Optimizing the Spinning Reserve Requirements Considering Reliability Of Composite Generation/Transmission Systems

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Abstract

This paper proposes an approach for optimizing location and amount of spinning reserve corresponding to the optimal customer load points risk with cost/benefit analysis in UC program and uses single credible contingency of generating units for evaluation of generation and composit systems reliability. Spinning reserve is provided by Gencos and interruptible loads, according to a day ahead pool market conditions. The expected cost of energy not supplied is considered as a probabilistic index of system's risk measurement in two reliability levels analysis for balancing between benefit derived from spinning reserve against an estimate of the cost of its provision. Finally, Simulation results and sensitivity analysis are presented to evaluate the impacts of change in some important factors such as, value of lost load on different load buses and offered power-price of interruptible loads in each time period of operation planning according to the next day pool market conditions.

Key Words: **Spinning Reserve, Reliability, Composit Power Systems**

Nomenclature

OCuc(Bi , Gi , t): Energy production offered cost of unit Gi on bus Bi in time period t ($/h).
NL(Bi , Gi , t): Number of segments of the offered cost of unit Gi on bus Bi in time period t.
PGLuc(Bi , Gi , t): Power produced in block L of the offered cost of unit Gi on bus Bi in time period t (MW).
KGL(Bi , Gi , t): Upper limit of block L of the offered cost of unit Gi on bus Bi in time period t (MW).
SGL(Bi , Gi , t): Price of block L of the offered cost of unit Gi on bus Bi in time period t ($/MWh).
U(Bi , Gi , t): Commitment state of unit Gi on bus Bi in time period t where 1 means on and 0 means off.
SGLF(Bi , Gi , t): Fixed running cost of unit Gi on bus Bi in time period t ($/h).
EENScost(t): expected cost of energy not supplied in each time period t ($).
EENSuc(t): expected energy not supplied duo to total different case of single contingency of generating unit in each time period t (fist stage of proposed algorithm) (MWh).
EENSloadiED(Bi , Loadi , t) : expected energy not supplied on Loadi connect to bus Bi duo to total different case of single contingency of generating unit in each time period t (second stage of proposed algorithm) (MWh).
γj(Bj , Gj , t): binary variable which takes the value 1, if unavailability of generating unit Gj on bus Bj in time interval t causes some loss of load, otherwise it is equal to 0.
MACj(Bj , Gj , t): Maximum system available capacity during lead time t and after outage of unit Gj on bus Bi (MW).
Prj(Bj , Gj , t): Unavailability of unit Gj on bus Bj during lead time t .
PD(t): total System load demand(MW).

Pdemand(Bi , Loadi , t): demand of loadi connect to bus Bi in time period t (MW).
PIL(Bi , Loadi , t): Interruptible load offer to ancillary services pool market by loadi connect to bus Bi has been contributed as spinning reserve in time period t (MW).
PIL(t): total amount of interruptible load bought by ISO from different loads connect to network for each time period t of next day pool market scheduling(MW).
IL(Bi , Loadi , t): amount of interruptible load bought by ISO from loadi connect to bus Bi for each time period t of next day pool market scheduling(MW).
ILprice(Bi , Loadi , t): Bidding price for interruptible loadi connect to bus Bi in time period t ($/MWh).
SRprice(Bi , Gi , t): Bidding price for spinning reserve of unit Gi on bus Bi in time period t ($/MWh).
SRuc(t): Spinning reserve contributed by unit Gi on bus Bi during lead t (fist stage of proposed algorithm) (MW).
SRED(t): Spinning reserve contributed by unit Gi on bus Bi during lead t (second stage of proposed algorithm) (MW).
PGuc(Bi , Gi , t): Active power Generation of unit Gi on bus Bi in time period t (fist stage of proposed algorithm) (MW).
PGED(Bi , Gi , t): Active power Generation of unit Gi on bus Bi in time period t (second stage of proposed algorithm) (MW).
PflowcmED(Bm , Gm , Bi , Bj , t): Active power flows between bus Bi and bus Bj after outage of unit Gm on bus Bm in time period t (MW).
L : Index for the segment of the offered cost.
Gi , Bi , loadi : Set of units and buses and loads of power system.
t : Index for the lead time or time period of market clearing.
λ(Bi , Gi) : failure rate of generating unit Gi on bus Bi.

1. Introduction

Independent system operator (ISO) as a responsible for the system's reliability maintaining and electricity market manager, should do energy and reserve market clearing while the total payment of energy and spinning reserve services in addition to expected cost of interruption sould be minimized. There are two approaches for dispatching energy and reserve services, namely, sequential dispatch and simultaneous dispatch. The sequential dispatch successively conducts the market commodities based on a priority list. In this dispatch, energy is cleared first followed by clearing reserve. The simultaneous dispatch is to clear the market for all the commodities such as energy and reserve at the same time. Basically, spinning reserve evaluation can be divided into deterministic and probablistic. deterministic criteria does not properly balance the cost of providing reserve at all times against the occasional socio_economic losses that consumers might incur if enough reserve is not provided. But probablistic criteria, can provide a lealistic evaluation of the risk by incorporating the stochastic nature of system components [1-5]. Over earlier decades, probabilistic criteria of operating reserve have been considered in the UC problem. Reference [6] was the first to consider how the spinning reserve could be optimized within the UC problem using an iterative Lagrangian relaxation(LR) approach. Reference [7] proposed a continuous approximation method to estimate the capacity outage probability table (COPT) explicitly within the reserve-constrained UC as a function of the commitment variables. Reference [8] proposed a pool market clearing process, including a probabilistic reserve determination. In [9], a technique has been suggested to balance the cost of providing spinning reserve against its benefits, which are measured in terms of EENS reduction. Reference [10], considered base load units' failure during it's synchronizing with network when system spinning reserve is optimized in UC program and implicity enter the failure probability of base load units during synchronism to network in generating unit unavailability formulation. A market clearing process was proposed in [11] in which both the reliability and performance records of the generators and interruptible loads were taken into consideration. The developed models based on generation system reliability in UC program, just determines optimal amount of spinning reserve requirment in daily operation planning and can not determine the exact optimal location of spinning reserve in different bus of network. Real contribution of Gencos which are located in different sites of network for maintaining the customer load poins reliability in bulk power system during emergency state are dependent to Genco's ability in decrease or increase active power generation and transmission network limitations. For example, keeping considerable amount of spinning reserve on the generation buses which are connected to congested transmission lines will not cause an improvement in customer load poins reliability because increasing in active power generation with these Gencos is limited by independent system operator for preventing extra damages in transmission equipments and cascading outage due to action of protection relays[12]. In this paper, a new formulation for expected cost of energy not supplied with respect to reliability concept in HLI and HLII based on binary and continous system variables in UC objective function is done by MILP method and proposes the new two-stage algorithm for optimizing amount and location of spinning reserve requirment corresponding to optimal customer load points risk. The rest of the paper is organized as follows: In Section 2, two stage proposed algorithm is described for opimizing amount and location of spinning reserve requirment corresponding to optimal customer load points risk with due attention to Genco's and intrupptible load bidding data in pool market with simultaneous clearing energy and ancillary services. In section 3, expected cost of energy not supplied formulation for reliability analysis in HLI and HLII levels is done by MILP method, under each single contingency state after DC power flow study the load curtailment implemented in network load buses for two reasons: generating units force outage of generation system greater than spinning reserve and relieve extra over loads in some transmission lines. In section 4, numerical results and sensitivity analysis with changing some important parameters such as, value of lost load and interruptible load bidding data on different load buses are presented on the four-bus typical test system by using two-stage new algorithm for solving risk based unit commitment problem with cost/benefit analysis. Finally, the conclusion in Section 5 express conceptual achivement from simulation results. the nomenclatures applied in UC formulation, the pool market conditions and network informations are used in different case study of simulation have been gathered from [13].

2. Two Stage New Proposed Algorithm

The new proposed algorithm determines optimal amount and location of spinning reserve requirment during two stages according to the fig. 1. In the first stage, RBUC program is solved with cost/benefit analysis in objective function based on generation system reliability (HLI) and primery results such as committed units, economic dispatch and optimal amount and location of spinning reserve coresponding to optimal customer load points risk are determined. By selecting on/off state of generating units of GenCos available in pool market from the first stage, In the second stage, RBUC program is solved with cost/benefit analysis in objective function based on composite generation and transmission system reliability (HLII), repeatedly. final correction on optimal amount and location of spinning reserve in network coresponding to optimal customer load points risk and economic dispatch on generating units which are connected to the system for decreasing in total operational and reliability costs following the pool market and network conditions is done in the second stage of proposed algorithm. It should be noted that in this paper have been assumed transmission system fully reliable.

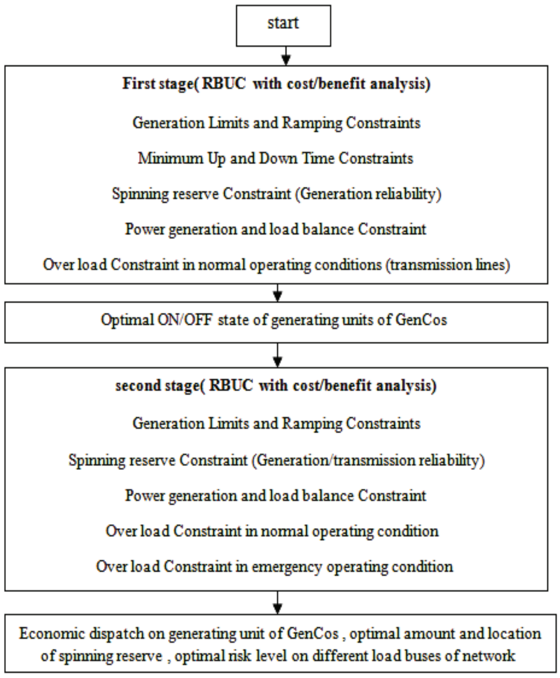

Fig 1. Two-stage new proposed algorithm

4. Unit Commitment Formulation by MILP Method

In this paper, Objective function of the risk based unit commitment program is to minimize the total operational cost, which is defined as the sum of the production offered cost, buying price of spinning reserve from generating units of GenCos and intruptible loads which are connected to system in each time period of next day operation planning according to pool market conditions with simultaneous clearing energy and reserve, as following relation (3).

$$Min \sum_{t} \left(COST_{OC}(t) + COST_{SR}(t) \right) + \sum_{t} EENScost(t) + \sum_{t} COST_{IL}(t) \tag{3}$$

Energy production offered cost of generating units of GenCos is a quadratic function of active power generation which is characterized by GenCos owners that are not adopted with real production costs, specially, in competetive condition of power pool market. Operational cost of GenCos thermal units in objective function for each time period (1 hour) is computed by equation (4).

$$COST_{OC}(t) = \sum_{Bi,\,Gi} OCuc(Bi, Gi, t) \tag{4}$$

Generally, GenCos submit hourly supply bid curves into many segments due to the incremental production cost of generating units. Fig. 2 shows the bid curves of GenCos into three segments and corresponding piecewise linear form of equations by MILP method is given in the following:

$$\begin{aligned}
&OCuc(Bi, Gi, t) = A(Bi, Gi) * u(Bi, Gi, t) + \sum_{l_i = L} PGLuc(Bi, Gi, L, t) * SGL(Bi, Gi, L, t) \\
&A(Bi, Gi) = SGLf(Bi, Gi) * PGmin(Bi, Gi) \quad t \varepsilon T,\ Bi \varepsilon Bus,\ Gi \varepsilon Gen \\
&PGLuc(Bi, Gi, L, t) \le KGL(Bi, Gi, L, t) - PGmin(Bi, Gi) \quad L = l1 \\
&PGLuc(Bi, Gi, L, t) \le KGL(Bi, Gi, L, t) - KGL(Bi, Gi, L-1, t) \quad L = L2 .. Nl-1 \\
&PGLuc(Bi, Gi, L, t) \le PGmax(Bi, Gi) - KGL(Bi, Gi, L-1, t) \quad L = Nl \\
&PGLuc(Bi, Gi, L, t) \ge 0 \quad L = 1 \ldots Nl,\ t \varepsilon T,\ Bi \varepsilon Bus,\ Gi \varepsilon Gen
\end{aligned} \tag{5}$$

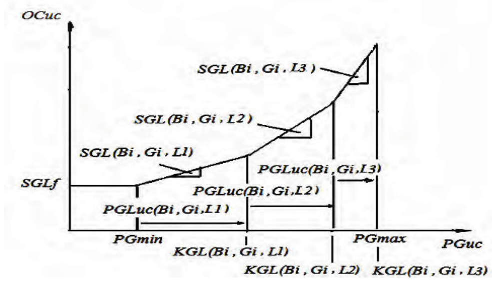

Fig2. Piecewise linear production cost of unit Gi on the bus Bi

Buying optimal amount of spinning reserve requirment from GenCos and intrruptible loads as a demand side participation, which are located in effective sites in network are implemented with ISO into the supplemental market for risk management. these costs in the UC analitical model expres by relations (6) and (7).

$$COST_{SR}(t) = \sum_{Bi,\,Gi} SRprice(Bi, Gi) * SRuc(Bi, Gi, t) \tag{6}$$

$$COST_{IL}(t) = \sum_{Bi,\,loadi} ILprice(Bi, loadi) * IL(Bi, loadi, t) \tag{7}$$

4-1. EENScost evaluation considering generation system reliability(HLI LEVEL)

The cost of load shedding is a socio-economic cost that represents the losses to individuals and businesses of being deprived of electrical energy. A standard technique for computing EENSuc(t) was described in [14]. To compute EENSuc(t), summing over the considered contingencies, the product of the relevant probabilities with the associated energy curtailed provides the EENS for the combination of generating units and the associated load level. But, in the presence of interruptible load, the evaluation is somewhat different because part of load is shedded in the form of interruptible load will not participate in system risk, therefore is modeled as load decrement(IL) from total load demanding for all of the associated contingency state by MILP method. In this paper single contingency of Generating units is considered and other operation planning uncertainities sach as transmission line forced outage and load fluctuation are neglected. Also, EENScost(t) index is computed into the first stage of proposed algorithm based on Binary and continous RBUC variables according to equations (8) , (9), (10), (11) and (12) .

$$EENScost(t) = EENSuc(t) * VOLLav(t) \tag{8}$$

$$EENSuc(t) = \sum_{Bj,\,Gj} \gamma j(Bj, Gj, t) * Prj(Bj, Gj, t) * \left(PD(t) - PIL(t) - MACj(Bj, Gj, t) \right) \tag{9}$$

$$\frac{PD(t) - PIL(t) - MACj(Bi,Gi,t)}{IC} \le \gamma j(Bi,Gi,t) \le 1 + \frac{PD(t) - PIL(t) - MACj(Bi,Gi,t)}{IC} \tag{10}$$

$$MACj(Bj,Gj,t) = \sum_{Bi,Gi \neq Bj,Gj} PGuc(Bi,Gi,t) + SRuc(Bi,Gi,t) \tag{11}$$

$$Prj(Bi, Gi, t) = ORR(Bi, Gi, t) * u(Bi, Gi, t) \tag{12}$$

The presented formulation of this section is not in a linear fashion, therefore, an approach to overcome such difficulty is to replace EENSuc(t) by its upper bound. the upper bounds of the probability of single outage events are expressed as (11) and The procedure of linearizing for this non-linear equation has been presented in [16]. The system Lead time t, with attention to simultaneous clearing energy and reserve pool market for next day scheduling is assumed 1hour and because of this short lead time the error in upper bound approximation of EENSuc(t) will be acceptable and negligible.

4-2. EENScost evaluation considering Generation and Transmission system reliability (HLII LEVEL)

the expected cost of energy not supplied index EENScostED(t) for whole of the power system and the expected energy not supplied index EENSloadiED(Bi , loadi , t) for loadi on bus Bi in each time period of pool market clearing due to composite generation/transmission system reliability evaluation in the second stage of the new proposed algorithm can be computed by (13) , (14). For determining amount of load shedding from load buses into the network, in each single credible contingency of generating units, DC power flow study with attention to amount of the value of lost load on different buses is applied.

$$EENScostED(t) = \sum_{Bi\,,\,loadi} EENSLoadiED(Bi\,,\,loadi\,,\,t) * VOLL(Bi\,,\,loadi\,,\,t) \tag{13}$$

$$EENSLoadiED(Bi,loadi,t) = \sum_{Bm\,,\,Gm} LshED\,(Bm\,,Gm\,,Bi\,,loadi\,,t)\,.\,Psm(Bm\,,Gm\,,Bi\,,loadi\,,t) \tag{14}$$

The aforementioned parameters or variables are formulated according to the relations (15), (16), (17) and (18). By the formulation of relationships (16) , (17) and (18) in risk based unit commitment, optimal amount of load shedding from loadi connected to the bus Bi, optimal amount and location of spinning reserve requirment on different sites of network in form of synchronoused unloaded capacity of generating units and intrruptible loads corresponding to the optimal risk of cunsumers load points, economic dispatch of generating units of GenCos with pool market clearing conditions can be computed.

$$Psm(Bm\,,Gm\,,Bi\,,loadi\,,t) = ORRi(Bm\,,Gm\,,t).\,(\,u.l(Bm\,,Gm\,,t)\cdot\prod_{Bj,Gj\neq Gm}(\,1 - ORRi(Bj\,,Gj\,,t).\,u.l(Bj\,,Gj\,,t)\,)\,) \tag{15}$$

$$\sum_{Bj,\,line} PflowCmED(Bm\,,Gm\,,Bi\,,Bj\,,line\,,t) = (\,\sum_{Bi.Gi}(\,PGED(Bi\,,Gi\,,t) + SRED(Bi\,,Gi\,,t)\,) - \sum_{Bi\,,\,loadi}(PDemand(Bi\,,loadi\,,t) - LoadintED\,(Bi\,,loadi\,,t) - LshED\,(Bm\,,Gm\,,Bi\,,loadi\,,t)\,)\,) \tag{16}$$

$$PflowCmED(Bm,Gm,Bi,Bj,line,t) = (\,(\,deltaCmED(Bm,Gm,Bi,t) - deltaCmED(Bm,Gm,Bj,t)\,) * Sbase * Bline(Bi,Bj,line)\,) \tag{17}$$

$$LshED(Bm\,,Gm\,,Bi\,,loadi\,,t) \leq PDemand(Bi\,,loadi\,,t) - LoadintED(Bi\,,loadi\,,t) \tag{18}$$

5. Numerical Study and Sensitivity Analysis

The two-stage proposed algorithm to solve RBUC formulation is applied for four-bus test system with single control area. This system consists of 4 gencos with 10 thermal generating units, 5 transmission lines and 3 loads. The thermal rating of transmission lines and inductive reactance are shown on the Fig.3.

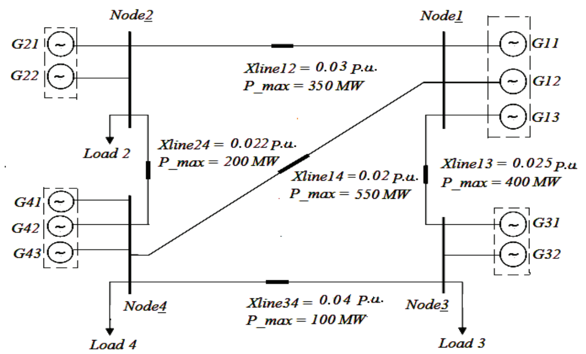

Fig 3. Four buses typical reliability test system

The ramp up and down rate, failure rate, segmented incremental heat rate, min up and down time data for gencos available in pool market and also, hourly load profiles, maximum amount of interruptible load ILmax(Bi , loadi , t) and its offered rate PRIL(Bi , loadi , t) as demand side participation in frequency control of each load connect to system for next day pool market are gathered from [16] . The offered rates of spinning reserve of GenCos units are assumed to be equal to 15% of their higher incremental cost of producing energy. The model has been implemented on a T7700 *ASUS(Intel)* with two processor at 2.4GHz and 2GB of RAM memory using MIP solver CPLEX 9.0 in the GAMS environment

Table 1. spinning reserve purchased by ISO from intrruptible loads and GenCos and optimal load points risk levels(case1)

SRED(Bi , Gi , t) MW		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15	t16	t17	t18	t19	t20	t21	t22	t23	t24
Genco1	BUS1.G13	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	5	5	5	0	0	0	5	5	5
Genco3	BUS3.G31	0	0	0	0	0	0	0	0	10	25	45	0	0	25	25	5	5	5	23	45	45	5	5	5
	BUS3.G32	0	0	0	0	0	0	10	40	15	15	7	0	0	15	15	10	10	10	15	0	15	10	10	10
Genco4	BUS4.G42	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0
IL(Bi , Loadi , t) MW		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15	t16	t17	t18	t19	t20	t21	t22	t23	t24
BUS2.Load2		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
BUS3.Load3		15	15	15	15	15	15	10	0	0	0	8	10	0	0	0	0	0	0	0	15	0	0	0	0
BUS4.Load4		0	0	0	0	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TotalSR		25	25	25	25	45	45	30	60	35	50	70	20	20	50	50	30	30	30	48	70	70	30	30	30
EENScostED(Bi , Loadi ,t) $		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15	t16	t17	t18	t19	t20	t21	t22	t23	t24
BUS2.Load2		465	492	519	560	619	729	801	815	996	911	742	1022	877	829	864	801	746	787	877	1038	898	855	760	630
BUS3.Load3		419	504	590	666	615	529	546	392	409	476	630	749	788	436	392	461	358	392	297	218	273	478	341	333
BUS4.Load4		133	92.3	51.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Two different case studies are conducted here. Case1 is the base case in which RBUC is solved by using the two-stage proposed algorithm when composite generation and transmission system reliability is considered (table1). The goal of study case2 is analysising the effects of changing in interruptible load biddig data IL(Bi , Loadi , t) onto the optimal risk of different load buses as compared to case1(table2).

Table 2. spinning reserve purchased by ISO from intrruptible loads and GenCos and optimal load points risk levels(case2)

SRED(Bi , Gi , t) MW		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15	t16	t17	t18	t19	t20	t21	t22	t23	t24
Genco1	BUS1.G13	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Genco3	BUS3.G31	0	0	0	0	0	0	0	0	10	40	0	0	55	20	20	0	0	0	13	45	38	0	0	0
	BUS3.G32	0	0	0	0	0	0	0	10	5	5	0	0	5	5	5	5	5	5	5	0	5	5	5	5
IL(Bi, Loadi, t) MW		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15	t16	t17	t18	t19	t20	t21	t22	t23	t24
BUS2.Load2		20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
BUS3.Load3		8	8	8	8	8	8	5	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0
BUS4.Load4		0	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TotalSR		28	28	28	28	38	38	75	20	35	65	20	20	75	45	45	25	25	25	38	70	63	25	25	25
EENScostED(Bi , Loadi ,t) $		t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15	t16	t17	t18	t19	t20	t21	t22	t23	t24
BUS2.Load2		437	465	492	533	598	708	733	815	829	671	741	995	624	813	842	778	723	764	871	1010	882	832	737	628
BUS3.Load3		443	528	613	690	673	588	548	546	549	616	875	783	792	484	444	512	409	444	365	252	331	529	392	358
BUS4.Load4		133	92.3	51.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Under the new conditions, maximum amounts of power in the form of interruptible load offered with loads connected to buses 3 and 4 decrease 50% while rate of interruptible load price compared to case1 is constant. For load connected to the bus2, maximum amount of power in form of interruptible load increases 100% while rate of interruptible load price decreases 50% compare to case1. As it can be seen from table2, with increasing maximum amount of interruptible load and decreasing rate of price for these aforementioned offeres in ancillary services, it is expected that optimal risk level for load connected to the bus2 decreases as compared to case1, whereas risk level for loads connected to buses 3 and 4 has an increamental form compared to case1 because of decreasing in maximum amount of the interruptible loads offered by load owners in ancillary services while rate of prices remain in force. But, it should be noted that decremental change in expected cost of energy not supplied for load connected to bus2 and increamental change for loads connected to buses 3 and 4, in spite of fixed VOLL(Bi , Loadi , t) during simultaneous clearing energy and reserve pool market, is because of decrease in expected energy not supplied for load2 and increase in this probabilistic index for load3 and load4 (fig 4).

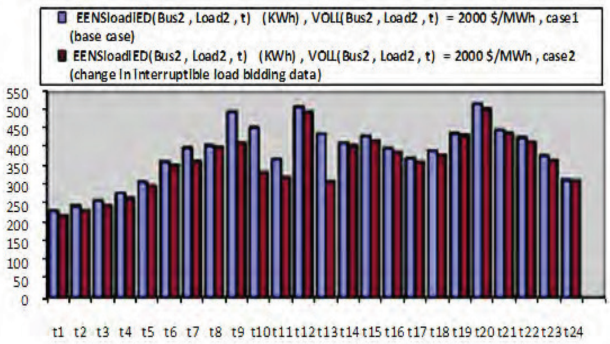

Fig 4. expected energy not supplied in case2 as compared to case1 for load connected to bus2

It can be concluded from case1, case2 that considering to composite generation and transmission system reliability with the two stage proposed algorithm in simultaneous clearing energy and reserve pool market results in optimal amount and location of spinning reserve corresponding to optimal load points risk for different buses in network and also, will decrease the overall cost of operation planning according to nex day pool market conditions as it follows (table3):

case study	overall cost of operation planning for next day pool market ($)	
	first stage (HLI LEVEL)	second stage (HLII LEVEL)
case1 (base case)	438071.484	410397.379
case 2	436567.018	409723.324

6. Conclusions

In this paper, two stage algorithm for determining optimal amount and location of spinning reserve requirment corresponding to optimal customer load points risk by using cost/benefit analysis in unit commitment program has been presented. Spinning reserve resources consist of synchronous unloaded capacity of GenCos and interruptible loads, which submite their bidding data in pool market with simultaneous clearing energy and reserve. Expected cost of energy not suplied takes into account as a probabilistic index and the analytical formulation carried out by MILP method for reliablility evaluation in two levels HLI and HLII. A set of numerical studies and sensitivity analysis on four buses typical test system demonstrates the accuracy and effectiveness of the two stage proposed algorithm for optimizing amount and location of spinning reserve requirment during minimizing overall payments of both bulk power and spinning reserve and the cost of system security.

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