

3.1 Initialization of problem and HS algorithm parameters

In this step, the optimization problem is specified as follows:

$$\begin{aligned} & Min\, f(x) \\ & S.t.\, g(x) = 0 \\ & \quad x_{k,\min} \le x \le x_{k,\max} \quad k = 1,2,\ldots,N \end{aligned} \tag{11}$$

where $f(x)$ is the objective function, $g(x)$ is the equality constraint, x is the set of decision variables, x_{min}, x_{max} are minimum and maximum limits of decision variables and N is the number of decision variables. The HS algorithm parameters are also specified in this step. These are the harmony memory size (HMS) or the number of solution vectors in the harmony memory, harmony memory considering rate (HMCR), pitch adjustment rate (PAR), bandwidth rate (BW) and the number of improvisations (NI) or the stopping condition.

3.2. Initialization of harmony memory

The harmony memory (HM) is a memory location where all the solution vectors (sets of decision variables) are stored. The HM is similar to the number of population in other evolutionary algorithms. The HM matrix (12) is filled with as many randomly generated values between its minimum and maximum limits.

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \tag{12}$$

3.3. Improvisation of a new harmony from the HM

A new harmony vector, $X' = (x'_1, x'_2, \ldots , x'_N)$ is generated based on three rules: (1) memory consideration, (2) pitch adjustment and (3) random selection. Generating a new harmony is called as improvisation.

In the memory consideration, the value of decision variables X' for the new vector are selected from (x^1 – x^{HMS}). The harmony memory considering rate (HMCR), which varies between 0 and 1, is the rate of choosing one value from the historical values stored in HM, while (1 – HMCR) is the rate of randomly selecting one value from the possible range of values as:

$$x'_i = \begin{cases} x'_i \in \{x_i^1, x_i^2, \cdots, x_i^{HMS}\} & if\ \ rand \le HMCR \\ x'_i \in X_i & otherwise \end{cases} \tag{13}$$

where *rand* is the uniform random number in the range between 0 and 1 and X_i the set of possible range of values for each decision variable, that is $x_{i,\min} \le X_i \le x_{i,\max}$.

For example, a HMCR of 0.7 indicates that the HS algorithm will choose the decision variable from historically stored values in the HM with a 70% probability or from the possible range of values with a 30% probability. After the memory consideration, every component is examined to determine whether it should be pitch adjusted. This operation uses the PAR parameter, which is the rate of pitch adjustment as follows:

$$x'_i = \begin{cases} x'_i \pm rand \times BW & if \ \ rand \le PAR \\ x'_i & otherwise \end{cases} \tag{14}$$

where *BW* is the arbitrary distance bandwidth. To improve the performance of the HS algorithm, PAR and BW are changed during each generation as follows;

$$PAR(g) = PAR_{\min} + \frac{PAR_{\max} - PAR_{\min}}{NI} \times g \tag{15}$$

where *PAR*(*g*) is the pitch adjusting rate of current generation, PAR_{min} is the minimum pitch adjusting rate, PAR_{max} is the maximum pitch adjusting rate, *g* is the current generation number and *NI* is the number of improvisations.

$$BW(g) = BW_{\max} \exp\left(\frac{Ln\left(\frac{BW_{\min}}{BW_{\max}}\right)}{NI} \times g \right) \tag{16}$$

where *BW*(*g*) is the bandwidth rate of current generation, BW_{min} is the minimum bandwidth rate and BW_{max} is the maximum bandwidth rate [12].

3.4. Updating the harmony memory

Updating the harmony memory in HS algorithm for multi-objective optimization problem differs from that of basic HS algorithm. In this work, non-dominated sorting and ranking scheme, proposed by [16], is used to find the Pareto optimal solutions. The New Harmony Memory, generated by improvisation process, is combined with the existing harmony memory to form 2*HMS solution vectors. Then non-dominated sorting and ranking procedure is performed on the combined harmony memory. Once the ranking is assigned to all the solution vectors in the combined harmony memory, a diversity rank is assigned to the solution vectors, which are in the same non-dominated front, using the crowding distance metric. The crowding distance is an indication of the density of the solution vectors surrounding a particular solution vector. The measure of crowding distance is generally based on the average distance of the two solution vectors on either side of a solution vector, along each of the objectives. Finally, the best harmony memory, which is of size HMS, is selected from the combined harmony memory in the order of their ranking for the next improvisation. To choose exactly HMS solution vectors from the last non-dominated front, crowded comparison operator is used to select the best solutions needed to fill the HMS.

3.5. Stopping criterion

The HS algorithm is stopped when the number of improvisations (*NI*) has been met. Otherwise Sections 3.3 and 3.4 are repeated [12].

Table 1. Load Data for the RBTS

Hours	P_D, MW				Hours	P_D, MW			
	$D_{2,5,6}$	D_3	D_4	Total		$D_{2,5,6}$	D_3	D_4	Total
1	13.40	56.95	26.80	123.95	*13*	19.00	80.75	38.00	175.75
2	12.60	53.55	25.20	116.55	*14*	19.00	80.75	38.00	175.75
3	12.00	51.00	24.00	111.00	*15*	18.60	79.05	37.20	172.05
4	11.80	50.15	23.60	109.15	*16*	18.80	79.90	37.60	173.90
5	11.80	50.15	23.60	109.15	*17*	19.80	84.15	39.60	183.15
6	12.00	51.00	24.00	111.00	*18*	20.00	85.00	40.00	185.00
7	14.80	62.90	29.60	136.90	*19*	20.00	85.00	40.00	185.00
8	17.20	73.10	34.40	159.10	*20*	19.20	81.60	38.40	177.60
9	19.00	80.75	32.25	170.00	*21*	18.20	77.35	36.40	168.35
10	19.20	81.60	30.80	170.00	*22*	16.60	70.55	33.20	153.55
11	19.20	81.60	30.80	170.00	*23*	14.60	62.05	29.20	135.05
12	19.00	80.75	32.25	170.00	*24*	12.60	53.55	25.20	116.55

3. CASE STUDY AND SIMULATION RESULTS

The proposed method in this paper has been applied and studied on IEEE-RTBS test system. This case system has 11 generating units with 240 MW total installed capacity and its peak load is 185MW. Information about units capacity, start up and shut down costs, Ramp rate, lines profiles and etc. is introduced in [17]. Figure 1 shows the single line diagram of test system. Maximum demand in each hour is presented in table 1. In a traditional environment which has no elastic load, demand is equal with this table's data.

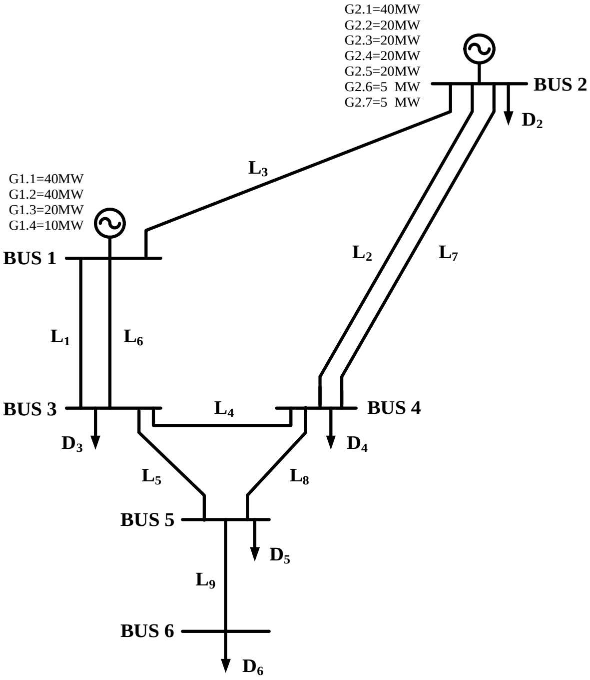

Figure 1. Single line diagram of the RBTS

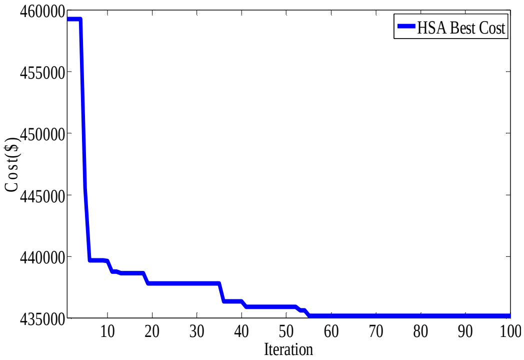

Figure 2. Harmony Search Algorithm Optimization Trend (Base Case)

According to result of study, if there was no contingency in the network, outputs of UC subprogram in traditional method and proposed method are the same. But in traditional environment, if there were some special contingencies like outage of units G1.1 or G1.3 which are the worst contingencies of system, outputs are faced with uneconomical load shedding. Also there is no feasible solution for contingency on line L.4.

Table 2 shows the units' on-off status for base case and Table 3, 4 and 5 show the outputs for outage of units G1.1, G1.3 and line 4 respectively. The HSA trend is illustrated in Figure 2. The simulation results show that the SCUC problem converged in few iterations and the HSA is not a time consuming method versus mathematical optimization techniques.

Table 2. SCUC Program Results-Base Case

	Daily Cost=43888.324 $, AMCP=11.619 $/MW
Unit	Hours (1-24)
1.1	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
1.2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1.3	0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 0 0 0
1.4	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2.1-5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2.6	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
2.7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

Table 3. SCUC Program Results-LINE.4 Outage

Daily Cost=43524.006 $, AMCP=11.581 $/MW

Unit	Hours (1-24)
1.1	0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
1.2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1.3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0
1.4	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2.1-5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2.6	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2.7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

Table 4. SCUC Program Results G1.1 Outage

Daily Cost=42629.844 $, AMCP=11.888 $/MW

Unit	Hours (1-24)
1.2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1.3	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
1.4	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
2.1-5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2.6	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2.7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

Table 5. SCUC Program Results G1.3 Outage

Daily Cost=44705.914 $, AMCP=11.793 $/MW

Unit	Hours (1-24)
1.1	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
1.3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1.4	0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0
2.1-5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
2.6	0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0
2.7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

4. CONCLUDING REMARKS

In this paper, the SCUC problem is introduced based on Harmony Search Algorithm. Network modeling via the proposed heuristic method is a robust and reliable methodology for contingency analysis and economic consideration. In this method all possible outage in generating units and transmission lines would be modeled by omitting or excluding the corresponding asset. The problem has been formulated as mixed integer dynamic linear optimization problem with competing fuel cost objectives.

In this paper we introduce the N-1 contingency for evaluating the robustness of proposed methodology. The proposed method does not impose any limitation on the number of contingencies and can be extended to include simultaneous (N-k) contingencies. Result of simulations shows that the proposed method is more efficient than the traditional ones, especially in evaluation of contingencies in power system. Simulation results verify the feasibility and capability of the proposed modeling of the short-term operation of power system.

REFERENCES

[1] A. J. Wood and B. F. Wollenberg, *Power Generation, Operation and Control*. New York: John Wiley & Sons, 1996.

[2] W. C. Merritt, C. H. Saylor, R. C. Burchett, and H. H. Happ, "Security constraints optimization—a case study," *IEEE Trans. Power Syst.*, vol. 3, no. 3, pp. 970-977, Aug. 1988.

[3] S. Wang, M. Shahidehpour, D. Kirschen, S. Mokhtari, and G. Irisarri, "Short-term generation scheduling with transmission and environmental constraints using an augmented Lagrangian relaxation," *IEEE Trans. Power Syst.*, vol. 10, no. 3, pp. 1294–1301, Aug. 1995.

[4] S. Wang and M. Shahidehpour, "Ramp-rate limits in unit commitment and economic dispatch incorporating rotor fatigue effect," *IEEE Trans. Power Syst.*, vol. 9, no. 3, pp. 1539-1545, Aug. 1994.

[5] T. S. Dillon, K. W. Edwin, H. D. Kochs, and R. J. Taud, "Integer programming approach to the problem of optimal unit commitment with probabilistic reserve determination," *IEEE Trans. Power Apparat. Syst.*, vol. PAS-97, pp. 2154-2166, Nov.-Sep. 1978.

[6] M. Shahidehpour, H. Yamin, and Z. Li, *Market Operations in Electric Power Systems*. New York: John Wiley & Sons, 2002.

[7] P. N. Biskas and A. G. Bakirtizis, "Decentralized security constrained DC-OPF of interconnected power systems," *IEE Proc. Gener. Transm. Distrib.*, vol. 151, no. 6, pp. 747-756, Nov. 2004.

[8] M. S. Javadi, R. Azami, and M. Hassan, "Security Constrained Unit Commitment of Interconnected Power Systems," *International Review of Electrical Engineering I.R.E.E,* vol. 4, no. 2, pp. 199-205, April 2009.

[9] Y. Fu, M. Shahidehpour, and L. Zuyi, "Security-Constrained Unit Commitment With AC Constraints," *IEEE Trans. Power Syst.*, vol. 20, no. 2, pp. 1538-1550, May 2005.

[10] G. B. Sheble, W. Charles, and J. Richter, "A Profit-Based Unit Commitment GA for the Competitive environment," presented at the IEEE/PES, 96WM New York, 2006.

[11] Z. W. Geem, J. H. Kim, and G. V. Loganathan, "A new heuristic optimization algorithm: harmony search," *Simulati,* vol. 76, no. 2, pp. 60-68, 2001.

[12] S. Sivasubramani and K. S. Swarup, "Multi-objective harmony search algorithm for optimal power flow problem," *International Journal of Electrical Power & Energy Systems,* vol. 33, no. 3, pp. 745-752, 2011.

[13] M. Fesanghary, M. Mahdavi, M. Minary-Jolandan, and Y. Alizadeh, "Hybridizing harmony search algorithm with sequential quadratic programming for engineering optimization problems," *Comput. Methods Appl. Mech. Eng.,* vol. 197, no. 33-40, pp. 3080-3091, 2008.

[14] M. Mahdavi, M. Fesanghary, and E. Damangir, "An improved harmony search algorithm for solving optimization problems," *Applied Mathematics and Computation,* vol. 188, no. 2, pp. 1567-1579, 2007.

[15] S. L. Kang and Z. W. Geem, "A new structural optimization method based on the harmony search algorithm," *Comput Structure,* vol. 82, pp. 781-798, 2004.

[16] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," *IEEE Trans. Evolut. Comput.,* vol. 6, no. 2, pp. 182-197, 2002.

[17] R. Billinton, S. Kumar, N. Chowdhury, K. Chu, K. Debnath, L. Goel, E. Khan, P. Kos, G. Nourbakhsh, and J. Oteng-Adjei, "A reliability test system for educational purposes- Basic Data," *IEEE Trans. Power Syst.*, vol. 4, no. 3, pp. 1238-1244, 1989.