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LR- EP Approach for solving Profit Based Unit Commitment Problem with Losses in Deregulated Markets

***Abstract**. In this paper, hybrid models between Lagrange Relaxation (LR) with Evolutionary Programming (EP) are used to solve the profit based unit commitment problem in a deregulated electricity market. In this study losses are included and it can be added to the revenue so that profit can be increased compare to other research work. A modest attempt has been made in this paper presents a simulated case study for the profit based unit commitment problem and demonstrates the effectiveness of the proposed approaches.*

***Streszczenie.** W artykule analizuje się procesy decyzyjne kiedy i jaką jednostkę generatora można dołączyć i odłączyć od sieci. Uwzględnia się straty w nieregulowanym rynku energii. (**Metoda LR-EP rozwiązywania problemu dołączania jednostek generatorów na nieregulowanym rynku energii**)*

Keywords: Profit-based Unit Commitment, Lagrange Relaxation, Evolutionary Programming .
Słowa kluczowe: rynek energii, jednostka generator, relaksacja Lagrange.

Introduction

Unit commitment is the process of deciding when and which generating units at each power station to start-up and shut-down[1].Unit commitment (UC) is an important task in the power system operation, which should determine the start-up and shut-down schedule of thermal units to meet system demand over a short term period. The restructuring of electric power systems has resulted in market-based competition by creating an open market environment. A restructured system allows the power supply to function competitively, as well as allowing consumers to choose suppliers of electric energy. According to this change, traditional methods for power generation, operation as well as control need some modification [7].

UC algorithms can be applied to large-scale power systems and have reasonable storage and computation time requirements. For the vertically integrated monopolistic environment in the past, UC is defined as schedule generating units to be in service (on/off) in order to minimize total production cost while meeting all constraints such as power demand, minimum up and down time, spinning reserve.On the other hand, UC under deregulated environment is more complex and more competitive than the traditional unit commitment. A UC algorithm that maximizes profit will play an essential role in developing successful bidding strategies for the competitive generator (GENCO's). Moreover in the past, utilities had an obligation to serve their customers so that means all demand and spinning reserve constraints can met. However, it is not necessary in the restructured system.A day-ahead power exchange is looked at. Market participants are free to submit supply or demand bids at their preferred price, for each hour of the next day. These auctions are then cleared simultaneously, resulting in a price of electricity for each hour of the next day, revealing which bids are accepted and which not. In order to gain as much profit as possible, a GENCO will try to make an adequate forecast of this spot price of electricity [8, 9, 15, and 16].

The PBUC problem is a mixed integer and continuous nonlinear optimization problem, which is very complex to solve. Many solution techniques such as mixed integer programming, dynamic programming, Lagrangian relaxation and genetic algorithm are used to solve the PBUC. Because of the inherent limitation of these methods, which have some one or another drawback for the solution of PBUC.In this paper LR, EP methods are used to update the lambda and maximize the profit for generation company (GENCO's) in deregulated electricity market [11-13].

Problem formulation for Profit based UC

The objective of PBUC is to maximize the generation company profit subject to all kinds of constraints. The optimization problem can be formulated mathematically by the following equations.
The objective function

Max.*Profit = RV-TC*
(or)
Min operating Cost= *TC-RV*

Subject to constraints
Real Power Constraints

$$(1)\qquad \sum_{i=1}^{N} P_{it} * U_{it} \le P_{dt} \qquad \text{for } t=1....T$$

Reserve Constraints

$$(2)\qquad \sum_{i=1}^{N} R_{it} * U_{it} \le SR_t \qquad \text{for } t=1....T$$

Real and Reserve power operating limits

$$(3)\qquad P_{i\min} \le P_i \le P_{i\max} \qquad \text{for } i=1...N$$

$$0 \le R_i \le P_{i\max} - P_{i\min} \qquad \text{for } i=1... N$$

$$R_i + P_i \le P_{i\max} \qquad \text{for } i=1.... N$$

Minimum Up and Downtime constraint

The amount of power and reserve sold depends on the way reserve payments are made. In this paper, we focused on selling of real power in the deregulated electricity market with the help of forecasted demand and spot prices [9].

LR optimization is done for the equation

$$(4)\qquad L(P,R,\lambda) = TC - RV - \sum_{t=1}^{T} \lambda t (P_{dt} - \sum_{i=1}^{N} P_{it} * U_{it})$$

$$(5)\qquad RV = \sum_{i=1}^{N} \sum_{t=1}^{T} (P_{it} * SP_t) U_{it} + \sum_{i=1}^{N} \sum_{t=1}^{T} r(RP_t * R_{it}) U_{it} + P_L$$

$$(6)\qquad TC = (1-r) \sum_{i=1}^{NT} \sum_{t=1}^{T} F(P_{it}) U_{it} + r \sum_{i=1}^{NT} \sum_{t=1}^{T} F(P_{it} * R_{it}) U_{it} + ST_i * U_{it}$$

The expected value of the profit is computed by expected revenues minus incurred operating costs for a given period (1). The revenue is the income from selling energy to the consumers and losses are included in the revenue itself (10). The three units are having different operational, start-up and shut-down costs.

Network loss is a function of unit generation. To calculate network losses, two methods are in general use. One is the penalty factors method and the other is the *B* coefficients method. The latter is commonly used by the power utility industry. In the *B* coefficients method, network losses are expressed as a quadratic function: Where Bmn are constants called B coefficients or loss coefficients. In this paper we are calculating losses by using B coefficient method.[19]

(7) $$P_L = \sum_m \sum_n P_m B_{mn} P_n$$

Solution Methodology

Algorithm Lagrangian Relaxation Method

Step (1) : Assume λ_t (lamda) value for all hours t

Step (2) : if $\min[(F(P) - \lambda(P)] < 0 : U = 1$

$\min[(F(P) - \lambda(P)] > 0 : U = 0$

Step(3) : Find the optimum generation

(8) $P_i = \lambda - b_i / 2a_i$

If $P_i > P_{i\max}$,then $P_i = P_{i\max}$

$P_i < P_{i\min}$, then $P_i = P_{i\min}$

Step(4) : Find the loading constraints

$$L_{at} = P_{dt} - \sum_{i=1}^{N} P_{it} * U_{it}$$

Step(5) : Calculate the economic dispatch

Step(6) : Calculate the dual function (maximizing λ) Using

(9) $$q(\lambda) = F(P_{it} * U_{it}) - \sum_{t=1}^{T} \lambda t(P_{dt} - \sum_{i=1}^{N} P_{it} * U_{it})$$

Step(7): Calculate the primal function (minimizing F)

(10) $$J = F(\sum_{t=1}^{T} P_{iedc} * U_{it}))$$

Step (8) : Calculate the Relative Duality Gap

(11) $$RDG = (j - q^* / q^*)$$

Step(9): Check for RDG ≤ 0.005 for convergence, if converged stop otherwise update lambda.

Step (9): Update the lambda value of using the following equation

(12) $$\lambda_{t+1} = L_{at} + [dq / d\lambda] * \alpha$$

Where α = 0.01 for $dq / d\lambda > 0$ and

0.002 For $dq / d\lambda < 0$

In this paper, we proposed EP method to update λ for the better convergence in the PBUC.

Step (10): Continue from the step 2 till it get converged

Evolutionary Programming Algorithm

More than 45 years ago, several researchers from US and Europe independently came up with the idea of mimicking the mechanism of biological evolution in order to develop powerful algorithms for optimization and adaptation problems. This set of algorithms is known as Evolutionary Algorithms (EA). One of the most commonly used evolutionary algorithms is EP.This technique was originally conceived by Fogel in the year 1960. The schematic diagram of the EP algorithm is depicted in Fig 1.The general scheme of the EP follows the sequence below [12, 14]:

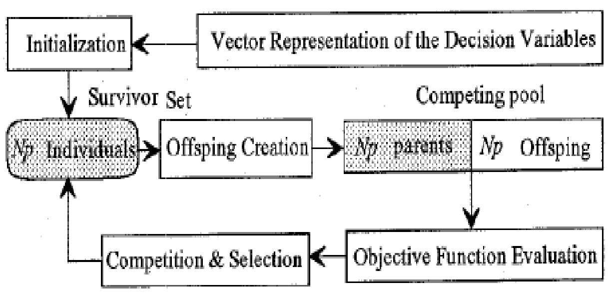

Fig. 1: Schematic diagram of the Evolutionary Programming algorithm

1. Initialization: An initial population of parent individuals Pi, i=1, NP, is selected randomly from a feasible range in each dimension. Typically, the distribution of initial trials is uniform.
2. Creation of Offspring: Equal number of offspring Pi *, i=1, …, NP, is generated by adding a Gaussian random variable with zero mean and pre selected standard deviation to each component of Pi. Therefore, individuals including parents and offspring exist in the competing pool.
3. Competition & Selection: Each individual in the competing pool must stochastically strive against other members of the pool based on the functions f (Pi) and f (Pi *). The Np individuals with the best function values (minimum for the minimization problem) are selected to form a survivor set according to a decision rule. The individuals in the survivor set are new parents for the next generation.

where,

Pi : Initial Population,
Pi* : Offspring Population,
NP : Number of Population,
f (Pi) : Fitness value of initial population
f (Pi*) : Fitness value of offspring population

4. Stopping Rule: The process of generating new trials and selecting those with best function values are continued until the function values are not obviously improved or the given count of total generations is reached

EP Implementation in to Profit Based Unit Commitment

The adjustment of the Lagrange multipliers must be done so as to maximize the profit so that we used EP and PSO methods to achieve this task. At first components of EP are described below and Fig 2 shows flow chart for the updating lambda using both methods

a) *Initialization*

For intervals in the scheduling periods, an array of control variable and vectors can be shown as Lagrange multiplier

$\lambda = [\lambda_1, \lambda_2 \ldots \lambda_T]$

Where T = Total no of hours,

To begin, the population of chromosomes is uniformly random initialized. This population of chromosome is called parent.

b) *Fitness Function*

The value q is used to indicate the fitness of the candidate solution of each individual

c) *Creation of offspring*

The initial parent population produces ‘n’ number of offspring vectors λ_{it} and P_{it} is created from each parents λ_t and P_{it} by adding to each components of λ_t and P_{it} a

Gaussian random variable with zero mean and a standard deviation proportional to the scaled values of the parent trial solution,

(13) $\lambda_{t'} = \lambda_t + N(0, \sigma t2)$

Where $N(0, \sigma 2t)$ represents a Gaussian random variable with mean μ and standard deviation σ_i .The standard deviation σ_i indicates the range the offspring is created around the parent trial solution σ_i is given according to the following equation:

(14) $\sigma_i = \beta * (\lambda_{it} / \lambda_{min}) * (P_{max} - P_{min})$

where β is a scaling factor, which can be tuned during the process of search for optimum. After adding a Gaussian random number to parents, the element of offspring may violate real power constraints.

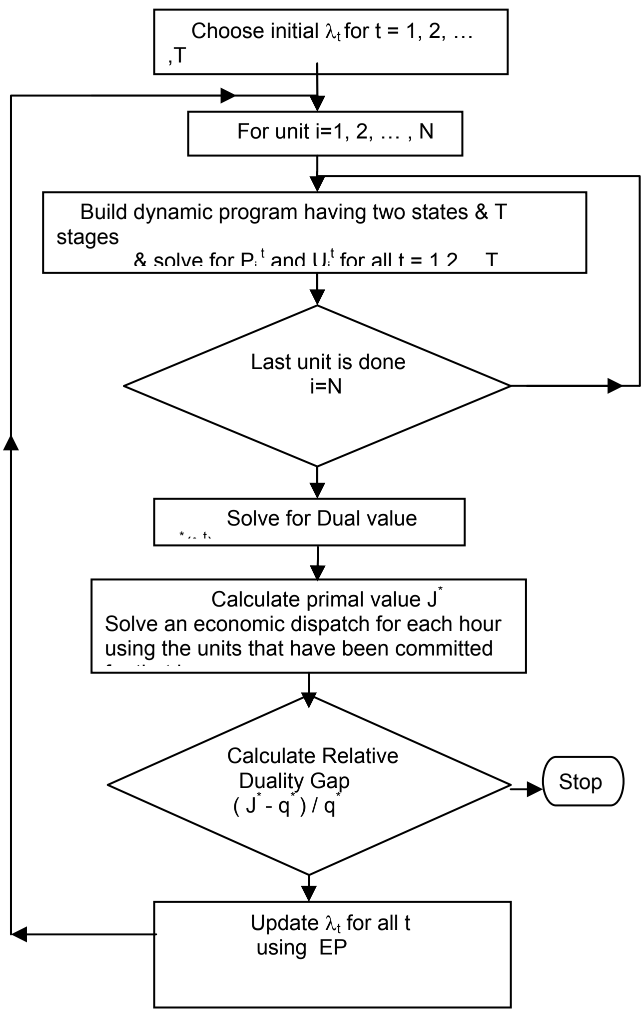

Fig 2: Flow Chart for update the λ using EP method

d) Competition & Selection

The parent trial vectors and their corresponding offspring and contend for survive with each other within the competing pool. The score for each trial vector after a stochastic competition is given by

(15) $W_{pi} = \sum_{t=1}^{Np} W_t$ = 0, otherwise

where $W_t = 1; \text{if}: u_1 > f_{pi} / f_{pr} + f_{pi};$

where the competitor Pr selected at random from among the 2Np trial solutions based on r = [2Np u2+ 1].u_1, u_2 are uniform random number ranging over[0, 1].After competing, the 2Np trial solutions, including the parents and the offspring, are ranked in the descending order of the score obtained. The first Np trial solutions survive and are transcribed along with their objective functions f_{pi} into the survivor set as the basis of the next generation. A maximum number of generations (i.e., iterations) N, is given.

e) Next generation and the terminating criteria

Steps c and d are repeated until terminating criteria is satisfied and the terminating criteria RDG = (J − q*) / q* or at least check for the RDG ≤ 0.005 for convergence

Test System and Simulation Results

The PBUC problem solution method is implemented in Mat lab-11.We use a generation company with 3 generating units to illustrate the proposed method. In our implementation, energy and reserve are considered simultaneously in the formulation 12 h scheduling period is considered. Fuel cost function of each generating unit is estimated into quadratic form .Unit data, forecasted demand, reserve and market prices are given in Tables 1, 2 and which is obtained from Reference [13].

Table 1: Generating Unit Data

	Unit 1	Unit 2	Unit 3
Pimin (MW)	600	400	200
Pimax (MW)	100	100	50
a($/h)	500	300	100
b($/MW-h)	10	8	6
c($/MW²h)	0.002	0.0025	0.005
Min up time (h)	3	3	3
Min down time (h)	3	3	3
Start up cost($)	450	400	300
Initial status(h)	-3	3	3

The loss coefficient matrix for three unit system

Bij = [0.000071 0.000030 0.000025
0.000030 0.000069 0.000032
0.000025 0.000032 0.000080]

Table 2: Demand Forecasting and Spot Price.

Time t (hours)	P_{dt} (load demand in MW)	Spot price ($ / MW-)	Forecasted Reserve (MW)
1	170	10.55	20
2	250	10.35	25
3	400	09.00	40
4	520	09.45	55
5	700	10.00	70
6	1050	11.25	95
7	1100	11.30	100
8	800	10.65	80
9	650	10.35	65
10	330	11.20	35
11	400	10.75	40

Table 3: Comparison methods for three unit system

S.NO	Method	Profit($)
1	LR- gradient search	8672.35
2	Muller method	9056.49[16]
3	LR-EP (without losses)	9074.3[13]
4	LR-EP (with losses)	9541.2

Simulations are carried out for the test system with 3 unit 12 period system. The unit data and forecasted demand and reserve data of this test system are given in Table1 and

Table 2.The proposed methodology is implemented on INTEL[R], Pentium [R] CPU 2 GHZ, 1GB RAM and simulated in MATLAB environment.

The proposed LR-EP approach was compared to the related methods in the references indented to serve this purpose,such as the LR-gadient search ,and muller method.By means of stochastically searching multiple points at one time and considering trail solutions of successive generations, the LR-EP approach avoids entrapping in local optimum solutions. Also, disadvantages of huge memory size required by the LR method are eliminated. In comparison with the results produced by the referenced techniques, the LREP method obviously displays a satisfactory performance with respect to the quality of its evolved solutions and to its computational requirements. The proposed method uses the advantage of EP which can provide a near-global solution combined with the advantage of LR which can find a solution within a short time.The results of Muller method [16] and hybrid methods such as LR-gradient search, LR-EP[13] for the same test system can be compared and tabulated as shown in Table 3.

Conclusion

In this paper, we have established a model of the unit commitment problem based on profit under the deregulated electricity market environment with losses. Moreover, in case of PBUC objective ,the flexibility in the demand constraint both in terms of possibility of buying and selling in the market gives better indication of the likely future scenarios so that better bidding strategy can be made. The numerical results on the generation company with 3 units demonstrate the quick speed convergence and higher accuracy of proposed approach, so it provides a new effective method of profit based unit commitment in deregulated electricity market.

REFERENCES

[1] A.J.Wood, B.F. Wollenberg, Power Generation Operation and Control, 2nd ed., New York: John Wiley & Sons, Inc., 1996.

[2] S. Sen and D.P. Kothari, Optimal thermal generating unit commitment: a review, Electrical Power & Energy Systs, vol. 20, no. 7, pp. 443-451, 1998.

[3] Hatim. Y.Yamin, senior Member, IEEE and S.Mohamed Shahidehpour, Fellow IEEE, Risk and Profit in self -Scheduling for GENCOs, IEEE Transaction on Power System, 2001

[4] B. Lu and M.shahidehpour, Short term scheduling of combined cycle units, IEEE Transaction on Power System, vol 19, pp. 1616-1625, August 2004.

[5] Feng GAO, Student Member , IEEE and Gerald Bushel IEEE Iowa state university Ames, IA, USA Economic Dispatch Algorithms for Thermal unit system involving combined cycle units, IEEE Transaction on Power systems,pp.1066-1072,November 2003.

[6] Sayeed Salam, Unit Commitment Solution methods, Proceedings of World Academy of Science, Engineering and Technology: volume 26 December 2007.

[7] BK Pokharel, GB Shestha, TT Lie and S.E Fleten, Profit Based Unit Commitment In competitive Markets, International Conference on Power System Technology–POWERCON2004; Singapore, pp 21 -24 November 2004

[8] K.Tong and S.M.Shahidehpour, Combination of Lagrangian - relaxation an linear - programming approaches for fuel-constrained unit-commitment problems,IEEE Transaction on Power System, pp 1121-1232, 2000.

[9] P.Attaviriyanupap, H.Kita, E.Tanakaand J. Hasegawa, A New Profit-Based Unit Commitment Considering Power and Reserve Generating, IEEE Transaction on Power Systems, 2003.

[10] P.Attaviriyanupap, H.Kita, E.Tanakaand J. Hasegawa, Member A Hybrid LR-EP for solving Profit-Based Unit Commitment under competitive environment , IEEE Transaction on Power Systems, vol .18,No.1, Feb 2003, 229 – 236.

[11] W.Yuan Xia.ohui, Yuan Yanbin, Wang Cheng and Zhang Xiaopan, An Improved PSO Approach for Profit-based Unit Commitment in Electricity Market, IEEE Transaction on Power Systems, May 2005

[12] Ei Fan, Xiaohong Guan, Qiaozhu Zhai, A new method for unit commitment with ramping constraints, IEEE Transaction on Power Systems, March 2001.

[13] P.Attaviriyanupap, H. Kita, E. Tanaka and J. Hasegawa, Member, IEEE A Hybrid LR–EP for Solving New Profit-Based Competitive Environment, IEEE Transaction on Power Systems, May 2005.

[14] P.Attaviriyanupap, H. Kita, E. Tanaka, and J. Hasegawa, A hybrid evolutionary programming for solving thermal unit commitment problem, in Proc. 12th Annual Conference Power and Energy Social Electrical Engineering. Japan.

[15] W. Richter, Jr. and G. B. Sheble, A profit-based unit commitment GA for the competitive environment, IEEE Transaction on Power Systems, vol. 15, pp 715–721, May 2000.

[16] G.B.Shrestha, B.K, Pokharel, T.T.Lie and S.E.Fleten, Management of price uncertainty in short-term generation planning. Generation,Transmission & Distribution, IET. 2(4), pp 491-504, Dec 2008.

[17] K.Chnadram , N.Subramaniyan, Improved pre-prepared power demand table with muller method for solving profit based unit commitment , IEEE conference TENCON ,November 2008.

[18] Azmi Saleh, Takao Tsuji and Tsutomu Oyama Optimal Bidding Strategies Generation companies in a Day-Ahead Electricity Market with Risk Management Taken into Account, American J. of Engineering and Applied Sciences 2 (1): 8-16, 2009

[19] Malahat Peik-Herfeh, H. Seifi , M.K. Sheikh-El-Eslami, Decision making of a virtual power plant under uncertainties for bidding in a day-ahead market using point estimate method, Electrical Power and Energy Systems , vol 44, pp 88-98 , July 2013.

[20] Masoud Rashidinejad, Hamid Khorasani, Amir Rashidinejad, Transmission Expansion Planning in Restructured Electricity Industry Using a Hybrid Heuristic Technique, International Review on Modeling and Simulations,Vol. 3. No. 3, pp 290- 298 ,June 2010.

APPENDIX

P_{it} : real power output of generator i at hour t,
U_{it} : the ON/OFF status of generator i at hour t,
ST_i :startup cost of generator i,
F_i : fuel cost function of generator i,
N : the total number of generator units,
P_{dt} : load demand at hour t,
P_{min} : minimum generation limit of generator i ,
P_{max} : maximum generation limit of generator i ,
Sp_t : the forecasted spot price at hour t ,
SR_t :the spinning reserve requirement at hour t
R_{it} : reserve power output of generator i at hour t,
P_i : real power output of generator i
R_i : real power output of generator i
λ^t : Legarangian Multiplier at hour t
r : the probability of calling
P_{iedc} : Eeconomic power output of generator.

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