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Research Article

Optimal Determination of Capacity Reserve Considering Transient Stability Improvement and Network Security Constrained

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Abstract: In this study represented a method for determining the capacity of reserve in deregulated systems with the goal of maximizing public benefits and network stability maintenance by Transient Energy Function method (TEF). Determining of required spinning reserve capacity of a system is the most important tasks of system operator for safe and ensures operation of power systems. The security is also one of the most important behavioral characteristics of the power system. Security is the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements. One of the factors affecting the security of the power system is the arrangement and distribution of generation unit's. With the advent of deregulated electricity market, a mechanism to determine the arrangement of the generation unit's is more degree of freedom. Given that system security can't be ignored, so the system security coordination in the process of the electricity market is one of the problems of the day. The proposed algorithm was applied to 9-bus IEEE network and has observed that this algorithm can easily prevent the payment of additional costs.

Keywords: Reserve, security, social welfare, stability, transient energy function

INTRODUCTION

By developing of power systems, environmental and economic considerations and security and continuity of the system results in problems put in challenges to planners, designers and system operators. Basically, equipment failure, testing, unanticipated events, refueling, operator errors and regulatory restriction, may cause generating unit unavailability. Independent System Operator (ISO) derived unit commitment of generating units with the target of enhancing power system reliability as well decreasing the whole system costs (Hasanabadi *et al*., 2012). Here, several constraints such as demand-supply equilibrium, spinning reserve capacity, generating rated capacity are contemplated to reflect the actual operating conditions. Furthermore, despite the increasing complexity, the security network constraints are also considered to obtain more realistic results. Although, system reserve ensures system security but it may cause an increase in the operating costs due to calling more expensive units while generated at a non-optimal point (Afshar *et al*., 2008). Therefore optimum allocating system reserve capacity among committed units is extremely crucial in a power system due to economic viability. Reliability driven utilizes several reliability indices such as expected energy not supplied (EENS), Loss of Load Probability (LOLP) and expected the lack of peak net reserve (Suresh and Kumarappan, 2012). To analyze transient stability, three main methods are used: Simulink in the time domain method, Transient energy function method or direct method (Transient Energy Function) TEF and Decreased dynamical method. Among these methods, a method of TEF is the most widely used. Some of the methods that have been used the concept of TEF are Potential Energy Boundary Surface method (PEBS), Method of controlling Unstable Equilibrium Point (UEP) and Acceleration techniques. Recently use as combination method. Generally, these methods can be used for calculating energy margin for removal of error critical time tcl. UEP Controller is the most critical point in the vicinity of the final point of stable work after the error. Here, in order to achieve optimal distribution of power with dynamic security constraints and with free access to the transmission system has been attempted. By formulating the limitations of dynamic stability, reprogramming allocation reserve has been optimized in such a way that the system provides transient stability conditions. In recent years, multifarious deterministic and probabilistic techniques have been expressed to determine spinning reserve necessity. Although, the stochastic nature of power system behavior is not contemplated in deterministic studies, but since they are much easier and more tangible than probabilistic methods preferable by most utilities (Adeli

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and Afshar, 2012). In some papers, spinning reserve requirement is usually considered as the largest unit capacity or a given percentage of the forecasted peak load to ensure system security. In Yong and Lasseter (1999) a method based on optimal load flow is provided for simultaneous dispatch energy and spinning reserve with respect to restriction network security. In Ortega-Vazquez (2006) determines optimal reserve in issue on the unit commitment. Consider the stochastic nature generating units and uses cost-benefits analysis to determine the optimal reserve value in the power market is the advantage of using this method in this study. A fuzzy model based on evolutionary programming technique is suggested in El-Sharkh *et al.* (2003) for the security constrained maintenance scheduling problem of generation systems considering uncertainties in the load and fuel as well as maintenance costs. In Fetanat and Shafipour (2011), Ant Colony (AC) optimization technique has been utilized to seek the optimum schedule of the unit maintenance which aims to improve the system economy as well as increasing the system reliability. In this study, appropriate system reserve allocation among committed units from transient stability and network security view is analyzed.

The constraint: The following subsections show a number of the constraint that should be included in the optimization.

Load flow constraints: Load flow constraints are given by Eq. (1) and (2):

$$0 = P_{shi} - V_i \sum_j V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}), i = 1,2, \ldots, N-1 \quad (1)$$

$$0 = Q_{shi} - V_i \sum_j V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}), i = 1,2, \ldots, N-1 \quad (2)$$

Transmission capacity limits: Every transmission line in the system has its transmission limit which is shown by Eq. (3):

$$|S_l| \le s_i^{max} \quad (3)$$

Generation capacity limits: Obviously, accepted power offers should be within a range specified by each unit, which is expressed by (4) and (5):

$$P_i^{min} \le P_i \le P_i^{max} \quad (4)$$

$$Q_i^{min} \le Q_i \le Q_i^{max} \quad (5)$$

Unit capacity limits: In a market settlement, the sum of the accepted bulk power and SR bids of one unit can't exceed the unit's maximum bidding capacity as expressed in Eq. (6):

$$P_i + SR_i \le P_i^{max} \quad (6)$$

In addition, the constraint (7) is added to avoid any the excessive dispatch of the SR:

$$\sum_i SR_i \le Max(P_i) \quad (7)$$

METHODS OF ANALYSIS

Access to the optimal distribution of power with dynamic security constraints and with free access to the transmission lines has been made. By formulating the limitations of dynamic stability, reprogramming allocation reserve has been optimized in such a way that the system provides transient stability conditions.

Transient energy function: In the classical model with n synchronous generator, the motion equation is as follows:

$$M_i \omega^{\sim \cdot} = P_i \{= P_{mi} - E^2{}_i G_{ii}\} - P_{ei} \{= \sum_{j=1}^{n} [C_{ij} \sin(\theta_i - \theta_j) + D_{ij} \cos(\theta_i - \theta_j)]\} - \frac{M_i}{\sum_{i=1}^{n} M_i} \sum_{l=1}^{n} (P_i - P_{ei}) \quad (8)$$

$$\theta^{\cdot}{}_i = \omega^{\sim}{}_i \quad (9)$$

For the above formula, the Energy Margin (EM) is written as follows:

$$EM = -\frac{1}{2} M_{eq} \omega^{\sim}{}_{eq}^{cL^2} - \sum_{i=1}^{n} P_i^{PF} (\theta_i{}^u - \theta_i{}^{cL}) - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} [C_{ij}^{PF} (cos\theta_{ij}^u - cos\theta_{ij}^{cL}) - B_{ij} D_{ij}^{PF} (sin\theta_{ij}^u - sin\theta_{ij}^{cL})]$$

$$B_{ij} = \frac{[\theta_i^u + \theta_j^u - \theta_i^{cL} - \theta_j^{cL}]}{\theta_{ij}^u - \theta_{ij}^{cL}} \quad (10)$$

$(\ )^{pf}$ Index represents the value of the variable in the final composition after a system error.

Energy margin sensitivity: For occurred Probability and a time error handling, initial Energy Margin Obtained. Energy margin sensitivity $\eta_{i \to j}$ as a change in system energy margin (ΔEM) Than Transfer in real power production from i th to j th generator ($\Delta P_{gi \to j}$) Can be defined. So we have:

$$\eta_{i \to j} = \frac{EM^{new} - EM^0}{\Delta P_{gi \to j}} \quad (11)$$

Sign of This formula ($\eta_{i \to j}$) means to the direction of transfer energy production to increase margins.

If EM^0 is positive, the system is stable and does not need to operate in the conditions. However, if EM^0 is negative, so must be done in order to improve system security.

Proposed algorithm: The proposed method: minimizing network security index and the cost of

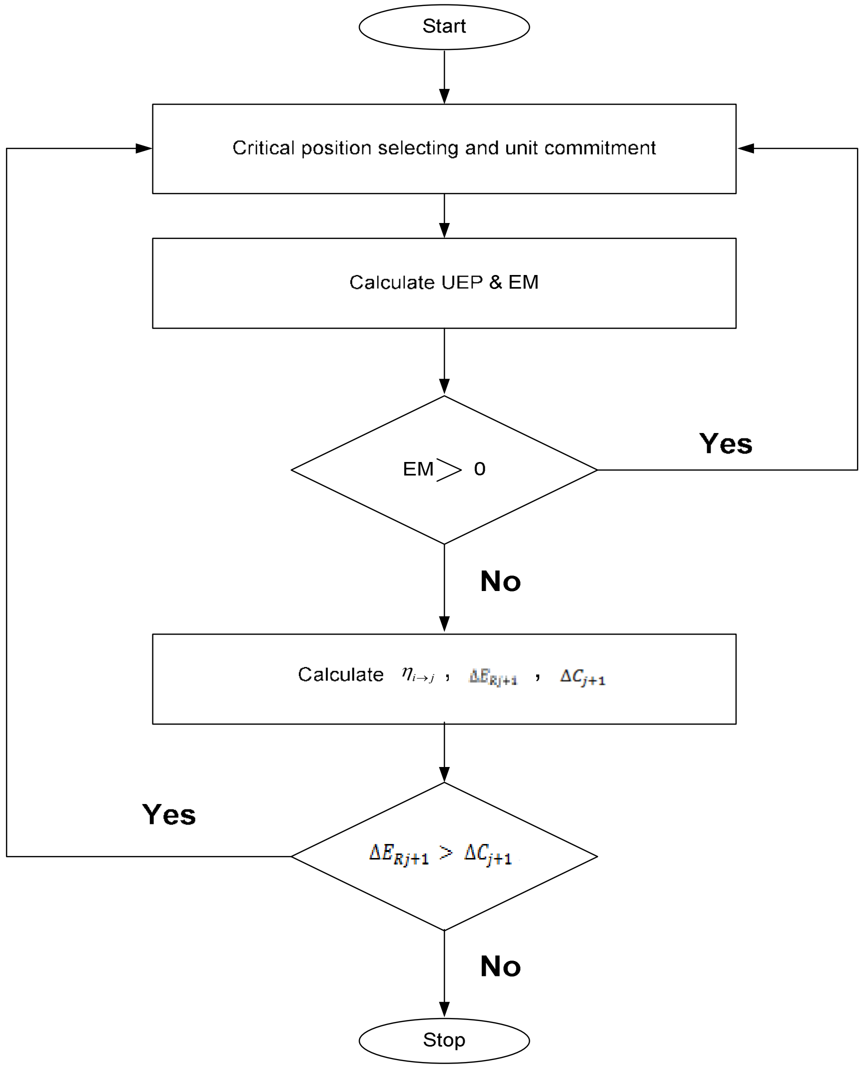

Fig. 1: Proposed flowchart

production as a multi-objective optimization problem by changing reactive power and voltage buses.

Reserve units are selected in such a manner that the network security index and generation cost become minimum simultaneously and dynamic constraint also be provided.

The flowchart of this method is as follows (Fig. 1).

PROBLEM FORMULATION

The whole problem can be expressed mathematically as minimizing the sum of the operating cost (C(rtd)) and the expected cost of outages (E(rtd)) (Abiri-Jahromi *et al*. (2007).

Then:

$$f_2(r_d^t) = \min_{\mathrm{P.SR}}\left[C(P_i) + \sum_{k=1}^{K} \Phi(k) \times (C(SR_i) + EENS(k) \times VOLL(k))\right] \quad (12)$$

$$EENS(k) \times VOLL(k) \quad (13)$$

$$\mathrm{C}(\mathrm{r_d^t}) = \sum_{\mathrm{gen,n}} (\mathrm{P_{Rj}} \times \mathrm{Rj}) \quad (14)$$

At the minimum, it is a necessary condition that:

$$\frac{\mathrm{d\,f}(\mathrm{r_d^t})}{\mathrm{d}(\mathrm{r_d^t})} = \frac{\mathrm{d\,C}(\mathrm{r_d^t})}{\mathrm{d}(\mathrm{r_d^t})} + \frac{\mathrm{d\,E}(\mathrm{r_d^t})}{\mathrm{d}(\mathrm{r_d^t})} = 0 \quad (15)$$

$$\frac{\Delta\,\mathrm{C}(\mathrm{r_d^t})}{\Delta(\mathrm{r_d^t})} + \frac{\Delta\,\mathrm{E}(\mathrm{r_d^t})}{\Delta(\mathrm{r_d^t})} = 0 \quad (16)$$

$$\frac{\Delta\,\mathrm{C}(\mathrm{r_d^t})}{\Delta(\mathrm{r_d^t})} \leq -\frac{\Delta\,\mathrm{E}(\mathrm{r_d^t})}{\Delta(\mathrm{r_d^t})} \quad (17)$$

For min $\mathrm{f}(\mathrm{r_d^t})$:

$$\mathrm{VOLL_R} \times \frac{\partial\,\mathrm{EENS_R}}{\partial\,\mathrm{R}} + \mathrm{EENS_R} \times \frac{\partial\,\mathrm{VOLL_R}}{\partial\,\mathrm{R}} + \frac{\partial\,\mathrm{C}}{\partial\,\mathrm{R}} = 0 \quad (18)$$

Table 1: Information about 9 bus IEEE network

Gen	At bus	Number of Units	Capacity (MW)	Forced outage rate	Price ($)
G1	1	4	100	0.01	$0.0060P^2 + 2.0P$
G2	2	6	50	0.04	$0.0075P^2 + 1.5P$
G3	3	4	50	0.03	$0.0070P^2 + 1.8P$

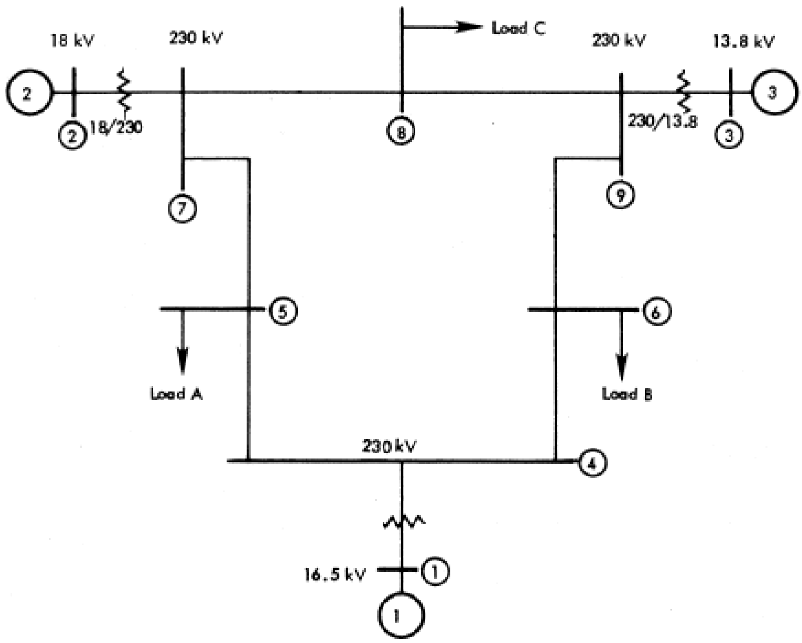

Fig. 2: A 9-bus IEEE testing system

Table 2: Loading and capacity of 9-bus system

	Pi(PU)	
Lines	Rating	Loading
1-4	1.30	1.190
3-9	1.20	0.966
2-7	1.20	1.059
4-5	1.50	1.269
4-6	0.50	0.077
6-9	1.00	0.977
9-8	0.80	0.049
8-7	1.20	1.050
7-5	1.00	-

Decision to buy for reserve unit j+1 th is with following equations:

$$\Delta C_{j+1} = C(R_{j+1}) - C(R_j) \quad (19)$$

$$\Delta E R_{j+1} = VOLL_R \times (EENS R_j - EENS R_{j+1}) + EENS_R \times (VOLL R_j - VOLL R_{j+1}) \quad (20)$$

After that, we implement formula 19 and 20 for applying the appropriate algorithm and then we have:

If $\Delta E_{Rj+1} > \Delta C_{j+1}$, then the reserve unit will be bought, otherwise, the cost of buying this reserve is more that reduction cost of interruption of energy and the buying cost is not affordable. So, in this step, buying the reserve will be stopped.

CASE STUDY

Nine (9) buses IEEE testing system is used for testing proposed model. In Fig. 2 is plotted single line diagram of this network.

This network consists of 3 generators, 9 buses and 6 lines of communication between the buses. Information about the generators and lines of this network is given in Table 1 and 2.

SIMULATION RESULTS

The assumptions in this issue are that the market would close for an hour and generators load into the system to supply total load 350 MW and their preparation cost is equal to proposed power cost. Changes in energy margins according to product changes in bus 2 are shown in Fig. 2.

Can be seen that the change in energy margin with produce in bus 2 on required controlled area is almost linear (Fig. 3).

Optimal distribution is as follows:

G1:132 MW, G2:118 MW, G3:99 MW

With this initial distribution, EM energy margins in this event are equal to -0.8367, which represents system instability.

$\eta_{2\rightarrow1}$ and $\eta_{3\rightarrow1}$ Sensitivity is calculated that values of which are obtained 6.460 and 9.229, respectively.

Table 3: Determination and allocation of reserve units by applying proposed algorithm

Energy capacity (mw)	Generator number	Reserve capacity (mw)
132	G1	168
118	G2	32
99	G3	100

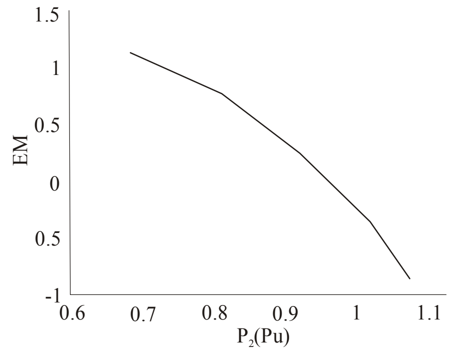

Fig. 3: Change in energy margin with respect to generator power change at bus 2

This process will continue and we will see that the application of this algorithm in determination and allocation of reserve units are as Table 3.

Comparison with deterministic criteria: If reserve considered according to the percentage of peak load and percentage is 10%, then the amount of reserve is:

$$reserve = 10\% \times 350 = 35 \text{ MW}$$

If reserve considered according to the largest unit, then amount of reserve is 100 MW.

In these cases, we will see that using both criteria cause consumer unreasonable pay more than outage cost, spend for a reserve that this is irrational.

CONCLUSION

System reserve procurement is considered as one of the imperative constraints that assure the system reliability and security against unforeseen breakdown. Today, in restructured electricity market, optimal system reserve procurement is extremely important due to economic consideration. In this study, appropriate system reserve allocation among committed units from transient stability and network security view is analyzed. Here an algorithm flowchart is proffered and has been then applied to the 9-bus IEEE network. As we saw, applying proposed algorithm can be easily prevented from unnecessary and complexity calculations, also the accuracy of this algorithm over other probability methods result from the superiority of this method. In addition, because most of the reliability parameters are unknown, this method shows its superiority once again.

NOMENCLATURES

P_{shi}	:	Net scheduled active power injection at bus i
Q_{shi}	:	Net scheduled reactive power injection at bus i
V_i and V_j	:	Bus voltages
G_{ij} and B_{ij}	:	Conductance and susceptance of transmission line connecting buses i and j
θ_{ij}	:	Bus angle difference
N	:	Total number of system buses
S_i	:	Corresponding power transmitted
s_i^{max}	:	Maximum transmission capability
P_i and Q_i	:	Power generations (bids) of generator i
$P_i^{min}, Q_i^{min}, P_i^{max}, Q_i^{max}$	:	Generation limits
Pmi	:	Input Mechanical power of generator i
Gii	:	Effective conductance of generator i
Ei	:	Constant voltage behind direct axis transient reactance of generator i
$\theta_i, \omega^{\sim}{}_i$	:	Rotor speed and angle of generator i
M i	:	Moment of Inertia of generator i
Bij(Gij)	:	Transfer Susceptance (conductance) in reduced Y matrix
θ^{cl}	:	Rotor angle at the end of disturbance
θ^{u}	:	UEP controller
P_i	:	Accepted generation bids, MW
SR_i	:	Accepted SR bids, MW
$C(P_i)$	:	Cost function of bulk power, $
$C(SR_i)$	:	Cost function of SR services, $
K	:	Total number of contingencies in consideration for the bidding stage
$\Phi(k)$	:	Probability of Kth contingency in consideration for the bidding stage
EENS (K)	:	Expected energy not served for each stage, MW

VOLL (K)	:	Value of lost load \$/mwh for the Kth contingency
$E(r_d^t)$	:	Outage cost for the reserve R
P_{Rj}	:	Reserve suggested price of unit j
Rj	:	Reserve amount Submitted by unit j.

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