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DETERMINATION OF OPTIMAL OPERATING RESERVES IN POWER SYSTEMS

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The paper is devoted to optimization of reserves and reliability level. The four approaches presented will need deeper scientific research. 1. The sum of reserves' costs and losses of consumers is minimized to the determination of optimal reserves. 2. Two-stage approach: 2.1. The sum of reserves' costs and consumers' losses is minimized to the determination of optimal requirements for reliability, security and supply, 2.2. The sum of reserves' costs is minimized to the determination of optimal reserves subject to the optimal reliability requirements. 3. The sum of reserves' costs is minimized to the determination of optimal reserves subject to the given reliability requirements. 4. Optimization of reserves by the market conditions. The paper also presents the possibilities to utilize higher share of transmission capacity avoiding violation of thermal transmission limits in network elements.

Introduction

To maintain reliability and quality of supply of a power system, reserves of active power and reactive power are required. The power systems and interconnected power systems cannot operate without reserves. The operating generating power reserves are needed for compensation of load deviations from prognosticated (expected) values and for covering generation deficit in the case of unexpected outages of power units [1-3].

The control over power systems is a multistage process. For every stage of control adequate reserves are needed. The operating reserves are usually divided into five parts [4]: 1) primary control reserve (available within 10 s), 2) secondary control reserve (available within 30 s), 3) tertiary control reserve (available within 15 min or less), 4) slow scheduling reserve, 5) contingency reserve, including instant reserve, rapid reserve and slow reserves. The reserves must be also in the electrical lines and networks (transmission reserve, stability reserve, distribution reserve, reactive power reserve, etc.).

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The power reserves caused the following kinds of costs in power plants and networks:

- the investment costs for creation of reserves;
- the operational costs bounded with keeping of reserves;
- the operational costs bounded with utilization of reserves.

Reliability and quality of power supply depend on the reserves and together with that the losses of consumers are always bounded with interruption of electricity supply and bad quality of electric energy. Therefore optimization of reserves is very important as for power plants and electrical networks, so for consumers.

Main tasks of planning the reserves are determination of the optimal size and geographical distribution of reserves around the power systems subject to reserves requirement [5]. Insufficient investments to new power sources or unsuitable allocation of reserves decrease the reliability and security of the power system and may lead to the system blackout.

One possibility to allow transmission over network with lesser security margins is to use market based retaliatory measures. The most common of those measures would be countertrade by which System Operator orders up-regulation of some power plants in the region of deficit when incidents in transmission network occur that limit the power transmission capability. The weakness of this method is that it assumes the availability of reserves in necessary regions. However, under market influences only, there is no incentive for market players to keep such reserves.

This paper describes the methods of calculation and optimization of operating reserves in the isolated and interconnected power systems. The paper is an extension of the work [5].

Traditional solutions of reserve problem

There are different principles of determining the needed capacity for operating reserve in different synchronous areas. In the synchronous area of the continental Europe (UCTE area) the requirements for reserve capacities are given separately for the primary reserve and the secondary reserve [4]. The requirement for the primary reserve is given by so-called “reference incident” which needs to be fully covered by primary reserves around the UCTE area. This reference incident is defined as the maximum instantaneous deviation between generation and demand in the synchronous zone by the sudden loss of generation capacity, load shedding or interruption of power exchanges. The reference incident depends on the size of the synchronous zone, the size of the largest generation unit or generation capacity connected to the power system.

The size of the secondary reserve to be held by each country is not precisely defined by UCTE. It can be derived from the defined purpose of the secondary reserve, which is to restore the balance between generation and demand within each Control Block. Therefore the secondary reserve must cover both the unexpected outages of generation and power demand fluctuations. The part of the secondary reserve related to unexpected outages of generation is equal to the largest generating unit in the Block. It is recommended by UCTE to calculate the reserve for demand fluctuations as a function of system size:

$$R_{\mathrm{sec}} = \sqrt{aL_{\max} + b^2} - b\,, \qquad (1)$$

where *a* and *b* – empirical parameters established for power system,
$L_{\max}$ – maximum load of the Control Block.

Within Control Blocks the secondary reserves may be divided according to agreements between countries.

The size of the tertiary reserve (manual reserve) in UCTE is directly related to the secondary reserve as the purpose of this reserve is to free up the secondary reserve shortly after they are activated.

The planning of operating reserves in Interconnected Power Systems of Baltic countries and Russia (IPS/UPS) takes into account that most of the frequency regulation is done centrally by the Central Dispatching Unit situated in Moscow, and the power plants used for this regulation are hydro plants in the Volga river cascade. Therefore there is no need to have pre-defined primary reserves for frequency regulation in each separate power system of IPS/UPS. The reserve, which needs to be held in each separate power system, is slow reserve with an activation time from 3 to 30 minutes. These reserves are quite identical to the requirements of the tertiary reserves in UCTE system as the activation of them is done mostly manually. Determination of reserve capacity is done separately for load deviations and power plant outages.

Principles of optimization

The value of reserves may be optimized by different ways:

1. One-stage approach: The sum of reserve costs and losses of consumers associated with non-sufficient reliability and quality of supply is minimized to the determination of optimal reserves in the power systems and interconnected power systems.
2. Two-stage approach: 2.1. The sum of reserve costs and losses of consumers is minimized to the determination of optimal requirements for reliability, security and quality of supply; 2.2. The sum of reserve costs is minimized to the determination of optimal reserves subject to the optimal requirements of reliability, security and quality supply.
3. Partial optimization: The sum of reserve costs is minimized to the determination of optimal reserves subject to the given requirements of reliability, security and quality of supply.

4. Optimization by market relations: Optimization of the reserves in the reserves' market conditions, if the requirements of reliability, security and quality of supply have been agreed.

The methods of reserve optimization on the basis of reserves' costs and losses of consumers have been considered in many works [6 and others]. One-stage approach (Approach 1) to the reserve optimization problems is usually too complicated. Most rational is the two-stage approach (Approach 2), where at the first stage the requirements of reliability, security and quality are optimized and at the second stage the power reserves are optimized if the requirements of reliability (indices of reliability), security and quality conditions are given.

Approaches 3 and 4 are simplified variants. In practice nowadays the solution of reserve problems is obtained mostly by the use of reserve markets [7].

All these approaches are very complicated and important. They are bounded with optimization problems under incomplete information [8-10]. The problems of reserve optimization are in a sense similar to the optimal load distribution and unit commitment problems. However, all approaches appointed above need more deep researches.

At first it is needed to study the reserves optimization problems under probabilistic and uncertain conditions. The most suitable criterion for these problems is minimization of maximal losses or risk caused by incompleteness of information.

Power demand is a non-stationary complicated Markov process with continuous time:

$$\tilde{P}_D(t) = \overline{P}_D(t) + \Delta\tilde{P}_D(t)\,, \tag{2}$$

where $\overline{P}_D(t)$ – mathematical expectation of power demand;
$\Delta\tilde{P}_D(t)$ – random component of power demand.

We assume that the intervals of power demand for primary (i=1), secondary (i=2) and tertiary (i=3) control in the power system are given:

$$\Delta P_{Di}^{-} \le \Delta P_{Di} \le \Delta P_{Di}^{+}\,. \tag{3}$$

Now, solving the economic dispatch problem between power units, we can find the maximum upward and downward reserves for every power unit for primary, secondary and tertiary control. Finally the characteristics of regulators must be accommodated with optimality conditions.

The optimization of reserve utilization, described above, enables to decrease fuel costs and emissions of thermal power plants.

Location of operating reserves in large systems

Like in the case of the capacity of reserves, there are also different philosophies of determining the location of operating reserve in different synchronous areas. In UCTE area the share of primary operation reserve to be handled by the Control Block *i* is determined by the coefficient of contribution. This coefficient is calculated as follows:

$$C_i = \frac{E_i}{E_\Sigma}, \tag{4}$$

where E_i – annual electrical energy generated in the *i*-th Block (including electricity generated for export to outside of the Block;

E_Σ – annual electrical energy generated in the entire synchronous area.

The distribution of reserve within Control Block is a subject to negotiations between Transmission System Operators (TSO-s) of the Block.

In IPS/UPS the location of reserves is mostly influenced by two different contractual limits to each subsystem – one value for normal operation and another in the case of disturbances (for instance when unexpected power generation outages occur). Therefore each subsystem may count on some system effect to cover its power deficit or surplus. The reserve for the *i*-th subsystem can then be calculated:

$$R_{k,i} = \frac{P_{k,i}^{\max}}{P_i^{\max}} \left(P_i^{\max} - \sum_j R_{ji} \right), \tag{5}$$

where $P_{k,i}^{\max}$ – largest generating unit in the *k*-th country of the *i*-th Block;

$P_i^{\max}$ – largest generating unit in the *i*-th Block;

R_{ji} – reserve power granted by Block *j* to Block *i*.

Generation reserve for enlarged transmission power

When large amounts of power are being transmitted *via* relatively weak interconnections between different parts of a power system, high enough security margins must be maintained to keep transmission system's state stable during and after disturbances. The classical approach for guaranteeing stable transmission is to set security margin factors for active power and voltage:

$$k_P = \frac{P_{\max} - P - \Delta P}{P} 100\% \tag{6}$$

$$k_U = \frac{U - U_{cr}}{U} 100\%, \tag{7}$$

where $P_{\max}$ – maximum power corresponding to the steady-state stability limit of an interconnection;
P – actual value of power transmitted through the interconnection;
ΔP – peak value of irregular power oscillations in the interconnection;
U – actual value of voltage in the node;
U_{cr} – critical value of voltage corresponding to the steady state stability limit of given load in the node.

According to the current Estonian Grid Code [11], k_P must be at least 20% in normal operation and 8% in restorative operation, while k_U must be at least 15% in normal operation and 10% in restorative operation. Those values are equal to those, used all over IPS/UPS.

The stability limits may not be violated during operation of a system even for a short term. But frequently, instead of stability, thermal capacity of the network becomes the limiting factor in power transmission. In other words, the desired power flow in the interconnection is greater than the thermal limit. Power of overload is usually calculated for the initial operating state:

$$P_{ij}^{overload} = P_{ij}^{desired} - P_{ij}^{safe}, \tag{8}$$

where $P_{ij}^{desired}$ – power flow through the interconnection resulting from marked needs;
P_{ij}^{safe} – maximal power flow through the interconnection which guarantees resulting power flow after an outage in the network below thermal limit of remaining network elements.

As thermal overload of power lines or transformers is not hazardous during short intervals of time, there is a possibility to use non-instantaneous generating reserves as a remedial action against it. As a most logical solution, the reserve should be activated in the power system region where the deficit is causing the overload. However it is often unlikely to find excess reserves in regions that are already importing power or the cost of holding the reserves in those regions turn out to be uneconomical. There is a possibility to use the help of neighbouring systems in a meshed network so that the reserve itself does not necessarily need to be located in the importing power system.

Let us assume that power system *i* is importing power and power system *j* is exporting it. The interconnection between those power systems may become thermally overloaded if there should occur an outage of an element of the interconnection. To relieve overload on the interconnection, activation of generation reserves is needed. In a meshed network, activation of reserves in power system *i* affects interconnection less than equal to the power of reserve activated. This can be described by effectiveness factor:

$$k_{ij}^{eff\,(i)} = \frac{P_{ij}^{wo.res(i)} - P_{ij}^{w.res(i)}}{R_i}, \tag{9}$$

where $P_{ij}^{wo.res(i)}$ – power flow through the interconnection without the activation of power reserve in power system i;

$P_{ij}^{w.res(i)}$ – power flow through the interconnection with the activation of power reserve in power system i;

R_i – power reserve activated in power system i.

Therefore the responsibilities for overloading an interconnection have to be shared between all importing power systems having the effectiveness factor greater than 0 on that particular interconnection. An additional reserve to be kept in power system k in order to use excess power transmission in interconnection ij for importing purposes can be calculated:

$$R_{ij}^{k} = P_{ij}^{overload} k_{ij}^{eff\,(k)} . \tag{10}$$

When there is any incentive to locate the reserve to another power system m, then the amount of reserve to be held in this other system must be calculated:

$$R_{ij}^{m} = R_{ij}^{k} \frac{k_{ij}^{eff\,(k)}}{k_{ij}^{eff\,(m)}} . \tag{11}$$

Conclusions

1. The optimization of operating reserves in power systems and in interconnected power systems is an important and complicated problem, which has not received sufficient attention so far.
2. The main attention has to be paid to the four approaches presented in the paper. At that the rational method of optimization of reliability, security and quality of supply and reserves includes the possibilities to take into account deterministic, probabilistic, uncertain and fuzzy information.
3. At planning of operating reserves one always has to take into account the possibilities of short-time overloading of generators and electric lines. There is a possibility to enable higher utilization of transmission capacities, when the limitations are caused by thermal overloading of power network elements.

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