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 composite 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, Composite 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 due to total different case of single contingency of generating unit in each time period t (fist stage of proposed algorithm) (MW).
EENSloadED(Bi , Loadi , t): expected energy not supplied on Loadi connect to bus Bi due to total different case of single contingency of generating unit in each time period t (second stage of proposed algorithm) (MW).
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 (MW).
Prj(Bj , Gj , t): Unavailability of unit Gj on bus Bj during lead time t.
Pd(t): total System load demand(MW).

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 could 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 probabilistic. 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 probabilistic criteria, can provide a realistic 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 implicitly 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 requirement 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 points 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 points 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 continuous 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 requirement 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 optimizing amount and location of spinning reserve requirement corresponding to optimal customer load points risk with due attention to Genco’s and interruptible 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 achievement 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 requirement 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 primary results such as committed units, economic dispatch and optimal amount and location of spinning reserve corresponding 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 corresponding 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.
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 interruptible 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).

\[
\text{Min} \sum_t \left( \text{COST}(t) + \text{COST}(t) + \sum_t \text{EENS}(t) + \sum_t \text{COST}(t) \right)
\]

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 competitive 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).

\[
\text{COST}(t) = \sum_{B_i \in \text{Gen}} \text{OCuc}(B_i, G_i, t)
\]

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:

\[
\text{OCuc}(B_i, G_i, t) = A(B_i, G_i) \cdot w(B_i, G_i, t)
\]

\[
+ \sum_{l = 1}^{L} \text{PGlac}(B_i, G_i, L, 0) \cdot \text{SGElc}(B_i, G_i, L, 0)
\]

\[
A(B_i, G_i) = \text{SGL}(B_i, G_i) \cdot \text{PGmin}(B_i, G_i)
\]

\[
\text{PGlac}(B_i, G_i, L, 0) \leq KGL(B_i, G_i, L, 0) \cdot \text{PGmin}(B_i, G_i)
\]

\[
L = 1, \ldots, N_G
\]

\[
\text{PGlac}(B_i, G_i, L, 0) \leq KGL(B_i, G_i, L, 0) \cdot \text{PGmin}(B_i, G_i, L, 0)
\]

\[
L = 1, \ldots, N_G
\]

\[
\text{PGlac}(B_i, G_i, L, 0) \leq 0
\]

\[
L = 1, \ldots, N_G
\]

\[
t = T, \ B_i \in \text{Bus}, \ G_i \in \text{Gen}
\]

Buying optimal amount of spinning reserve requirement from GenCos and interruptible 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 analytical model expresses by relations (6) and (7).

\[
\text{COST}(t) = \sum_{B_i \in \text{Gen}} \text{SRprice}(B_i, G_i) \cdot \text{SRuc}(B_i, G_i, t)
\]

\[
\text{COST}(t) = \sum_{B_i \in \text{Bus}, \ G_i \in \text{Gen}} \text{ILprice}(B_i, G_i) \cdot \text{IL}(B_i, G_i, t)
\]

4.1. EENS\text{cost} 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 EENS\text{cost}(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 uncertainties such as transmission line forced outage and load fluctuation are neglected. Also, EENS\text{cost}(t) index is computed into the first stage of proposed algorithm based on Binary and continuous RBUC variables according to equations (8), (9), (10), (11) and (12).

\[
\text{EENS}\text{cost}(t) = \sum_{B_i \in \text{Bus}, \ G_i \in \text{Gen}} \text{VOLLav}(t)
\]

\[
\text{VOLLav}(t) = \sum_{B_i \in \text{Bus}, \ G_i \in \text{Gen}} \left( \text{PD}(t) \cdot \text{PL}(t) \cdot \text{MAC}(B_i, G_i, t) \right)
\]

\[
\text{MAC}(B_i, G_i, t) = \sum_{B_j \in \text{Bus} \neq B_i} \left( \text{PGlac}(B_i, G_i, t) \cdot \text{SRuc}(B_i, G_i, t) \right)
\]

\[
\text{PD}(t) \cdot \text{PL}(t) \cdot \text{MAC}(B_i, G_i, t) \leq \text{PR}(B_i, G_i, t) \leq 1 + \text{PD}(t) \cdot \text{PL}(t) \cdot \text{MAC}(B_i, G_i, t)
\]

\[
\text{PR}(B_i, G_i, t) = \text{ORR}(B_i, G_i, t) \cdot w(B_i, G_i, t)
\]

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. EENS\text{cost} evaluation considering Generation and Transmission system reliability(HLII LEVEL)

the expected cost of energy not supplied index EENS\text{costED}(t) for whole of the power system and the expected energy not supplied index EENS\text{loadED}(t) for load on bus \( B_i \) 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.

\[
EENS_{CostED}(t) = \sum_{Bi, loadi} EENS_{LoadED}(Bi, loadi, t) \times VOLL(Bi, loadi, t)
\]

(13)

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 requirement on different sites of network in form of synchronized unloaded capacity of generating units and interruptible loads corresponding to the optimal risk of consumers load points, economic dispatch of generating units of GenCos with pool market clearing conditions can be computed.

\[
Prm_{Load}(Gen, Bi, loadi, t) = ORR(Bi, Gen, t)
\]

(15)

\[
Prm_{Load}(Gen, Bi, loadi, t) = \sum_{Bi, loadi} (\text{Power}(Bi, Gen, t) \times \text{ORR}(Bi, Gen, t))
\]

(16)

\[
Prm_{Load}(Gen, Bi, loadi, t) = \left( \sum_{Bi, loadi} \left( \text{Power}(Bi, Gen, t) \times \text{ORR}(Bi, Gen, t) \right) \right)
\]

(17)

\[
Prm_{Load}(Gen, Bi, loadi, t) = \left( \left( \delta \text{Power}(Bi, Gen, t) \times \delta \text{ORR}(Bi, Gen, t) \right) \times \text{Slew} \right)
\]

(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](image)

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 IL_{max}(Bi, loadi, t) and its offered rate P_{RIL}(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 interruptible loads and GenCos and optimal load points risk levels(case1)

<table>
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<tr>
<th>Bi</th>
<th>Load 1</th>
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<th>Load 3</th>
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Table 2. spinning reserve purchased by ISO from interruptible loads and GenCos and optimal load points risk levels(case2)

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<tr>
<th>Bi</th>
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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 bidding data IL(Bi, Loadi, t) onto the optimal risk of different load buses as compared to case1 (table2).

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 offers in
ancillary services, it is expected that optimal risk level for load connected to the bus 2 decreases as compared to case 1, whereas risk level for loads connected to buses 3 and 4 has an incremental form compared to case 1 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 bus 2 and incremental 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 load 2 and increase in this probabilistic index for load3 and load4 (fig 4).

![Fig 4. expected energy not supplied in case 2 as compared to case 1 for load connected to bus 2](image)

It can be concluded from case 1, case 2 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 next day pool market conditions as it follows (table 3):

<table>
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<tr>
<th>case study</th>
<th>overall cost of operative planning for next day pool market ( $ )</th>
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<td>first stage (HLI LEVEL)</td>
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<td>second stage (HLII LEVEL)</td>
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<td>case 1 (base case)</td>
<td>43071.464</td>
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<td>case 2</td>
<td>43957.018</td>
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6. Conclusions

In this paper, two stage algorithm for determining optimal amount and location of spinning reserve requirement 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 submit their bidding data in pool market with simultaneous clearing energy and reserve. Expected cost of energy not supplied takes into account as a probabilistic index and the analytical formulation carried out by MILP method for reliability 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 requirement during minimizing overall payments of both bulk power and spinning reserve and the cost of system security.

References